

Project Report

# **LCA of Biodiesel**

## **in Costa Rica**

**An Environmental Study on the  
Manufacturing and Use of Palm Oil  
Methyl Ester**



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**An Environmental Study on the Manufacturing and Use of  
Palm Oil Methyl Ester**

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¡Muchisimas gracias!

## Preface

The author of this report is a student in environmental science at the ETH in Zurich, Switzerland. The curriculum includes an internship in the seventh semester intended to provide the students with a valuable working experience.

The University of Applied Sciences Northwestern Switzerland (FHNW), Institute for Ecopreneurship (IEC), serves as a reference centre for the cleaner production centres (NCPC) in Central America, setting up the institutional structures of the NCPC as well as providing technical support and training. Occasionally, volunteers and students are invited to make contributions to specific projects at the centres. FHNW has enabled the author to collaborate for the present study at the NCPC in Costa Rica.

During his research work and the development of the LCA, the author was supported by Mr. Fredy Dinkel, registered environmental auditor of Carbotech Ltd., Switzerland, who had also developed the LCA software EMIS. In their occasional meetings, Fredy Dinkel and the author discussed the results, identified areas where further progress could be made and considered the next steps. Mr. Jürg Walder, Project Manager of the Central American Cleaner Production Project and Research Associate at the FHNW, Switzerland, provided the conceptual framework and conceptual guidance.

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# 1 Executive Summary

Prices on the global palm oil market are currently very low. Since Costa Rica has quite a big palm oil industry, this has affected the country quite badly. About 27,500 people in Costa Rica depend directly or indirectly on this industry. As a first measure to confront this problem, the government has been looking into alternative uses of palm oil and found a possibility in biodiesel. A biodiesel project was conceived and commissioned to the National Cleaner Production Centre in San José (Centro Nacional de Producción Más Limpia, CNP+L). This project is divided into three stages. In stage one, basic economic and ecological inquiries are carried out. Stage two involves palm oil methyl ester production on a laboratory scale including emission and engine compatibility research studies. In stage three, a pilot installation will be built and the laboratory process will be scaled up. The project is partially funded by the Costa Rican Ministry of Environment and provided with logistical and technical support support from the Swiss Government and the FHNW reference centre respectively.

This Life Cycle Assessment (LCA) on palm oil methyl ester was a part of stage one. It is partly based on an LCA on rapeseed methyl ester which had been previously conducted in Europe.

Generally speaking, the emissions from combustible biodiesels such as palm oil methyl ester or rapeseed methyl ester are lower than the emissions produced by conventional diesels, especially as far as SO<sub>2</sub> emissions and particles are concerned. This makes the combustion of palm oil methyl ester attractive from an ecological point of view.

The transesterification in the production of palm oil methyl ester causes the biggest environmental problems. This is why different alternatives were investigated:

- Palm oil methyl ester transesterified with methanol which is made from fossil fuel
- Palm oil methyl ester transesterified with methanol which is made from waste wood and certain plastics
- Palm oil ethyl ester transesterified with ethanol which is made from sugar cane

The production of palm oil methyl ester uses up fewer non-renewable energy resources than the production of diesel oil and also contributes less to global warming while the eutrification potential of palm oil methyl ester is higher than that of diesel. The other environmental indicators which were investigated (see chapter 4.1.2) are roughly equal. By changing the transesterification agent and the production technique, the need for non-renewable energy resources was reduced as were the potentially harmful (in terms of global warming) emissions. Here, too, the other environmental indicators stayed roughly the same.

The comparison between the use of ethanol fuel and palm oil methyl ester established that all values for ethanol – except for the eutrification potential – were significantly superior to those of palm oil methyl ester.

It was shown that the production of palm oil methyl ester requires an energy input of about 36 % of its calorific value. (The value for conventional diesel fuel is 30 %).

With a view to the eventual concretisation of the palm oil methyl ester project, the three alternatives to transesterifying palm oil should be more closely scrutinized. The use of ethanol from sugar cane as a fuel additive could be an interesting option for other applications, too, since it allows the production of environmentally friendly as well as inexpensive fuel.

## 2 Introduction

### *History*

Between 1975 and 1982, the large banana-producing corporations left Costa Rica and moved their plantations to other countries. After their departure, Costa Rica had to find other purposes for her agricultural land and other jobs for her agricultural labourers. This was the hour of birth for Costa Rica's palm oil industry. Twenty-five years later, only Malaysia and Indonesia are producing higher quantities of palm oil, but in the same period, the world price for palm oil has substantially fallen. Costa Rican agriculture is again facing some tough challenges. The livelihoods of about 27,500 people depend directly or indirectly on the palm oil industry.

So far, palm oil has been used as an ingredient in washing powder, margarine and other food products. Because of the above-mentioned problems, the government has been searching for alternative uses of palm oil to increase the demand. It was found that palm oil could be used as a fuel in diesel vehicles. Other biodiesels had already turned out to be more environmentally friendly than conventional diesel fuel. SO<sub>2</sub> emissions and particle counts in particular were substantially lower.

### *Concept of the palm oil project*

Within the UNIDO's (United Nations Industrial Development Organization) Cleaner Production (CP) program, National Cleaner Production Centres (NCPC) were set up in 1994 in many parts of the world to "increase competitiveness, to facilitate market access and to strengthen the productive capacity of developing economies taking into consideration the two other dimensions of sustainable development, environmental compliance and social development" (UNIDO, document 5133).

The NCPC of Costa Rica initiated the palm oil project as such a cleaner production activity. Three stages were defined:

#### *Stage one*

- Evaluation of economical feasibility
- First experiences with the production of biodiesel
- Evaluation of the environmental impact of biodiesel

#### *Stage two*

- Evaluation of possible process optimisations during the production of biodiesel from palm oil on a laboratory scale
  - Estimation of chemical and physical properties
  - Biodiesel tests in diesel engines and emission measurements
-

### *Stage three*

- Development of a pilot plant
- Up-scaling of the laboratory process
- Application of best available technology

This project, the evaluation of the environmental impact, was carried out within stage one and has been largely finished. Stages two and three are yet to begin.

### *Production*

Palm oil is produced from the Palma Africana. In Costa Rica, this palm tree is cultivated at sea level in big plantations. The fruits which have the size of a baby's fist and grow in bunches are continuously harvested throughout the year. After the harvest, they are brought to a plant as fast as possible to prevent the generation of fatty acids. Several steps are necessary to extract the oil. The process starts with a steam pre-treatment while the fruits are being separated from the bunch. The fruits are then pressed to obtain the actual oil. Before the oil can be used in food and soap as well as fuel, it has to be refined. Use of the oil as fuel requires an additional transesterification with methanol, which means that the oil which consists of a glycerine type ester is separated into fatty acids ester and glycerine. (The chemical reaction is explained in more detail in Appendix D.) This process produces glycerine as a by-product which can be sold separately. The palm oil methyl ester (PME) is ready to be used in combustion engines.

### *Report*

This report shall give a first overview of the ecological aspects and consequences of the manufacture and combustion of palm oil methyl ester in Costa Rica. It is also intended to demonstrate different ways of making use of Costa Rica's resources in the future.

Chapter 2 of this report will deal with social and general economic aspects of the palm oil production in Costa Rica. Chapter 3 will feature a detailed comparison of the different fuels and a short description of the PME characteristics and energy considerations. Chapter 4 will focus on the methodology and procedure of the LCA, providing detailed descriptions of the processes and assumptions with a view to making the work as transparent as possible. The conclusions in chapter 5 will be based on a general evaluation of the results and a summary of the study. The report will conclude with a description of the situation of biodiesel in Europe.

### *Terminology*

The Environmental Management and Information System (EMIS) software has been used as the calculation tool for this life cycle assessment (LCA). A more detailed description of this software will be provided later in this report. In order to help the reader understand the earlier parts of the report, however, I shall provide a brief (one-paragraph) introductory note here.

The fundamental unit of EMIS is a process. Each process has an input, an output and emissions. The input of a process consists of other processes that are either in the EMIS database or self-created. In turn, each of these input processes has input processes of itself and so on. The visualisation of this chain of processes generates the image of a process tree. Each individual “process” always has a whole process tree behind it. To indicate this in the text, each process is always set between ‘...’ such as ‘PME-Imeth’ or ‘Diesel C.R.’. If no ‘...’ are set, we are talking about a single product.

## 3 Social and Economic Aspects

### 3.1 Social Aspects

As this study is mainly dedicated to the environmental and technical part of the production and use of palm oil methyl ester and similar fuels, only a brief synopsis of the social situation will follow. The information was compiled from different sources and shall give the reader an idea about the social circumstances in Costa Rica's palm oil industry.

El Centro de Estudios Económicas Ambientales, one of the leading economic research institutions in Costa Rica which has recently specialised on environmental issues, reported in 2002 – in its feasibility study about the use of palm oil as biodiesel – the following facts from a palm oil company in Costa Rica.

Some employers apparently did not insure all of their workers, at least not straight away (only after a few weeks of work). Some employers refused to pay social security contributions. Workers were often not informed about the health and accident risks of their work or only after the event. Another common practice employers were using to save money was to fire the workers after less than three months, avoiding any obligation to fund paid leaves etc. Some workers were then re-hired one day after. Workers were also hired without due registration: they received their pay in cash, another way of bypassing legal obligations, of guarding the cash flow from the prying eyes of the fiscal authorities and of avoiding having to pay taxes. Migrant workers from Nicaragua or Columbia, for example, were often paid very little and were given no social security at all.

No information is provided as to how widespread the above-mentioned practices are, how many people are working illegally and how many of the workers have no papers.

More than 1000 large, medium-sized and small producers are operating in the country, most of them members of different Cooperativas or associations. The association CIPA R.L. alone counted about 1050 family groups as its members before it closed down. The average monthly income of such a producer family is 92,477 Colones, about US-\$ 250. 75 percent of the families have a monthly income of less than 100,000 Colones (US-\$ 272), 25 percent have a monthly income of less than 50,000 Colones (US-\$ 136). Very few families earn more than 200,000 Colones per month (US-\$ 544) (Centro de Estudios Económicas Ambientales, 2002). For comparison: the average annual income of people in Costa Rica is US-\$ 4040 (World Bank, 2002), i.e. US-\$ 337 per month. The average income of a farmer's family therefore reaches only 74.2% of the national average.

This low income level restricts the farmers' access to education. There are schools in the individual regions, but children who are attending classes cannot work on the farm at the same time and earn money. Taking advantage of educational opportunities exerts a

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particularly high price at such a low level of income. Interviews with adult workers in the palm industry showed that about 22 percent of women and 9 percent of men do not even have a basic education. 80 percent of the families live in their own homes, 62 percent without a mortgage. This is roughly on a par with the national average of 64.8 percent (Centro de Estudios Económicas Ambientales, 2002).

The dependency of the local population on palm oil producing companies is partially quite high. A company in the south of Costa Rica reported that about 50 % of the whole population in the surrounding villages were more or less depending on its production. 50 % of the land in this region was cultivated by small producers working on their own land, whereas the other 50 % were managed by companies. Most land used to be the property of small producers, but when the business climate in the palm oil industry changed, many of them had to sell. Many of the people who used to own and cultivate their own land were now working on corporate palm plantations, often earning considerably less.

## **3.2 Economic Aspects**

The export of palm oil from Costa Rica has massively decreased over the past few years, by 30 percent each year between 1999 and 2001. In 1999, palm oil exports generated 0.28 percent of Costa Rica's gross domestic product. By 2001, this percentage had fallen to 0.1 percent. In the space of two years, the share of palm oil exports in the GDP had decreased by 65 percent. Even more significantly, while palm oil exports fell, the import of diesel fuel rose steadily. In 1997, palm oil exports paid for 45.6 percent of the diesel imports, in 2001 only for 12.5 percent. The steepest fall took place in 1999 when palm oil exports lost 20 percent of the value of diesel imports (Centro de Estudios Económicas Ambientales, 2002). Ever more money flows out of the country for fuel imports and ever less money comes in from palm oil exports, begging the question why Costa Rica does not use palm oil as fuel. This would produce several advantages: firstly, less money would need to be spent on diesel, reducing the cash outflow. Secondly, by using palm oil as biodiesel, the demand for this product would increase, driving up its price. Thirdly, the financially stricken palm oil industry would get more work as more oil was consumed and more workers could be hired. Finally, it is scientifically proven that the combustion of biodiesel causes less environmental damages than the combustion of fossil fuels (diesel). Biodiesel has a far lower sulphur content than fossil diesel. Costa Rican fossil diesel, for example, has a sulphur content of about 0.5 percent, biodiesel a sulphur content of practically nil. This would also reduce the external cost of biodiesel use.

The feasibility study claimed that the use of biodiesel could save a lot of money because much lower amounts of fossil diesel would have to be imported. The exact savings were quantified as follows:

Table 1 Estimated import savings by substituting fossil diesel with biodiesel. In millions of US-\$, for 100% biodiesel (B 100) and 20% biodiesel (B 20)

	Year	B 100		B 20	
		100%	10%	100%	10%
Estimated Savings	2000	159.9	1.5	32	0.3
	2010	173.8	1.6	34.8	0.3

Source: Centro de Estudios Económicas Ambientales, 2002, Costa Rica

If in 2000 hundred percent of fossil diesel had been substituted with B100, an annual amount of US-\$ 159.9 million could have been saved. If by 2010 hundred percent of fossil diesel are replaced by B 100, US-\$ 173.8 million will be saved every year. Assuming that in 2000 only ten percent of fossil diesel had been substituted with B100, the annual sum of US-\$ 1.5 million would have been saved. A 10 % substitution of fossil diesel with biodiesel by 2010 would generate savings of US-\$ 1.6 million US per year.

These two aspects are two of the three sustainable main pillars. The third main pillar would be the ecological aspect which will be dealt with in the following.

## 4 Realization of the LCA

### 4.1 Methodology

#### 4.1.1 Eco-balancing

In general terms, eco-balancing tries to capture the material and energy flows as well as the use of resources (like land, fossil fuels, etc.) and the generation of environmental stress factors such as noise. The method can be applied to a product, a process or a whole enterprise (Skript Ökobilanzen, 2001). The application of eco-balancing to a product is also known as a LCA (Life Cycle Assessment). Such a LCA subjects the whole life span of a product to an ecological investigation, from the beginning of its production to its end use or disposal.

In our case, a product LCA for palm oil methyl ester was conducted.

According to ISO 14040, an eco-balance features the following steps:

- Definition of system boundaries and objectives
- Data collection (material balance)
- Determination of environmental stress factors (impact balance)
- Weighting of environmental stress factors in view of the objectives (subjective operation)
- Measures

In order to make the LCA comply with the needs and desires of the different project stakeholders, objectives and system boundaries must first be defined. After this, one can start to collect the data, the most time-consuming part of the LCA. The determination of environmental impacts and their weighting in view of the objectives require judgment and profound analysis. Finally, based on the results, measures can be taken to resolve or improve environmental as well as economical and social problems. (For more details about the theory of eco-balancing see the bibliography. E.g.: Skript Ökobilanzen, 2001)

In today's global economic and environmental climate, eco-balancing has become more important than ever. Firstly, because the environmental legislation across the world is becoming ever stricter, secondly because the quality of life in some parts of the world has deteriorated to the point where measures must be undertaken to protect life, and thirdly, because eco-balancing is not only a tool of reducing harmful emissions but also a tool of cutting costs and therefore of making commercial enterprises more efficient.

### 4.1.2 Impact Indicators

In the following, only those impact indicators will be listed which are used in the LCA. (The selection of indicators is explained in chapter 4.2.3.)

#### *Non-renewable energy resources*

The term “non-renewable energy resources” covers all fossil fuels such as oil or coal, deposits of organic matter which were built up over thousands of years in a continuous process. Now, they are exploited and burnt very fast to generate energy, releasing vast quantities of CO<sub>2</sub> and causing some of the urgent global environmental problems we are confronted with today.

The non-renewable energy resources indicator gives an idea of how much fossil fuel equivalent is used during the life cycle of a product, for example during the production of one tone of palm oil methyl ester from *Palma Africana*.

#### *Global warming potential*

Scientists are virtually certain that a big part of the global warming potential has been caused by the excessive CO<sub>2</sub> emissions of the last and current centuries. Other compounds which are contributing to the global warming potential are methane, N<sub>2</sub>O and halogen-containing compounds (Heijungs, 1992).

#### *Acidification potential*

The acidification potential describes the contribution of different emissions to the generation of acids in the atmosphere. These acids slowly sink down the atmosphere where they release heavy metals and damage many species of plants. Heavy metals which have been washed out can contaminate drinking water resources.

The acidification potential is expressed by the number of H<sup>+</sup>-Ions that are released with one kilogram of a compound. The potentials are standardized to one kg H<sup>+</sup>. The results are expressed in kg SO<sub>2</sub> (EMIS Handbook, 2002).

#### *Eutrofication potential:*

High concentrations of the elements N and P strongly inhibit the growth of plants. If additional amounts of these elements are fed into ecological terrestrial systems, their stability will therefore be upset, and only a few plants will grow very fast. As a consequence, the biodiversity of the system will be adversely affected. If an aquatic system is contaminated with too much N and P, large quantities of algae will be produced which use up all the oxygen in the water. Such a lack of oxygen will greatly disadvantage aquatic animals which may have too little oxygen to survive.

Additional amounts of N or P can be fed into an ecological system either directly from the source or through the atmosphere. An example for the latter is NO<sub>x</sub> which is generated

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through fuel combustion, emitted into the air, transported over large distances and washed out by rain before it finally reaches the terrestrial system. This is an important process for our purposes of considering and comparing different fuels.

The eutrication potential of each compound is standardized to  $\text{PO}_4^{3-}$  and expressed in  $\text{kg PO}_4^{3-}$ . (EMIS Handbook, 2002)

*Ozone formation potential:*

One must not confuse the ozone formation potential with the ozone degradation potential. The ozone formation occurs in the troposphere, i.e. in the area where life exists and where  $\text{O}_3$  can damage living creatures. The ozone degradation caused by anthropogenic activities occurs in the stratosphere where such  $\text{O}_3$  is very important to protect life on earth from dangerous UV rays.

EMIS uses data from Heijungs (1992) for its calculation of the ozone formation potential. The catalyzing function of  $\text{NO}_x$  with regards to the ozone formation, however, has not been appropriately taken into account by Heijungs (EMIS Handbook, 2002).

Together with NMVOC,  $\text{NO}_x$  is able to contribute significantly to the ozone formation potential, depending on the rate of NMVOC and  $\text{NO}_x$ .  $\text{NO}_x$  can therefore also be included in the chemical reaction, or it may only react as a catalyst. That means it assists the process of NMVOC degradation into different smaller molecules. Together with  $\text{O}_2$  it generates ozone (Staehelin, 1994). Sun rays are the energy resource for these chemical activities, which is why during hot sunny days and under the right chemical conditions, particularly large amounts of ozone are formed in the troposphere.

### 4.1.3 Total Impact Indicators

A Total Impact Indicator condenses all the different environmental indicators into a single value, enabling the researcher to subject the environmental impact of different processes, different products and different enterprises to a quick comparison and to determine immediately if one product, process or enterprise is more environmentally friendly than the other. For the purposes of the investigation into palm oil methyl ester, two different Total Impact Indicators were chosen: UBP 97 and Eco-Indicator 99. Both indicators are either based on Swiss measurements or on European standards, which may raise questions – at least at first sight – about their suitability to the specific circumstances in Costa Rica. In the following, both indicators as well as their potential benefits and their significance shall be briefly explained.

*UBP 97*

UBP 97 is a method of rating different types of material flow and of assessing them in terms of Swiss environmental policy objectives. This means that each single impact indicator such as the ozone formation potential, the global warming potential etc. is weighted according to

the importance and priority of the specific environmental issue as defined by Swiss Law or the overall environmental concept for Switzerland.

The weighting factor for the different indicators is the “ecological deficit” defined as the ratio between the maximum permissible amount of a certain compound in the environment (critical amount) and the current amount in a certain area (Switzerland). The critical amount is defined on the political level by the duly authorized decisions-making bodies.

The mathematical formula is quite simple:

$$\text{Environmental Stress Factor}_i = c * F_i / F_{ik}^2$$

c: factor to reach desired level,  $10^{12}$

$F_i$ : current amount in the environment

$F_{ik}^2$ : critical amount of a compound i with an exponent of 2

In the end, the resulting environmental stress factor for a compound i has to be multiplied with the actual emissions of this compound to calculate the total environmental stress, in German ‘Umweltbelastungspunkte’ UBP.

$$\text{UBP}_i = \text{Environmental Stress Factor}_i * \text{Emissions}_i$$

These UBPs provide a standardised unit which make all environmental indicators comparable to one another. In order to calculate the Total Impact Indicator, one only has to add up all UBPs of the different indicators. (BUWAL, SRU 271, 1997)

#### *Eco-Indicator 95 / 99*

The Eco-Indicator is based on another weighting method which does not rate the individual environmental impacts in reference to political decisions but to each other. For each class of compound, a characteristic factor is allocated which reflects the specific impact on the environment. The weighting factor links this characterisation factor with a reduction factor (which describes by how much an emission has to be reduced to reach a sustainable level) and a standardisation factor:

$$\text{Weighting Factor} = \text{Characterisation Factor} * \text{Reduction Factor} * \frac{F}{\text{Standardisation Factor}}$$

F: Factor to reach desired level

The characterisation factor and the standardisation factor are therefore different, depending on the individual impact indicators such as acidification potential, eutrication potential, etc. To calculate the number of Eco-Indicator points, one only has to multiply these points with the actual emission (following the same method as for UBP):

$$\text{Eco-Indicator Points} = \text{Weighting Factor} * \text{Emission}$$

Since the allocation of all the characterisation factors to the compound classes turned out to be both difficult and very time-consuming, an improved version of the Eco-Indicator

methods was developed in 1999. For more information about the Ecoindicator see the EMIS Handbook, 2002, or Goedkop, The Eco-Indicator, 1995.

#### *Assessment of both methods*

Both methods are trying to reduce the different environmental impacts to a single value. One method is using government policies and objectives as its point of reference, the other method concentrates on the ratio between the different environmental factors. Depending on the life cycle assessment under investigation, the results between those two methods can differ quite substantially. This indicates that there may be no universal method to establish the Total Impact Indicator and that one has to be fully aware of the chosen method when assessing the results.

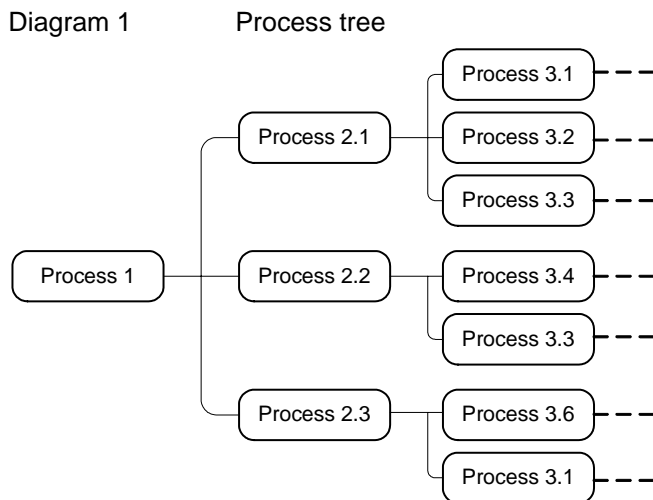
For the purposes of the PME project, both methods could be used to compare the different fuels under investigation with each other. Since both methods of establishing the Total Impact Indicator were mainly developed for European and Swiss standards, however, the figures from the PME project cannot be compared to other European fuels, for example. Furthermore, eco-balancing is not particularly widespread in Central America which is why the palm oil methyl ester cannot be compared with other industrial products for the purpose of assessing the potential environmental damages from PME.

For those reasons, the results of those methods of establishing the Total Impact Indicator are considered to be reactive.

#### **4.1.4 Tools**

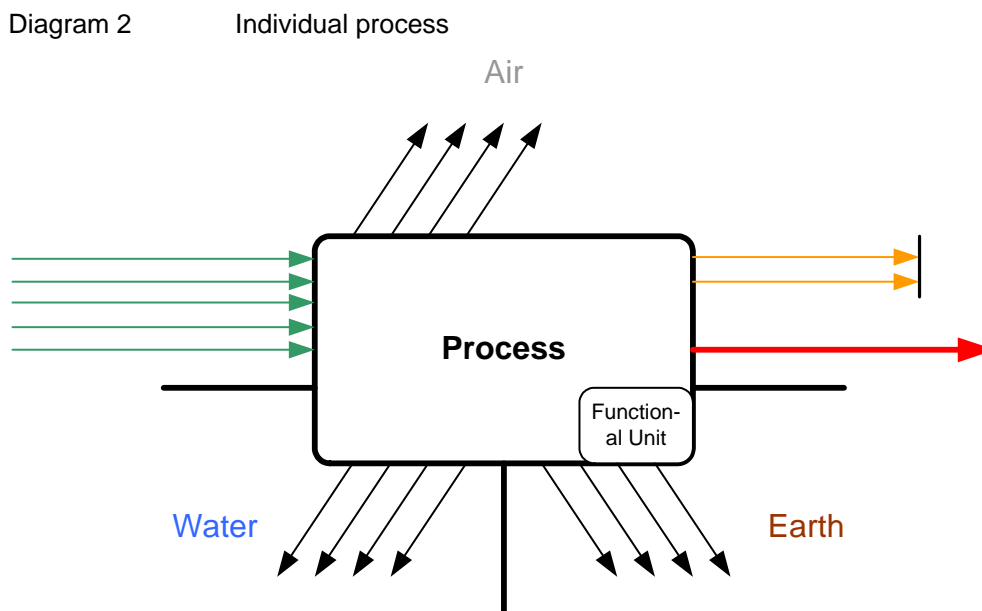
The Environmental Management and Information System (EMIS) is a powerful tool to calculate the environmental impact of inputs and outputs during an entire lifecycle. This software, developed by Carbotech AG, Switzerland, takes into account all aspects of an eco-balance and assists in an effective data administration. On top of that, a database with project-related data is available.

As we already mentioned in the introduction, the fundamental unit of EMIS is a process. Each process has an input, an output and emissions. The input of a process consists of other processes in the EMIS database or self-created processes. In the production chain of a product, these input processes are located upstream of the process in question. In turn, each of these input processes has input processes of its own and so on. A process tree has developed.



As can be seen apart from Process 1, each process is an input into other processes and also has its own inputs. One process can figure as an input process more than once as is shown for processes 3.3 and 3.1. Process 3.3, for example, could be a transport and is used for processes 2.1 and 2.2. At the end of each branch of the process tree, one can find natural resources such as fossil fuel, minerals etc.

Looking more closely into a single process, the following picture illustrates which dimensions are taken account of by EMIS:



This diagram illustrates the inputs and outputs as well as the emissions into air, earth and water. The horizontal green arrows from the left describe the inputs of this process which are themselves the outputs from upstream processes. These could be energy, raw materials or semi-finished goods.

The single horizontal red arrow on the right stands for the output, itself at the same time an input into another process. Horizontal arrows are always describing the technological sphere. Each of the horizontal arrows on the left stands for a product which had been produced in a previous processing step as well as all environmental impacts occurring during its production. The single arrow on the right will be an input into the next processing step. The brief vertical line in front of the orange arrows on the right indicates that there is no further way to go. Thus, they do have other purposes: Some processes have by-products which can be sold or used in another way. It would therefore be wrong to allocate all of the environmental impacts to the next process in the production chain. Depending on the value of the by-product (economic, ecological, social), certain environmental impacts are allocated to them. In the end this means that not all environmental impacts occurring during a life cycle are allocated to the final product and that some can also go to by-products.

The black diagonal arrows stand for the flow of compounds or materials into air, earth or water. That could be combustion-generated NO<sub>x</sub>, an organic compound in the form of wastewater created during production or fertilizer from the treatment of plants.

Each process has a functional unit to which the amounts of inputs and outputs refer, for example the amount of electricity required (input) to produce one litre of milk. (One litre is the functional unit in this example.) One could also go further and ask how many litres of milk were required (input) to produce one kg of cheese. The functional unit in this example would be one kg.

All horizontal and diagonal arrows as well as the functional units are parameters which can be freely chosen to create a process. There are other parameters which define a process more precisely. For more information see the EMIS Handbook, 2002.

## **4.2 Procedure**

This chapter describes chronologically how the palm oil methyl ester LCA was performed.

### **4.2.1 Combination of two LCAs**

First of all, to obtain an initial rough process tree of the LCA of PME, two other LCAs were combined. The first was a study about palm-oil-based soap from Ghana, the other a European study on rapeseed methyl ester (Bernauer Breu et al. 2002; Dinkel, Real, 1998). This made it easier to evaluate the data, since each Life Cycle Assessment was dealing with a specific part of the PME LCA: the Ghana soap project with the production of palm oil from *Palma Africana* and the rapeseed methyl ester project with transesterification and combustion.

In order to reflect the PME LCA correctly, a totally new process tree was developed during research, and some processes from the combination of the Ghana and rapeseed methylester LCAs were changed.

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## 4.2.2 Data Collection

The following sources were used to collect the data:

- Other studies
- World Wide Web
- Discussions with experts
- Visit in a palm oil manufacturing plant in Costa Rica
- EMIS Database

Information from the world wide web was handled with particular care. Wherever possible, at least two different sites were consulted for each issue. The visit at the palm oil manufacturing plant and the discussions with experts turned out to be the most valuable sources.

The process of obtaining data is an iterative one. After most of the data had been collected, an initial analysis was performed to evaluate which steps in the production process had the strongest environmental impact. Those parts were then subjected to closer examination. It turned out that the production of methanol to transesterify the refined palm oil and the cultivation of palm trees are the two steps which potentially create the highest number of environmental problems.

## 4.2.3 Selection of Impact Indicators

The impact indicators were selected with the help of an LCA expert from Switzerland (F. Dinkel, Carbotech AG). It was the intention to concentrate only on the most important indicators to keep track on the environmental impact. The following indicators were chosen:

- *Non-renewable* energy resources
- Global warming potential
- Acidification potential
- Eutrication potential
- Ozone formation potential

Initially, air and water toxicity were also considered to be important environmental indicators. They were found, however, to be very sensitive to specific compounds. Since the different emissions of compounds and their contributions to the toxicity indicators are not exactly known, it was feared that the results might easily be compromised by such “artificial effects”. And this was exactly what happened during some early attempts to establish the levels of air and water toxicity, and it was subsequently decided to leave these indicators out, at least for the purpose of the EMIS calculations.

The following example where a NMVOC increases the levels of air toxicity shall illustrate the meaning of the term “artificial effect”.

*An example for an artificial effect*

The air toxicity level in the process of ‘PME-Imeth’ was substantially increased by the NMVOC which had been released in the sites for the wastewater treatment and biological waste disposal. At the palm oil manufacturing plant, approximately 960 m<sup>3</sup> of water which has been highly contaminated with oily substances is fed into the wastewater site (total water capacity: 46,800 m<sup>3</sup>) every day. The average retention time in those basins is app. 48 days. The cleansed water leaves the site with acceptable COD and BOD<sub>5</sub> values. The solid waste is spread across about four hectares (10 acres) and mainly consists of EFB (Empty Fruit Bunches), leftovers from the Palma Africana fruit processing operation.

To estimate the levels of air toxicity, EMIS uses a weighting factor (GWF) which considers three parameters:

Retention time in the troposphere (VZ)

Security factor (SF)

Quality target (QZ)

Retention time in the troposphere describes how long a certain substance remains in the air. There are three ways for substances to “disappear”: degradation, adsorption and absorption. The longer a toxic substance remains in the air, the more damage it can cause.

The creators of this system (Ökoscience, 1994) also added a security factor. Depending on the knowledge and toxicity of products generated by substance degradation, they allocated the factors 1, 10, 30 and 100 to each compound under investigation. More detailed information about this security factor can be found in the EMIS handbook (EMIS 2001) or at the Ökoscience Switzerland website under [www.oekoscience.ch](http://www.oekoscience.ch).

The third parameter takes account of the sensitivity of humans, animals and plants to chemical substances in the air and serves to assess the concentrations of various chemicals which are not life-threatening as such. For this purpose, a quality target (QZ) was established.

These three parameters are mutually linked as follows:  $VZ * SF / QZ = GWF$

For the purposes of the ‘Diesel C.R.’ and ‘PME’ LCAs, the following chemicals were considered:

Table 2 QZ, VZ, SF and GWF of 5 relevant chemicals

Chemicals	QZ [ $\mu\text{g}/\text{m}^3$ ]	Retention Time, VZ [a]	SF	GWF [ $\text{a} \cdot \text{m}^3/\mu\text{g}$ ]
CO	8	0.208	1	0.026
NMVOC*	0.03	0.008	100	27
Particles	0.07	0.03	1	0.43
SO <sub>2</sub>	0.03	0.012	1	0.4
NO <sub>x</sub>	0.03	0.003	1	0.1

\*Non-Methane Volatile Organic Compounds

A security factor of 1 indicates that the decomposition process of a compound is known and that no other more toxic substances occur. A security factor of 100 means that the decomposition process is not known and many downstream products could be much more toxic than the emitted compound. This was precisely where the artificial effect occurred. Since many different and possibly highly toxic compounds could be produced by the process of NMVOC degradation, a security factor of 100 was assigned. Since it was known, however, that no significant amounts of toxic compounds were released from either the water treatment or waste disposal sites, the GWF was excessively high and the level of air toxicity was consequently too heavily weighted.

## 4.3 Scope

### 4.3.1 System Boundaries

The diagram underneath shows what products and processes were considered for the purposes of the PME LCA. The green arrows on the left indicate the manufacturing input. The orange arrows on the right stand for the by-products and the brown arrows on the right (outside of the dashed box) for the finished products made from them. All emissions into the environment are included.. The finished product, PME, is located in the red box at the bottom.

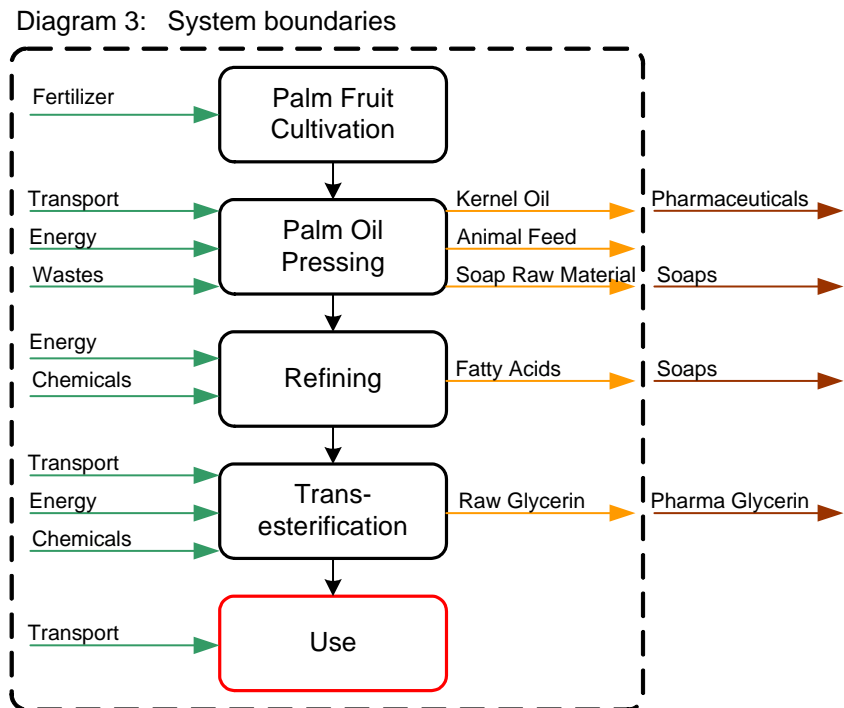


Table 3: Aspects within the system boundaries

The following processes were taken into account:

The following processes were NOT taken into account:

- |  |  |
|--|--|
| <ul style="list-style-type: none"> <li>• Production of fertilizer and its use during cultivation</li> <li>• Transportation of fruits and products</li> <li>• Use and type of energy during production</li> <li>• Transport, use and production of additives</li> <li>• Production and treatment of wastes</li> <li>• Impact allocation of by-products</li> <li>• Transport of PME to gas stations</li> <li>• Emissions during combustion of PME</li> </ul> | <ul style="list-style-type: none"> <li>• Production of palm seedlings</li> <li>• Land acquisition for cultivation of Palma Africana</li> <li>• Loss of biodiversity caused by palm plantations</li> <li>• Washed-out fertilizer</li> <li>• Transportation of workers to the production plant</li> <li>• Manufacturing of production installations</li> <li>• Manufacturing of vehicles</li> <li>• Facility change of petrol pumps</li> <li>• Facility change of vehicles by using B 100</li> </ul> |
|--|--|

### 4.3.2 Data Quality

The general research data quality can only be assessed here in the briefest of terms. The data of each individual process will be more thoroughly evaluated in chapter 4.4.

Many of the palm oil production data used for this LCA were collected from a single palm oil manufacturing plant in the south of Costa Rica. It was decided not to subject these data to a comparison with data from similar enterprises. The company was extremely cooperative and all requested data, if possible, were made available.

No plant for the transesterification of vegetable oil has ever been built in Central America. The data for this part of the LCA were based on a tender for biodiesel plant equipment submitted by Kirchfeld Ferrostaal in Germany on the invitation of FHBB in Switzerland (Ferrostaal AG, 2002). This tender describes the transesterification of palm oil methyl ester with all necessary specifications. Sound estimates could be performed on the basis of this tender.

The most serious problem of this study was to determine the assumptions on which the emissions resulting from PME combustions in Costa Rican diesel engines were to be estimated. No such data are yet in existence. These assumptions were eventually based on the data from rapeseed methyl ester in Europe. The emissions of this fuel, also made from plants, were taken over and multiplied with a certain factor to reflect the fact that the most engines in Costa Rica are fairly old. Emission values for the diesel vehicles currently being driven on Costa Rican roads were equally in short supply and had to be estimated, too. Since, however, large amounts of data about rapeseed methyl ester emissions in Europe exist and since rapeseed oil and palm oil are both vegetable-based, any such estimates will be fairly reliable. The Swiss Government also released a study about the history of vehicle emissions, published by the Swiss Federal Laboratories for Materials Testing and Research (EMPA), ensuring that the assumptions made for the purposes of this study were of high quality and scientifically based. (BUWAL, SRU Nr. 255). More details about the assumptions made are provided in chapter 4.4.

Despite the assumptions described in the above paragraph and in view of the purpose of these investigations – i.e. to estimate the ecological impact of the production of palm oil methyl ester – the estimates seem sufficiently reliable and justifiable. A medical research study into the same phenomenon would, for instance, have required a much higher level of data accuracy.

### 4.3.3 Allocation

The purpose of an allocation is to allocate the environmental impacts not only to the product under consideration but also to all usable or economically relevant by-products which occur during a given process.

All allocations were performed on an economic basis. Wherever references are made to the income from selling (Crude Palm Oil) CPO or RPO (Refined Palm Oil), any income from by-products was taken into account for the calculation of the economic allocation factor.

Example:  $\text{Income of by-products} / \text{Income of main products} = \text{Allocation factor}$

## 4.4 Description of Processes - Assumptions

In order to make this work as transparent as possible, the different processes and assumptions will be described in the following paragraphs. Each relevant process will be discussed, starting with the use and combustion of the individual fuels treated in the report. An overview over all processes in the LCA of PME and all data (inputs, outputs, emissions etc.) used in the text and calculations will be provided in Appendix A.

### *'Diesel C.R.'*

This process describes the operation of a heavy goods vehicle (HGV) with diesel from Costa Rica including all environmental impacts occurring during its production.

**Functional unit** In all final processes discussed in this report such as 'Diesel C.R.', 'PME I-Meth', 'PME Bio-Meth', 'PME EthCR' and 'Ethanol C.R.', the functional unit of 'per kWh on the shaft' was selected, in line with an already existing study from Europe about rapeseed methyl ester (Dinkel et al., 1998). This functional unit has the advantage that it works with all types of vehicle. Virtually no energy loss occurs between the fuel combustion engine and the shaft, the first energy transmitter. How far a vehicle can go with one kWh on the shaft depends on a range of factors such as its weight, its type of wheels etc.

**Inputs** Only one input process is listed. It describes the amount of diesel that is used to produce one kWh on the shaft: 0.3 kg.

**Assumptions** No reliable data of the emissions from Costa Rican diesel-fuelled vehicles could be found. This is why the following assumptions were made: the heavy goods vehicles (HGV) in today's Costa Rica are comparable with heavy goods vehicles from the 1970s in Europe (Dr. Sergio Musmanni, CNPML Costa Rica). The earliest data about atmospheric emissions are from the 1980s. Recorded estimates exist for emissions from previous years (BUWAL, SRU 255), multiplying the emissions from a 1980s HGV by the following factors:

- CO: 1.9
- HC: 1.9
- NO<sub>x</sub>: 1.25

The factor 1.9 for CO means that the CO emissions in the 1970s were about 1.9 times higher than in the 1980s. The same applied to HC whereas NO<sub>x</sub> was multiplied by a factor of 1.25.

#### *'PME I-Meth'*

This process describes the operation of a HGV with palm oil methyl ester, taking into account all environmental impacts occurring during its production. The term PME-Imeth indicates that the palm oil has been transesterified with industrially produced methanol.

Functional unit kWh on the shaft

**Inputs** Two inputs are considered: firstly, the Transesterification I-Meth which includes the transesterified fuel which is ready for use. The production of one kWh on the shaft requires the combustion of 0.37 kg of PME. Secondly, the transport truck 28t C.R. (1970) which describes the distribution from the national fuel pipeline to the gas stations. It was assumed that on average 20 tons of fuel are transported at a time and that a distance of 50 km to each gasoline station has to be covered, resulting in 0.000925 tkm per kWh on the shaft.

**Assumptions** As mentioned above in chapter 4.3, no data were available about the air emissions of PME combustions in Costa Rican vehicles. The following technique was applied to provide an estimate: Since both PME and rapeseed methyl ester (RME) are vegetable oils, it was assumed that they produce roughly similar levels of emissions. Data about RME emissions and data about conventional diesel emissions are available in Europe. Emission values of those two fuels were compared for each emission compound, and their factor was calculated. Combustion of the fuels took place in the same engine. Those factors were then applied to the emissions of a diesel combusting vehicle in Costa Rica in order to calculate the PME emissions.

The SO<sub>2</sub> emissions from PME combustions were ignored as vegetable oils contain virtually no sulphur.

#### *'PME Bio-Meth'*

This process describes the operation of a HGV with palm oil methyl ester, taking into account all environmental impacts occurring during its production. The term Bio-Meth indicates that the methanol for transesterification has been produced from old treated wood and some plastics (pyrolysis). This is why the input process is now called Transesterification Bio-Meth rather than Transesterification I-Meth as it was for PME I-Meth. That is the only difference to PME I-Meth. All the other parameters stay the same.

#### *'PEE EthCR'*

This process describes the operation of a HGV with palm oil ethyl ester, taking into account all environmental impacts occurring during its production. Ethanol from national sugar cane rather than methanol is used for the transesterification. The data for the ethanol production are based on data from sugar cane manufacturing in Brazil. Some parameters have been changed to adapt these data to Costa Rican conditions. As above, all the other parameter stay the same as for PME I-Meth.

*'Ethanol C.R.'*

This process describes the operation of a HGV with ethanol from sugar cane, taking into account all environmental impacts occurring during its production. Data about the operation of HGVs with ethanol were taken over one-on-one from the EMIS database. This is why no adaptations to Costa Rican circumstances were made. This process was mainly used to get an idea about the environmental impact caused by ethanol in comparison with PME.

*'Transesterification I-Meth'*

This process describes the transesterification of RPO (Refined Palm Oil), taking into account all environmental impacts occurring during previous production steps. I-Meth again stands for industrially produced methanol, methanol made from fossil fuels.

Functional unit one (metric) ton of transesterified fuel

**Inputs** Almost all inputs in this process come from a tender submitted by Kirchfeld Ferrostaal, a heavy engineering company in Germany. This tender was submitted on the invitation of FHBB (Institute of Applied Science and Technology Basel, Switzerland) which had wanted to obtain information about the possible construction of an transesterification plant in Central America. The production of one metric ton of transesterified fuel requires 115 kg of industrially produced methanol (made from fossil fuel).

To obtain one ton of transesterified oil, 1.03 t of refined oil from a refinery is required. The refinery process in this case also includes degumming and deacidification.

**By-products** During transesterification, glycerine is generated as a by-product which can be sold for pharmaceutical use. This raw glycerine, however, is only approximately 80% pure (P. Koester, Ferrostaal). Pharmaceutical glycerine requires a purity of 99%. Pure glycerine fetches about 900 US\$/ton, 80 % glycerine about 300 US\$/ton. The production of one ton of transesterified fuel generates about 130 kg of raw glycerine.

The economic allocation of environmental impacts can be performed on the basis of these facts and figures.

*'Transesterification Bio-Meth'*

This process describes the transesterification of RPO including all environmental impacts occurring in previous production steps. The methanol used for transesterification is not produced from fossil fuel but from waste wood and some plastics. The advantage of this method is that almost no non-renewable energy is used and consequently no CO<sub>2</sub> emissions are produced which could increase the risks of global warming.

The other parameters are identical to those for the Transesterification I-Meth.

*'Transesterification EthCR'*

This process describes the transesterification of RPO including all environmental impacts occurring in previous production steps. Instead of methanol, ethanol from sugar cane is used to transesterify RPO. All data from the methanol-based transesterification process were taken over except for those for the amounts of methanol and ethanol. Stoichiometric calculations showed that 160 kg of ethanol was required to produce one ton of PME (compared to 115 kg of methanol).

*'Refinery'*

This process describes the steps required to refine CPO into RPO including all environmental impacts occurring in previous production steps. Crude palm oil (CPO) from the extraction of oil is brought to the refinery plant to prepare the oil for transesterification.

Functional unit (metric) ton of refined palm oil

**Inputs** 1.069 t of crude palm oil is required to produce one ton of refined palm oil. The energy used is divided into four categories according to the different sources: energy from the mains, energy from burning bunker in stoves, energy from burning organic matter in stoves and energy obtained from burning diesel. The first three types of energy are obtained from the general energy supply on the plant, whereas the last type of energy is specially generated for refinery purposes.

NaOH is used to clean filters and afterwards used for cleaning other equipment and floors rather than being thrown away.

Two other inputs were not considered in the LCA as there was insufficient information about the environmental impacts occurring during their production: Adsorbent is being used to dry the oil. Adsorbent is consumed in a ratio of about 0.6:100, meaning that 6 kg of adsorbent are applied for the production of one ton of RPO. Citric acid in a ratio of 0.01:100 (RPO) is used to degum CPO.

**By-products** During the refinery process, fatty acids are generated which can be sold for a price of US-\$ 120 to soap manufacturers and others. About 30 kg of fatty acids are generated per ton of RPO. The allocation factor is 0.01.

*'Extraction of palm oil'*

This process describes the extraction of palm oil from the fruit including all environmental impacts occurring in previous production steps.

Functional unit (metric) ton of extracted crude palm oil

**Inputs** Six inputs are considered: Three to describe the energy use of the plant, one to account for the transport of fruits, one to account for the waste disposal on the plant and one to describe the raw material.

Two processes are worth a particular mention:

There is a power station on the plant which uses two steam turbines to generate electricity. Stoves are producing the steam. In those stoves, bunker as well as organic matter is burnt. In order to take into account that the organic matter is a renewable energy resource, the process 'Combustion Biomass' was developed which is based on the input of a NEGATIVE NON-renewable energy resource, ensuring that CO<sub>2</sub> emissions and the resulting global warming risks are reduced.

The extraction of palm oil produces a lot of liquid and solid organic waste. Oily, liquid organic waste is treated in a company-operated wastewater treatment plant. Solid waste is disposed on a designated disposal site. Those two waste disposal sites are working with biodegradation, producing emissions such as methane and other volatile organic compounds. The treated water which flows back into a river also contains traces of COD and BOD which have an impact on the environment. This is why the process 'Kompostierung und Lagunen C.R.' was developed.

**By-products** Different by-products are produced during the extraction of oil from the fruits of Palma Africana:

Oil can be recovered from the above-mentioned wastewater lagoons and sold as fuel, animal feed or for soap production. The economic allocation factor does not exceed one percent.

The palm kernel oil which is also produced will not be used for biodiesel but for pharmaceutical and beauty products instead. The economic allocation factor is 2%.

High-grade animal feed can be extracted (and sold) from the residues of palm kernel oil. The economic allocation factor does not exceed one percent.

*'Electricity mix C.R.'*

This process describes the different types of electricity production in Costa Rica including all environmental impacts occurring in previous production steps.

Functional unit MJ of used electricity

Inputs Costa Rica has four different sources of electricity:

- Hydropower
- Geothermal energy
- Energy from fossil fuel
- Wind power

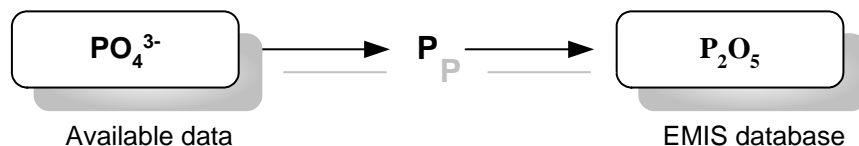
Water power meets most of Costa Rica's energy requirements (80.3 %), followed by geothermal energy (12.7 %), fossil energy (5 %) and wind power (2 %). ([www.costarica.com](http://www.costarica.com), Energy and Transportation; Cámara de Industrias de Costa Rica)

#### 'Cultivation of Palma Africana'

This process describes the use of fertilizer utilised to cultivate Palma Africana including all environmental impacts occurring in previous production steps.

Functional unit 1 hectare of Palma Africana plantations

Inputs Inputs covering the use, production and transportation of fertilizer. The following calculations were made: In the EMIS database, phosphorus and nitrogen appear in the form of  $P_2O_5$  and  $N(25\%)$  respectively, while the fertilizers actually applied were based on  $PO_4^{3-}$  and  $NH_4^+$ .  $N(25\%)$  means that nitrogen accounts for 25 % of the total fertilizer mass. As P and N are the main fertilizer ingredients, the actual amounts of P and N brought to the field were stoichiometrically calculated and scaled up to comply with the fertilizer data in the EMIS database. For example:



The fertilizer is imported from the U.S., so the following assumptions were made to estimate the transport costs.

- Average distance from the manufacturer to the plantation: 2,000 km
- Average load per HGV: 15 tons

- 750 kg fertilizer used per year and hectare

On the basis of these data, 6.65 tkm are used for the transport of fertilizers.

## 5 Biodiesel from Palm Oil

### 5.1 Results

The following sub-chapters will compare the environmental impact of the manufacture and use of different fuels, focusing on:

- Manufacturing and combustion of Palm Oil Methyl Ester (PME), transesterified with industrial methanol made from fossil fuel. Abbreviation: *PME-Imeth*
- Manufacturing and combustion of PME, transesterified with biological methanol, which is methanol from pyrolysis. Abbreviation: *PME-Biometh*
- Manufacturing and combustion of commercially distributed Costa Rican diesel: *Diesel C.R.*
- Manufacturing and combustion of ethanol from sugar cane: *Ethanol C.R.*
- Manufacturing and combustion of Palm Oil Ethyl Ester (PEE), transesterified with Ethanol from Costa Rican sugar cane: *PEE EthCR.*

Since the production of the transesterification agent such as (for our purposes) methanol or ethanol plays an important role in the Life Cycle Assessment (LCA) of PME as far as the non-renewable energy resources and other environmental impacts are concerned, three “different” PMEs will be created: firstly, PME produced with industrial methanol; secondly, PME transesterified with methanol which has been produced in a more biological way i.e. which has been generated from the combustion of waste wood and certain plastics; and thirdly, PEE which has been transesterified with ethanol from Costa Rican sugar cane.

The environmental impact of the biological methanol production is also economically allocated to the energy which has been generated during the pyrolysis of the wood. This means that the environmental impacts of the methanol production are not totally allocated to the methanol but also to the usable energy. This is accounted for by an economical factor (EMIS Database).

The chemical composition of diesel in South and Central America is different from that of diesel in other parts of the world including Europe. The sulphur content, e.g., is much higher in Costa Rica than in Europe. Shell Costa Rica for example reported an average sulphur content of about 0.5 % whereas in Switzerland any sulphur content above 0.035% (350 ppm) would be illegal (Shell Costa Rica, EMPA Switzerland).

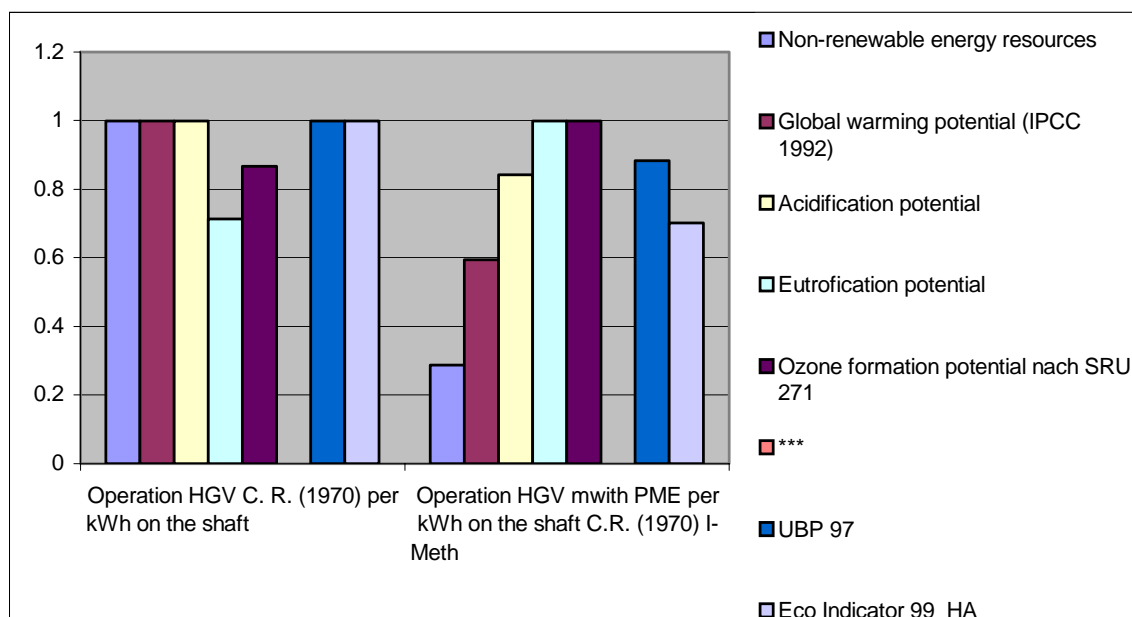
Carbotech Switzerland has conducted biofuel experiments with ethanol in Brazil. Ethanol biodiesel was used as a PME reference for two reasons. Firstly, ethanol made from sugar

cane is already being used as a fuel in Brazil and represents another alternative to conventional diesel. Secondly, sugar cane production (about 0.2% of GDP) is economically only slightly less important than palm oil production (about 0.8% of GDP) (Cámara de Industrias de Costa Rica).

### 5.1.1 Diesel C.R. versus PME-Imeth

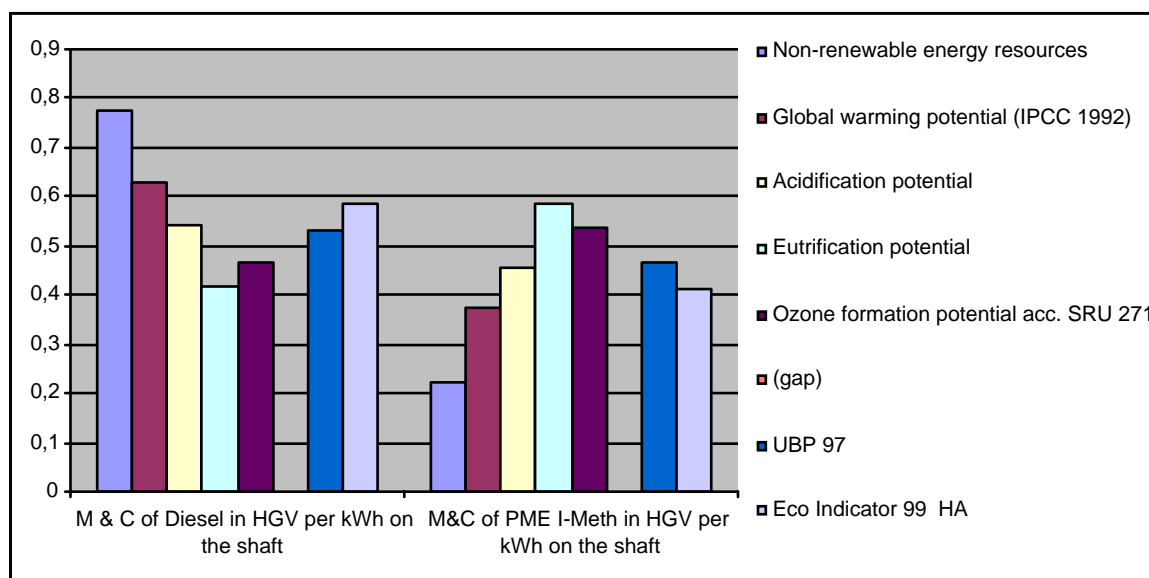
Two different types of bar diagrams are shown below. In diagram 4, the indicators of environmental impacts are standardized to the maximum of each impact (SMI), i.e. the environmental impact of one fuel is expressed as a ratio to the impact of the other fuels. In diagram 5, the indicators of environmental impacts are standardized to the sum of each impact (SSI). The sum for each impact indicator of ‘Diesel C.R.’ and ‘PME-Imeth’ is always 100 percent – if, for example, one impact amounts to 60 % for ‘Diesel C.R.’ the same impact indicator for ‘PME-Imeth’ will amount to 40%.

Diagram 4: Comparison of environmental impacts: ‘Diesel C.R.’ v. ‘PME-Imeth’, standardized to the maximum of each impact (SMI)



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

Diagram 5: Comparison of environmental impacts: 'Diesel C.R.' v. 'PME-Imeth', standardized to the sum of each impact (SSI)



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

*Non-Renewable Energy:* The use of non-renewable energy resources for 'PME-Imeth' in diagram 4 amounts to only 30 % of the value for 'Diesel C.R.' which is not surprising, as the conventional diesel is a non-renewable energy resource whereas 'PME-Imeth' is a mostly renewable energy resource. Most of the thirty percent can be allocated to the methanol production. The use of bunker to produce electricity on the plantation, the transport of Fresh Fruit Bunches (FFB) to the plant and other forms of transport only account for a few percent.

*Global Warming Potential:* Most of the CO<sub>2</sub> emissions in both processes are generated during the fuel combustion in the engine. The amount of CO<sub>2</sub> emissions during combustion is roughly the same, whether the engine is running on 'Diesel C.R.' or 'PME-Imeth'. The global warming potential of 'PME-Imeth' is nevertheless only half of that for 'Diesel C.R.' because of the different origins of the CO<sub>2</sub>. The CO<sub>2</sub> generated from the 'Diesel C.R.', after all, comes from a non-renewable source like fossil fuel, whereas the CO<sub>2</sub> from 'PME-Imeth' comes from a biological source, i.e. the oil of Palma Africana. This "biological" CO<sub>2</sub> has been assimilated out of the atmosphere by Palma Africana during the growth of FFB. The circle closes when 'PME-Imeth' is being combusted in engines and CO<sub>2</sub> is released into the atmosphere, ready to be absorbed again by Palma Africana.

A close look at the compounds which contribute to the process of global warming reveals that the CO<sub>2</sub> contributes 30 %, N<sub>2</sub>O 60% (!) and CH<sub>4</sub> 10% of the 'PME-Imeth' emissions whereas app. 99% of the global warming potential provided by the 'Diesel C.R.' is made up of CO<sub>2</sub> and one percent of methane. Nitrous oxide (N<sub>2</sub>O) is generated when using nitrogen fertilizer. The more nitrogen fertilizer is used, the higher the production of nitrous oxide.

Diagram 6: Global Warming Potential



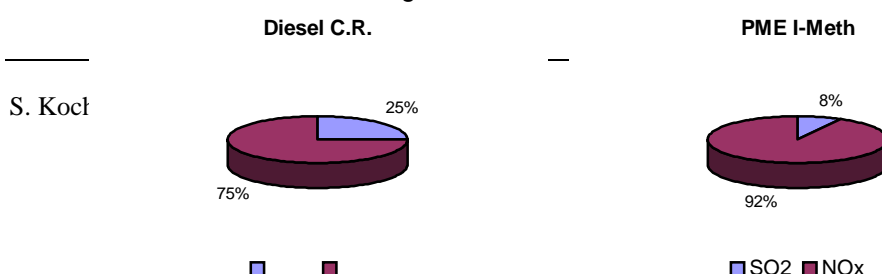
*Acidification Potential:* The contribution of different molecules to the acidification potential is standardized to the acidification potential of  $\text{SO}_2$ , i.e. the acidification potential of  $\text{SO}_2$  is weighted as 1 whereas all the other molecules are weighted in their relation to  $\text{SO}_2$ . After the combustion of fuels, the  $\text{NO}_x$  and  $\text{SO}_2$  molecules in particular make a major contribution to the acidification potential.  $\text{SO}_2$  is generated because of the S content in the oils, whereas  $\text{NO}_x$  is a product of the reaction with atmospheric  $\text{N}_2$  and mainly a matter of combustion technology. Both the 'Diesel C.R.' and the 'PME-Imeth' process therefore produce similar amounts of  $\text{NO}_x$  emission, estimated at 14.75 g/kWh. This figure is subject to deviations of up to 20%.

The sulphur content in fossil fuels is much higher than in vegetable oils. The S content in vegetable oils is actually so low that it can be totally ignored.  $\text{SO}_2$  emission of 'Diesel C.R.' combustion amounts to 3 g/kWh whereas  $\text{SO}_2$  emissions for 'PME-Imeth' combustion are very low. A brief look at the acidification table of Heijungs, 1992 shows the following factors for  $\text{SO}_2$  and  $\text{NO}_x$ :

$\text{SO}_2$ : 1  
 $\text{NO}_x$ : 0.7  
 (Heijungs, 1992)

The acidification potential of 'Diesel C.R.' is made up by  $\text{SO}_2$  and  $\text{NO}_x$  in a ratio of 1:3. For 'PME-Imeth', this ratio is nearer 1:10 (8 %  $\text{SO}_2$ , 92%  $\text{NO}_x$ ).  $\text{SO}_2$  emissions in 'PME-Imeth' are mainly caused by the production of methanol from fossil oil for transesterification. As the estimated  $\text{NO}_x$  emissions of both combustion processes are roughly equal and the combustion of both fuels accounts for most of the  $\text{NO}_x$  emissions in the respective process trees, the difference in the acidification potentials is caused by the different  $\text{SO}_2$  contents.

Diagram 7: Acidification Potential



*Eutricification Potential:* The most limiting nutrients for plants and bacteria are phosphorus and nitrogen. A look at the eutricification potential table reveals the following factors:

$\text{PO}_4^{3-}$ : 1 (standardized)

$\text{P}_2\text{O}_5$ : 0.67

N: 0.42

$\text{NO}_x$ : 0.13

$\text{NO}_3^-$ : 0.1

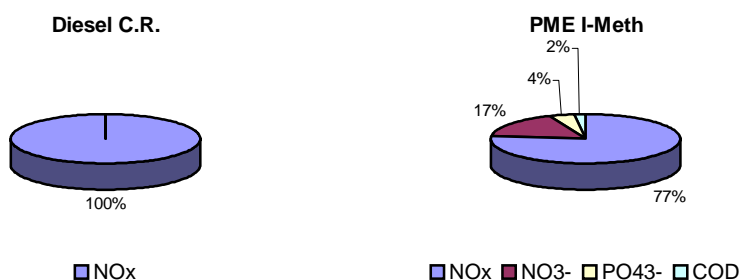
P: 3.06

(Heijungs, 1992)

The fertilization data were collected from a palm oil manufacturer in the south of Costa Rica who uses fertilizers in the form of  $\text{Na}_2\text{SO}_4$ ,  $\text{MgSO}_4$  and  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$  - DAP (Di Ammonium Phosphate). Because of data insufficiencies, some assumptions had to be made as far as the fertilizer and its processing in EMIS is concerned (see chapter 4.4).

A brief look at diagram 4 above shows that the eutricification potential of 'Diesel C.R.' is about 30 % lower than that of 'PME-Imeth'. Almost the whole eutricification potential of 'Diesel C.R.' is caused by the release of  $\text{NO}_x$  in the fuel combustion process of the engine, a generator or a similar appliance. The same indicator for 'PME-Imeth', meanwhile, can be divided into several sub-groups. The nitrate ( $\text{NO}_3^-$ ) contributes 17 %, the  $\text{NO}_x$  from combustion 77% percent and  $\text{PO}_4^{3-}$  4%. Most of these emissions are caused by the use of fertilizer on the Palma Africana plantations. According to Heijungs et al, 1992, the chemical oxygen demand (COD) also contributes to the eutricification potential (2 % in this case).

Diagram 8: Eutricification Potential



*Ozone Formation Potential:* Looking at diagram 4, the ozone formation potential appears slightly higher for ‘PME-Imeth’ than for ‘Diesel C.R.’. This small difference of about 13 % is caused by the NMVOCs (Non-Methane Volatile Organic Compounds) which are released from the disposal sites for wastewater and solid waste. The ozone formation potential of ‘PME-Imeth’ is made up of NMVOC and NO<sub>x</sub> in a ratio of 1:4 (20 % to 80 %), whereas the same ratio for the ozone formation potential of ‘Diesel C.R.’ is more like 1:6 (14 % and 86 % ).

Diagram 9: Ozone Formation Potential



A closer look at the two processes reveals that in the ‘Diesel C.R.’ process, 86 % of the ozone formation potential has been generated by the combustion of diesel in vehicle engines. The other 14% are shared by the other production steps of diesel. In the ‘PME-Imeth’ process, 74 % of the ozone formation potential derives from PME combustion, app. 13% are generated during the refining process and another 13% are generated by the disposal sites for wastewater and solid waste – because, as mentioned before, much of the NMVOC is released in those sites. The role of the NMVOC in the generation of the ozone formation potential is explained in greater detail in chapter 4.1.2.

The first of the last two paragraphs described which compounds are causing the ozone formation potential, whereas the second of these paragraphs explained where in the production chain these compounds are generated.

*Total Impacts:* UBP ’97 and Eco Indicators ’99 are two different attempts to express all environmental impacts in a single value. The two systems including some of their problems are discussed in more detail in chapter 4.1 where you can also find a critical assessment. Right now, we shall concentrate on the differences in the “total impacts” of the two products ‘Diesel C.R.’ and ‘PME-Imeth’.

Both methods, UBP ’97 and Eco Indicator ’99, produce values in the SMI diagram which are lower for the ‘PME-Imeth’ (by 10 % and 30 % respectively). The differences on the SSI diagram are between 10 % and 20 %. These results indicate that ‘PME-Imeth’ is, taking into account all listed environmental impacts, slightly superior from an ecological point of view.

But no single factor is clearly showing that ‘PME-Imeth’ is definitely better than ‘Diesel C.R.’.

### 5.1.2 Diesel C.R. versus PME-Biometh

As mentioned above, the only difference between ‘PME-Imeth’ and ‘PME-Biometh’ is the way in which the methanol for the transesterification is being produced. In ‘PME-Imeth’, it is produced from fossil fuel, whereas in ‘PME-Biometh’ the methanol is produced by the pyrolysis of waste wood. Waste wood for our purposes means wood with treated surfaces such as writing desks or painted wooden walls from old buildings etc. “Waste wood” in this sense may also include certain plastics. This type of methanol production requires special equipment and additional investments.

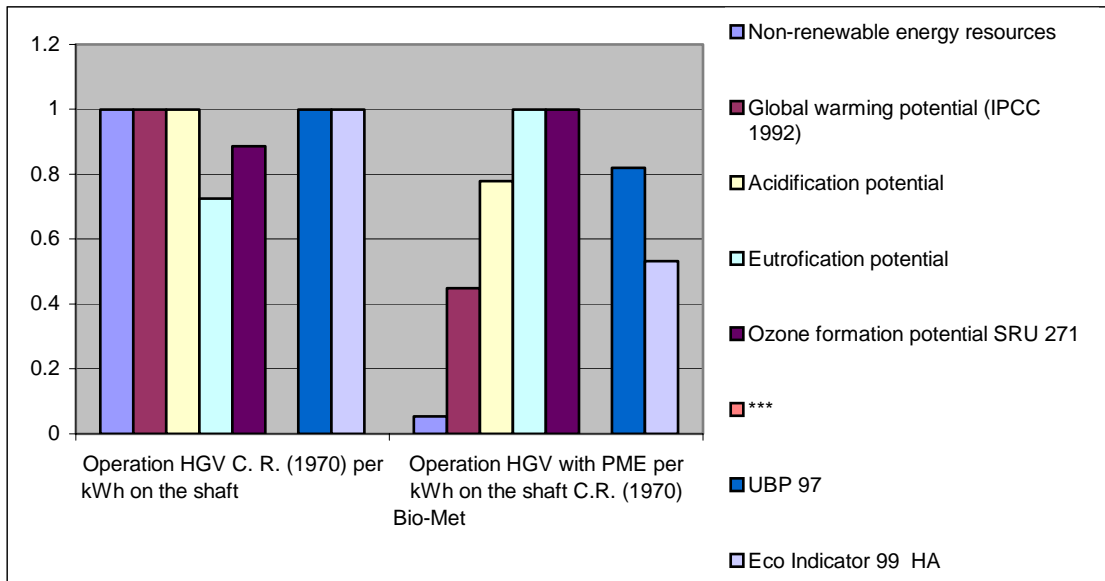
The comparison between diagrams 4 and 10 reveals that the requirements for non-renewable energy resources decrease by more than twenty percent and the global warming potential falls from 60 % in ‘PME-Imeth’ to 45 % in ‘PME-Biometh’. These percentages always refer to the hundred percent of ‘Diesel C.R.’ as shown in the diagrams 4 and 10. The other indicators are virtually unchanged.

The large majority of the non-renewable energy resources needed for ‘PME-Imeth’ and ‘PME-Biometh’ is consumed by the industrial production of methanol. This is why the production of methanol from old wood and old plastics has two big advantages. Firstly, Costa Rica becomes more independent from non-renewable energy resources. Secondly, the use of waste wood and certain types of plastic waste for the production of methanol encourages recycling and the use of waste in a clever way. Once this methanol producing operation has reached a certain scale, waste products could be profitably imported.

The second indicator which is reduced by the replacement of Imeth through Biometh is the global warming potential. As the CO<sub>2</sub> emissions are mainly caused by biomass, the CO<sub>2</sub> which is being released is not considered as a contributor to the global warming risk. This is why this indicator falls when Biometh is being used.

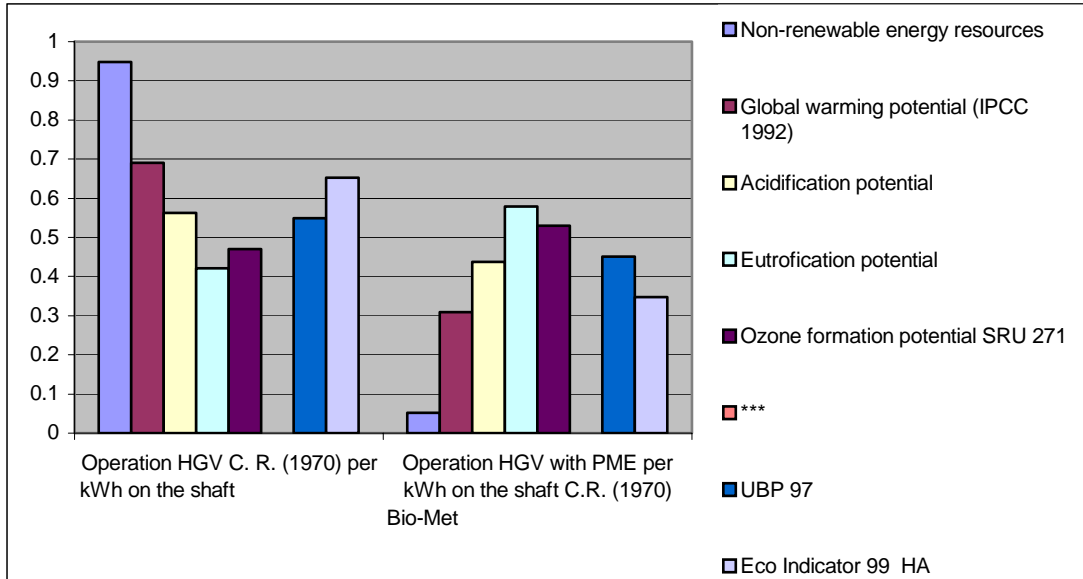
Other bar diagrams in Appendix C show which compounds or materials contribute how much to a specific indicator. These diagrams make the diagrams below more transparent and easier to understand.

Diagram 10: Comparison of environmental impacts: 'Diesel C.R.' v. 'PME-Biometh', SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

Diagram 11: Comparison of environmental impacts: 'Diesel C.R.' v. 'PME-Biometh', SSI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

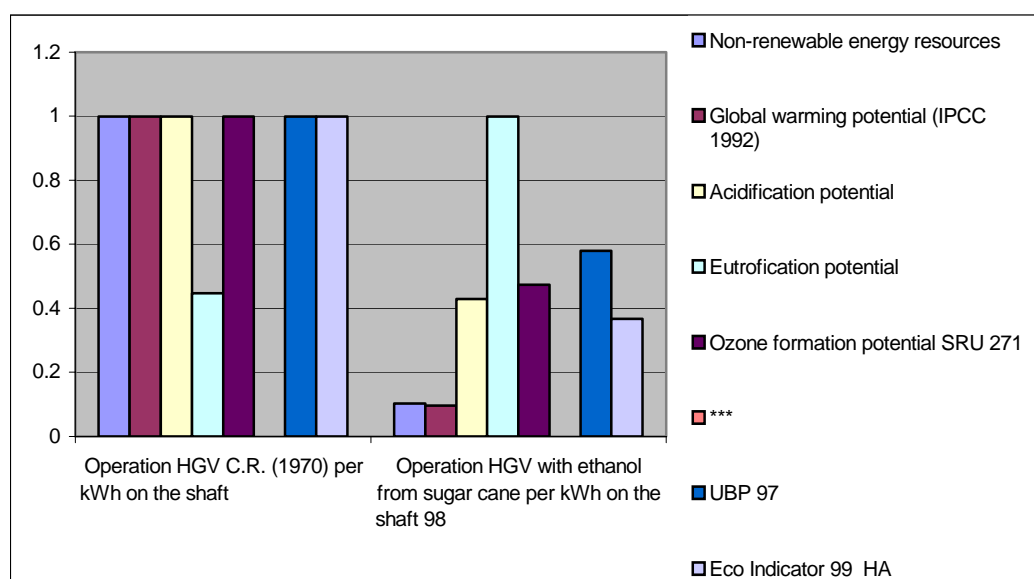
### 5.1.3 Diesel C.R. versus Ethanol

As mentioned earlier, ethanol is another alternative of replacing diesel. Ethanol is also frequently cultivated in Costa Rica. The production of ethanol for fuel use in Brazil has been

investigated by various organizations such as Carbotech AG, Basel, Switzerland. The process 'Ethanol' has been taken from the EMIS database without any attempt to adapt it to the specific Costa Rican situation. Nevertheless, the comparison of 'Ethanol' with other fuels such as 'Diesel C.R.' or 'PME-Imeth' displays some tendencies which can be useful for further considerations.

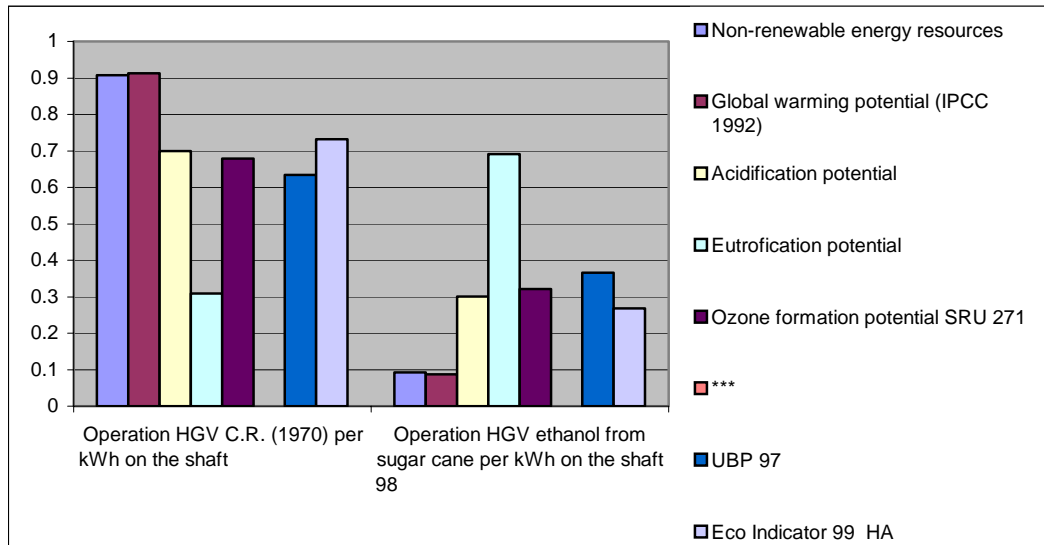
All environmental indicators on the list are significantly lower for 'Ethanol' than for 'Diesel C.R.' except for the eutrofication potential. The high eutrofication potential of 'Ethanol' is probably due to its high fertilizer consumption. This is because sugar cane is a one-year plant and every year large amounts of fertilizer need to be applied. For Palma Africana, on the other hand, much lower amounts – depending on the specific age of the plant – are required. This is why the production of biofuel from sugar cane is supposed to make sense from an overall ecological point of view. The eutrofication potential is nevertheless very high, and the local biodiversity is being restricted. It is a matter of priority if the production of fuel from sugar cane is considered to make sense – as is equally true in the case of palm oil methyl ester.

Diagram 12: Comparison of environmental impacts: 'Diesel C.R.' v. 'Ethanol', SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

Diagram 13: Comparison of environmental impacts: 'Diesel C.R.' v. 'Ethanol', SSI

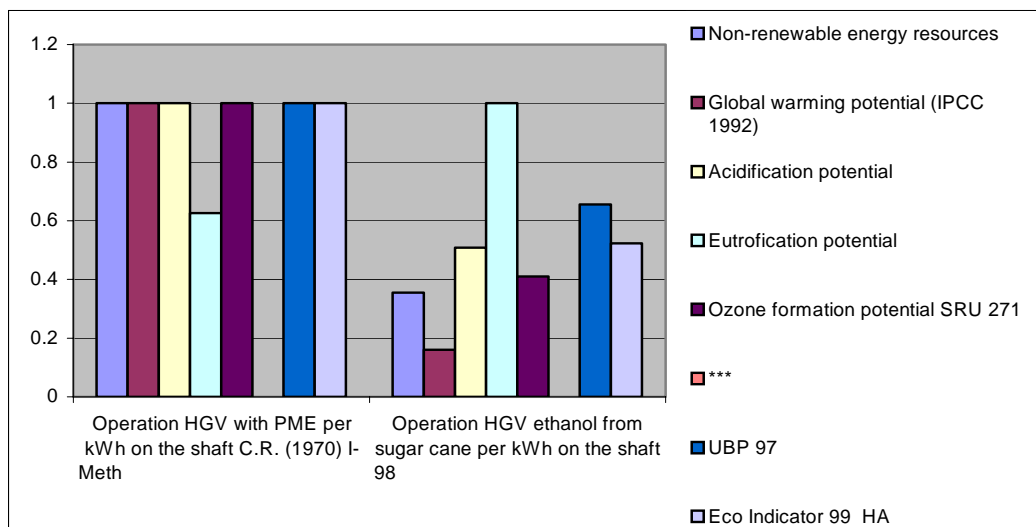


HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

### 5.1.4 PME-Imeth versus Ethanol

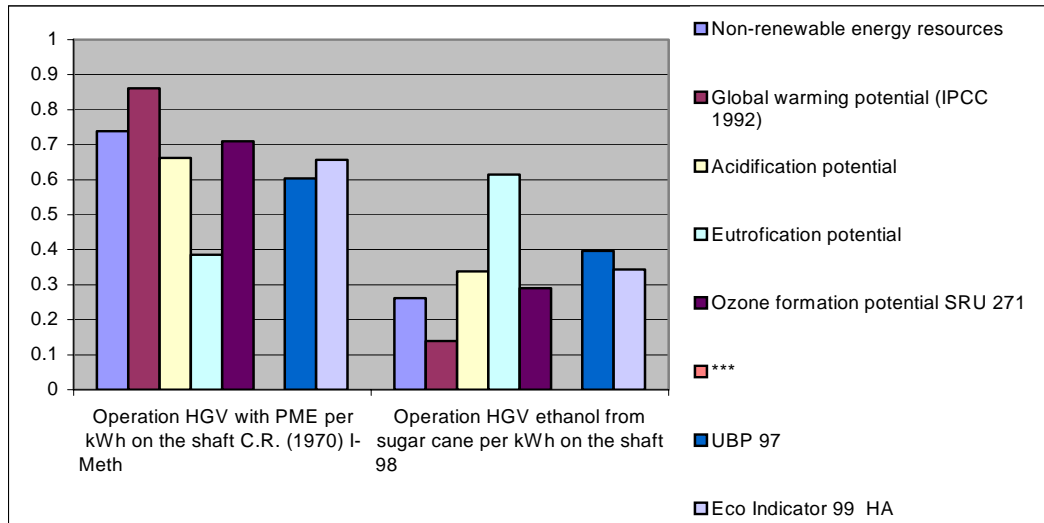
It is pretty much the same picture for the comparison between the production and use of PME-Imeth and ethanol. Again, all indicators on the list are lower for of 'Ethanol' than for 'PME-Imeth' except for the eutrification potential. The eutrification potential of 'Ethanol' is higher than that of 'PME-Imeth', because – as explained in the above – larger amounts of fertilizer are required to produce sugar cane.

Diagram 14: Comparison of environmental impacts: 'PME-Imeth' v. 'Ethanol', SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

Diagram 15: Comparison of environmental impacts: 'PME-Imeth' v. 'Ethanol', SSI



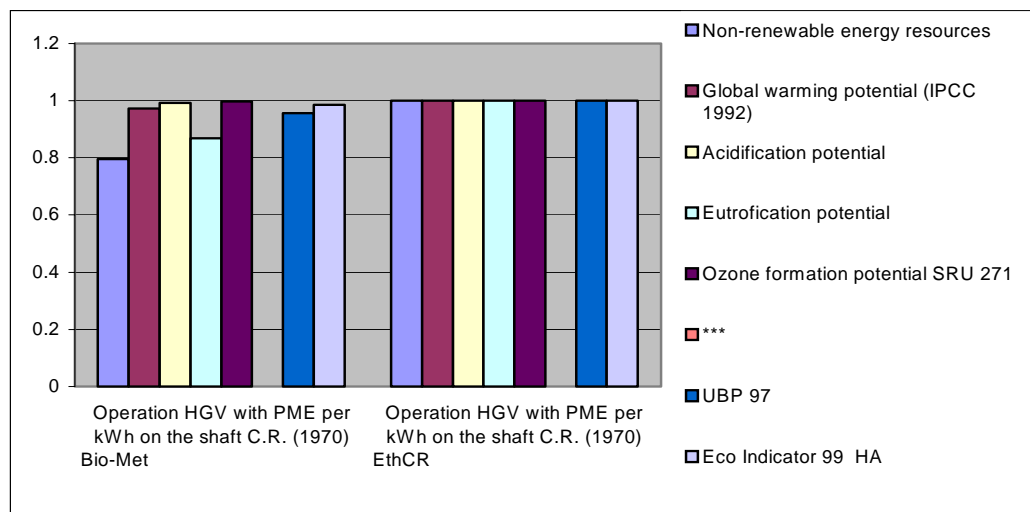
HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

### 5.1.5 PME Bio-Met versus PEE EthCR

Diagram 16 shows in the comparison between 'PME Bio-Met' and 'PEE EthCR' that palm oil ETHYL ester seems to have pretty much the same environmental impact as palm oil METHYL ester, where the methanol is produced from waste wood and plastics. Only the non-renewable energy resources and eutrofication potential are slightly lower for 'PME Bio-Met' (20%).

No diagram for a "Comparison of environmental impacts: 'PME Bio-Met' v. 'PEE EthCR', SSI" will appear since there is virtually no difference in environmental impact between the manufacturing and use of 'PME Bio-Met' and 'PEE EthCR'.

Diagram 16: Comparison of environmental impacts: 'PME Biomet' v. 'PEE EthCR', SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

### 5.1.6 Ratio of environmental emission contribution

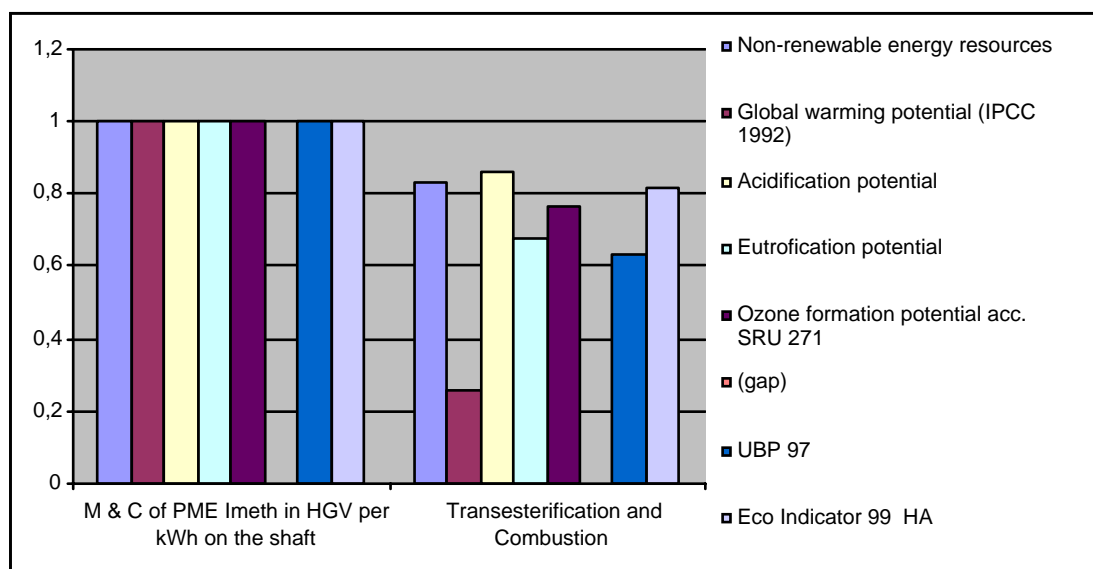
The diagrams No. 17 & 18 show the environmental impact of the manufacturing and use of PME I-Meth on the left hand side and an isolated part of the whole process on the right hand side, summed up to the maximum of each impact (SIM). The diagrams refer to palm oil methyl ester which has been transesterified with industrial methanol as the "I-Meth" suffix indicates. The right side of diagram 17 describes the fuel-specific part, i.e. the environmental impacts that occur during the transesterification and combustion of PME in the engine. The right hand side of diagram 18 describes the environmental impacts of the manufacturing part of PME I-Meth until the refining process. The sum of the two right hand sides of the diagrams is equivalent to the 100 percent of the left hand side.

The environmental impacts of the fuel-specific part in diagram 17 reach an average of approximately 70 % throughout the entire PME production process, cultivation and palm oil extraction making up the other 30%. These figures clearly indicate that most environmental impacts of producing PME I-Meth occur during the – as yet hypothetical – part of transesterification and combustion. Emissions resulting from combustion cannot and will never be totally avoided. Emission levels are also largely a product of the engine's technology.

This requires the consideration of other possibilities to transesterify the refined oil. In this report, three different agents for transesterification will be discussed:

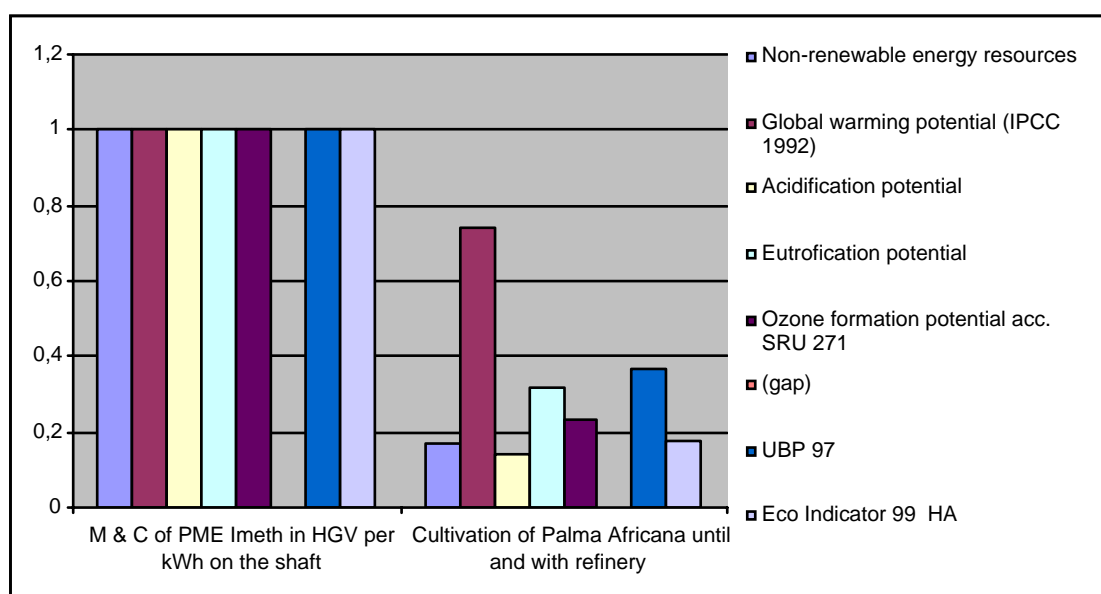
- Transesterification with industrial methanol
- Transesterification with biological methanol
- Transesterification with ethanol from sugar cane

Diagram 17: Comparison of environmental impacts: 'PME-Imeth' v. the fuel-specific part of the process, SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

Diagram 18: Comparison of environmental impacts: 'PME-Imeth' v. the palm-oil-extraction part of the process, SMI



HGV: Heavy Goods Vehicle; M & C: Manufacturing and Combustion

## 5.2 Qualities of PME / Compatibility in Engines

Palm oil methyl ester has a melting point of 14°C, which is relatively high for a fuel. Taking account of the wind chill factor, the minimum temperature under which pure PME can be

used as a fuel climbs to 18 to 20°C (P. Koester, Ferrostaal Germany). This means that under the specific circumstances of the typical Costa Rican climate, pure PME would not be usable. PME would need to be mixed with a certain proportion of conventional diesel fuel (Dr. Sergio Musmanni, CNPML, Costa Rica)

Furthermore, only modern diesel engines have elastomeric fuel lines and seals which are not attacked by biodiesel (Ferrostaal Germany). Diesel engines in Costa Rica are normally quite old and cannot be expected to be compatible with pure biodiesel. This is another reason why the PME has to be mixed with conventional diesel.

### 5.3 Energy Considerations

Two figures are important in view of the energy aspect of the different fuels: firstly, the energy content of the fuel, and secondly, the amount of energy required to produce one kg of it. Table 4 shows the figures:

Table 4 Energy values of different fuels

<b>Fuel</b>	<b>Energy content MJ/kg</b>	<b>Consumption of non- renewable energy for production MJ/kg<sup>1</sup></b>	<b>Energy factor</b>
Diesel	41*	53.3	1.3
PME I-Meth	37.3	13.4	0.36
PME Bio-Meth	37.3	2.6	0.07
Ethanol	27*	4.1	0.15

<sup>1</sup> kg of fuel

\*Source: Fachagentur nachwachsende Rohstoffe e.V.

Diesel has the highest energy content followed by biodiesel (app. 11 per cent less) and ethanol.

The third column (“Consumption of non-renewable energy for production in MJ/kg”) reveals that the production of diesel requires substantially more non-renewable energy than any other fuel. Consequently, the energy factor of diesel in column four – i.e. the quotient of the third and second columns – is much higher than the energy factor of the other fuels. The big difference between diesel and the other fuels has something to do with the parameters of the software. By calculating the environmentally relevant use of non-renewable energy resources, the program also takes account of the crude oil which is the raw material for the diesel production. The raw material for the biofuel production, on the other hand, is not taken into account as it is not a non-renewable energy resource. Taking this into account and subtracting one full unit from the energy factor, it still remains a fact that the production of diesel requires an energy input of about 30 % of its energy content. This number is a little bit higher for PME I-Meth at 36 %, but substantially lower for ethanol (15 %), which is a biological and not an industrial product. The figure is so low because no transesterification is

required to produce it and a lot of energy can therefore be saved. Altogether, an energy input of 15 to 36% percent of the energy content of the fuels under consideration is required for the fuel production.

The energy factor of PME Bio-Meth is extraordinary low because methanol is produced from biological waste and the energy required to produce this 'waste' is not taken into account. One may ask whether this is a fair and true reflection of the situation. If this kind of waste treatment is the treatment of first choice and no other more favourable method exists, it makes indeed sense not to consider it. One must not forget, however, that the production of methanol from biological waste requires more thorough investigations. In Europe at least, such a facility would only be economically viable if people and companies were charged for the amounts of waste they have produced (Dr.Fredy Dinkel, Carbotech AG).

## 6 Conclusions

This chapter provides a synthesis of the findings obtained during this study. The LCA doesn't claim to be complete and free from deficiencies, but it seems clear that the results point to a certain direction and can be used as a reliable basis for a rough generalization.

### 6.1 General Remarks

Nature is a highly complex system and difficult to understand. The parameters for a LCA of this type therefore require a range of assumptions. It is important to be precise, but, on the other hand, there is no point in calculating any figures, like inputs, emissions, etc, too precisely when dealing with natural phenomena.

In view of the diagrams in chapter 3, indicators which are 50 % or more below the figures for another fuel can reliably said to be of significance.

The evaluation of results in a LCA is always subjective and varies according to one's point of view. A fisherman, for example, may be particularly sensitive to fresh water eutrophication as this tends to reduce the number of fish in his lake whereas people living in big cities may be more concerned about ozone in their environment. The evaluation of results also depends on the current environmental situation in the area under investigation (in this case Costa Rica). If the loss of biodiversity is a particularly urgent problem, one will pay more attention to the eutrophication potential. If the earth were to become supercharged with acid and farming an impossibility, the interest would inevitably shift towards the acidification potential.

This report makes therefore some general points about the results and accepts that they may be interpreted differently, depending on the observer's point of view.

### 6.2 Biodiesel from Palm Oil for Costa Rica

Compared to conventional diesel, palm oil methyl ester transesterified with methanol made from fossil fuel has significant ecological advantages regarding the use of non-renewable energy resources and the global warming potential with respect to the selected environmental impact indicators in this LCA, which were:

- Non-renewable energy resources
- Global warming potential
- Acidification potential
- Eutrophication potential

- Ozone formation potential

The emissions produced by the production and use of palm oil methyl ester are lower than the emissions generated by conventional diesel. This was confirmed by tests with rapeseed methyl ester in Germany (Ferrostaal AG, Germany). For example, particle emissions are more than 50 % lower than those produced by conventional diesel fuel. Virtually no SO<sub>2</sub> emissions are generated.

Chapter 3.1.6 showed that the biggest environmental impact in the production of biodiesel from palm oil is created by the transesterification process. Three alternatives for this production step were subsequently discussed:

- PME I-Meth
- PME Bio-Meth
- PME EthCR

The production of methanol from waste wood and certain plastics (Bio-Meth) showed clear improvements as far as the use of non-renewable energy resources and global warming were concerned. The other indicators stayed more or less the same. Similar improvements could be observed when ethanol was used to transesterify palm oil. By selecting different raw materials for the transesterification, the figures for non-renewable energy resources and global warming in particular were changed.

If plans for the commercial production of palm oil methyl ester become reality, the different alternatives of transesterification as outlined above should be considered. The different raw materials required to transesterify palm oil have not only ecological advantages. Methanol production from waste wood and certain plastics opens up economically interesting opportunities of waste disposal. A methanol production facility, however, requires substantial investments. In Europe at least, such a facility would only be economically viable if people and companies were charged for the amounts of waste they produce.

Transesterification with ethanol from Costa Rican sugar cane holds out the opportunity of opening up new markets for the sugar cane industry. Replacing methanol with ethanol in the production of palm oil ester, however, is not quite as easy as that: Because of the stoichiometric ratio of methanol to ethanol (32/46), about 36% more ethanol (mass unit) than methanol would be required. Furthermore, the recovery of excess methanol during transesterification is easier than the recovery of ethanol, because of the methanol's higher volatility which makes the whole process more economically viable. Finally, transesterification reactions of palm oil with ethanol are slower. This reduces the capacity of the facility and makes the business potentially less profitable (P. Koester, Ferrostaal AG Germany).

Nevertheless, ethanol as a fuel would make an interesting alternative for conventional fuels and is already used as such in Brazil, for example.

From an energy point of view, it makes perfect sense to produce biodiesel from palm oil. The energy input required to produce PME is only 36 % of its total energy content, only a little higher than the value for diesel (30 %).

The most important findings of this work are therefore:

- SO<sub>2</sub> and particle emissions of biodiesel combustion are lower than those of conventional diesel combustion.
- The use of non-renewable energy resources and the global warming potential can be reduced by using PME.
- The biggest environmental impact during PME production is created by the transesterification process.
- Ethanol would be another interesting and ecologically sound fuel alternative.
- PME production requires an energy input of 36 % of the PME's total energy content, only slightly more than diesel (30 %).

For Costa Rica, the PME production can provide an opportunity of becoming more independent from foreign oil industries. Domestic fuel production would decrease the amount of fuel imports and have a consequently benevolent impact on the balance of payments. The continuous production of palm oil would furthermore secure jobs in the weak Costa Rican agro-industry and help the country to solve some of its social problems. The construction of a viable biodiesel industry would be an investment into the future.

### **6.3 Biodiesel in the European Union**

About ten years ago, the commercial distribution of rapeseed methyl ester (RME) as fuel for diesel vehicles began. The speed of the introduction was generally quite slow, and only small amounts of RME were initially consumed. The demand for biodiesel only picked up after tax incentives for biofuels were introduced. In the last few years, the biodiesel production capacity in the European Union (EU) has grown considerably. From 1996 to 2002, it increased by a factor of four and has meanwhile reached an annual capacity of 2 m tonnes. Due to an initiative of the EU Commission for the promotion of biofuels, it can be expected that biodiesel production will grow further in the next few years. The EU action plan for biofuels encourages all member states to continuously rise the market share of biofuels from 2 % in the year 2005 to 5.75% in the year 2010.

In Europe, Biodiesel is not an unknown product anymore. Germany, for example, currently has more than 1500 gas stations which offer biodiesel, and in the future this number will increase. By the end of 2003, 1700 gas stations – every tenth station in Germany – provided biodiesel. 30 % of biodiesel is distributed through public gasoline stations, the other 70% are delivered to major customers such as public transport operators and taxi companies.

Surveys have demonstrated, however, that the actual rise in the demand for biodiesel falls short of the increase in biodiesel production capacity. This excess supply keeps the prices down and benefits the consumer. (Bockey, D., Die Produktion von Biodiesel, [www.ufop.de](http://www.ufop.de)).

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## Glossary

BOD <sub>5</sub>	Biological Oxygen Demand of 5 days
BUWAL	Bundesamt für Umwelt Wald und Landschaft (Swiss Environmental Protection Agency)
COD	Chemical Oxygen Demand
CPO	Crude palm oil
EMIS	Environmental Management and Information System
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt
EFB	Empty Fruit Bunches
FFB	Fresh Fruit Bunches
GDP	Gross Domestic Production
GWF	Gewichtungsfaktor / weighting factor
HGV	Heavy Goods Vehicle
NMVOG	Non-Methane Volatile Organic Compounds
PME	Palm Oil Methyl Ester
PME-Biometh	PME biological Methanol
PME-Imeth	PME industrial Methanol
ppm	parts per million
QZ	Qualitätsziel / quality target
RME	Rapeseed Methyl Ester
RPO	Refined palm oil
SF	Sicherheitsfaktor / security factor
SMI	Standardized to the Maximum of each Impact
SRU	Schriftenreihe Umwelt (Descriptions of Environmental Standards commissioned by BUWAL)
SSI	Standardized to the Sum of each Impact
UV	Ultra Violet
VZ	Verweilzeit in der Troposphäre / Retention time in the troposphere

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## **APPENDIX A**

## **Data sheets EMIS**

## **APPENDIX B**

## **Data sheets Coopeagropal**

## **APPENDIX C**

## **Additional graphics**

# **APPENDIX D      Reaction of Transesterification**