

Chapter 7

Land Use Change Impacts: National and Regional Scales



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7.1 Introduction

Growing demands for food and biofuels are causing deforestation in the tropics. Although the rate of deforestation is decreasing, it is still high and problematic (FAO 2010). Deforestation is mainly the transformation of tropical forest to agricultural land, and it causes environmental problems related to climate change, soil carbon sequestration, ecosystem services, and biodiversity. Reducing tropical deforestation is an international priority especially for the production of Indonesian palm oil and Brazilian soybean oil.

The purpose of this chapter is to perform land use impact assessment within the framework of life cycle assessment (LCA). After observing recent trends in land use change in Indonesia and Brazil, which are important countries in discussing the transformation of tropical forest to agricultural land, land use impact assessment in LCA is reviewed. Plant oils are used as an example to illustrate the importance of land use change in LCA, and the framework for land use impact assessment within LCA is presented. Then, case studies on palm oil production in Indonesia and Malaysia are conducted with illustrating inter-temporal inequality between Europe and Southeast Asia and regionalization of land use impact assessment.

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7.2 Global Land Availability for Biofuels

Recent trends of arable land and forest area in Indonesia and Brazil are shown in Fig. 7.1. Arable land in Indonesia is as a whole increasing, after a small decline in the early 1990s. Arable land in Brazil is also increasing; the increased area during 1990–2008 is more than 10 M ha. In contrast, forest area in both countries is decreasing drastically. 23 M ha forest area (12% of the surface area) in Indonesia and 51 M ha forest area (6% of the surface area) in Brazil have been disappeared during the same period.

These trends illustrate that land availability for biofuels is limited. Global land use for biofuels is estimated at around 13.8 M ha (the sum of the USA, EU, Brazil, and China), which is about 1% of the world cropland (1500 M ha) (Renewable-Fuels-Agency 2008). Large additional land is required for achieving current policy targets of biofuels, even if larger yield increase is possible. Global biofuel targets to 2020 are estimated to require between 56 and 166 M ha (Renewable-Fuels-Agency 2008), which are 1.5 and 4.4 times larger than the surface area of Japan.

7.3 Land Use Change Impacts in LCA

The global land use change discussed so far necessitates the introduction of land use impact assessment into LCA. In this section, after demonstrating the importance of land use change in LCA using the examples of plant oils, the framework of land use impact assessment within LCA is presented.

7.3.1 *Importance of Land Use Change in LCA: An Expository Analysis of Plant Oils*

The purpose of this expository study is to present a comparative LCA of plant oils at oil mills. Plant oils under investigation are castor oil (India), crude coconut oil (Philippines), jatropha oil (India), olive oil (Cyprus), palm kernel oil (Malaysia), palm oil (Malaysia), palm oil, no clear-cutting (Malaysia), rape oil (Switzerland), rape oil (Europe), rape oil, organic (Europe), soybean oil (Europe), soybean oil (Brazil), and soybean oil (USA).

The system boundaries for plant oil production include agricultural production such as the production of palm fruit bunches and milling processes. Since the former includes production processes of agricultural inputs such as fertilizers and pesticides, the boundaries are termed “cradle to gate.” The functional unit is 1 kg of oils. Attributional LCA, which analyzes a single full life cycle, was applied to illustrate typical practices (Reinhard and Zah 2009; Schmidt 2010).

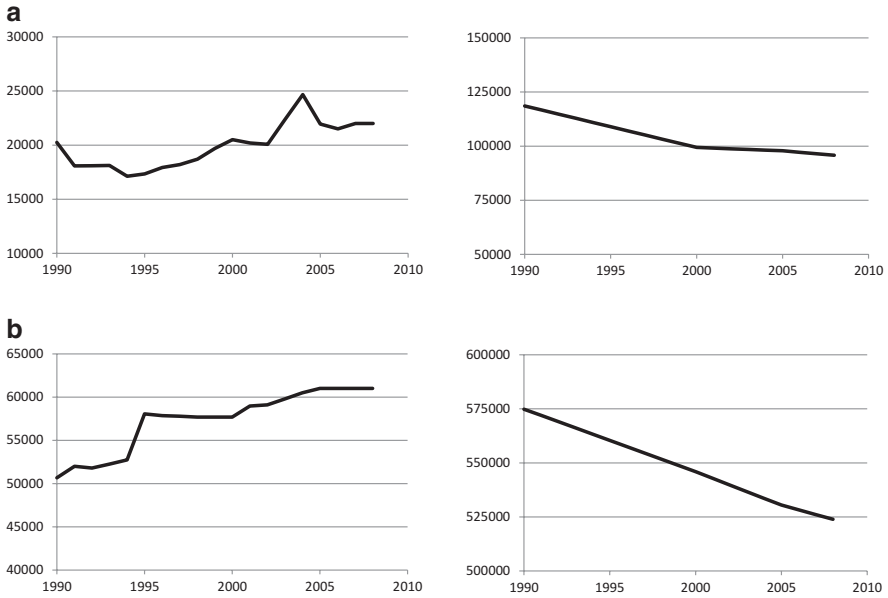


Fig. 7.1 Land use change in Indonesia and Brazil (Source: FAOSTAT). (a). Arable land in Indonesia (1000 ha), forest area in Indonesia (1000 ha). (b) Arable land in Brazil (1000 ha), forest area in Brazil (1000 ha)

A life cycle inventory (LCI) database, ecoinvent 2.2 (Jungbluth et al. 2007), and LCI data prepared by ESU-services (Jungbluth et al. 2009) were used for the analysis. Impact categories used for the assessment are GHG emissions (global warming potential; GWP), energy consumption (cumulative energy demand; CED), and land occupation and transformation (ecosystem damage potential; EDP), which is based on assessment of impacts of land use on species diversity (Koellner and Scholz 2008).

The results of the impact assessment are shown in Fig. 7.2. GHG emissions from plant oil production processes illustrate that the environmental impact of palm oil, especially palm oil without clear-cutting of trees, is relatively small. CED (nonrenewable) demonstrates the same tendency. Since oil palm has the highest oil production efficiency among the oil crops, the values of EDP (occupation) for palm oil are lower than the other oils. However, there is a different trend in EDP (transformation). The value of soybean oil in Brazil is the highest. Although the value of palm oil in Malaysia is high, the value of palm oil without clear-cutting is near zero. In other words, the result is dependent on whether clear-cutting exists or not.

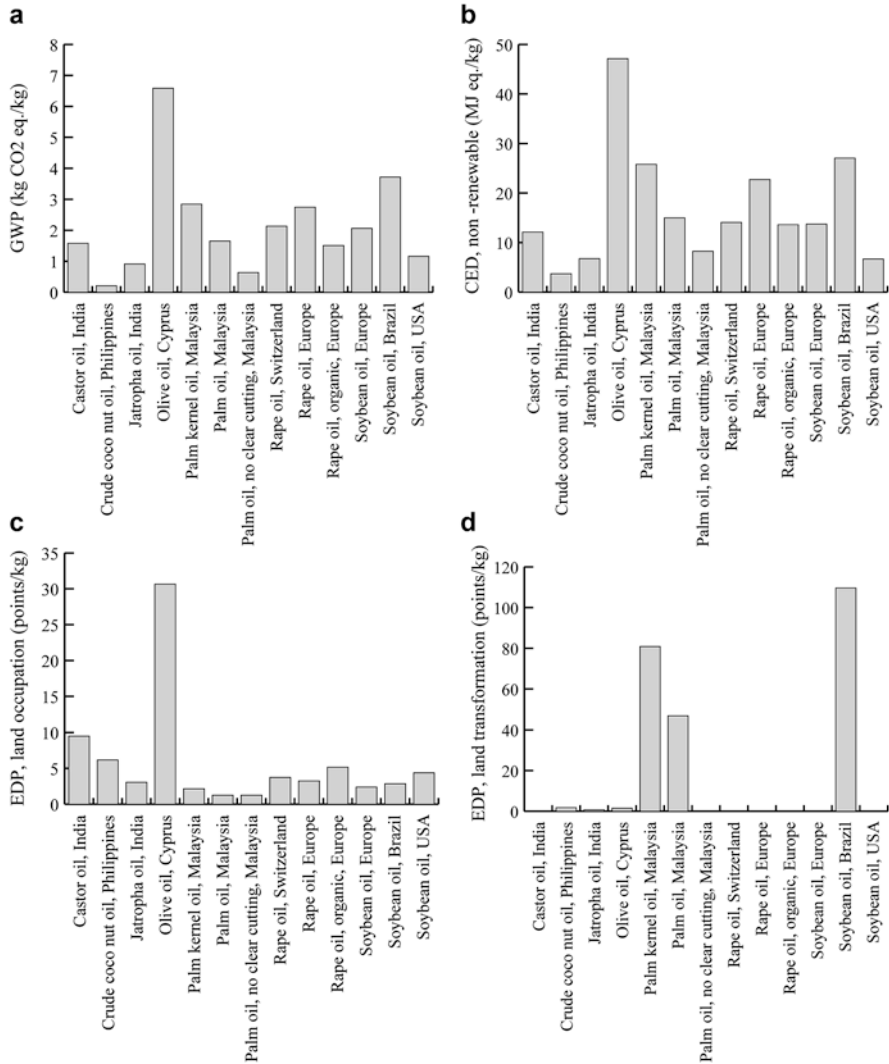


Fig. 7.2 Life cycle GHG emissions, CED, and EDP for various plant oils. (a) GHG emissions of plant oils, (b) CED for plant oils, (c) EDP (occupation) for plant oils, (d) EDP (transformation) for plant oils

7.3.2 Methodologies for Land Use Impacts in LCA

One of the striking results in the comparative LCA is the difference between “palm oil, Malaysia” and “palm oil, no clear-cutting, Malaysia.” This implies the importance of land use impact assessment in LCA.

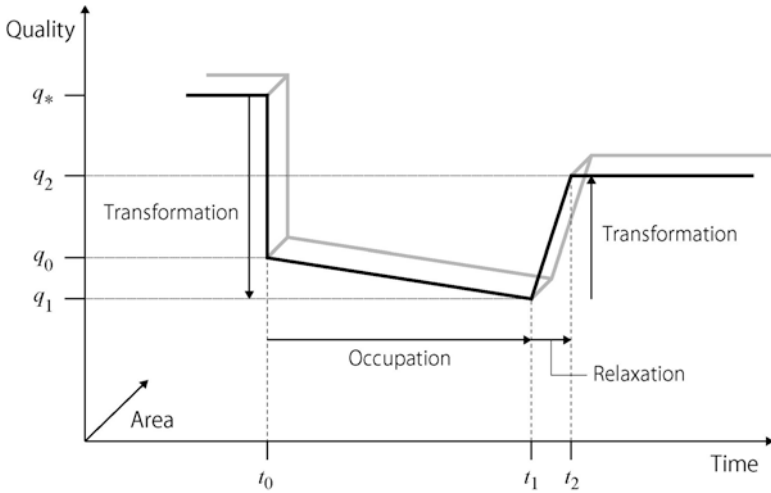


Fig. 7.3 Framework of land use impact assessment in LCA

7.3.2.1 Integration of Land Use into LCA

Land use is an important topic in LCA and gaining much interest in LCA communities recently. Some commodities such as agricultural products have high impacts on land in the production stage, and land use-related environmental impacts should be considered from a product life cycle. The land use impacts are dependent on the location of the land; spatial information will be important. The basic concept in the assessment is ecosystem services of the Millennium Ecosystem Assessment (MEA).

7.3.2.2 Framework for Land Use Impact Assessment Within LCA

The framework for land use impact assessment within LCA is shown in Fig. 7.3, which is based on the UNEP-SETAC task force on the integration of land use impacts into LCA. The characteristics of the framework are summarized as follows: (1) land occupation and land transformation are separated explicitly; (2) land quality is defined during land use (q_* , q_0 , q_1 , and q_2); (3) the degree of impacts is determined in relation to reference situation (q_*); and (4) the definition of the duration (from t_0 to t_1 or t_2) is important in the assessment.

7.4 Case Studies of Land Use Impact Assessment: Palm Oil Production

Before making case studies of land use impacts of palm oil production, a general overview of LCA applied to palm oil production is given.

7.4.1 Literature Review of LCA Applied to Palm Oil

After a feasibility study of LCA on crude palm oil production in Malaysia by Yusoff and Hansen (2007), the number of papers published in scientific journals was increased. Vijaya et al. (2008) made life cycle inventories of 12 palm oil mills in Malaysia. Wicke et al. (2008) analyzed GHG emissions of crude palm oil and palm fatty acid distillate production in northern Borneo (Malaysia), their transport to the Netherlands, and their co-firing with natural gas for electricity production. They stressed that land use change is the most decisive factor in overall GHG emissions and that degraded land should be used for palm oil production. Lam et al. (2009) conducted LCA of palm and jatropha methyl ester (biodiesel) and assessed land requirement, energy balance, and CO₂ emissions and sequestration in Malaysia.

Case studies were not restricted to Malaysia. Angarita et al. (2009) analyzed the life cycle energy balance in palm methyl ester in Brazil and Colombia. Pleanjai and Gheewala (2009) compared the net energy balance and the net energy ratio of palm methyl ester with those of coconut and jatropha methyl ester in Thailand. Pamong et al. (2010) analyzed life cycle energy efficiency of palm methyl ester in Thailand.

7.4.2 Inter-temporal Inequality

This subsection makes a comparison between plant oil production in Germany and that in Malaysia, to illustrate the relationship between land use impact assessment and policy issues. The inventory data used for both of the oil production are ecoinvent 2.2. The environmental impacts measured are land use impacts on biodiversity developed by Schmidt (2010). Characterization factors for Denmark and Malaysia were used in the assessment, and the unit of the impact is weighted species richness on a standardized area at 100 m² (wS_{100}).

The result is depicted in Table 7.1 and summarized as follows: First, the impact of occupation for rape oil is larger than that for palm oil. Second, the impact of transformation from nature to agriculture is larger than that from agriculture to agriculture. Third, the impact of transformation from nature to agriculture in Europe is larger than that in Southeast Asia.

The result implies that there is an inter-temporal inequality between Europe and Southeast Asia. In other words, the environmental impact of past transformation in

Table 7.1 Impact of land use change on species richness (wS_{100}/kg)

Product	Scenario	Occupation	Transformation
Rape oil	Feedstock production: conventional production in Saxony-Anhalt, Germany, from intensive grassland to intensive crop production	0.0191	0.0398
	Oil production: Europe		
Rape oil	Feedstock production: conventional production in Saxony-Anhalt, Germany, from natural forest to intensive crop production	0.0191	6.01
	Oil production: Europe		
Palm oil	Feedstock production: Malaysia, from intensive rubber to agroforestry	0.00473	0.000851
	Oil production: Malaysia		
Palm oil	Feedstock production: Malaysia, from natural forest to agroforestry	0.00473	0.0421
	Oil production: Malaysia		

Europe would be larger than that of current transformation in Southeast Asia; there is a *disadvantage of newcomers*.

7.4.3 Regionalization of Land Use Impact Assessment

Although the previous section clarified the significance of scenarios in land use impact assessment through conducting hypothetical comparisons, more detailed regional conditions have to be specified in land use scenario construction.

7.4.3.1 Regionalization Based on Oil Palm Productivity

The purpose of this subsection is to assess land use impacts of oil palm production. Twelve provinces of Indonesia in Borneo and Sumatra are selected as case study regions (Fig. 7.4). Characterization factors of ecosystem damage potential (EDP) are tentatively used as the impact category.

Inventory data of palm fruit bunches at the farm level (ecoinvent 2.2) were modified to reflect yield differences of oil palm production among provinces. The oil palm productivity data in each province are based on the values of CPO in JIRCAS and MURCI (2006), which are changed into the values of FFB using the conversion coefficient in Corley and Tinker (2003).

The results are shown in Table 7.2. First, EDPs of land transformation are larger than those of land occupation. The former values are in general 38 times larger than the latter values. Second, EDPs of North Sumatra and Riau, the main production areas of oil palm in Indonesia, are relatively low.

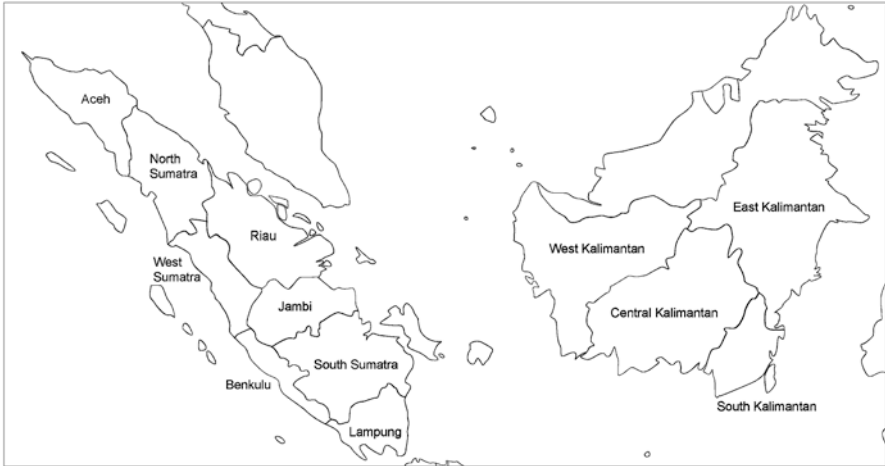


Fig. 7.4 Case study areas in Indonesia

Table 7.2 Ecosystem damage potentials of oil palm production in each region (EDP/kg FFB)

	Occupation	Transformation
Borneo		
West Kalimantan	0.533	20.1
Central Kalimantan	0.518	19.6
South Kalimantan	0.486	18.3
East Kalimantan	0.598	22.6
Sumatra		
Aceh	0.541	20.4
North Sumatra	0.390	14.7
Riau	0.432	16.3
West Sumatra	0.529	20.0
Jambi	0.509	19.2
Bengkulu	0.533	20.1
South Sumatra	0.515	19.4
Lampung	0.551	20.8

7.4.3.2 Regionalization Based on the Share of Peat Land

The above EDP values are useful in understanding the differences of environmental impacts among provinces. However, the conversion of tropical peat land is not considered in the assessment. Thus, this subsection introduces the share of peat land in each province into the assessment. CO₂ emissions from land transformation are used as the criteria.

Table 7.3 CO₂ emissions from land transformation to oil palm production in each region (kg CO₂/kg FFB)

	CO ₂ emissions from land transformation			Fossil CO ₂ emissions
	Case 1	Case 2	Case 1/Case 2	
Borneo				
West Kalimantan	0.861	0.289	3.0	0.165
Central Kalimantan	0.491	0.281	1.8	0.164
South Kalimantan	0.263	0.263	1.0	0.162
East Kalimantan	0.326	0.324	1.0	0.170
Sumatra				
Aceh	0.705	0.293	2.4	0.166
North Sumatra	0.656	0.211	3.1	0.156
Riau	1.038	0.234	4.4	0.159
West Sumatra	1.417	0.287	4.9	0.165
Jambi	0.824	0.276	3.0	0.164
Bengkulu	1.061	0.289	3.7	0.165
South Sumatra	0.560	0.279	2.0	0.164
Lampung	0.712	0.298	2.4	0.167

Case 1: The percentage of peat soil is considered

Case 2: The percentage of peat soil is not considered

In the calculation process, land transformation is separated into two parts: one is the provision of stubbed land (clear-cutting of primary forest) and the other is the production of palm fruit bunches at the farm level (direct emission). The former is the transformation from tropical rain forest to intensive forest by clear-cutting, and the latter is the transformation from intensive forest to intensive short rotation forest. Burning of the 20% of the biomass is supposed in clear-cutting. CO₂ emissions from land transformation are counted in direct emissions from the stubbed land provision process and direct emissions from the oil palm production process. The percentages of peat soil in oil palm plantations in each province are taken from Koh et al. (2011). CO₂ emissions from peat decomposition related to oil palm plantations are based on Uryu et al. (2008).

The results are summarized as follows (Table 7.3): First, CO₂ emissions from land transformation are larger than fossil CO₂ emissions even if peat land is not considered. Second, if we introduce the percentages of peat land into the calculation, the values increase drastically. The values for West Sumatra and Riau increase more than four times and for Bengkulu, North Sumatra, Jambi, and West Kalimantan increase more than three times. CO₂ emissions from land transformation with considering peat land in West Kalimantan are more than eight times larger than fossil CO₂ emissions. These results indicate the importance of regional land conditions in the assessment.

7.5 Discussions

From the land use trends at the global level, the focus of attention in this chapter has evolved into the province level. Since the next analytical step will be the detailed assessment at the plantation level, the first point to be discussed here is LCI data. It is important to point out that the background data used for modeling agricultural production such as fertilizers and pesticides in ecoinvent are European or Swiss ones. Therefore, adaptation and development of the regionalized data are important; e.g., Indonesian background data are appropriate for LCA of palm oil in Indonesia.

A pragmatic method to regionalize background data is the modification of European LCI data. In other words, if local industrial LCI data (as background data for, e.g., fertilizer production) exist, they can be used to regionalize the European LCI data (e.g., LCIs of fertilizers). Ossés de Eicker et al. (2010) demonstrate the usefulness of the modification method through conducting a case study of triple superphosphate in Brazil. Hayashi et al. (2010) illustrate the effectiveness of the method in constructing LCI database for crop production systems in Japan. Recent LCI inventories of palm oil production developed by, for example, Malaysian Palm Oil Council (MPOC) and Indonesian Oil Palm Research Institute (IOPRI) will play an important role in conducting LCA of palm oil.

The second point is how to cope with indirect impacts. Indeed, there are intensive discussions on indirect land use change after the *Science* papers (Fargione et al. 2008; Searchinger et al. 2008). Although the assessments in this chapter are restricted to direct impacts because there is no consensus in the methodology including consequential modeling, indirect effects of biofuels should not be neglected (Renewable-Fuels-Agency 2008; Miller et al. 2010).

7.6 Concluding Remarks

The implications of the case studies in this chapter are summarized as follows: First, land use impact assessment within the framework of LCA can be applied to inter-temporal comparisons based on hypothetical scenario construction. The result revealed that there is a disadvantage of newcomers and it means social issues are deeply related to environmental impact assessment of land use change. Second, land use impact assessment can be regionalized using land productivity and conditions. The province-level assessment showed that land transformation is crucial both in reducing GHG emissions and in conserving biodiversity. Although land use impact assessment within LCA is still on the development, it will play an important role in policy-making processes.

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