Pontifícia Universidade Católica do Rio de Janeiro

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Parametric Sensitivity Analysis Considering the Life Cycle of Base Oils for the Production of Mineral and Vegetable Lubricants

DISSERTAÇÃO DE MESTRADO

Thesis presented to the Programa de Pós-Graduação em Engenharia Urbana e Ambiental of the Departamento de Engenharia Civil, PUC-Rio as partial fulfillment of the requirements for the degree of Mestre em Engenharia Urbana e Ambiental (Professional option).

Advisor: Prof. Celso Romanel

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To my parents,

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Abstract

Gallardo, Pedro Emilio; Romanel, Celso (advisor). **Parametric sensitivity analysis considering the life cycle of base oils for the production of mineral and vegetable lubricants.** Rio de Janeiro, 2015. 200p. Master's Thesis – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

The continuously effort to reach the sustainable development has led to the creation of new techniques for assess environmental costs of the production systems. Nowadays the production of mineral oil base lubricants is assessed due to the large environmental impacts generated in their production, use and final disposal. As alternatives to the substitution of mineral oil base lubricants, vegetable oil base lubricants have been studied and used because their environmental characteristics.

Hence, this study focused on execute a simplified LCA (cradle-to-gate analysis) for the production phase of 1 kg of mineral base oil and 1 kg of jatropha base oil trough a sensitivity analysis. The comparison for both oil bases was performed under the same production scenarios. Results shown that the jatropha base oil production scenario presented 1,01 kg more than the base mineral oil production scenario; the fresh water eutrophication potential had 2,06E-04 kg more than the base mineral oil scenario; the human toxicity potential presented 0,08 kg more than the base mineral oil scenario; the water depletion potential showed 1,33E-01 kg more than the base mineral oil scenario. On the mineral base oil production scenario, the fossil depletion potential shown 0,70 kg more than the base jatropha oil production scenario.

However, it had to still take in consideration parameters such as geographic limitations, due to some discrepancies in the life cycle assessment of oils can occur.

Keywords

Allocation; life cycle; assessment; sensitivity analysis; jatropha base oi; mineral base oil.

Resumo

Gallardo, Pedro Emilio; Romanel, Celso (orientador). **Análise de sensibilidade paramétrica no ciclo de vida de óleos base para produção de lubrificantes minerais e vegetais.** Rio de Janeiro, 2015. 200p. Dissertação de Mestrado – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

A constante procura por desenvolvimento sustentável tem originado a criação de novas técnicas de avaliação dos custos ambientais nos sistemas de produção. Atualmente a produção de óleos lubrificantes está sendo ambientalmente avaliada devido aos grandes impactos ambientais gerados pela produção, utilização e disposição final dos óleos de base mineral. Como alternativa para os óleos de bases minerais vem-se estudando a substituição por óleos oriundos de bases animais e vegetais, os quais apresentam melhores características ambientais. Este trabalho teve por objetivo realizar uma análise de ciclo de vida simplificada (berço-porta) das fases de produção de 1 kg de óleo de base mineral e 1 kg de óleo de base de óleo de jatropha com a utilização de uma análise de sensibilidade. A comparação para a obtenção dos dados foi realizada nos mesmos cenários de produção tanto para os óleos lubrificantes de base de jatropha quanto para os óleos lubrificantes de base mineral. Os resultados nestes cenários indicaram que na produção do óleo de jatropha, o potencial de aquecimento global foi 1,01 kg maior do que o cenário base da produção do óleo mineral; o potencial de eutrofização de água foi 2,06E-04 kg maior do que o cenário base da produção do óleo mineral; o potencial de toxicidade humana foi 0,08 kg maior do que o cenário base da produção do óleo mineral e o potencial de depleção de água foi 1,33E-01 kg maior do que o cenário base da produção do óleo mineral. No cenário base da produção do óleo mineral, o potencial de depleção de combustíveis fósseis foi 0,70 kg maior do que o cenário base da produção do óleo de jatropha. Entretanto, no contexto desta modelagem deve-se ainda levar em consideração outros parâmetros, como os relacionados às limitações geográficas, pois algumas discrepâncias nas análises do ciclo de vida dos óleos podem ocorrer.

Palavras-chave:

Alocação; análise de ciclo de vida; análise de sensibilidade; óleo de base de jatropha; óleo de base mineral.

Contents

List of Figures

List of Tables

List of abbreviations

LCC – Life cycle costing.

LCI – Life cycle inventory assessment.

LCIA – Life cycle impact assessment.

ISO – International Standard Organization.

MWF – Metalworking fluids.

SETAC – Society of Environmental Toxicology and Chemistry.

SLCA – Social Life Cycle Assessment.

LCSA – Life Cycle Sustainability Assessment.

UNEP – United Nations Environment Program.

1.
Introduction

Before industrial revolution human being developed in direct relation with the laws of the nature, this relation conformed the interactions with ecosystems where aliments, clothes and material were taken. Together with all these activities at that moment, human being also produced in a major part organic waste, which was recycled by the action of the ecosystems. After this lifestyle changed, human being started to impose a lifestyle based on consumption of prime substances for the elaboration of products that would cover its necessities (Lima, 2007).

Nowadays human being enhances the conception of the capacity of creation through the use of its capacities to dislocate and to transform main substances through a value chain, where economies of the countries are based on (Marzullo, 2007). However this rhythm of transformations has lead to a consumption degree where natural resources are removed in a higher rhythm than their spare capacity, and the inadequate final disposal of residues compromises the ecological balance of ecosystems (Lima, 2007).

In 1970, the Club of Rome as a respond to this rhythm of growth of the population and consumption of substances, elaborate the report "The Limits of the Growth" where were established that, this uncontrolled rhythm of growth and consumption would affect and bring into a possible collapse of the population (Lima, 2007).

According to Cohen (2003) from 1990 to 2000 the atmospheric carbon emissions went up from 300 to 1.200 kg, the growth of the population in the beginning of the 20th century will take up these same emissions from 500 to 7.300 million tons/year. In this same period of time, water consumption run up from 500 km^3/year to estimative levels between 3.300 to 4.000 km^3.

From 1950 to 2000 to cover the demand of the industrial and domesticate sector, the capacity of electric energy generation increased in 2.100%, and is supposed that this generation would had a increase of 60% by 2030, the production of cellulose increased in 1,425%, also the number of vehicles growth 1.000% (Kitagawa and Yamamoto, 2006).

Trying to reach an environmentally sustainable progress for the planet, there are necessary environmental strategies, which would be used as part of the decision making process in the production sector, as well as in the managers of the products in the context of industrial management and life cycle of the products (Moretti, 2011). According to Marcelino (2013) strategies such as economic and environmental analysis, are used from the beginning of the 20th century to try to find an economic efficiency in the manufacture process.

The interest for the environmental conscience of industries has had an increase due to the creation of preventive legislations, pollution and the demand of greener processes and products (de Oliveira and Alves, 2007). This has taken the adoption and inclusion of the sustainable development in the value chain creating a effective way to improve economy, environmental and social responsibility in industries (Pusavec *et al.*, 2009) nerveless to reach it, is necessary to cover the requirements of clients thinking without compromising the conservation of the natural wells (Sánchez, 2004).

This could be observed in the petroleum industry and its derivatives since after local and global environmental, biodiversity (Bravo, 2007; Canchumani, 2013) and occupational accidents (e.g. Exxon Valdes, spilling on the Mexican gulf), this industry is changing standards and the way to create its derivatives. Nowadays there are alternative ways to create petroleum-derived products, a case of this are oil bases for elavorating metalworking fluids that passed to be elaborated from mineral oil bases to alternative bases.

Mineral based metalworking fluids have negative environmental impacts due to the incomplete consumption in their entire life cycle (Canchumani, 2013), also the production of diseases such as dermatitis. There are concerns relating to allergic alveolitis, occupational asthma and the possibility of cancer and complaints associated with eyes, nose and throat (Simpson *et al.*, 2000). In addition mineral oil based metalworking fluids produce negative environmental impacts due to their conformation, volume, inappropriate use and low biodegradability properties (Kuram *et al.*, 2013; Shashidhara and Jayaram, 2010), for these reasons metalworking fluids have changed on their conception, bases used for their production are obtained in a major part from vegetable resources.

Vegetable bases destined for metalworking fluids constitute a new way in their production; application and conception of the green chemistry of these products also attend to demand of safer metalworking products for the environment and operators.

The use of vegetable bases in the production of metalworking fluids occur due to the elaboration and application of new and stricter laws, under the concept that raw materials are a finite source and the compounds cause large negative impacts on ecosystems for their primary combinations of nitrogen, sulfur, hydrocarbons and heavy metals (Lathi and Mattiasson, 2006) and their cost is not economically stable because has a relation with the petroleum value (Lawal, 2013).

In addition vegetable based metalworking fluids have advantages not only for their environmental and occupational benefits but also for their lubricating performance, lower volatility, high viscosity index. However alternative base metalworking fluids still have environmental and performance harms because their formulation and production is the same that is used for mineral oil based metalworking fluids (Lawal, 2013).

Increase in the production of vegetable based metalworking fluids in the US and Europe, brought to accomplishing studies therefore on the impacts that are generated mainly in the life cycle but in the production phase and the extraction of the raw material (Cuevas, 2010). According to McManus *et al.* (2011) and Miller *et al.* (2007), most studies shown that the largest environmental impact of these fluids occur in the raw materials production because the contribution to soil acidification and eutrophication.

It is necessary to compare the information of the vegetable and mineral oil based metalworking fluids through a methodology that allows obtaining information of the real environmental cost for a making decisions process.

The main purpose of this thesis, is to identify the most influential parameters in the production phase of 1 kg of mineral base oil and 1 kg of jatropha base oil, by using a parametric sensitivity analysis within an LCA, to obtain data, which will allow a future decision making process from an environmental friendly point of view.

1.1.
Research question

How do decisions, assumptions, and allocation approach influence the production of 1 kilogram of jatropha base oil and mineral base oil?

1.2. Objectives

1.2.1. General objective

The goal of this study is to execute a simplified LCA (cradle-to-gate analysis) for the production phase of 1 kg of mineral base oil and 1 kg of jatropha base oil trough an sensitivity analysis, for determining which are the most influential parameters used in the production.

1.2.2. Specific objectives

- To define a base scenario, to identify and to adjust the shifting parameters in modeling the production of the mineral base oil and jatropha base oil;
- To model the production phase of the mineral and jatropha base oil through an LCA software tool, the variation of the parameters identified and the assessment of environmental impacts;
- To execute an sensitivity analysis to determine which are the most influential parameters on the production phase of 1 kg of jatropha base oil and 1 kg de mineral base oil.
- To compare the base scenarios with the sensitivity scenarios in the production of the 1 kg of mineral base oil and jatropha base oil.

1.3. Justification

Currently use of mineral bases shown a large environmental, health and occupational problems. As previously mentioned these problems had led to a decision making process when manufacturing. So for these decisions making process can be consistent with the levels of sustainability, it is necessary to obtain data to create operational criteria and safer and environmental friendly oil bases.

To reach this it should be developed studies, analysis and comparisons between mineral and vegetable base oils; these analysis should force to a full environmental life cycle assessment, within a standard methodology thus reaching truthful results of the environmental cost of the bases.

For this study it was selected jatropha base oil as an vegetable oil source due to, the actual interest to replace mineral oil-based products with alternative base oils, it represents a big base stock of base oils for MWF and lubricants; can be cultivated in marginal land, and is not an edible source.

1.4. Thesis structure

Chapter 1. Introduction: In this chapter it was write a brief description about the evolution of the environmental problems, mineral and vegetable bases, and the research question, hypothesis, and objectives.

Chapter 2. Literature review: In this chapter It is detailed a description about life cycle assessment, mineral base oil and jatropha base oil, also it was described the production steps for these fluids.

Chapter 3. Life cycle assessment: In this chapter it is modeled the production phase of mineral base oil and jatropha base oil. Also it was determined the parameters for the life cycle assessment, allocation and production scenarios.

Chapter 4. Interpretation: It is described the interpretation of the results obtained from the production scenarios modeled.

Chapter 5. Conclusions: It is shown conclusions of the life cycle assessment of mineral base oil and jatropha base oil production.

Bibliography: It is cited all the bibliography used for the thesis.

2. Literature review

2.1. Life cycle assessment

The increasing trend on the importance, protection, environmental control and the negative impacts that are generated by products, have increased the industrial interest to produce environmental friendly products through the adoption of green processes and methodologies focused on the determination, comprehension and treatment of the negative environmental impacts. A methodology in this context is the life cycle assessment (LCA) (Chacón, 2008; Cuevas, 2010; EPA, 2006; ISO, 2006a).

LCA is a tool or methodology that can be used for the identification of the possible chances for improving an environmental performance of the products in any stage of the production, selection of environmental performance indicators, access to important information for making decisions in governmental or no governmental organizations and industries, and for marketing of products (ISO, 2006a).

According to Cuevas (2010) LCA considers extraction of raw materials, transportation, production, use and final disposal. Also phases as recycling and reuse phases are included; this kind of analysis is called “Cradle to Grave” (Cuevas, 2010). Fig 1 described all the stages for an LCA.

LCA is developed in a holistic approach that considers all the environmental impacts at anytime and anywhere. The application of this approach contemplates the relation between the well consumption and economics, indirect environmental management opportunities in the production processes and focuses in eco-design of products (Guinée *et al.*, 2004). Also the benefits of this approach are to provide information to characterize the environmental changes associates with the product or the alternatives of the processes (EPA, 2006).

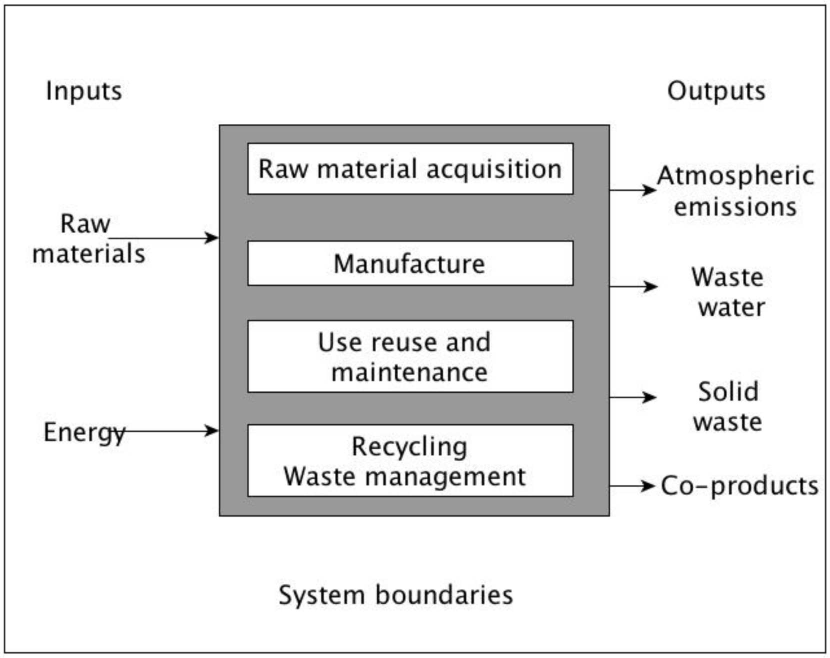

FIG. Nº 1. Life cycle stages (Adapted from EPA, 1993)

According to EPA, (2006) to perform an LCA leads to:

- Develop a systematic evaluation of the environmental consequences of a product;
- Analysis the environmental trade-offs of a product or process with the purpose to inform all the actions to stakeholders;
- Quantify the emissions to the atmosphere, water and ground in all the life cycle stages of a product;
- Identification of the main changes created between the environmental impacts and the life cycle of a product;
- Assess the human and ecological effects of the consumption of substances and the emissions to the environment at local, regional and global scale;
- Compares the health of ecosystems and ecological impacts between two or more different products or processes or identifies the impacts of a specific product or processes;
- Identifies the impacts in one or many environmental concern areas.

2.1.1.
History of LCA

The vision of the limited amount of resources and the energy lost in the production had led to consider different ways of energy accumulation, protection and use of the resources (EPA, 1993; EPA, 2006). It is recognized that the major impacts of some products do not occur in the use phase but in the production, transportation and final disposal phase (ES&T) does (Guinée *et al.*, 2010). Figure 3. shown the number of articles mentioning LCA in ES&T.

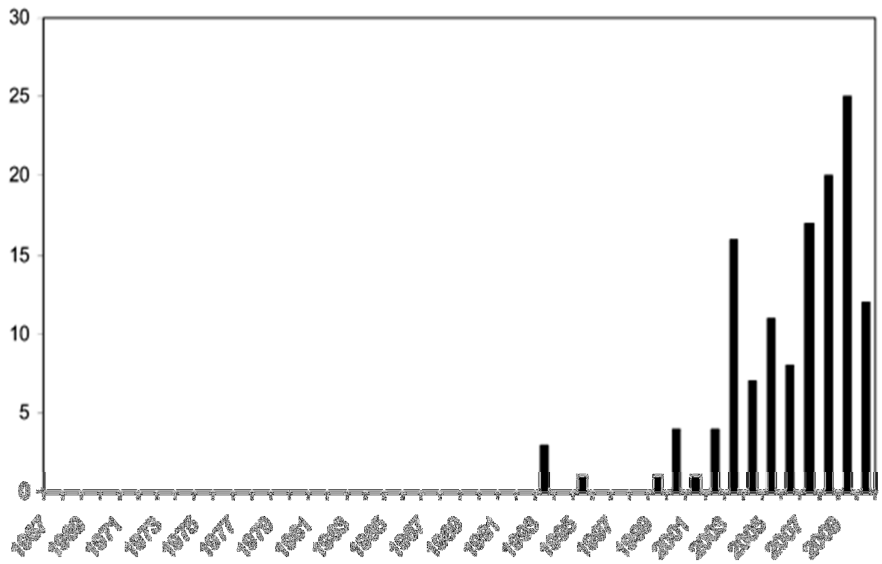

FIG. Nº 2. Number of articles mentioning LCA in ES&T (Adapted from Guinée, 2010)

2.1.1.1.
Past of LCA

The first referring study to life cycle assessment occurred in 1969 when the Coca-Cola Company altogether with the MidWest Research a study, which had as an objective to quantify the energy, material and environmental effects of the complete life cycle of a beverage (Hunt and Franklin, 1996; EPA, 2006).

Between 1975 and 1980 LCA studies decreased because the fading influence of the oil crisis. At this moment environmental studies changed to analysis environmental concerns of toxic waste management. In this same period in Europe the interests to develop LCA methodologies grew up and was established the Environmental Directorate (DG X1) that in 1985 issued the Liquid Food Container Directive, which was charged the monitoring of waste production, energy consumption and raw materials utilization for producing liquid food containers (EPA, 1993).

In 1988 when the problem of the solid waste crisis occurred, the interest for the LCA was retaken applying it as a tool of analysis to the problems related with the environment (Chacón, 2008; EPA, 2006). This leaded to consider the problem of the waste management and to include under the LCA thinking, phases such as recycling, substitution of materials and reusing of the products (Hunt and Franklin, 1996).

In 1991 the inappropriate use of LCAs mostly by product manufacturers resulted in a declaration published by eleven State Attorneys General in the USA reproving the inappropriate usage of the results of LCAs to support products. This action altogether with the international environmental concern formed an environmental organism headed to standardize the LCA into the International Standardization Organization, specifically into the ISO 14000 standard (EPA, 2006). Nowadays two ISO standards are available; the ISO 14040: Environmental management -- Life cycle assessment -- Principles and framework and the ISO 14044: Environmental management -- Life cycle assessment -- Requirements and guidelines.

2.1.1.2.
Decade of elaboration

In 2002 the SETAC working together with the UNEP, started an international partnership recognized as the Life Cycle Initiative, which focused principally in putting life cycle philosophy on practice and improving the supporting tools through better data, indicators, risks, opportunities and benefits of the products and services, through, their life cycle using the life cycle inventory and life cycle impact (Guinée *et al.*, 2010; Lima; 2007).

In 2003 the Integrated Product Policy: Building on Environmental Life-Cycle Thinking recognized the importance of the life cycle thinking in the relations with the stakeholders of IPP (Comissão das Comunidades Europeias, 2003).

In 2005 the European Platform on LCA was established, assigned to promote the accessibility, exchange, and use of value-guaranteed life cycle data and studies for trustworthy decision support in public policy and in business. At this moment EPA started to promote the use of LCA in the United States (Guinée *et al.*, 2010).

2.1.1.3. Decade of Life Cycle Sustainability Analysis

Life cycle sustainable assessment was established in order to launch a relation in whom scientists from different disciplinary subjects might discuss the challenges in focusing sustainability with a life cycle perspective. The focus was SLCA, LCC and LCSA (Zamagni, 2013).

LCSA thinking besides considers the scope from primarily product-related questions to all the questions associated to a sector level or economy-wide levels (Guinée *et al.*, 2010), trough an specific analysis of the all positive and negative impacts related with a product for making decisions and the production of greener and sustainable products (UNEP and SETAC Life Cycle Initiative, 2011).

The methodology for an LCSA is represented into the Kloepffer formula:

$$LCSA = LCA + LCC + SLCA$$

LCC summarize all the costs in a determinate life cycle of a product that are assumed by one or more actors in this period of time, these costs are relative to the truthfully economic flows in order to circumvent the overlay between LCA and LCC (Burchart, 2011). LCC contemplates that all the privates' benefits, costs and externalities are monetized (UNEP and SETAC Life Cycle Initiative, 2011).

S-LCA is a social impact assessment method used for evaluating the social and socio-economic aspects of products and their positive and negative impacts by their life cycle involving all the life cycle phases of a product (UNEP, 2009). The social component captures the impact of a product manufactured process or organization (Finkbeiner *et al.*, 2010); the social benefits could be measured by analyzing the stakeholders satisfaction, this analysis could be done in a local, national and global level (Global Reporting Initiative, 2002).

Nevertheless there are social impacts, which are difficult to quantify by a certain studies because even the studies contemplate many variables, there are a number of social indicators that comprehends qualitative values of systems and accomplishments of the organization, including operational principles, methods and managing practices. These indicators needs specific details to social issues such as forced labor, working hours or existence of trade unions (Finkbeiner *et al.*, 2010).

2.1.2.
Phases for an LCA

According to ISO (2006a) there are four phases to perform a LCA:

- Goal and scope definition;
- Life Cycle Inventory Analysis;
- Life Cycle Impact Assessment;
- Interpretation.

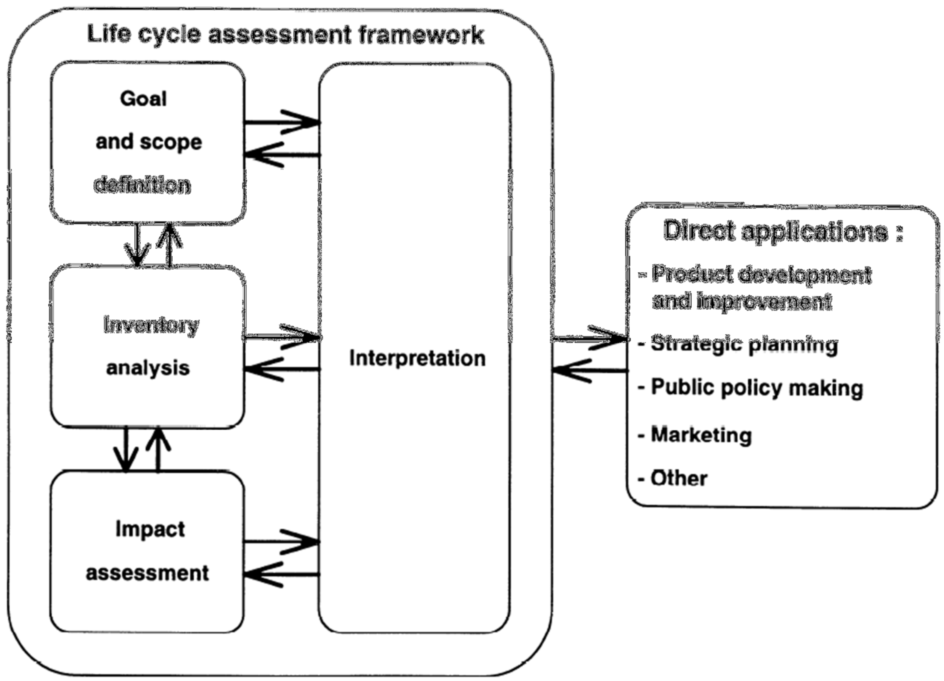

FIG. Nº 3. Life cycle assessment phases (Adapted from ISO, 2006a)

2.1.2.1.
Goal and scope definition

This LCA phase defines the initial alternatives, which determine the entire LCA working plan. It is formulated for an exact question, targets, proposed application. In this phase also is defined in terms of temporal, access to technologies, geography location and the sophistical characteristics of each study (Guinée *et al*., 2004). In this stage it is defined the goal, scope, functional unit, system boundaries, data quality and the critical review (Jensen *et al*., 1997).

Goal definition: This is the first step for conducting an LCA study; The goal definition process defines the proposed uses of the results and, consequently, the type of evaluation required and the mode in which the results will be presented and determines the extensiveness, complexity, and scope of the system and the kind of data desired for the evaluation.

The study would be intended to involve all the relevant information that will have a relation with the decision or activity; it might eliminate info that is unrelated (Todd *et al*., 1999).

Scope definition: Scope definition arrays the boundaries of the assessment what is integrated in the system and what detailed evaluation techniques will be used for (Jensen *et al*., 1997). In this process it should be considered all the system boundaries and also the relation with the purpose of the study (ISO, 2006a).

According to ISO (2006a) to define the scope it might describe:

- The functions of the product system, or, in the case of comparative studies, the systems;
- The functional unit;
- The product system to be studied;
- The product system boundaries;
- Allocation procedures;
- Types of impact and methodology of impact assessment, and subsequent interpretation to be used;
- Data requirements;
- Assumptions;
- Limitations;
- Initial data quality requirements;
- Type of critical review;
- If any type and format of the report required for the study.

Functional unit: at the beginning of an LCA, the system that will be studied and its function need to be identified. The function is associated with the questions, which the study was designed to answer, and the functional unit must be chosen as the core for the study (Todd *et al.,* 1999).

The definition of the functional unit is the base of an LCA study, due to the purpose of the functional unit is to provide a reference of the relation between inputs and outputs, also a functional unit sets the scale to compare two or more products involving improvement to one product (Jensen *et al.*, 1997; ISO, 2006a).

When defining a functional unit the LCA study team should consider that the functional unit must guarantees the equivalence and allows comparisons between complementary systems (Todd *et al.*, 1999). To define the functional unit, it must be consider the efficiency and durability of the product and the performance quality standard (Lindfors *et al.*, 1995 in Jensen *et al.,* 1997).

System boundaries: For defining the systems boundaries is necessary to analysis the scope of the study because it describes the limits, which will define the system studied. The system boundaries also delimit the unit processes or activities that will be incorporated in the system studied (Todd *et al.*, 1999). For establishing the system boundaries it is necessary to consider where the unitary process starts by means of where the raw materials and intermediate products are delivered; the characteristics of the transformations and the entire operations occurring in the process and where the process ends by means of destiny of the intermediate or final product (ISO, 2006b).

It would model the product system considering that all the inputs and outputs in its boundaries are an elementary and product fluxes. This is an interactive process that finds the inputs and outputs into the environment (ISO, 2006b).

In practice an LCA study considers several cut-off criteria for delimiting the inputs to be evaluated in the study, these inputs regularly are mass, energy and environmental importance (ISO, 2006b).

According to ISO (2006b) the inputs considers:

- Mass: when using mass as a evaluating criteria it must contemplate the inclusion of the all inputs, that in an accumulative way represent more than a defined percentage in relation with the mass incorporated in the analyzed system;
- Energy: As the same of mass, when is used as a evaluating criteria it is important to establish a criteria which considers all the inputs that in an accumulative way represent more than a percentage in relation with the energy incorporated in the analyzed system;
- Environmental importance: The decisions about the selection of criteria must consider not only inputs that represent more than an additional defined quantity to the estimated amount of data.

Data quality: LCA data consider environmental inputs and outputs; data also must describe the processes, which determines the origin and destination of the inputs, this description must cover the product system that results from a specific combination of these processes (Weidema *et al*., 2003). Data used in an LCA study must be depended and have relation with the goal and scope defined previously; the goal of the LCA could require that the organization has access to sufficient information that could be issued by itself or secondary sources (Todd *et al*., 1999).

Data quality requirements are determined by estimating the importance and uncertainty. Comparing the requirements with the existing data from the current data collection system, results in a prioritized list of data that need to be collected (Weidema *et al*., 2003).

Data for raw materials acquisition involves inputs of energy, materials and equipment necessary to acquire raw materials; also these kinds of data include raw material transportation until the place of manufacture. Energy data for these processes have to focus not only in the emissions or energy use in the activity but on the same numbers related to the energy production; manufacture involves all energy, material or water inputs and releases to the environment that are occurring at the moment of manufacturing. Data for final product manufacture would describe the use of inputs and releases related with filling and packaging operations; transportation and delivery must be calculated employing criteria for the usual distance transported and the common mode of transportation employed.

Consumer use and discarding consider use, maintenance and reuse. Reuse, recycling, composting, incineration and land filling must be also considered. Other variables such as post-consumer waste collection and transportation should be analyzed (Svoboda, 1995).

2.1.2.2.
Life Cycle Inventory Analysis (LCI)

This is an interactive process where once the data have been found, the information about new requirements and boundaries required to reach the objectives are obtained (ISO, 2006b).

In this phase, the product system is defined by setting the system boundaries, aiming the flow schemas with the unit processes, gathering the data for respectively processes, assigning phases for multifunctional processes, and finishing the closing results (Zhu, 2004). The inventory analysis and the tasks to be attained could be reinforced by a flow sheet for the studied product (Jensen *et al.*, 1997).

The inventory analysis involves a collection and treatment of data, which includes values of waste and emissions for all the phases of the whole life cycle (Jensen *et al.*, 1997). Particularly the LCI data describes in *intermediate flows* the relation of exchanges in terns of mass or energy between two processes, although *elementary flows* shown the relation of mass or energy exchanges between a process and the natural environment (Weidema *et al.*, 2003). The average data is usually got from LCI databases; for the site or specific data is necessary to spend more time due to this data must be collected from many measurements and different people (Logaras, 2008).

Data would be classified in primary data that are collected by direct measurement, estimations or calculation from the original source. Measured data can be upgraded and specified on the other hand calculated data are not affected by possible errors of individual measurements and are based on theoretical models; secondary data, which are collected from literature and issued sources (Weidema *et al.* 2003).

Once all the data required for the LCA have been collected, it must start the data calculation. According to ISO (2006a) in this step it would be considered validation of the data; data relation with the unitary process and the relation between data and reference flux of the functional unity. After performed the data calculation it would start the calculation of the environmental loads in relation to the functional unit. (Baumann and Tillman, 2004).

For the environmental loads and their relation with the functional unit is necessary to considerate the normalization, where all the data will be transformed into an unique unit; calculation, which calculates linking phases established before using a flow, which represents the functional unit defined for the study, the summary that presents a summarized report about the emissions to the environment from the entire system and finally the documentation where all the calculations are documented (Baumann and Tillman, 2004). For this phase commonly, LCA software such as GaBi or SimaPro are used for the establishment of the calculations and further analysis of the technical system (Logaras, 2008).

2.1.2.3. Life Cycle Impact Assessment (LCIA)

This is a relative focus methodology due to; it uses as a base of analysis the functional unit (ISO, 2006b). The impact assessment considers a revision of the LCA objective and scope and their completion. It is employed for reconsidering the objective and scope when is not possible to reach them (ISO, 2006a).

The initial activity for conducting an impact assessment is to select the applicable impact groups that match the goals established, after this activity LCI results are assigned to their particular impact category that is associated with ozone depletion potential, ecotoxicity, acidification potential, global warming potential, eutrophication potential, photochemical smog, land use and energy use (Baumann and Tillman, 2004).

The second activity of LCIA is the characterization, in this step the impacts caused by the LCI are calculating and expressed in common units for comparing results, last activity is the normalization in this step weighting or valuation is accomplished, weight or value is related to the impact depending of its importance (Baumann and Tillman, 2004).

2.1.2.4. Sensitive analysis

An sensitive analysis may assistance in the identification of parameters that ought be know precisely before concluding or identifying non sensitive parameters for which, the variance can be determinated in the region of its variance that allows to get a factor fixing model (Saltelli *et al.*, 2008). Its application has two benefits (Wainwright and Mulligan, 2004):

- To act as a check on the model logic and the robustness of the simulation;
- Defines the importance of model parameters and thus the effort that must be invested in data acquisition for different parameters.

The model parameters is defined by their function in the model structure and if the roll has an important representation on the system studied, therefore there is some similarities between the sensitivity of model output to parameter change and the sensitivity of the real system response to physical or process manipulation (Wainwright and Mulligan, 2004).

Sensitivity analysis have many advantages such as the facility to understand and perform, time-consuming for a large system allowing performing a study that does not consider all the parameters into account and moreover this type of analysis let overlook possible sensitive parameters (Groen *et al*., 2014).

Essentially it is possible to differentiate three types of sensitivity analysis: local sensitivity analysis (one-at-a-time; matrix perturbation), screening (method of elementary effect) and global sensitivity analysis (standardized regression coefficients); for these methods, it is still not clear the situations that they optimally perform, or if they can outdo the standard practices in LCA (Groen *et al*., 2014). Wang *et al*. (2010) describes that traditional, statistical, sampling methods could be use as well.

The one-at-a-time approach addresses parameter sensitivity relative to the point estimates chosen for the parameters held constant. According to Groen *et al*. (2014) this approach is easy to execute and to comprehend, but this type of sensitivity analysis is time-consuming for a large system and, consequently could not consistently take all parameters into account and might overlook possible sensitive parameters.

The matrix perturbation approach uses the first order partial derivatives as estimators of local sensitivity that is converted into relative multipliers. If the multiplier is higher, the alterations in the input parameter will alter the result more than when the multiplier is almost zero. Information such as the type of distribution function or parameter of dispersion is not used (Groen *et al*., 2014). Essentially this approach consider that in the equation $g= BA^{-1} f$ how the elements of g change if one or more elements on A or B change. The matrix perturbation concept has established many diagnostic measures. One of the most important of these is the condition number, commonly shown as κ (Heijungs, 2002).

According to Saltelli *et al*. (2008) this approach could be regard as an extended one-at-a-time approach. This approach uses the alternative values of each parameter and calculates the result; the difference that occurs between the original model and the new calculation of each combination is the elementary effect (Groen *et al*., 2014).

Standardized regression coefficients are found from the position of the line from minimum square fitting and estimate the influence to output variance for each input parameter. It is taken samples from the all input parameters and for each run the output is calculated. Afterwards, for every single parameter the regression coefficient is calculated and are homogenizing into their standard deviation (Groen *et al.*, 2014).

Sensitivity analysis in LCA studies could be executed by a one-at-a-time approach, which considers that a subgroup of set of the input parameters are changed one at a time, to see the influence that every single parameter have in the final results. (Groen *et al.*, 2014; Guinée *et al.*, 2004). These considerations are purposely introduced to establish the robustness of the results according to the variations (Guinée *et al.*, 2004).

The sensitivity analyses, which evaluate the sensitivity of each parameter in the model, are frequently executed by sampling based approaches, through an added procedure for variance decomposition. Despite this type methodology have numerous benefits such as the ease to execute and undestand; however it also have desadvantages due to when analizing a large system, this approach is time-consuming and it could not take all parameters in the analysis and, overlook possible sensitive parameters (Groen *et al.*, 2014).

According to Guinée *et al.* (2004), for a simplified LCA it is necessary to consider:

- *"Choice and justify a limited set of topics for sensitivity analysis, which are based on the results of contribution analysis, perturbation analysis and the subjects identified as issues for interpretation in the various steps.*
- *Conduct sensitivity analyses on the issues selected, at the level of: the inventory table; the environmental profile; the normalised environmental profile; the weighting results.*
- *Report the results of the sensitivity analyses and possible uncertainty analyses conducted in table and, if useful, in graphic format.*
- *If possible, compare the results of a sensitivity and uncertainty analysis with results of such analyses reported in previous studies on related products.*
- *Pay special attention to processes and process data whose data quality gives reason for concern or processes whose data were based on estimations, due to If the sensitivity analysis shows that changes in these processes or flows can have important effects on*

the results of the LCA, this may be a reason to go back to the data collection step to collect more data, or data of a better quality.

- *Pay special attention to differences in completeness between alternative systems. Are the results very sensitive to changes in the data missing in one alternative?"*

For a detailed LCA Guinée *et al*. (2004), specified that:

- *"Conduct more detailed sensitivity analyses or, if possible, conduct partial uncertainty analysis on the issues selected and on parameters for which uncertainty ranges are known, for instance by Monte Carlo simulations*."

2.1.2.5.
Allocation and system expansion

Numerous industrial processes have many outputs that include more that only one product; raw materials usually could be intermediate or discarded products (Guinée *et al*., 2004). Allocation is a boundary setting activity where is define how the co-products obtained in the system will be treated after they are out of it (Young, 1996). This process considers the specific nature of the system boundaries, due to this, inputs and outputs that will be analyzed and the association with the function of interes are determined (Guinée *et al*., 2004). When partitioning, it should be considered a function of the co-product, utilities involved and, physical and socio-economic dimensions (Young, 1996). According to ISO (2006b), when applying many different allocation methods, a sensitivity analysis must be done for illustrating the consequences of changing variables. For allocation procedures it will be consider that data from allocated database is applied only for simplified LCAs and the co-production, recycling and waste treatment have the same criteria on the basis of the equal allocation principles (Guinée *et al*., 2004).

There are two possibilities that could be used to avoid allocation; the first one is to subdivide a process into sub processes compiling information of the inputs and outputs related to individual co-products (Curran, 2012; ISO, 2006b). According to Curran (2012) this approach could be used when managing data into an industrial facility are feed as a black box, nonetheless the co-products can be traced to distinct process in the facility.

The second procedure to avoid allocation is the system expansion, which consists in maintaining compatibility of the product system in terms of product outputs within matching a variation in output quantity of a co-product, which occurs barely in one of the product systems, by enhancing an equivalent production in the other systems (Weidema, 2003). This procedure could not be an appropriate technique when the evaluated system is the only primary route to produce one or more co-products, so that is not a basis to grant the credit (Curran, 2012).

When expanding the system, it could occur four complications. The first one is that attributional studies normally requested to describe a status-quo situation, which means that there are no changes in production quantity, this removes the option of the system expansion, due to, the system expansion implicates matching a change in output quantity of a co-product obtained in one system with an equivalent change in other systems to be compared. The second complication focuses on the difficulty of distinguish which processes are disturbed when matching a variation in need for a certain co-product. The third complication has to do with the system expansion could implicate processes, which produce different products, it has been proposed that there are conditions that turn impossible to expand the system due to, it could engage a continuous regression. Finally the fourth complication is related when the co-product is not an alternative for another product. System expansion could be considered as discordant with the requisite that compared systems must have same functions (Weidema, 2003).

However the complications can be solve by distinguishing the type of study (attributional and consequential), which allows a clary identification of the situations where the system expansion is required or irrelevant.

The uncertainty in the identification of the processes affected by a modification in demand, and the primary uncertainty of potential market situations are intrinsic to the method. The continuous regression can be avoid by using a method that includes the identification of the scale and time horizon of the studied, market delimitation, identifying the market trend, identifying production constraints and identifying the suppliers and technologies that are sensitive to change, this method leads to a clear cut-off criteria and decreases the quantity of processes that could be intricate in a system expansion. The last solution for the complications cited above, is that co-products nearly always replacement for other products, even when this is not the situation, the systems are still equivalent (Weidema, 2003).

Nerveless according to Guinée *et al.* (2004), a realistic approach of the system expansion has to do with the use of market analysis for the principal co-products; this considers taking into account the real elasticities of source and request. These analyses are pretty complex at the level of detail required for LCA. As economic associations are not involved in the specified version of inventory modeling, this leads to use sensitivity analysis of new market effects in the model. However the multi-functionality problem will not decline but growth by introducing market mechanisms.

To avoid allocation by using system expansion, it could be used the classical system expansion, system expansion and substitution, cascade approach. Avoiding allocation with the classical system expansion approach considers an expansion of the system boundaries to incorporate all the added functions resulting from multifunctional processes in the system. This is not commonly a possibility for all multifunctional processes, because it involves an extension of the analysis to the entire world, as each expansion implicates multifunctional processes. This approach should be applied for functional outputs (Guinée *et al.*, 2004).

The system expansion and substitution approach involves an identification of the product or function, which will be replaced by a co-product or a co-function of the studied product, then the emissions that occurred in the production have to be calculated and are credited to the main studied product (Brander, 2012).

The 50–50 approach indirectly accepts return of material of the same quality to the same system. Fifty per cent of the production is allocated to the product system according to the quantity of primary or secondary input. This methodology is a compromise between remunerating use of secondary material and remunerating supply of recyclable material. (Guinée *et al.*, 2004). This method leads to some implicit assumptions such as how material manufacture for a function system is being substituted, and on the viability of other multiple outputs within function system being clever to be distributed with in a similar trend (Guinée *et al.*, 2004).

The cascade approach means that a product after having realized one function, is recycled into alternative purpose but with a reduced quality. When the purpose of an LCA is to study the environmental loadings related with one of the products in the cascade, setting the system boundaries enhances difficulties (Tillman and Baumann, 1993).

When expanding a system it is necessary to consider that if the sensitivity analysis shown flows through the system boundaries and stocks were insignificant, cut-off criteria would be introduced. The easiest way to expand the system could be using a wider functional unit. It ought be proved whether substitution brings to nested-system boundary problems (Guinée *et al.*, 2004).

System expansion allows the use of a single product system level by the substitution of the burden method. The material replaced would have similar characteristic as the recovered material. This methodology would only be used when it is totally clear which material is replaced. This method results very difficult so a sensitivity analysis have to be executed to clary show the difference in the results (Guinée *et al.*, 2004).

When the allocation cannot be avoided, it should be separated the inputs and outputs in between their different co-products and when the physic relation could not be established or used as the allocation basis, it should be allocated the inputs between products and functions, which allows obtaining their relations (Curran, 2012).

When physical relations cannot be established as the basis, the inputs would be allocated between the products and the functions in a way that suggests other relations between them (ISO, 1998).

In many cases some outputs could be a portion of a co-product and other portion residues, in this case, it is necessary to identify the portion that exist between both co-products and the residues. The allocation procedures must be used uniformly in the similar inputs and outputs of a system (ISO, 2006b).

When allocating it must be considered that the inventory is established on material balances between input and output. Allocation procedures ought then estimate as much as possible the input-output relationships and characteristics. For co-products, internal energy allocation, and recycling, it must be considered that the study will recognize the common processes with other product systems and deal with them fitting with the amount of the allocated inputs and outputs of a unit process, which will be equal to the unallocated inputs and outputs of the unit process and whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach (ISO, 1998).

According to Curram (2012) physical relations such as mass or energy could be used to allocate process flows with useful outputs. Also economic value can be used to allocate co-products. This approach applies the cost of allocation and cost of analysis, which is extensively applied in business and economics. However this method could lead to certain complications especially when markets are deficient, or prices are unfair or owing to government intervention (Guinée *et al.*, 2004).

Also the fluctuation of the prices of the co-products could lead to incongruent conclusions even if the co-products did not change their characteristics (Curran, 2012). In the other hand allocation by mass often provides reasonable results. In calculating energy, heat of reaction could be the proper base for allocating energy to the various co-products (EPA, ¿?).

2.1.2.6. Interpretation

Basically in this step the results are presented in diagrams, which contain the LCI result, the impact assessment description and the weighted results also quantitative assessment of the results could be presented (Logaras, 2008). The principal application of this step is to summarize the quantity of data to the key results for facilitating a decision making process based on (Jensen *et al.*, 1997).

2.2. Lubricants (MWF)

Lubricants have been used for lubricating machines and materials for many years (Shashidhara and Jayaram, 2010). Issued articles shown that in 2005 approximately 8 million metric tons of lubricants were used globally with an increase of 1,2% in the next decade (Kline and Company, 2006).

MWF are lubricants that have a wide use in machining industries (Lawal, *et al.*, 2011) due to their capacity to combine the coolant and lubricating properties acquired in many metalworking activities (Kobya *et al.*, 2007), these fluids are also applied to carry out the chips generated in the cutting processes (Hasib *et al.*, 2010; Herrmann *et al.*, 2007). Fig. 4. shows the purpose of a MWF.

Nevertheless, in terms of workers health, MWF are related with diseases such as dermatitis, allergic alveolitis, occupational asthma; complaints associated with eyes, nose and throat, the possibility of cancer (Alves and de Oliveira, 2008; Simpson *et al.*, 2000) and infections related to dermatological and respiratory diseases (Aronson, 1994).

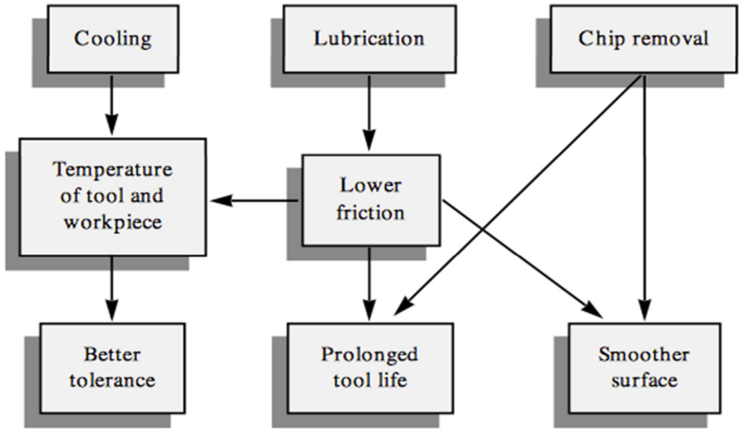

FIG. Nº 4. Purpose of a MWF (Adapted from Nymas, 2001)

2.2.1.
Brief history of MWF

MWF have been used since mid-nineteenth for lubricating tools and work piece. In 1868 W.H. Northcott observed that applying a cutting fluid improved the tool life, by 1983 Taylor showed the importance of applying water as a cutting fluid. He observed that by applying water the cutting speeds increased by 30–40% (Kuram *et al.*, 2013).

In the UK nearly 1300 tones of mineral oil MWF are used per month, and water mix MWF use is about 600 tonnes per month (Simpson *et al.*, 2000). In the European Union the consumption of MWF reach approximately 320,000 tonnes per year (Abdalla *et al.*, 2007).

Nowadays, MFW are produced considering workers security, health, and environmental and final disposal (Gérald, 2004). The demands of the industries and the environmental concerns made that the MWF producers considers in their formulations the exclusion of rust inhibitors, elimination of polychlorinated biphenyls, decrease in use of diethanolamines, removal of dichromates, reduction of phenolic compounds, elimination of 4-tert-Butylbenzoi acid, severe refining of mineral oils to reduce polynucleararomatic, substitution of glycol ethers and reduction in use of barium sulfates (Cohen and White, 2006).

2.2.2. Metalworking fluids classification

MWF are complex combinations of chemicals such as mineral oil or water, which are know as water mix metalworking fluids (Simpson *et al.*, 2000). Commonly, MWF are classified by their quantity of mineral oil present in the fluid (Bittorf *et al.*, 2011). Table. 1. shown the MWF classification and their lubricity, cooling and replacement frequency. Fig. 5. shown the relative proportion of water, oil, and additives in MWFs.

2.2.2.1. Mineral oil bases

These kinds of MWF are based on a limited raw material source; also they cause environmental issues and workers health problems (Herrmann *et al.*, 2007).

Mineral oil MWF generally consist on one or more severely refined mineral bases, in these oils there are extreme pressure additives such as esters, chloroparaffins and sulphurised esters added, usually compounds such as odorants and anti-corrosion additives are present in this formulations. Mineral oil MWF could be manufactured with same base fluids and different kinds of diluents and additives; these elements will cover a range of volatilities. Droplets and vapor will compose an aerosol and will be dynamic with material moving between the two phases (Simpnson *et al.*, 2000).

Mineral oil MWF are used principally in machining of aluminum magnesium, brass and sulphurized or leaded free machining steel because their processing does not require high cooling or lubricating properties (El Baradie, 1996). Their main application in MWF is as a base for other blends and additive oils (Foltz, 1990).

Classes	Lubricity	Cooling	Replacement frequency
Straight Oil	↑	↓	N/A
Soluble Oil			↑
Semi-Synthetic			
Synthetic			

TABLE Nº 1 MWF classification and its lubricity, cooling and replacement frequency (Adapted from The Navy´s Environmental Magazine, 2006)

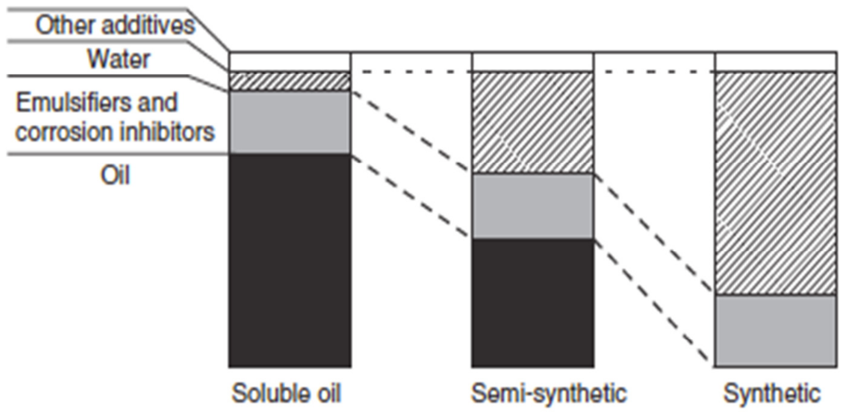

FIG. Nº 5. Relative proportion of water, oil, and additives in MWFs (Adapted from Oberwalleney and Sheng, 1996)

According to Cohen and White (2006) MWF could be classified in Straight oils, soluble oils, semisynthetic fluids and synthetic fluids.

2.2.2.2.
Straight oils

Mostly are mineral oil based, but some could have a vegetable or animal oils with non-water content. The composition of these fluids could be conformed by severely hydrotreated or severely solvent refined for reducing polynuclear aromatic hydrocarbon content (Cohen and White, 2006; Kuram *et al.*, 2013).

Straight oils are used when machines need a cutting fluid as a lubricant and when it is easy to filtrate and reuse them (Nymas, 2001). To improve the wettability, lubrication and antiwelding properties for severe uses, extreme pressures additives (e.g. sulfur, or phosphorus) and an amount up to 20% of fatty acids are used (Foltz, 1990; Mamidi and Xavior, 2014; Wang, 2010).

When heavy tools are used in a process as tapping or broaching where the cutting forces are particularly high, it is necessary to add extreme pressure additives (EP). EPs offer stability lubricating the chip-tool interface. The EP additives involve sulphur, or phosphorus compounds, which react at high temperatures in the cutting zones and form metallic sulphates, chlorides and phosphides. In sulphurized fatty mineral oil mixtures there is a sulphur added in a powerfully attached, inactive form, which may be totally no staining. (El Baradie, 1996).

The advantages obtained by using these MWF are excellent lubrication, good rust protection, good sump life, easy maintenance and rancid resistant (IOWA WASTE REDUCTION CENTER, 1996; Wang, 2010). The disadvantages of these oils involve poor heat dissipating properties, increases the fire risk, they could generate a mist or smoke; for cleaning the oil film it is usually necessary to use dissolvents; limited raw material resources, odor and their expense (Foltz, 1990; Kuram *et al.*, 2013; State of Ohio Environmental Protection Agency, 1993; IOWA WASTE REDUCTION CENTER, 1996).

Vegetable oil base: The incorporation of the sustainable development criteria in production offers to the industry an effective cost to consolidate an economic and social performance. The idea of sustainable development have been implemented and accepted on the production macro level, nonetheless there is a lack of implementation of these practices on the shop floor dealing with machining technologies (Pusavec *et al.*, 2009).

Consequently the introduction of vegetable base oils, as MWF has made possible to achieve significant growths in overall performance, table 2 shows some advantages and disadvantages of vegetable oils. Vegetable base oils have been well known by their excellent lubricating properties since the 1960s (Krahenbuhl, 2002). According to Alves and de Oliveira (2008) rapeseed oil, soybean oil, and native esters can be used as base fluids.

Besides vegetable oils are sustainable and renewable sources of environmentally friendly oils. The increased need for renewable and biodegradable lubricants can be traced to stronger environmental concerns and growing regulations about contamination and pollution (Alves and de Oliveira, 2008). In terms of biodegradability esters and vegetable base oils are better when manufacturing cutting fluids, since they are readily biodegradable in contrast to mineral oils the additive concentrations are commonly below 10% w/w (Eisentraeger *et al.*, 2002).

Advantages of vegetal oil based MWF	Disadvantages of vegetal oil based MWF
High biodegradability	Low thermal stability
Low pollution	Oxidative stability
Compatibility with additives	High freezing point
Low production cost	Poor corrosion protection
Wide production possibilities	--
Low toxicity	--
High flash points	--

TABLE N^o 2 Advantages and disadvantages of vegetable oils based MWF (Adapted from Fox and Stachowiak, 2006)

Vegetable oil based MWF have numerous environmental benefits such as susceptible degradation by oxidation (Alves and de Oliveira, 2008); good lubricity properties due to their fundamental composition, which is based on vegetable oil molecules, as well as the chemical structure (Krahenbuhl, 2002) that consist on triglyceride molecules with three long fatty acids chains attached at the hydroxyl groups via ester linkages with an average of 14 to 22 carbons long (Fig. 6 shown the chemical structure of triglyceride of a typical vegetable oil). Nevertheless the unsaturation level could be different (Kuram *et al*., 2013).

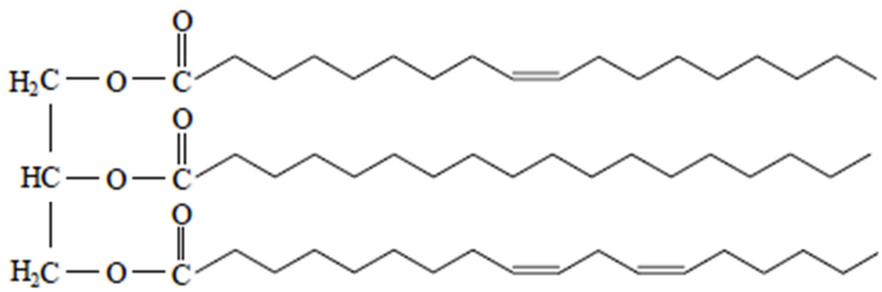

FIG. Nº 6. Chemical structure of triglyceride of a typical vegetable oil (Herrmann *et al*., 2007)

Additionally vegetable base oils are amphiphilic in nature because the presence of the extended fatty acid chain and the polar groups, this allows to use them as a boundary and hydrodynamic (Adhvaryu *et al*., 2004). To reach the demands for stability in tribochemical processes, oils´ structure needs to withstand high ranges of temperature variation, shear degradation and preserve excellent lubricating properties with a strong physical and chemical adsorption on the tool-workpiece surfaces (Adhvaryu *et al*., 2004).

Polar heads presents in the molecules have a chemical affinity for surfaces that creates a strong connection with the metal resulting in a dense, homogeneous alignment of the molecules, perpendicular alongside the metal surface, that produces a dense, strong, and durable film layer of base oil offering a greater capacity to absorb pressure (Krahenbuhl, 2002; Lawal *et al*., 2011).

Additionally these fluids have a good viscosity; it drops more slowly than mineral oils. This permits when temperature falls they remain more fluid than mineral oils and a faster drainage from chips and workpieces. The higher viscosity index of vegetable oils warrants more unremitting lubricity across the operational temperature range (Woods, 2005).

Moreover vegetable oils have a higher flash point than mineral oils, which decrease smoke formation and fire hazard (Krahenbuhl, 2002). The strong intermolecular interactions are also resilient to changes in temperature (Kuram *et al.*, 2013; Lawal *et al.,* 2011).

However, the strong intermolecular interactions whereas providing a durable base oil film also creates a poor low-temperature properties (Lawal *et al.*, 2011), because triacylglycerols relates first of all to their crystallization kinetics (Larsson, 1994) which generally has a relation with temperature fluctuations and related factors such as cooling rate or thermal history (Asadauskas and Erhan, 1999).

Another disadvantage present in vegetable oils is their inadequate oxidative stability because the presence of unsaturation level in the triacylglycerol molecule due to C=C from oleic, linoleic and linolenic acid moieties (Adhvaryu *et al.*, 2004), The oxidation stability has a relation with the quantity of unsaturated products. At low unsaturation levels exist better oxidative stability, but a higher melting point (Koushik *et al.*, 2012).

2.2.2.3. Soluble oils

These kinds of oils are mixes of water and oils, they have enlarged the cooling potentials of the straight oils (IOWA WASTE REDUCTION CENTER, 1996) bringing them to be used in about the 80% in metal cutting activities that includes high cutting speed operations and low cutting pressures accompanied by considerable heat generation (Aronson, 1994; El Baradie, 1996).

The content of naphthenic or paraffinic emulsifiers and additives goes around the 30–85% of the oil containing (Cohen and White, 2006), the blend is almost made up with emulsifiers; this provides oil stabilization in the water phase (Bittorf *et al.*, 2011). To increase lubricating properties improving also EP, wetting agents, sulfur, or phosphorus can be add, in the other hand as the blend includes much more oil than water the cooling properties of these oils is not good as the chemical, surface-active fluid (Huebcore, 1994).

According to El Baradie (1996) there are:

- Clear - type soluble oils: these have less oil and much more emulsifier than milky emulsions and consists of oil dispersions with smaller oil droplets that are more widely distributed;

- Fatty Soluble Oils: These fluids are composed by animal or vegetable fats or oils or other esters originating from mineral oils theses components are used to provide a range of fluids with improved lubricating properties;
- Extreme pressure soluble oils: are composed by sulphur, or phosphorus additives. These elements improve the load carrying performance. Meanwhile the EP concentrate is integrated by an enulision, which carries an amount of 5 to 20 parts.

2.2.2.4. Semisynthetic fluids

Semi-synthetic MWFs are water-based which in presence of water generate an emulsion. The water contains emulsified oil droplets and dissolved compounds. Substances use for formulating these fluids are anti-wear additives using to form the lubricating film, high-pressure additive, foam retardant agent, antirust additive, antifog agent, dispersing agent and surface-active substances, biocides, odorous and colouring substances, amines, borate, nitrates, nitrites, polyalkyl sulphonate, glycerol, esters and ester glycols (Gérald, 2004).

Semi-synthetical MWF natures depends on the oil emulsion, this is produced by using emulsifiers that can be ionic or polymeric, in the major part of the formulations both are used. Also in the fluid base alcohols are introduce; when are water based, it creates a blend with oil droplets that includes a part of soluble molecules which pass to the diluting level providing more stability to the blend.

The stability depends as much as the emulsifier as on the size of the droplet, which is underneath 0.2μm, but they are not necessarily transparent due to the Tyndall effect (Gérald, 2004).

2.2.2.5. Synthetic fluids

These MWF are a mixture of organics and additives that provide lubricity and corrosion prevention, water content goes around 70–95% (Cohen and White, 2006). Consist on inorganic and organic compounds, biocides corrosion inhibitors dissolved in water and no containing oils, the chemical elements using when formulating synthetic MWF. Their chemical elements and use are shown in table 3 (El Baradie, 1996).

Chemichal element	Use
Amines and nitrites	Inhibitors
Nitrates	Nitrite stabilization
Phosphates and borates	Water softening
Soaps and wetting agents	Lubrication and reduction of the surface tension
Glycols	Blanding agents and humectants
Germicides	Bacterial grow control

TABLE N° 3 Chemical elements using in synthetic MWF and their function (Adapted from El Baradie, 1996)

According to El Baradie (1996): Synthetic oils are classified into four categories:

- True Solution: Contain corrosion inhibitors such as inorganic and organic nitrites sequestering agents, amines, phosphates, borates, glycols or ethylene or propylene oxide condensates. Many of these fluids contain sodium nitrite (for cast iron) triethanolamine (for both cast iron and steel) and sodium mercaptobenzothiazole (for reducing corrosion on brass, zinc and aluminum);
- Surface active: There are colloidal solutions on them include also anti foaming agents, humectants, mild base oils (organic or inorganic) and water softeners. The colloidal solutions are composed by inorganic and organic materials dissolved in water with the addition of surface-active agents, which increase the wetting action of the water, and form a greater uniformity of heat dissipation and anti rust action;
- The surface active: It is a chemical fluid with a fair lubricity, low surface tension, and good rust inhibiting properties. Frequently its use leaves a dry, hard or powdery residue, which can be removed easily. The foam produced by these fluids is not a problem; their use is usually made in a 1-part concentrate in l0 to 40 parts water;
- EP Surface Active: have the same characteristicas that are presented in the surface active but EP provides better machining performance, sulphur or phosphorus additives to offer extreme pressure lubrication effects. The EP Surface Active, are used in dilution between 1:5 and 1:30. Fig. 14. Sown common phosphorus derivatives used as antiwear agents.

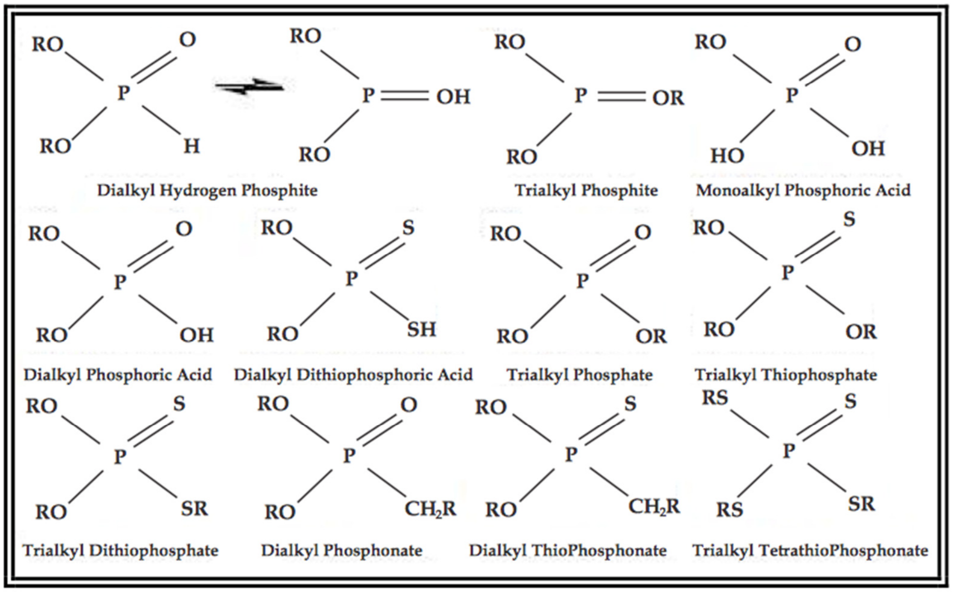

FIG. Nº 7. Common phosphorus derivatives used as antiwear agents (Adapted from Ahmed and Nassar, 2011)

2.3. Description and presentation of the production steps for mineral base oil and Jatropha base oil

2.3.1. Production of mineral oil

The production of mineral oil involves the next phases (McManus, 2001):

2.3.1.1. Exploration

Exploration is a high-risk activity into the petroleum industry (Suslick *et al.*, 2009). Much of the activities have relation with geophysical companies (McManus, 2001), which concenter their activities on extensive areas to establish all the benefits for the operation of the yield by the use of seismic testes using explosives. First it is necessary to perforate 2 – 3 meter wells with a separation between 5 to 100 meters, then the explosive material is placed and finally the soil extracted is used to fill the wells, before the explosion, cables are placed along the wells, this cables will bring the information after the explosion (Calao, 2007).

From this steps several environmental impacts are generated including the consumption of the energy in terms of transporting machines, the construction of ways for transporting the material and machines until the yield, solid waste, soil compaction, erosion, noise, loss of fauna (McManus, 2001; Calao, 2007).

2.3.1.2. Drilling and extracting

Drilling is the first phase in the extraction of the crude oil, this is a way to determinate if a potential yield could or not be exploited. Once the drilling showed that the field could be operated and it is economically viable the next step is to perforate the rock using explosives charges, this allows that the oil contained in the reservoir can flow into the well. Once all the control instruments and valves have been put into place the well starts its production (McManus, 2001).

The natural pressure into the well will push out the crude oil but, if it is not enough pressure is possible to use the secondary recover, this uses the water which was into the reservoir to maintain the pressure, this is possible by reinjecting the water into the reservoir (McManus, 2001).

For drilling many lubricants are used to lubricate the perforation instruments. Common additives are used in the formulation of the lubricant fluids; these formulations are commonly conformed by clay and barytes, biocides, bactericides; anticorrosion compounds and many pH chemical regulators (Calao, 2007). These substances can potentially cause many environmental issues (McManus, 2001). Also waste produced by the drilling process, can be conformed by heavy metals (Calao, 2007).

Negative environmental impacts such as loos of biodiversity, alteration of vegetable coverage, erosion, alteration of water resources, solid waste, pollution by chemicals and radioactive substances and noise are produced in the drilling and extracting processes (Calao, 2007).

2.3.1.3. Transportation and storage

Crude oil is transported using large seagoing tankers, barges, rail tank cars, tank trucks, and pipelines (EPA, 2008). Regularly these forms of transport are used at diverse steps of transferring the fluid from the oil field to the refining center. Crude oil is transported along pipelines by pumping stations at regular intervals (McManus, 2001).

Petroleum arrives into refineries in high magnitudes and is storaged in metallic tanks; in some places the crude oil could be storage in caverns at times of low demand in tankers (McManus, 2001).

Furthermore of the impacts generated by the emissions from the internal combustion engines used in this step, there are negative impacts relating with spills as produced by Exxon Valdes, Braer, Treasure, Macondo (McManus, 2001; Griggs, 2011).

2.3.1.4. Refining

In this production step the crude oil is distilled into many fractions with molecular mass less than that the present on the original crude. Also, sulphur is removed from the fluid and trace. Metals are recovered (McManus, 2001).

Atmospheric distillation: the crude oil is separated form the desalted crude oil, this allows to obtain specific hydrocarbons groups that have similar boiling points, which are about 371,11°C. The crude form the desalter is heated about 371,11°C in a tubular pipe furnace, which could use numerous different configurations being the most used hot furnace fuel gases to preheat pipes, which reduces energy requirements as well as the amount of time the crude must spend at extremely high temperatures (Energetics Incorporated, 2007).

Feed flow to the furnace is divided into many fractions to guarantee heat distribution. For obtaining an equal flow within each pass there is a control valve, which is adjusted by input from a flow meter. For assure correct operation of the valves, flow have to be single phase. Heated petroleum enters into the atmospheric distillation column that is a vertical cylindrical tower, which can be as large 13 feet width and 80 feet high and the operation ranges are just above atmospheric pressure (Energetics Incorporated, 2007). Some crude oils, diesel fuels and heavy fuel oils can be produced in this way and marketed directly (McManus, 2001).

Emissions	Effluents	Waste, Residuals or By-products
Heater stack gas (CO, SOx, NOx, hydrocarbons and particulates)	Oily sour water from the fractionators	Little or no residual waste or by-products

TABLE N° 4 Emissions, effluents and waste production of the atmospheric distillation (Adapted from Energetics Incorporated, 2007)

Vacuum distillation: Upsurges the quantity of the middle distillates and creates lubricating oil base stocks and asphalt. The feed to the unit is the residue from atmospheric distillation (Matar and Hatch, 2000). Usually it is cohesive with the atmospheric distillation unit as far as heat transfer is concerned (Jones and Pujadó, 2006).

The material obtained in the atmospheric distillation is heated by an exchange between the hot product and pumparound streams before being vaporised in the distillation unit heater (Jones and Pujadó, 2006), uninterruptedly the material is sent to a vacuum distillation tower (Matar and Hatch, 2000), which recovers additional fluids at 4.8 to 10.3 kPa at absolute pressures between 350 to 1400 kg/m2 (Jukić,¿?) and have an atmosphere superheated of steam, which reduces the formation of coke and decrease the partial pressure of hydrocarbons (Matar and Hatch, 2000).

The separation of the topped crude is done by vaporization and condensation (EPA, 1995). The temperature required for vaporizing, reach a range of 400ºC to 440ºC and a pressure of 25 to 40 mmHg (Matar and Hatch, 2000).

The vapors formed will be condensed into the tower using a transfer of mass and heat with the cold reflux that goes to the inferior of the tower as the side streams in the atmospheric unit. The products are cooled by exchanging heat between colder fluxes present on the atmospheric unit, this occurs by using air, coolers or occasionally heating mediums to light end reboilers (Jones and Pujadó, 2006).

The overhead stream light vacuum gas oil may be used as a lube base stock, heavy fuel oil, or as feed to a conversion unit. Heavy vacuum gas oil is pulled from a side draw (Jukić,¿?). The products obtained from the vacuum distillation are vacuum gas oil a heavy pitch bottom residue, and asphalt that could be used for asphalting roads can be sent to a delayed coking unit (Energetics Incorporated, 2007; Matar and Hatch, 2000).

Emissions	Effluents	Waste, Residuals or By-products
Heater stack gas (CO, SOx, NOx, hydrocarbons and particulate) and steam injector emissions (hydrocarbons)	Oily sour water from the fractionators (hydrogen sulfide, ammonia, suspended solids, chlorides, mercaptans, phenol	Little or no residual waste or by-products

TABLE N° 5 Emissions, effluents and waste production of the vacuum distillation (Adapted from Energetics Incorporated, 2007).

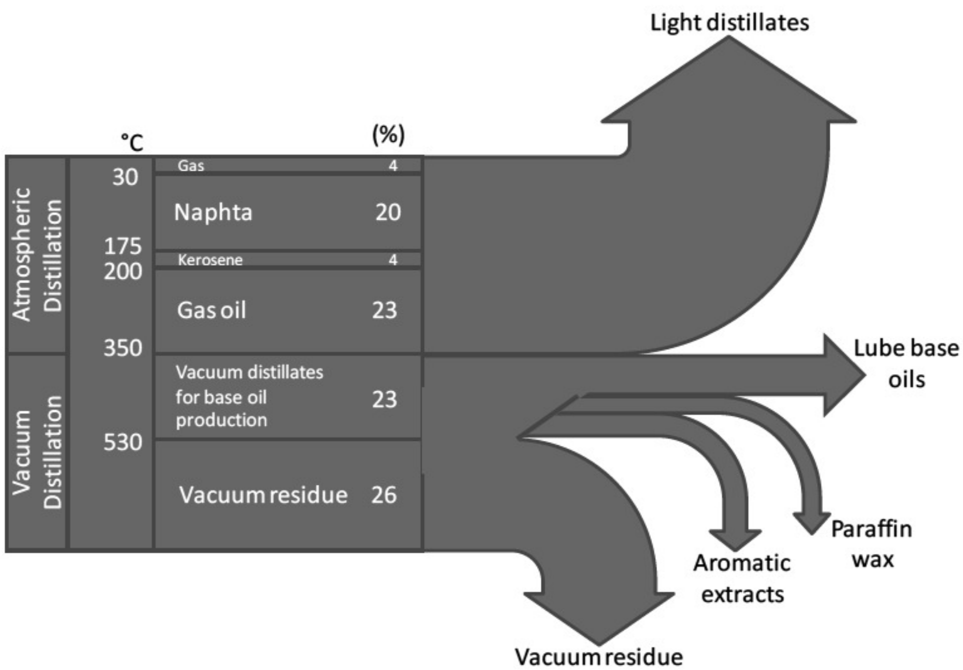

FIG. Nº 8. Products of the vacuum and atmospheric distillation (Adapted from Cuevas, 2010)

According to Fehrenbach (2005) base oil production consist in:

Deasphalting: In this step, asphalt components and gas oil components are separated from the residuum of the vacuum distillation using a solvent, which is compressed and contacted with the residuum. The products extracted are a mix of deasphalted oil and asphaltic components. The extract and raffinate streams go to a separate solvent recovery systems that recover the solvent (EPA, 1996).

The major deasphalting process use propane, butane pentane and some other aliphatic asphaltic components from the feed and its choice depends on the quality and yield of the deasphalted oil. In fixed temperatures there is an increase of the solubility of the oil and in the heavier components, which are in the solvent (Salem *et al.*, 2011).

Aromatic extraction: It is performed by using a liquid solvent, where the elements present on the mixture allocate themselves in dissimilar proportions. For this, agents as aldehyde derive from corncobs and oat hulls, N-methylpyrrolidone phenol, liquid sulfur dioxide and nitrobenzene are used (Agnello, 2000).

Into the extraction tower both, the oil and solvent are mixed, this forms a two liquid phases being the first, the heavy phase that consists on undesirable components dissolved in the solvent and the second one, which consist on high-quality oil containing some solvent. Both phases are separated and the solvent is recovered by distillation and could be reused fifteen times per day (Agnello, 2000; Energetics Incorporated, 2007), and the extract could be sold sparely as a co-product to the plastic, rubber or ink manufacturing industries (Energetics Incorporated, 2007).

Hydrotreating: is a hydrogen-consuming process**,** which is used to remove nitrogen, sulphur and metal brougth by the feeds, which can be composed for any petroleum fraction or naphta or crude residues (Matar and Hatch, 2000).

The process considers a mix between the feed and hydrogen and it is heater to a proper temperature and then it is introduced on the reactor, which contains a catalyst. The treated feed might affect energy use. Energy intensity assumptions are established on a diversity of fonts, and balanced on the basis of available data. Many different literature sources offer varying assumptions for several processes, particularly for electricity consumption (Worrell and Galitsky, 2005).

A typical condition for this process also considers temperatures ranges between 260ºC to 425ºC. When increasing the temperature range and the hydrogen partial pressure, there are an icrease of the hydrogenation and hydrodesulphurization (Matar and Hatch, 2000).

Catalyst used for this process must be sulphur-resistant, an effective kind of catalyst is obalt-molybdenum system supported on alumina. In the initial stages of operation before use, the catalyst ought be reduced and sulfied (Matar and Hatch, 2000).

There are two principal reactions occurring on the hydrotreating units, the hydrodesulfurization and hydrodenitrogenation of sulfur and nitrogen compounds.

In the hydrodesulfurization the H2S is formed lengthwise with the hydrocarbon. In the latter case, ammonia is released (Matar and Hatch, 2000).

Dewaxing: this process uses the deasphalted oil and the heavy vacuum gas, oil produced in the vacuum distillation tower as feedstock, this will produce lubricating oil and distillate fuels. The main objective of this process is: to remove hydrocarbons which would increase the pour point of the lube oil base stock and turn them into a desirable range of -22,77°C to -10°C (Graham, 2014).

Solvents as methyl, ethyl, ketone and toluene are mixed with the base oil; methyl, ethyl, ketone dissolve the wax, and the toluene dissolves the oil; this is made at 18 ºC temperature. The wax precipices and the base oil with a pour point of approximately 18°C, is filtered out (Agnello, 2000).

Hydrofinishing: is required to subtract chemically active compounds, which alter the color and stability of lube oils and create a thermal / oxidative stability of base oil (Graham, 2014; Soudel, 1974).

In the hydrofinishing process, hydrogen is added to the base oil at an elevated temperature in the presence of a catalyst. By reaction of hydrogen with some remained sulfur and/or nitrogen containing molecules, these sulfur/nitrogen-contained compounds are decomposed into smaller molecules to improve product color and stabilities (S-oils, accessed, 18-09-14).

Cobalt-molybdate catalysts are used in many hydrotreating operations. These components are operated at a severity set by the color improvement needed, the main objective of this oil base production step is to remove the organic nitrogen compounds that affect the color and color stability of oils (Soudel, 1974).

Fig. 9. Shown the stages in for mineral oil base production (Fehrenbach, 2005).

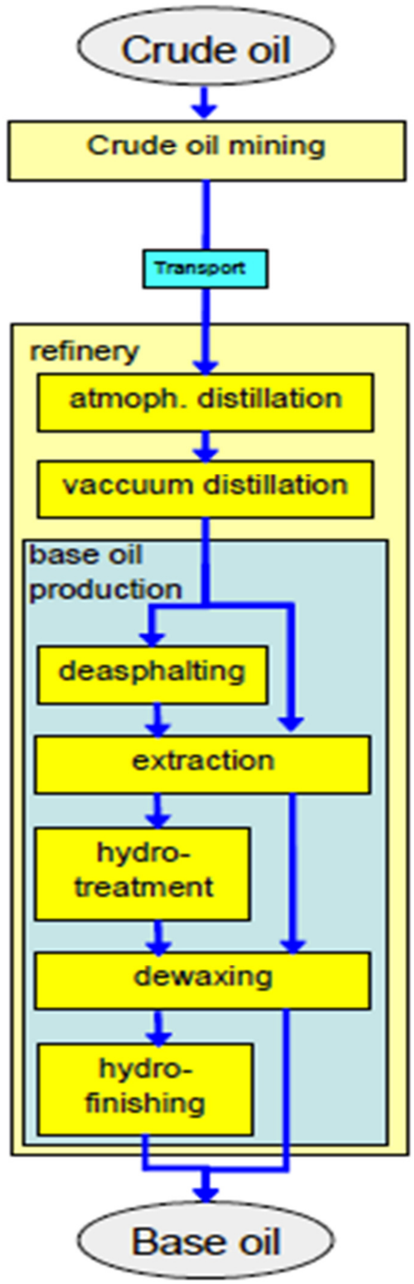

FIG. Nº 9. Mineral oil base production (Fehrenbach, 2005)

2.3.2.
Production of Jatropha oil

Jatropha curcas belongs to the Euphorbiaceae family. The plants grow quickly. In 9 months there is a thick bushy fence formed that could be 4 m tall with branches in 2 or 3 years, its seeds look like castor seeds but are smaller and presents a brown pigmentation (Sampattagul *et al.*, 2009; Sotolongo *et al.*, 2007). This plant has applications such as medical, prevention of the erosion, decoration and oilseed, which have economic significance (Aregheore *et al.*, 2003). The seed cake is an excellent source for organic manure due to the high level of nitrogen. *Jatropha curcas* incorporates the carbon present in the atmosphere in the woody tissues contributing in the diminution of the effects of global warming and assists in the buildup of soil carbon (Baggash and Abdulrahman, 2010).

It occurs in all tropical and subtropical areas; its growth is possible on poor soils and in a high hot temperature ranges, leaves drop in cold weather and arid conditions (Goembira and Ihsan, 2013; Prueksakorn and Gheewala, 2006). Rainfall requirement is about 250 mm per year but also it can grow well at 900-1200 mm (Prueksakorn and Gheewala, 2006). Jatropha oil seed composition is 21% saturated fatty acids and 79% unsaturated fatty acids (Raja *et al.*, 2011). It offers a potential as feedstock in terms of production of vegetable base oils and biodiesel due to, the oil contained on the seed has similar characteristics than diesel, however the kinematic viscosity, solidifying point, flash point and ignition point are high (Rahman *et al.*, 2010).

The production of Jatropha oil involves nursery, cultivation and harvest, oil extraction and refining, transesterification and end of use (Almeida, 2009), the production phases are shown in Fig. 10.

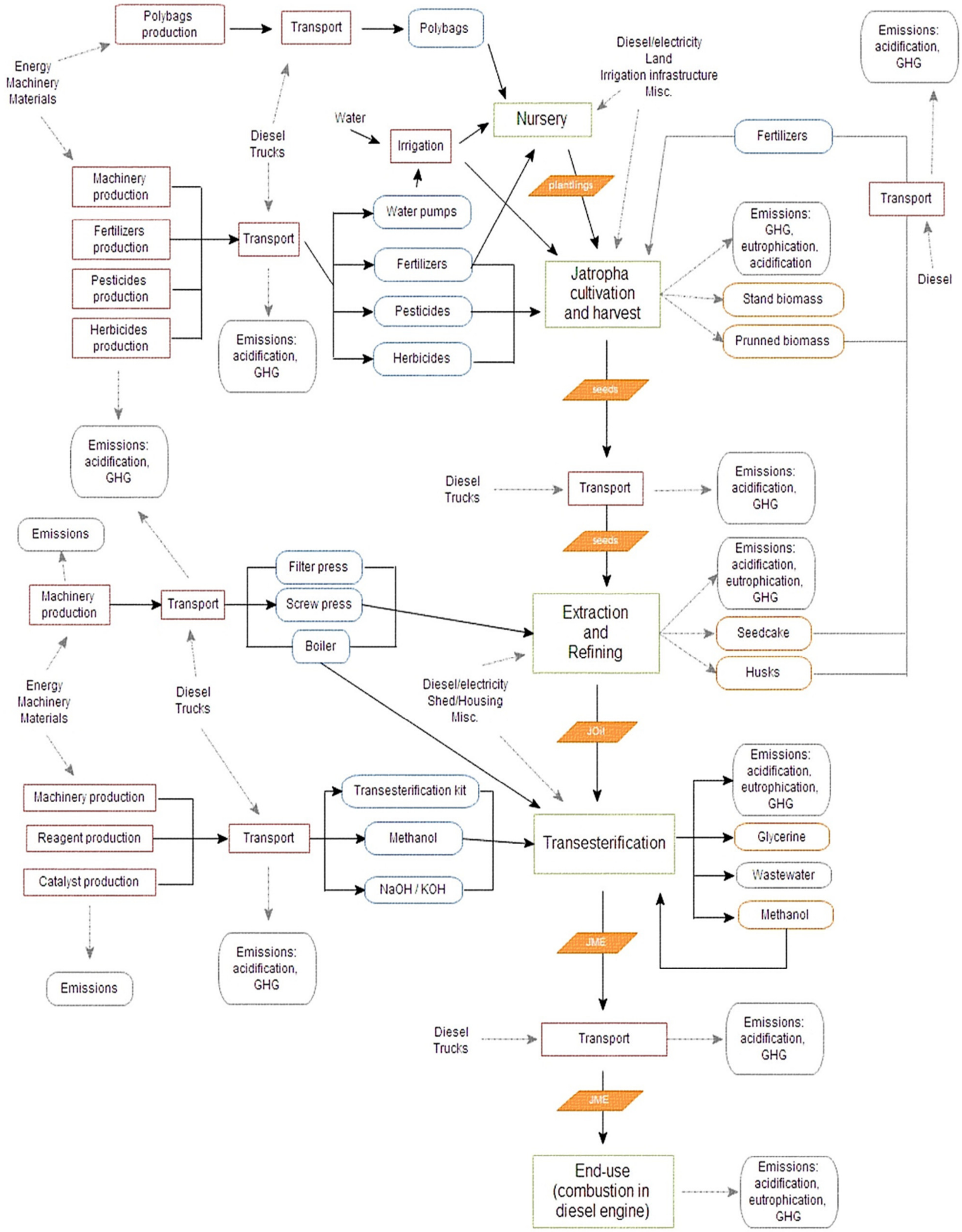

FIG. Nº 10. Phases for the full production of Jatropha methyl ester (Adapted from Almeida, 2009)

Jatropha cultivation is considered the first step to produce jatropha ester nevertheless this phase is not well documented yet (Almeida, 2009). According to Almeida (2009), nursery and crop parameters must be quantified. According to Achten *et al.* (2008) yield ought fluctuate from 4000 to 5000 kg of dry seed ha-1 yr-1.

According to Reinhardt *et al.* (2008), on a best scenario that includes agricultural optimization and improved plant breeding, different inputs are needed for cultivating Jatropha.

Oil extraction occurs after the seeds have been dried, the fruit is placed into a cracking machine to remove coats. Around 10 – 18 kg of crude oil is extracted per hour (Chatterjee *et al.*, 2012), once the oil is extracted; is purified by filtrating to remove waxes, fatty acids and phosphatides (Chatterjee *et* al., 2012; Prueksakorn and Gheewala, 2006) form this process soap is obtained as a co-product (Chatterjee *et* al., 2012).

After oil extraction it is considered that one Ha of Jatropha generates about 1000 kg of seed cake (Pandey *et al.*, 2012). Seed cake is a good source for manure because the content of nutrients (Foidl *et al.*, 2001), table. 6. Shown the micronuntrients present in Jatropha seed cake. Also seed cake could be used as fuel in wood stoves or ovens (Rahman *et al.*, 2010). In concordance with Parawira (2010) 40 – 50% oil contended in the seeds will produce around 1000 kg seed cake per hectare crop.

N (%)	P (%)	K (%)	Ca (%)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	B (ppm)	Mg (%)
4,91	0,9	1,75	0,31	55	772	22	85	20	0,68

TABLE N° 6 Micronutrients present in Jatropha seed cake (Adapted from Wani *et al.*, 2006)

Jatropha seed cake can also be used for producing biogas; 1000 kg of seed cake will produce 170 – 250 m3 with an amount of approximately 60% methane, and a 6 kWh/m3 energy value. This means that 6.000.000 kg of seed cake will produce a megawatt of electricity and up to 2 MW of heat, with an average of 430.000.000 kg of seed cake it is possible to generate 70 MW of electricity and at least 140 MW of heat from its production of biogas (Lang and Abdelraheem, 2013).

The oil extracted in the last phase is processing by transesterification (Jain and Suhane, 2012), where an ester reacts with an alcohol forming another ester and another alcohol. For this reaction methanol or ethanol are used and the catalyst is KOH or NaOH (Rahman *et al.*, 2010; Raja *et al.*, 2011). Fig. 11. shown the transesterification reaction.

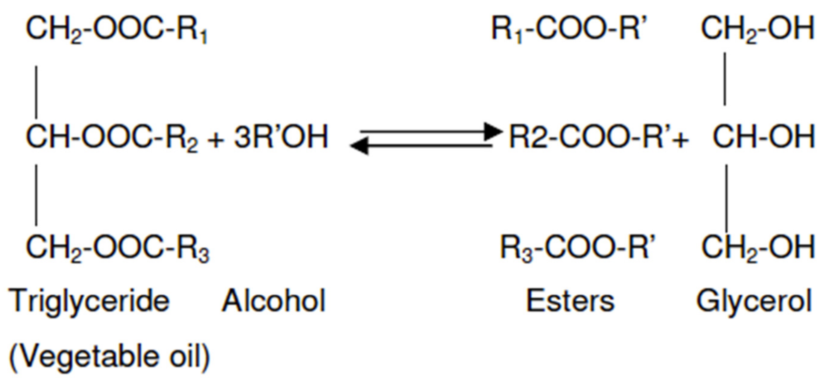

FIG. Nº 11. Transesterification reaction (Adapted from Parawira, 2010)

To start the transesterification the first input is the oil extracted previously from Jatropha seed. The oil, methanol, and catalyst are mixed in a temperature between 55ºC to 60ºC (Rahman *et al.*, 2010). The base-catalyzed transesterification is a product of the base reacting with the alcohol, which produces an alkoxide and the protonated catalyst, and then the triglyceride goes into a nucleophilic reaction.

At this moment the alkoxide attacks the carbonyl group of the triglyceride and produces a tetrahedral intermediate that forms a diglyceride anion and an alkyl ester; this forms an alkyl ester that deprotonate the catalyst that regenerates the actives species and sets them for start another catalytic cycle, altogether with other molecule of the alcohol (Payawan Jr *et al.*, 2010).

As a main product of the transesterification, biodiesel is obtained and glycerin as main co-product (Parawira, 2010). The co-product need further process to be used in other industrial applications (Varadharajan *et al.*, 2008).

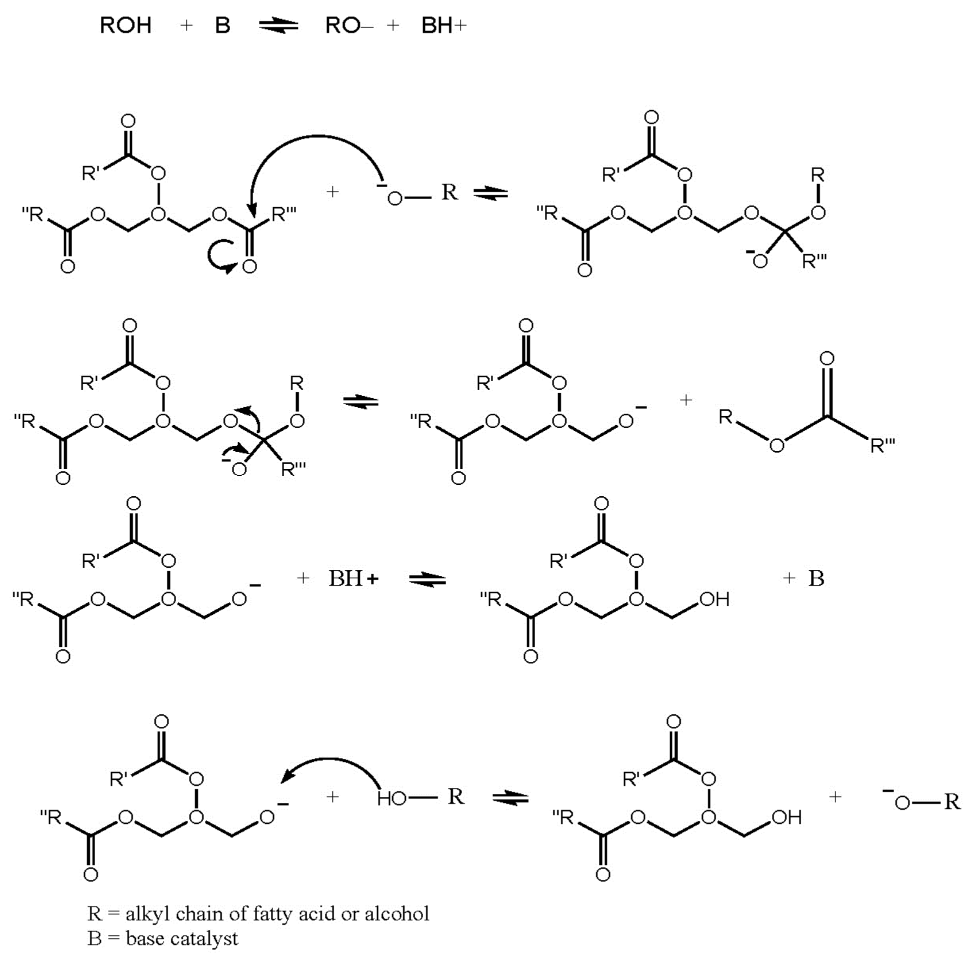

FIG. Nº 12.Base-catalyzed transesterification reaction of triglycerides with methanol (Adapted from Payawan Jr *et al.*, 2010).

Jatropha oil production co-products and their possible use are described in fig. 13.

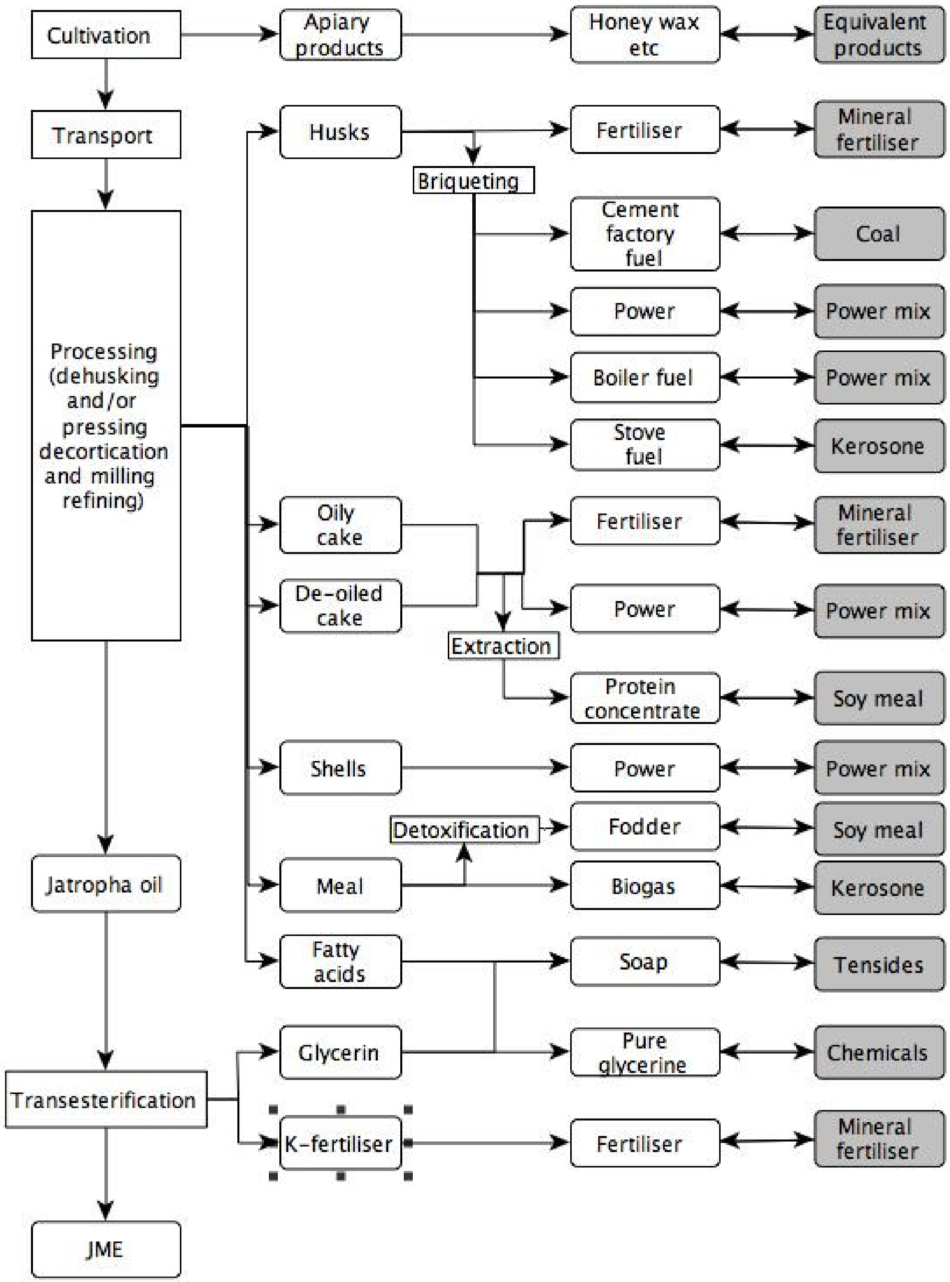

FIG. Nº 13.By products of Jatropha oil production and their equivalents (Adapted from Reinhardt *at al.*, 2007).

2.4.
LCA in lubricants

Genrally it was assumed that vegetable base oils are environmental friendly products than mineral base oils. To confirm this assumption, there are necessary quantitative comparisons of energy, materials and emissions. Some works releated to these parameters have been performed. Some issued informations about LCA in lubricants are shown in table. 7.

Author	Resarch topic
Cuevas (2010)	Comparative Life Cycle Assessment of Biolubricants and Mineral Based Lubricants
Reinhardt *et al*. (2007)	Screening Life Cycle Assessment of Jatropha Biodiesel
Clarens *et al*. (2008)	Comparison of Life Cycle Emissions and Energy Consumption for Environmentally Adapted Metalworking Fluid Systems
Ekman and Börjesson (2011)	Life Cycle Assessment of Mineral Oil-based and Vegetable Oil-based Hydraulic Fluids Including Comparison of Biocatalytic and Conventional Production Methods

TABLE N° 7 Issued informations about LCA in lubricants

Although, the studies cited in table 7, exist differences between them and this thesis. The authors cited in table 7, have performed LCA of bio-lubricants, however there are some differences particularly in the selection of the functional unit, e.g. Cuevas (2010) used as a functional unit 1 kg of lubricant; Reinhardt *et al*. (2007), used the potential of use of Jatropha fruit from 1 ha of land in one year; Clarens *et al*. (2008) performed the LCA using as a functional unit the service of a MWF provided to one machine tool for one year and Ekman and Börjesson (2011) used 1 l of base fluid for hydraulic fluids. In this thesis it was used as functional unit 1 kg of mineral and jatropha base oils.

Also other differece between the studies cited above are the use of inventories presented in the selected tool. Cuevas (2010) used SimaPro; Reinhardt *et al*. (2007), used IFEU´s database / IFEU 2007; Clarens *et al*. (2008) used BUWAL, Association of Plastic Manufactures in Europe; for this thesis it was used the inventories presented in the Umberto NXT LCA, which is explained in chapter 3. Allocation, geographical ubication, avalivility of data and the type of LCA (Cradle to Gate analysis / Cradle to Grave analysis) also are other differences. These differences do not mean that the LCA executed by the autors are incorrect however it leads to a certain complication when comparing results.

Table 8. presents a summarized overview of the results obtained by the authors cited above.

Category	Author	Result (contributions)
Global Warming	Cuevas (2010)	Mineral oi > Vegetal oil
	Clarens *et al.* (2008)	
	Ekman and Börjesson (2011)	
Acidification Potential	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	Petroleum oil > Rapesead oil
	Ekman and Börjesson (2011)	Vegetabel oil > Mineral oil
Carcinogenics	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	
Non-carcinogenics	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	
Respiratory Effects	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	
Eutrophication Potential	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	Vegetabel oil > Mineral oil
Ozone Depletion Potential	Cuevas (2010)	Mineral oil > Rapesead oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	
Ecotoxicity	Cuevas (2010)	Rapesead oil > Mineral oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	
Modified Ecotoxicity	Cuevas (2010)	Mineral oil > Rapesead oil and Soybean
	Clarens *et al.* (2008)	N/A
	Ekman and Börjesson (2011)	

Photochemical Smog	Cuevas (2010)	Mineral oil > Rapesead oil and Soybean
	Clarens *et al*. (2008)	N/A
	Ekman and Börjesson (2011)	

TABLE N° 8 Results obtained in different LCA studies

3.
Life cycle assessment

3.1.
Goal and Scope definition

The goal of this study is to execute a simplified LCA (cradle-to-gate analysis) for the production phase of 1 kg of mineral base oil and 1 kg of jatropha base oil trough an sensitivity analysis, for determining which are the most influential parameters used in the production.

The results of this study were shown to the scientific community of the TU Braunschweig and Pontificia Universidade Católica do Rio de Janeiro.

3.2.
Functional unit and system boundaries

For this study the functional unit was 1 kg of mineral base oil and 1 kg of jatropha base oil. It was assume that 1 kg of jatropha base oil is equal to 1 kg of mineral base oil; due to the production of the mineral base oil requires other products, which will be remove from the final product. This definition allowed the comparison between de data from the LCI and environmental categories.

3.3.
Inventory analysis

3.3.1.
System boundaries

The production steps considered in this study were; for Jatropha oil ester: jatropha cultivation, dehusking, screw press, crude oil transportation, refining and transesterification. Jatropha cultivation, dehusking and screw press processes took place in India; refining and transesterification took place in a decentralized plant in Europe.

In the other hand, for the production of the mineral base oil it was considered: crude oil production, atmospheric distillation, vacuum distillation, deasphalting, aromatic extraction, dewaxing and hydrofinishing. For the refinery processes, it was assumed that the refinery was located in Europe. Fig. 14. shown the system boundaries of this study.

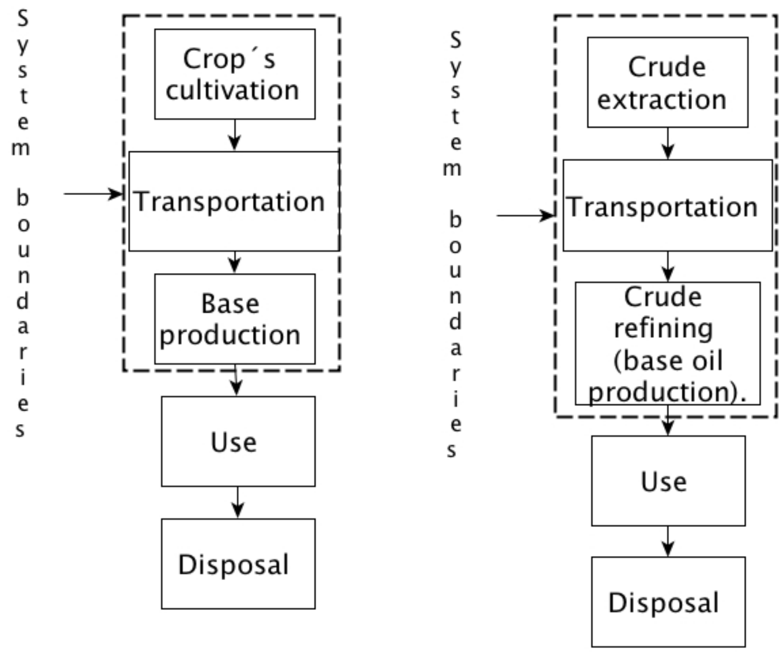

FIG. Nº 14.General description of the boundaries of the study

3.3.2.
Data compilation

For the mineral base oil scenarios, processes for the background system were taken from the Ecoinvent v 2.2 database available on the Umberto NXT LCA software. Data for the production processes were taken from the set values in Fehrenbach (2005).

In the case of the jatropha scenarios, processes for the background systems were taken from the Ecoinvent v 2.2 database available on the Umberto NXT LCA software. Data for the production processes were taken from the today and best scenarios established in Reinhardt *et al*. (2008).

Inputs acquire for the jatropha cultivation on the today and best scenario are shown in table. 7. Table. 8. shown inputs and outputs in the production of the jatropha oil on the today and best scenario in a decentralized jatropha oil production plant. Data acquire for the mineral base oil production are shown in table. 9.

3.3.3.
Sensitivity analysis and allocation

For the jatropha base oil it was assumed that on the base scenario there was not allocation of co-products; on the alternative scenarios was not considered allocation of glycerin, husks and seeds. Also it was used scenarios, which contemplated that ammonium sulphate replaced the ammonium nitrate; potassium chloride was used instead of potassium sulphate, and a scenario where the background system did not use infrastructure. Moreover, there were used two best scenarios; the first one considered allocation of co-products and the second one did not consider allocation of co-products.

For the sensitivity analysis on the mineral base oil, the parameters compared were the Nigerian crude oil; the Russian, Great Britain and rest of African region crude oil mix; the RER crude oil mix and the CH crude oil mix. Also it was used a scenario, which did not consider the use of infrastructure on the background system. Finally it was used a scenario where the aromatic extracts were not allocated.

Allocation considered gas, naphtha, gas oil of the atmospheric distillation, residue of atmospheric distillation, gas oil of vacuum distillation, residue of vacuum distillation, waxy distillates, asphalt fraction, deasphalted fraction, aromatic extracts, dearomatized fraction, dewaxed fraction, wax and the base oil. For both base oils the allocation considered mass in kilograms.

	Input	Today scenario		Best scenario	
		Unit	Amount	Unit	Amount
	Capsules	Kg sun dried part / ha*yr	Average 2270	Kg sun dried part / ha*yr	Average 2270
	Seeds	kg x 1000 kg of capsules	625	kg x 1000 kg of capsules	675
	Husks		375		325
	Cake		448		465
	Oil		177		210
	Diesel fuel (cultivation) [1]	(L / ha*yr)	55	(L / ha*yr)	141
	Irrigation water[1]	(m^3 ha*yr)	333,2 [3]	(m^3 ha*yr)	333,2 [3]
Mineral fertilizer	Nitrogen (N) [2]	(kg / ha*yr)	48	(kg / ha*yr)	141
	Phosphorus (P2O5)[2]		19		56
	Potassium (K2O) [2]		53		139

TABLE Nº 9 Inputs on the today and best scenario for cultivating Jatropha (Adapted from [1]CSMCRI 2007, [2]IFEU based on CSMCRI; [3]granted a necessary irrigation period of 3 years *pumps 7500 l of water from well in 1 h; **with trailer; ***commercial transport cited in Reinhardt *et al.*, 2008)

Phase	Input	Unit	Quantity
Dehusking	Electricity	kWh / t capsules	9
Briquetting		kWh / t husks	50
Screw press	Electricity	kWh / kg seed	0,15
	Steam	kg / kg seed	0,30
Refining	Electricity	kWh / kg raw oil	0.014
	Alkali	kg / kg raw oil	0.0056
Transesterification	Electricity	kWh / kg JME	0,42
	KOH	kg / kg JME	0,026
	Methanol	kg / kg JME	0,2
Output		Unit	Quantity
Husks		kg / t capsules	375
Glycerin		kg / kg refined oil	0,05

TABLE Nº 10 Inputs and outputs in a decentralized production of Jatropha oil (Adapted from CSMCRI 2007 in Reinhardt *et al.*, 2008)

Processes	All data per Mg input	Unit	Set Value
Atmospheric distillation	Electricity	MJ	52,3
	Process heat		614
	Process steam		26,2
Vacuum distillation	Energy		52,3
	Process heat		614
	Process steam		26,2
Deasphalting	Electricity		60
	Process heat		159
	Process steam		1.599
Aromatic extraction	Electricity		21
	Process heat		913
	Process steam		194
Dewaxing	Electricity		396
	Process heat		1035
	Process steam		1650
Hydrofinishing	Electricity		117
	Process heat		383
	Process steam		375

TABLE N° 11 Data acquire for the mineral base oil production scenarios (Fehrenbach, 2005)

3.3.4.
Base oil production scenarios and assumptions

For both base oils production software´s data and the geographical limitation brought to incongruences in energy mixes levels, which leaded to assume that the main environmental impact analyzed in this study had the same global consequences.

3.3.4.1. Jatropha base oil production scenarios

For the production of jatropha base oil, the following production scenarios were considered:

1. Base jatropha oil production scenario, which did not consider allocation of co-products;
2. Alternative jatropha oil production scenario with allocation of co-products;
3. Alternative jatropha oil production scenario without allocation of glycerin;

4. Alternative jatropha oil production scenario without allocation of cake and husks;
5. Alternative jatropha oil production scenario with ammonium sulphate as nitrogen;
6. Alternative jatropha oil production scenario with potassium chloride as K2O;
7. Alternative jatropha oil production scenario without infrastructure on the background system;
8. Best jatropha oil production scenario with allocation of co-products;
9. Best jatropha oil production scenario without allocation of co-products.

Data used for the base and alternative scenarios were taken from the today scenario in Reinhardt *et al*. (2008); data used for the best jatropha oil production scenarios, were taken from the best scenario in Reinhardt *et al*. (2008). The today scenario shows the present conditions of the jatropha cultivation and its incomes. The best scenario exposed the agricultural optimization and increase of plant breading; this scenario brings to account higher yields than the base scenario (Reinhardt *et al*., 2008). Table. 10. shown a comparison of the allocation factors between the jatropha oil production scenarios. Table. 11. gives an overview of the base, alternative and best jatropha oil production scenarios.

Base scenario parameters and assumptions

- Ammonium nitrate as nitrogen: This parameter was chosen due to, in the literature review it was not found a specific nitrogen source, so it was admitted that for the base scenario the ammonium nitrate as nitrogen, was the nitrogen source for the jatropha cultivation process. This process followed the 1999 inventory in Europe, which is considered in the Umberto NXT LCA database. The amount of ammonium nitrate as nitrogen used was 48 kg;
- Potassium sulphate as K2O: This parameter was selected since in the literature review it was not possible to find which was the specific potassium source. It was assumed that for the base scenario, the potassium source was the potassium sulphate as K2O. This process followed the 1999 inventory in Europe, which is considered in the Umberto NXT LCA database. The amount of potassium sulphate used was 53 kg;

- Ammonium nitrate phosphate as P2O5: This parameter was selected because in the literature review it was not possible to find, which was the specific phosphorus source. It was assumed that for the base scenario, the phosphorus source was the ammonium nitrate phosphate as P2O5. This process followed the 1999 inventory in Europe, which is considered in the Umberto NXT LCA database. The amount of ammonium nitrate as nitrogen used was 19 kg;
- Diesel: It was assumed that the diesel followed the Swiss inventory due to; the Umberto NXT LCA software database did not present an Indian inventory. The amount of diesel used was 44 kg. This process followed the 1989-2000 inventory in Switzerland;
- Irrigation: It was assumed that the irrigation followed the Swiss inventory due to; the Umberto NXT LCA software database did not present an Indian inventory, the amount of water used was 49,98 m3. This process followed the 1991-2002 inventory in Switzerland;
- Electricity, medium voltage production, PL, at grid: was chose since it was assumed that the electricity production in India had the same characteristics that the electricity production in Poland. The amount of electricity used on the dehusking process was 9kWh. In the screw press the amount used was 93,75 kWh. This process followed the 1992-2004 inventory in Poland;
- Electricity, medium voltage at production UCTE, at grid: this parameter was chose from the Umberto NXT LCA database since; it was assumed that the refining and transesterification took place at Europe. It was assumed that both process used the electricity medium voltage produced by UCTE. For the refining process it was used 2,48 kWh and in the transesterification it was used 0,42 kWh. This process followed the 1992-2004 inventory in the UCTE;
- Alkali: For this parameter it was assumed that in the refining process it was used sodium hydroxide 50% in H2O due to, in the literature review there was not a stablished a specific source. This process was chose in the Umberto NXT LCA and followed the 2000 inventory in Europe. The amount used was 0,99 kg;
- Ethanol from ethylene at plant: This parameter was chosen due to in the literature review it was not found a specific ethanol source. It was assumed that the source of ethanol was the ethanol from ethylene at

plant. This parameter was selected from the Umberto NXT LCA database. The ethanol from ethylene at plant considered the 1986-2005 inventory. The amount used of ethanol was 0,15 kg;

- Potassium hydroxide: This parameter was chosen due to; in the literature review it was not found the specific KOH source. It was assumed that the source of KOH was potassium hydroxide, which considered the 1988-2004 inventory, which is detailed on the Umberto NXT LCA database. The amount used was 0,03 kg;
- Allocation: for this scenario the co-products were not allocated due to; it was assumed that were considered waste;
- Infrastructure on the background system: this parameter was chosen due to, it was considered that the background system used infrastructure;
- Transportation: it was assumed that a transoceanic freight ship transported the raw oil.

Shifted parameters and assumptions

For the alternative scenarios the shifted parameters and assumptions were:

- Ammonium sulphate as nitrogen: As cited above, there was not possible to find a nitrogen source on the literature, so in the sensitivity analysis, it was considered as nitrogen source the ammonium sulphate. This process was taken from the Umberto NXT LCA database, which considered the 1998 inventory;
- Potassium chloride as K2O: As cited above, it was not possible to find a specific potassium source on the literature, so in the sensitivity analysis, It was assumed that the potassium source was the potassium chloride as K2O. This process was taken from the Umberto NXT LCA database, which considered the 2000 inventory. The amount used was 53 kg;

- Not allocation of husks and cake: It was assumed that husks and cake were not used as co-products; the allocation factors are presented in table 10;

- Not allocation of glycerin: it was assumed that glycerin was not used as a co-product. The allocation factor is presented on table 10;
- Not infrastructure on the background system: It was assumed that the background system did not considered infrastructure, this was chosen from the Umberto NXT LCA software;
- Both best scenarios were used due to, it was assumed that the amount and the production yields were important for the sensitivity analysis since, both scenarios shown a wide cultivation range, and the inputs required are higher than in the today scenario. The values used for these both scenarios were: 141 kg of ammonium nitrate as nitrogen, 139 kg of potassium sulphate as K2O, 56 kg of phosphorus nitrate phosphate, 112,80 kg of diesel and 49,98 m3 of water. For the electricity for the dehusking and the screw press processes there were used 9 kWh and 101,25 kWh correspondingly. Fort he alkali it was used 1,18 kg. In the case of KOH it was considered 0,30 kg. It was used 0,15 kg of ethanol. Electricity for the refining and the transesterification were 2,49 kWh and 0,42 kWh correspondingly.

<table>
<tr><th>Scenario</th><th colspan="2">Allocation (%)</th><th>Scenario</th><th colspan="2">Allocation (%)</th></tr>
<tr><td rowspan="18">- Base jatropha oil production scenario</td><td rowspan="3">Husks</td><td rowspan="3">--</td><td rowspan="6">- Alternative jatropha oil production scenario with allocation of co-products.
- Alternative jatropha oil production scenario with ammonium sulphate as N.
- Alternative jatropha oil production with potassium chloride as K2O.
- Alternative jatropha oil production scenario without infrastructure on the background system.</td><td>Husks</td><td>38</td></tr>
<tr><td>Seeds</td><td>62</td></tr>
<tr><td>Cake</td><td>72</td></tr>
<tr><td rowspan="3">Seeds</td><td rowspan="3">100</td><td>Raw oil</td><td>28</td></tr>
<tr><td>Base oil</td><td>91</td></tr>
<tr><td>Glycerin</td><td>9</td></tr>
<tr><td rowspan="3">Cake</td><td rowspan="3">--</td><td rowspan="6">- Alternative jatropha oil production scenario without allocation of glycerin</td><td>Husks</td><td>38</td></tr>
<tr><td>Seeds</td><td>62</td></tr>
<tr><td>Cake</td><td>72</td></tr>
<tr><td rowspan="3">Raw oil</td><td rowspan="3">100</td><td>Raw oil</td><td>28</td></tr>
<tr><td>Base oil</td><td>100</td></tr>
<tr><td>Glycerin</td><td>--</td></tr>
<tr><td rowspan="3">Base oil</td><td rowspan="3">100</td><td rowspan="6">- Alternative jatropha oil production scenario without allocation of husks and cake</td><td>Husks</td><td>--</td></tr>
<tr><td>Seeds</td><td>100</td></tr>
<tr><td>Cake</td><td>--</td></tr>
<tr><td rowspan="3">Glycerin</td><td rowspan="3">--</td><td>Raw oil</td><td>100</td></tr>
<tr><td>Base oil</td><td>91</td></tr>
<tr><td>Glycerin</td><td>9</td></tr>
<tr><td rowspan="4">- Best jatropha oil production scenario with allocation of co-products</td><td>Husks</td><td>32</td><td rowspan="4">- Best jatropha oil production scenario without allocation of co-products</td><td>Husks</td><td>--</td></tr>
<tr><td>Seeds</td><td>68</td><td>Seeds</td><td>100</td></tr>
<tr><td>Cake</td><td>69</td><td>Cake</td><td>--</td></tr>
<tr><td>Raw oil</td><td>31</td><td>Raw oil</td><td>100</td></tr>
</table>

Scenario	Allocation (%)		Scenario	Allocation (%)	
	Base oil	91		Base oil	100
	Glycerin	9		Glycerin	--

TABLE Nº 12 Comparison of the allocation factors between the jatropha oil production scenarios

Scenario	Production process	Input	Overview
Base, alternative and best jatropha oil production	Cultivation	Diesel	Included the inventory for the distribution of petroleum product to the final consumer incorporating all necessary transports at Switzerland.
		Irrigation	Used a mobile irrigator system, which includes water pipe and hydrant, turbine propulsion, 300 m water hose, the exterior diameter is 75 mm and a fix installed pump that uses 30 m3/h, 7-8 bar, 22 kW.
		Phosphorus	Referred to 1 kg of nitrogen that represents 1 kg of P_2O_5 in form of ammonium nitrate phosphate with 8.4% of nitrogen content and 52.0% of P_2O_5-content.
		Nitrogen	Referred to 1 kg of nitrogen with 2.86 kg of ammonium nitrate, which has a nitrogen content of 35.0%.
		Potassium	Refers to 1 kg of K_2O responsible for 2 kg of potassium sulphate with a K_2O content of 50%.
	Dehusking	Electricity	Included the transformation from high to medium voltage as well as the transmission of electricity at medium voltage in Poland.
	Screw press	Electricity	Included the transformation from high to medium voltage as well as the transmission of electricity at medium voltage in Poland.
	Raw oil transportation	Transport	Included 6905,57 km sailed by a transoceanic freight ship. This process considers the entire transport life cycle.
	Refining	Electricity	Included the transformation from high to medium voltage as well as the transmission of electricity at medium voltage in the European region.

Scenario	Production process	Input	Overview
Base, alternative and best jatropha oil production		Alkali	As an alkali it was used sodium hydroxide, which is 50% in water and produced in the European region.
	Transesterification	Electricity	Included the transformation from high to medium voltage as well as the transmission of electricity at medium voltage in the European region.
		Alcohol	Considered ethanol from ethylene. Ethanol 99.7% in H2O and diethyl ether 99.95% in H2O The production occurs in the European region.
		KOH	Considered potassium hydroxide the manufacture using electrolysis of potassium chloride brine in electrolytical cells. The production occurs in the European region.

TABLE N° 13 Overview of the background system and assumptions on the base jatropha oil production scenarios

3.3.4.2. Mineral base oil production scenarios

For the production of mineral base oil, the following production scenarios were considered:

1. Base mineral oil production scenario;
2. Alternative mineral oil production scenario;
3. Alternative mineral oil production scenario without infrastructure on the background system;
4. Alternative mineral oil production scenario without allocation of aromatic extracts;
5. Alternative mineral oil production scenario with CH oil mix;
6. Alternative mineral oil production scenario with RER oil mix.

Data for the base and alternative mineral oil production scenarios were taken from Fehrenbach (2005). Table. 12. shown a comparison of the allocation factors between the mineral oil production scenarios. Table. 13. shown an overview of the background system used in the base and alternative mineral oil production scenarios.

Base scenario parameters and assumptions

- Nigerian crude oil: This parameter was chose due to; the European crude oil imports in 2012, reached 40% of the Nigeria´s crude oil production (US Energy Information Administration, 2013a). It was assumed that after the refining process from 1 ton of the Nigerian crude oil 1 kg of mineral base oil is produced. This parameter was chosen from the Umberto NXT LCA database, which used the 1992-1994 inventory;
- Refinery gas burned in furnace: This parameter was chosen due to; in the literature it was not possible to identify which was the specific heat source, however in the Umberto NXT LCA was possible to find the refinery gas burned in furnaces process to use as heat source. It was assumed that this process was used since the refining process considered the consumption of the refinery gas and emissions released when burning it at refineries in Europe. This process followed

the 1980-2000 inventory. The amount used on the atmospheric distillation was 614 MJ. On the vacuum distillation it was used 614 MJ, on the deasphalting process it as used 159 MJ, the aromatic extraction process used 194 MJ, the dewaxing process used 1035 MJ, finally the hydrofinishing process used 383 MJ;

- Heavy fuel oil, burned in furnace: This parameter was chosen due to; in the literature it was not possible to identify which was the specific heat source, however in the Umberto NXT LCA was possible to find the heavy fuel oil, burned in furnace process and it was assumed that it was used as steam source since, this process considered the emissions released when burning it at refinery in Europe. This process followed the 1980-2000 inventory. The amount used on the atmospheric distillation was 26,20 MJ. The vacuum distillation process used 26,20 MJ, the deasphalting process used 1599 MJ; the aromatic extraction used 194 MJ, the dewaxing process considered 1650 MJ and the hydrofinishing process used 375 MJ;
- Electricity, medium voltage production UCTE, at grid: As was assumed the refining process took place at Europe, the electricity followed the UCTE production model. For the atmospheric distillation process it was used 52,30 MJ, the vacuum distillation process used 52,30 MJ, the deasphalting process used 60 MJ, the aromatic extraction process used 21 MJ; the dewaxing process used 396 MJ, finally the hydrofinishing process used 117 MJ. This process followed the 1992-2004 inventory in the UCTE.

Shifted parameters and assumptions

The shifted parameters in the mineral oil production scenarios were the crude oil mixes.

- Russian, Great Britain and rest of the African region crude oil mix: This mix was taken into account due to by 2012 the European importations scored 79% of the Russian crude oil; Great Britain crude 576,000 bbl/d (US Energy Information Administration, 2013b, c), and rest of Africa crude oil due to; it was possible to find this information in the Umberto NXT LCA database. The Russian, Great Britain and rest of the African region crude oil mix was totally assumed and the percentages used were 50,8% of the Russian crude oil, 25% of the Great Britain crude oil and 24,20% of the rest of the Africa crude oil. The production in the database considered the 1992-1994 inventory;

- RER crude oil mix: this mix was selected from the Umberto NXT LCA database. Russian, Great Britain, rest of the African region, rest of Latin American region, Nigeria, Norway, and Netherlands and the rest of the Mediterranean region, composed it. This crude oil mix was chosen due to, in Umberto database it was found that this mix is used at European refinery. It was composed by 18,4% of Russian crude oil, 18% of Great Britain crude oil, 10,8% of the rest of the African region, 1,19% of the rest of the Latin America region, 3,41% of the Nigerian crude oil mix, 22,5% of the Norway crude oil, 0,336% Netherlands crude oil and 25,3% of the rest of the Mediterranean region crude oil;
- CH crude oil mix: this mix was selected from the Umberto NXT LCA database. The rest of the Mediterranean region crude oil, rest of the African region crude oil and Nigerian crude oil composed it. This crude oil mix was chosen due to, in the Umberto database it was found that this mix is used at Swiss refinery. This mix was composed by 7,4% of the rest of the Mediterranean region crude oil, 55,2% of the rest of the African region crude oil and 37,4% of the Nigerian crude oil;
- Allocation of the aromatic extracts: this parameter was selected due to; according to Fehrenbach (2005), the market for these co-products is declining;
- Not infrastructure on the background system: This parameter was chosen due to; it was required to assess its influences. The selection of a background system was done in the Umberto NXT LCA software.

In the appendices are presented the base mineral oil production scenario, the alternative mineral oil production scenario, and the alternative mineral oil production scenario with CH oil mix and the alternative oil production scenario with RER oil mix.

Scenario	Allocation (%)		Scenario	Allocation (%)	
- Base mineral oil production scenario. - Alternative mineral oil production scenario. - Alternative mineral oil production scenario without infrastructure on the background system. - Alternative mineral oil production scenario with CH oil mix. - Alternative mineral oil production scenario with RER oil mix.	Gas	2	- Alternative mineral oil production scenario without allocation of aromatic extracts.	Gas	2
	Naphtha	21		Naphtha	21
	Gas oil of aromatic distillation	36		Gas oil of aromatic distillation	36
	Residue of atmospheric distillation	41		Residue of atmospheric distillation	41
	Gas oil of vacuum distillation	4		Gas oil of vacuum distillation	4
	Residue of vacuum distillation	40		Residue of vacuum distillation	40
	Waxy distillate	56		Waxy distillate	56
	Asphalt fraction	30		Asphalt fraction	30
	Deasphalted fraction	70		Deasphalted fraction	70
	Aromatic extracts	35		Aromatic extracts	--
	Dearomatized fraction	65		Dearomatized fraction	100
	Dewaxed fraction	80		Dewaxed fraction	80
	Wax	20		Wax	20
	Base oil	100		Base oil	100

TABLE N° 14 Comparison of the allocation factors between the mineral oil production scenarios

Scenarios	Input	Overview
Base and alternative mineral oil production scenarios	Electricity	Included the transformation from high to medium voltage as well as the transmission of electricity at medium voltage produced by the Union for the Coordination of Transmission of Electricity.
	Steam	Heavy fuel oil, burned in refinery furnace in the European region.
	Heat	Refinery gas, burned in furnace in the European region.

TABLE N° 15 Overview of the background system used for the base and alternative mineral oil base production scenarios

The alternative mineral oil production scenario without allocation of aromatic extracts, alternative mineral oil production scenario with CH oil mix, alternative mineral oil production scenario with RER oil mix and the alternative mineral oil production scenario without infrastructure on the background system, used the same description that is shown on table 13.

3.4.
Life cycle impact assessment

3.4.1.
Environmental impact categories

Life cycle impact assessment was performed using Umberto NXT LCA. The method used in the LCIA was ReCiPe Midpoint (H) w/o LT, which is performed by the Umberto NXT LCA. Table. 14. shown the selected impact categories and units used in the LCIA of both base oils.

Impact categories	Unit
Global warming	kg CO2-Eq
Fossil depletion	kg oil-Eq
Human toxicity	kg 1,4-DCB-Eq
Freshwater eutrophication	P-Eq
Water depletion	m3

TABLE N° 16 Selected environmental impact categories and units

The global warming category was chosen because of the emissions of CO2 in both production lines, afterwards also for its contribution to the climate change. The fossil depletion potential category was chose due to its relation with the climate change, its limit source characteristics and its future depletion. Human toxicity impact category was selected because; it reveals the potential damage of a chemical element, which is disposed on the ecosystems. The freshwater eutrophication category was selected due to the increase of the nutrient levels in the water, which could produce the losses of water biodiversity. Finally the water depletion category was selected due to the extraction and consume of water can cause majors impacts on ecosystems and human health.

3.4.2. Life cycle impact assessment limitations

The main limitation for this LCIA was the access to precisely data, due to the Ecoinvent 2.2 lacks of data for the inputs; for the case of jatropha Indian production and not always coincident of the length of this LCA.

According to Reap *et al*. (2008) in site generic LCA as this study is, it is possible to admit inexactness on the spatial information and it could be done an intrinsic assumption of globally homogeneous effects.

3.4.3. Life cycle impact assessment results

In this section the results for each environmental impact category are presented. Data for both jatropha oil and mineral oil contributions are organized and presented in tables. Additionally this section presents a comparison between the base scenario, the lowest and the higher values obtained into the impact categories of both oils. A detailed description of total contributions (background system, products and co-products) of the jatropha oil production scenarios and mineral oil production scenarios is presented from table 1 to table 73 in the appendices.

3.4.3.1. Global warming potential

Scenarios								
Best jatropha oil production scenario without allocation of co-products	Base jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of seed and husks	Best jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of glycerin	Alternative jatropha oil production scenario whit allocation of co-products	Alternative jatropha oil production scenario whit potassium chloride as K2O	Alternative jatropha oil production scenario without infrastructure	Alternative jatropha oil production scenario whit ammonium sulphate as N
2,72 kg CO2-Eq	2,49 kg CO2-Eq	2,27 kg CO2-Eq	1,33 kg CO2-Eq	0,96 kg CO2-Eq	0,87 kg CO2-Eq	0,85 kg CO2-Eq	0,83 kg CO2-Eq	0,76 kg CO2-Eq

TABLE N° 17 Global warming potential of the jatropha oil production scenarios

Scenarios					
Alternative mineral oil base production scenario with allocation of aromatic extracts	Base mineral oil production scenario	Alternative mineral oil base production scenario without infrastructure	Alternative mineral oil base production scenario with CH oil mix	Alternative mineral oil base production scenario	Alternative mineral oil base production scenario with RER oil mix
2,10 kg CO2-Eq	1,48 kg CO2-Eq	1,45 kg CO2-Eq	1,16 kg CO2-Eq	1,06 kg CO2-Eq	0,92 kg CO2-Eq

TABLE N° 18 Global warming potential of the mineral oil production scenarios

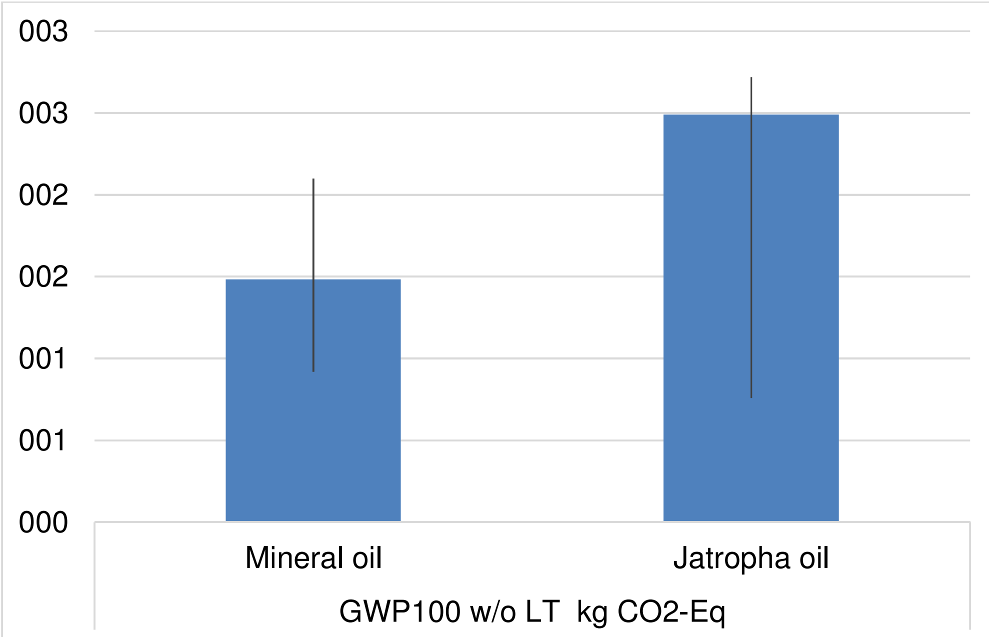

FIG. Nº 15.Comparison between minimum and maximum contributions of the mineral and jatropha oil production scenarios for the global warming potential

3.4.3.2. Fossil depletion potential

Scenarios								
Best jatropha oil production scenario without allocation of co-products	Base jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of seed and husks	Best jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of glycerin	Alternative jatropha oil production scenario with allocation of co-products	Alternative jatropha oil production scenario with ammonium sulphate as N	Alternative jatropha oil production scenario with potassium chloride as K2O	Alternative jatropha oil production scenario without infrastructure
0,90 kg Oil-Eq	0,83 kg Oil-Eq	0,75 kg Oil-Eq	0,50 kg Oil-Eq	0,39 kg Oil-Eq	0,35 kg Oil-Eq	0,35 kg Oil-Eq	0,35 kg Oil-Eq	0,34 kg Oil-Eq

TABLE Nº 19 Fossil depletion potential of the jatropha oil production scenarios

Scenarios					
Alternative mineral oil base production scenario without allocation of aromatic extracts	Base mineral oil production scenario	Alternative mineral oil base production scenario without infrastructure	Alternative mineral oil base production scenario	Alternative mineral oil base production scenario with CH oil mix	Alternative mineral oil base production scenario with RER oil mix
2,29 kg Oil-Eq	1,53 kg Oil-Eq	1,52 kg Oil-Eq	1,47 kg Oil-Eq	1,46 kg Oil-Eq	1,42 kg Oil-Eq

TABLE Nº 20 Fossil depletion potential of the mineral oil production scenarios

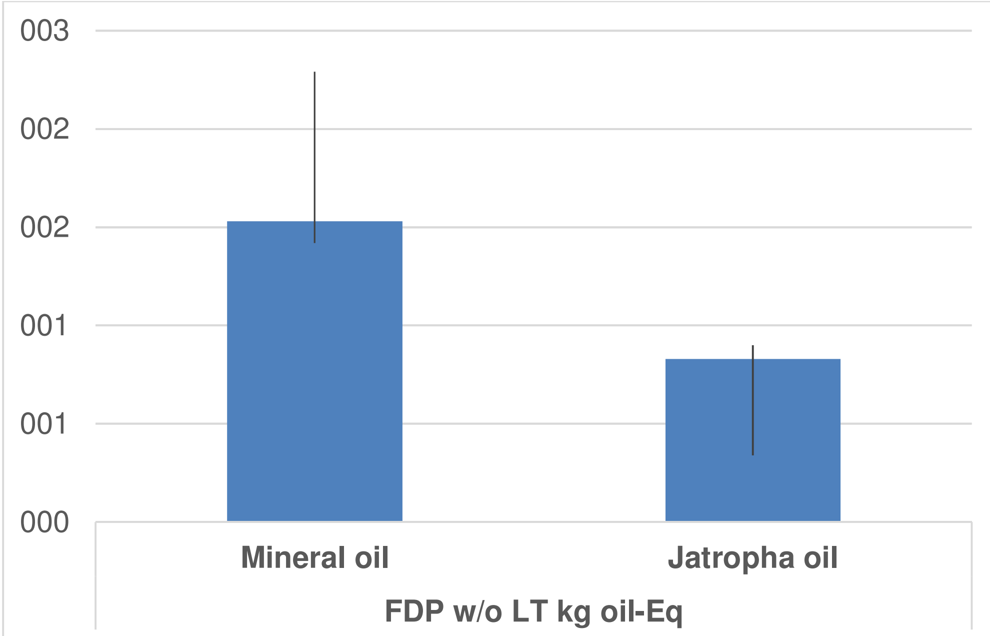

FIG. Nº 16.Comparison between minimum and maximum contributions of the mineral and jatropha oil production scenarios for the fossil depletion potential

3.4.3.3. Freshwater eutrophication potential

Scenario								
Best jatropha oil production scenario without allocation of co-products	Alternative jatropha oil production scenario with potassium chloride as K2O	Base jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of seed and husks	Best jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of glycerin	Alternative jatropha oil production scenario with allocation of co-products	Alternative jatropha oil production scenario with ammonium sulphate as N	Alternative jatropha oil production scenario without infrastructure
2,45E-04 P-Eq	2,26E-04 P-Eq	2,22E-04 P-Eq	2,01E-04 P-Eq	1,47E-04 P-Eq	1,20E-04 P-Eq	1,09E-04 P-Eq	1,08E-04 P-Eq	9,75E-05 P-Eq

TABLE N° 21 Freshwater depletion potential of the jatropha oil production scenarios

Scenario					
Alternative mineral oil base production scenario	Alternative mineral oil base production scenario without allocation of aromatic extracts	Alternative mineral oil base production scenario with RER oil mix	Alternative mineral oil base production scenario with CH oil mix	Base mineral oil production scenario	Alternative mineral oil base production scenario without infrastructure
2,81E-05 P-Eq	1,90E-05 P-Eq	1,82E-05 P-Eq	1,56E-05 P-Eq	1,55E-05 P-Eq	1,17E-05 P-Eq

TABLE N° 22 Freshwater depletion potential of the mineral oil production scenarios

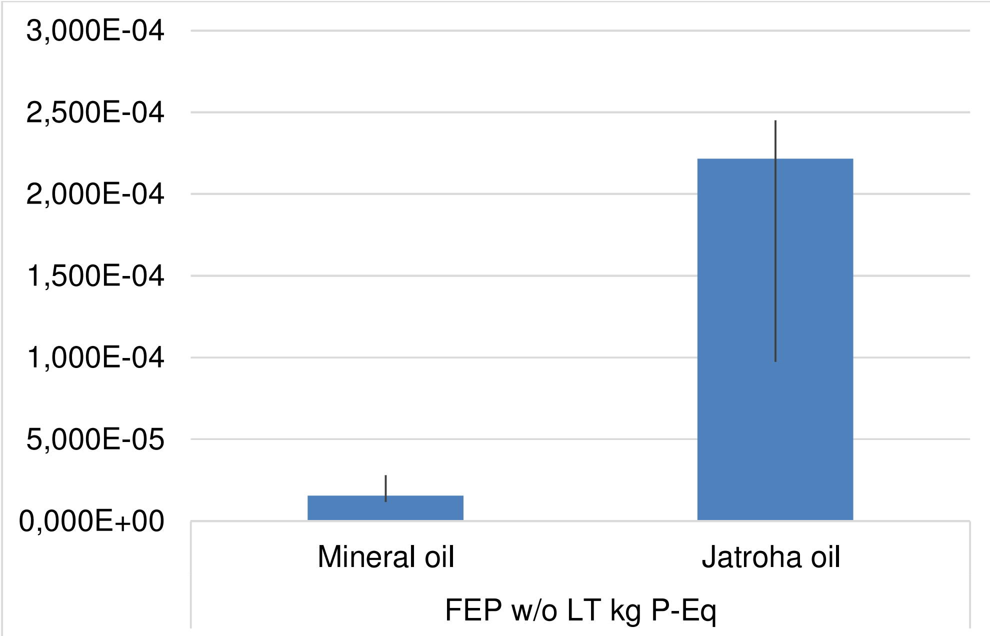

FIG. Nº 17.Comparison between minimum and maximum contributions of the mineral and jatropha oil production scenarios for the freshwater eutrophication potential

3.4.3.5. Human toxicity potential

Scenario								
Best jatropha oil production scenario without allocation of co-products	Base jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of seed and husks	Best jatropha oil production scenario	Alternative jatropha oil production scenario without allocation of glycerin	Alternative jatropha oil production scenario with ammonium sulphate as N	Alternative jatropha oil production scenario with potassium chloride as K2O	Alternative jatropha oil production scenario with allocation of co-products	Alternative jatropha oil production scenario without infrastructure
0,16 kg 1,4-DCB-Eq	0,15 kg 1,4-DCB-Eq	0,14 kg 1,4-DCB-Eq	0,07 kg 1,4-DCB-Eq	0,05 kg 1,4-DCB-Eq	0,04 kg 1,4-DCB-Eq	0,04 kg 1,4-DCB-Eq	0,04 kg 1,4-DCB-Eq	0,03 kg 1,4-DCB-Eq

TABLE N° 23 Human toxicity potential contributions of the jatropha oil production scenarios

Scenarios					
Alternative mineral oil base production scenario	Alternative mineral oil base production scenario without allocation of aromatic extracts	Base mineral oil production scenario	Alternative mineral oil base production scenario with CH oil mix	Alternative mineral oil base production scenario with RER oil mix	Alternative mineral oil base production scenario without infrastructure
0,10 kg 1,4-DCB-Eq	0,09 kg 1,4-DCB-Eq	0,07 kg 1,4-DCB-Eq	0,07 kg 1,4-DCB-Eq	0,07 kg 1,4-DCB-Eq	0,06 kg 1,4-DCB-Eq

TABLE N° 24 Human toxicity potential contributions of the mineral oil production scenarios

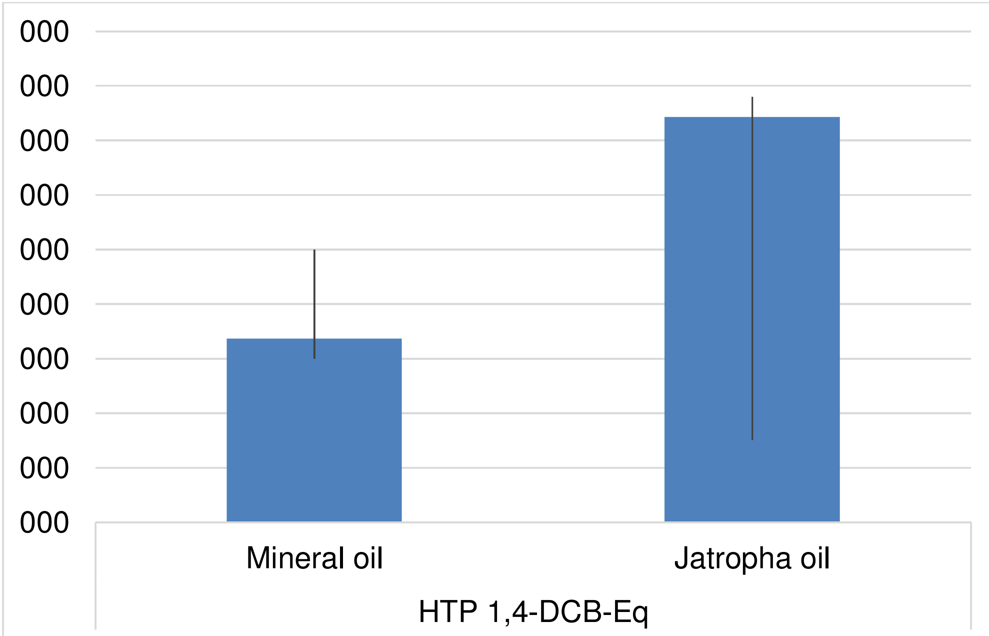

FIG. Nº 18.Comparison between minimum and maximum contributions of the mineral and jatropha oil production scenarios for the human toxicity potential

3.4.3.6. Water depletion potential

Scenario								
Base jatropha oil production scenario	Alternative jatropha oil production scenario whitout allocation of seed and husks	Best jatropha oil production scenario without allocation of co-products	Alternative jatropha oil production scenario without allocation of glycerin	Alternative jatropha oil production scenario with ammonium sulphate as N	Alternative jatropha oil production scenario with potassium chloride as K2O	Alternative jatropha oil production scenario without infrastructure	Best jatropha oil production scenario	Alternative jatropha oil production scenario with allocation of co-products
0,13 m3	0,12 m3	0,05 m3	0,03 m3	0,02 m3	0,02 m3	0,02 m3	0,02 m3	0,02 m3

TABLE N° 25 Water depletion potential of the jatropha oil production scenarios

Scenario					
Alternative mineral oil base production scenario	Alternative mineral oil base production scenario with CH oil mix	Alternative mineral oil base production scenario with RER oil mix	Alternative mineral oil base production scenario without allocation of aromatic extracts	Base mineral oil production scenario	Alternative mineral oil base production scenario without infrastructure
0,01 m3	4,52E-03 m3	4,39E-03 m3	2,50E-03 m3	1,96E-03 m3	1,38E-03 m3

TABLE N° 26 Water depletion potential of the mineral oil production scenarios

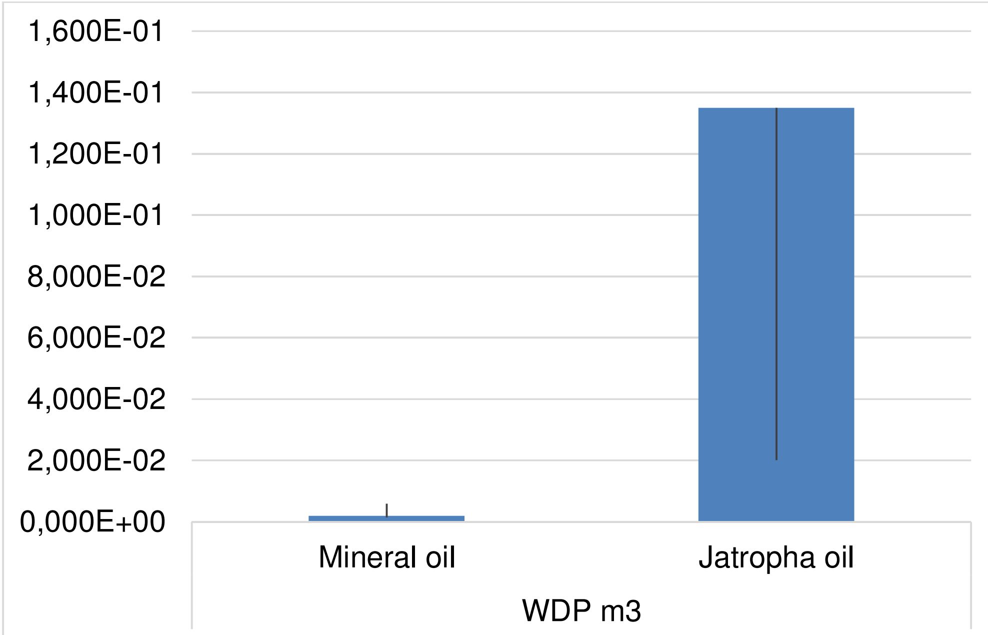

FIG. Nº 19.Comparison between minimum and maximum contributions of the mineral and jatropha oil production scenarios for the water depletion potential

The results of the contribution of the background system, products and co-products of each scenario are presented in the appendices.

4. Interpretation

The sensitivity analysis exhibited that for the global warming potential category in the jatropha oil production, the most influence parameter was the allocation of the co-products due to, when comparing the alternative jatropha oil production scenario with allocation of the co-products whit the base scenario, the global warming potential decrease 1,62 kg CO2-Eq.

Another influence parameter that shown a high contribution for the global warming potential, was the use of infrastructure on the background system because, when the background system with infrastructure was replaced with a background system that did not used infrastructure the global warming potential was reduced 0,13 kg CO2-Eq.

The ammonium nitrate as nitrogen was another influence parameter since, when comparing it with ammonium sulphate as nitrogen, there was a reduction of 0,11 kg CO2-Eq. The potassium sulphate as K2O also presented an influence on the global warming potential due to; when it was replaced with a potassium chloride as K2O the global warming potential was reduced 0,02 kg CO2-Eq.

For the mineral oil production, the major influence parameters into the global warming category were the allocation of the aromatic extracts and the use of the Nigerian crude oil. When the aromatic extracts were allocated the global warming potential shown a reduction of 0,61 kg CO2-Eq.

In the other hand when the Nigerian crude oil was compared with the RER crude oil mix; it was found a reduction of 0,56 kg CO2-Eq. When the Nigerian crude oil was compared with the Russian, Great Britain and rest of Africa crude oil mix the reduction of the global warming potential reached 0,42 kg CO2-Eq. A comparison between the uses of the CH crude oil mix instead of the Nigerian crude oil shown that existed a reduction of 0,32 kg CO2-Eq.

Into the fossil depletion potential category, in the case of the jatropha oil production, it was possible to see that the major influence parameter was the allocation of the co-products due to when these were allocated; there was a reduction of 0,47 kg Oil-Eq. However by using ammonium nitrate as nitrogen, potassium sulphate as K2O and infrastructure on the background system, it was possible to see an influence, since when it was used the ammonium sulphate as nitrogen there was a reduction of 0,01 kg Oil-Eq. Using potassium chloride as K2O instead of potassium sulphate as K2O, this category reduced 0,01 kg Oil-Eq and finally, changing the background infrastructure with a model that did not considered there was a reduction of 0,01 kg Oil-Eq.

In the mineral oil production, the parameter with the major contribution was the allocation of the aromatic extracts since, when the aromatic extracts were allocated; there was a reduction of 0,76 kg Oil-Eq.

The second major influence parameter for the depletion potential category was the use of the Nigerian crude oil, due to, when it was replaced by the RER crude oil mix, the fossil depletion potential was reduce on 0,11 kg Oil-Eq. Also when the Nigerian crude oil mix was replaced with the CH crude oil mix there was a reduction of 0,07 kg Oil-Eq. and finally when comparing the Nigerian crude oil with the Russian, Great Britain and rest of the African region crude oil mix, it was possible to see that the fossil depletion potential was reduce on 0,06 kg Oil-Eq.

The use a background system without infrastructure showed a reduction of 0,01 kg Oil-Eq.

For the freshwater eutrophication potential in the jatropha oil production, it was found that the parameter with the major contribution was the allocation of the co-products since, when these were allocated existed a decreased of 1,13E-04 P-Eq.

By using ammonium sulphate as nitrogen instead of ammonium nitrate as nitrogen, there was a reduction of 5,88E-07 P-Eq. In the case of the potassium parameter, it was possible to see that the potassium chloride generated an increase of 1,17E-04 P-Eq.

When using a scenario without infrastructure on the background system, the sensitivity analysis shown that existed a reduction of 1,15E-05 P-Eq.

In the other hand the sensitivity analysis show that in the mineral oil production, the most influence parameter was the Russian, Great Britain and rest of the African crude oil mix, due to, when comparing it whit the Nigerian crude oil there was a reduction of 1,26E-05 P-Eq; when it was compared whit the RER crude oil mix it was a reduction of 9,97E-06 P-Eq. Finally when the Russian, Great Britain and rest of the African crude oil mix was compared whit the CH crude oil mix the freshwater eutrophication potential was reduced on 1,25E-05 P-Eq. Other influence parameter was the allocation of the aromatic extracts since, when these were allocated it was a reduction of 0,02 P-Eq. The use of a model that did not considered infrastructure on the background system shown a reduction of 3,79E-06 P-Eq.

Into the human toxicity potential on the jatropha oil production the largest influence parameter was the allocation of the co-products, since when the co-products were allocated, this potential was reduced on 0,11 kg 1,4-DCB-Eq.

When using ammonium sulphate as nitrogen and potassium chloride as K2O there was not any change. Nonetheless when it was a model without infrastructure on the background system, there was a reduction of 0,01 kg 1,4-DCB-Eq.

In the mineral oil production, the sensitivity analysis shown that the most influences parameter was the Russian, Great Britain and rest of the African crude oil mix, since, when comparing with the Nigerian crude oil the human toxicity is reduced on 0,04 kg 1,4 DCB-Eq. Also when it was compared with the RER and CH crude oil mixes, it was possible to see that exited a reduction of 0,03 kg 1,4 DCB-Eq. Comparing the Russian, Great Britain and rest of the African crude oil mix.

The allocation of the aromatic extracts shown a decrease of 0,02 kg 1,4 DCB-Eq. Finally the use of background system without infrastructure reduced 0,01 kg 1,4 DCB-Eq.

For the water depletion potential, on the jatropha oil production scenario, the sensitivity analysis shown that the parameter with the major effect was the allocation of the co-products due to, when these were allocated there was a reduction of 0,11 m3. The ammonium sulphate as nitrogen, potassium chloride as K2O and the infrastructure on the background system did not show any change.

In the other hand in the mineral oil production the most influence parameter was the Russian, Great Britain and rest of the African crude oil mix. When it was compared with the Nigerian crude oil it was a reduction of 3,92E-03 m3. Comparing the Russian, Great Britain and rest of the African crude oil mix with the CH crude oil mix there was a decrease of 1,36E-06 m3 and comparing it with the RER oil mix there was a decrease of 1,49E-03 m3.

In the case of the best jatropha oil production scenarios, the sensitive analysis shown that the allocation of the co-products was the largest parameter due to, when comparing between the best jatropha oil production scenario and the best jatropha oil production scenario without alloction of the co-products, the global warming potential was reduced on 1,38 kg CO2-Eq. The fossil depletion potential was reduced on 0,40 kg Oil-Eq. The freshwater eutrophication potential, decrease on 9,81E-05 P-Eq. The human toxicity potential was reduced on 0,07 kg 1,4-DCB-Eq. Finally the water depletion potential was reduced on 0,03 m3.

As overview it could be said that in the jatropha oil production the most environmental influence parameters were the allocation of the co-products, the use of ammonium nitrate as nitrogen and potassium sulphate as K2O since, these parameters showed an environmental influeces in all the impact categories selected.

In the mineral oil production, the most influence environmental parameters were the Nigerian crude oil, Russian, Great Britain and rest of the African region crude oil mix and the allocation of the aromatic extracts, because all of these parameters showed that when they were took into account, the values of the impact categories reduced.

5. Conclusion

As a methodology the sensitivity analysis could be considered an effective tool to improve decisions trough the LCA, for a decision making process and assessing the environmental impacts and loads in the entire life cycle of mineral and vegetable base oils. Nevertheless as it was motioned before, LCA presents some restrictions, particularly in the database. This was possible to regard because of the results obtained in this thesis were acquire from a limited database; this limitation brought to consider that the results are not compromised by the data´s year publications and, the sensitivity parameters from the used database, have the same consequences in the actuality. Notwithstanding, it was possible to compare the sensitivity parameters as well as the impacts generate on different base oil production scenarios.

Although the use of renewable sources is a focal idea into the sustainability, products that use these kinds of sources could present undesired concequences on the environment. As was cited on the objective of this study; the goal was to execute a simplified LCA (cradle-to-gate analysis) for the production phase of 1 kg of mineral base oil and 1 kg of jatropha base oil trough a sensitivity analysis. The LCA was completed by gathering jatropha base oil and mineral base oil data from diferent scientific publictions, and the Umberto NXT LCA database.

From the results obtained in the LCA, it is possible to conclude that under the models and parameters used in this study, the production phase of 1 kg of the jatropha base oil, have the largest contributions in the global warming potential category, freshwater eutrophication potential category, human toxicity potential category and water depletion potential category. In the other the mineral base oil presented a large contribution on the fossil depletion potential.

These results used shown that for the production phase of 1 kg of base oil, the use of renewable sources could not be such an environmental friendly and sustainable decision. However it is necessary to execute a cradle to grade analysis to identify, which phase and paramenters have the most environmental importance considering the environmental aspects and loads, due to as cited in the studies mentioned in chapter 2; mineral base oils have large and significative environmental contributions in the use and final dispoasal phases, despite Jatropha base oil reduces its environmental contributions in these phases, which could turns its use a favorable environmental decision.

For a future LCA it could be considered the expansion of systems and an analysis about credits for the co-products, which are produced by the processes used for the production of the mineral and jatropha base oils. Also it will be important to consider for the production of the mineral base oils, parameters such as the ones used for the production of electricity, heat, steam and the extraction of the petroleum in Brazil.

In the case of the vegetable base oils, it will be important to consider other kind of sources such as soja, castor bean oil and oil palm, and their production in countries such as Brazil due to, these sources are the three major cultures for producing alternative bases in this country.

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Appendices

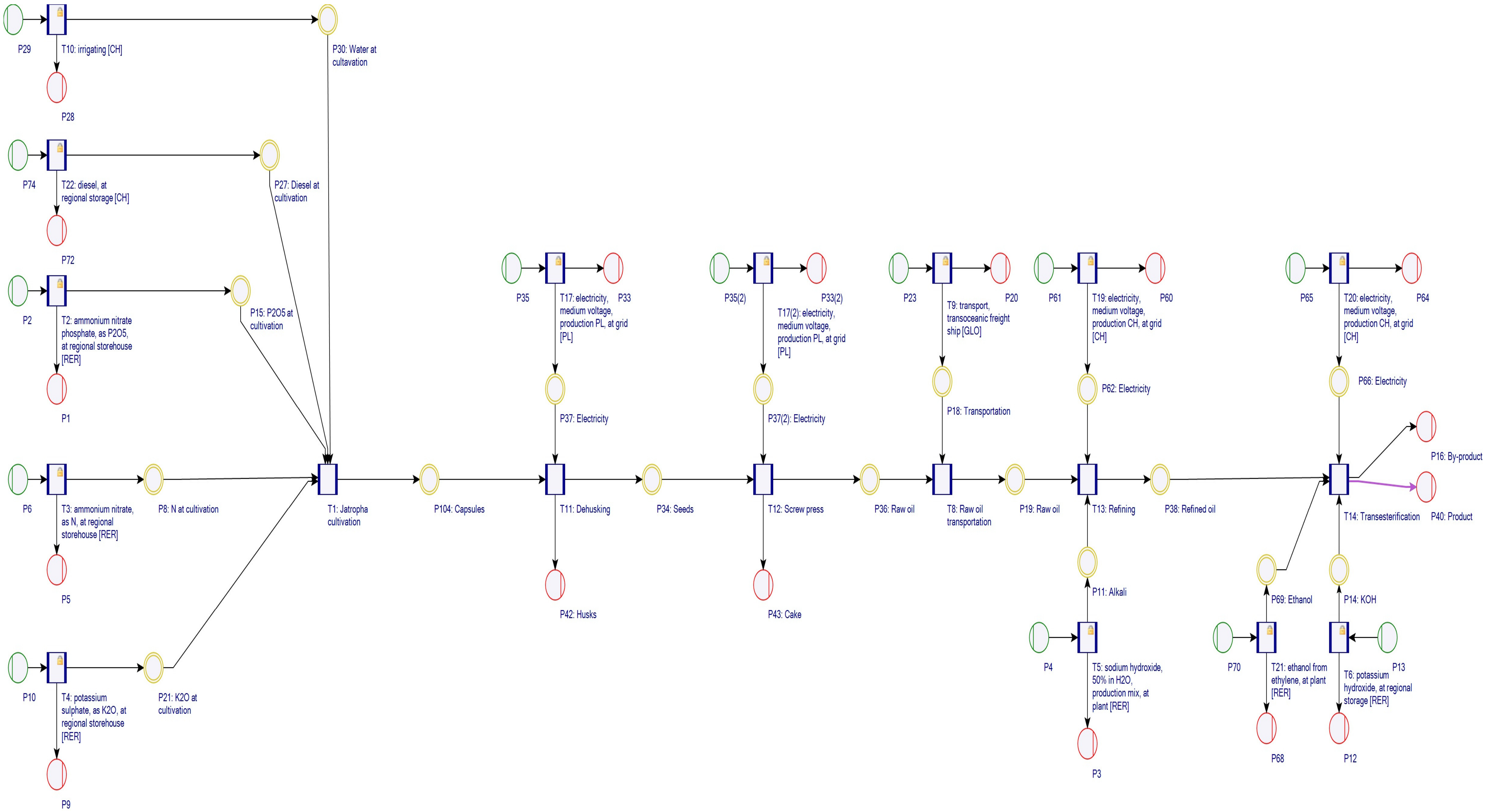

FIG. Nº 20. Base jatropha base oil production scenario

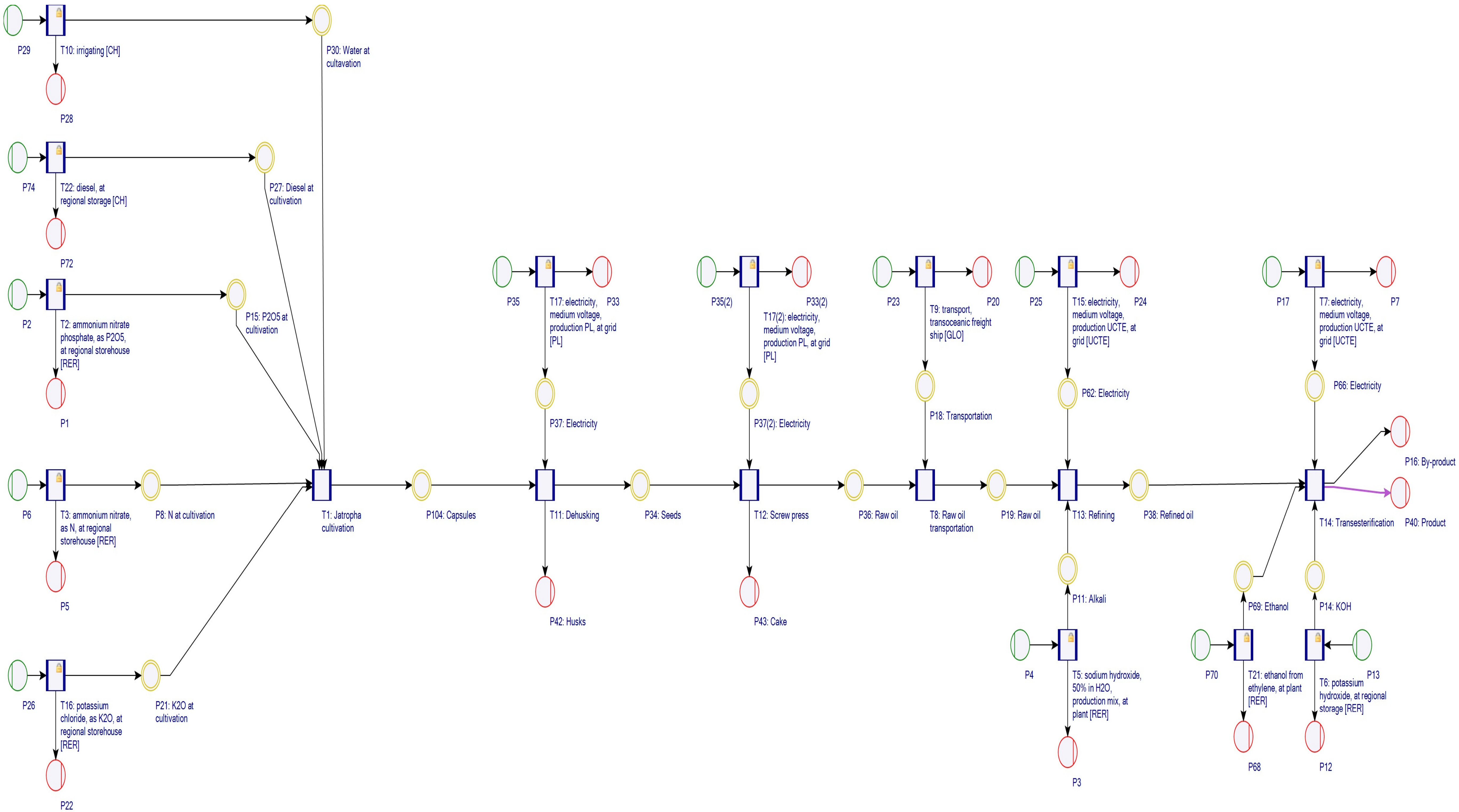

FIG. Nº 21. Alternative jatropha base oil production scenario with potassium chloride as K2O

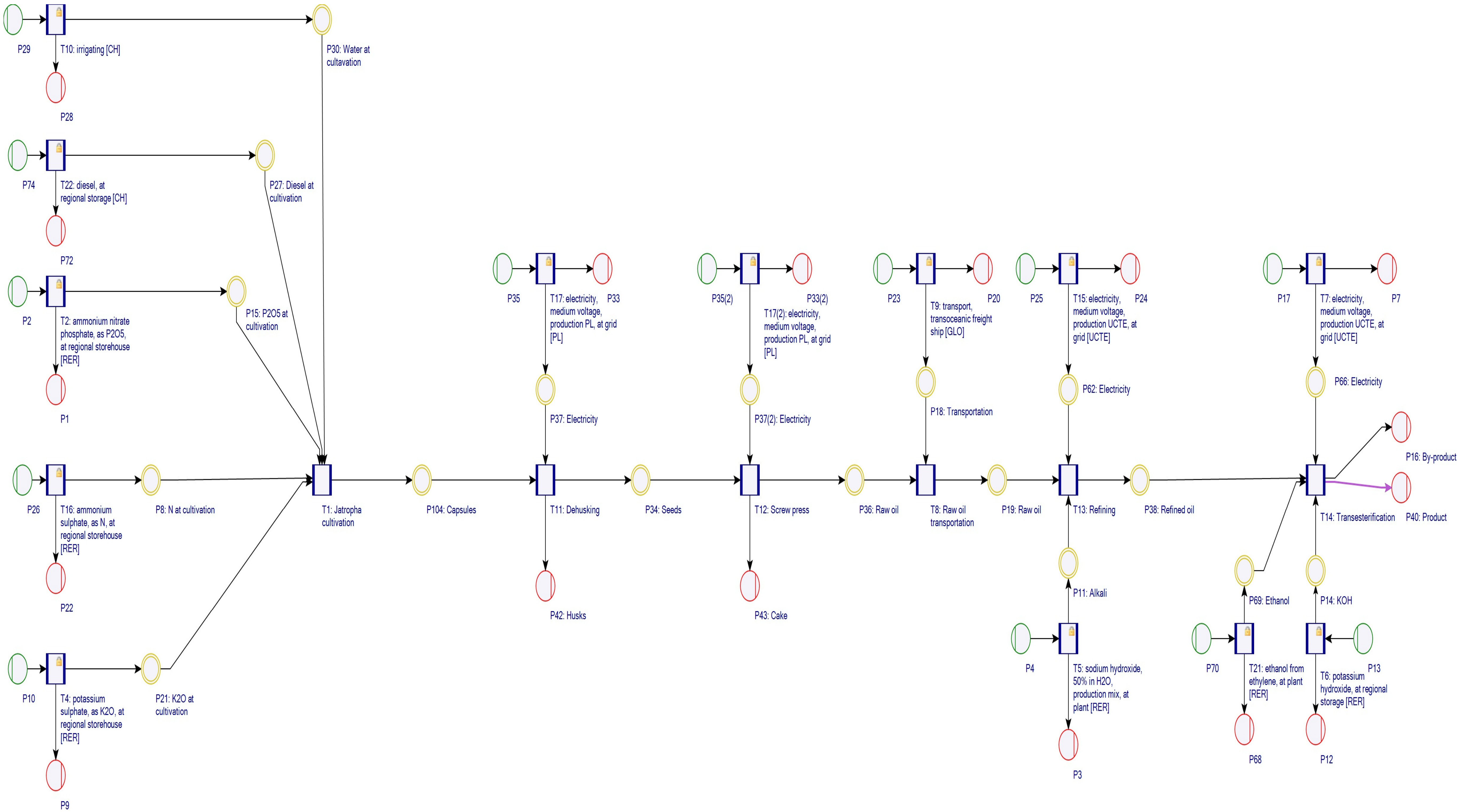

FIG. Nº 22. Alternative jatropha base oil production scenario with ammonium sulphate as N

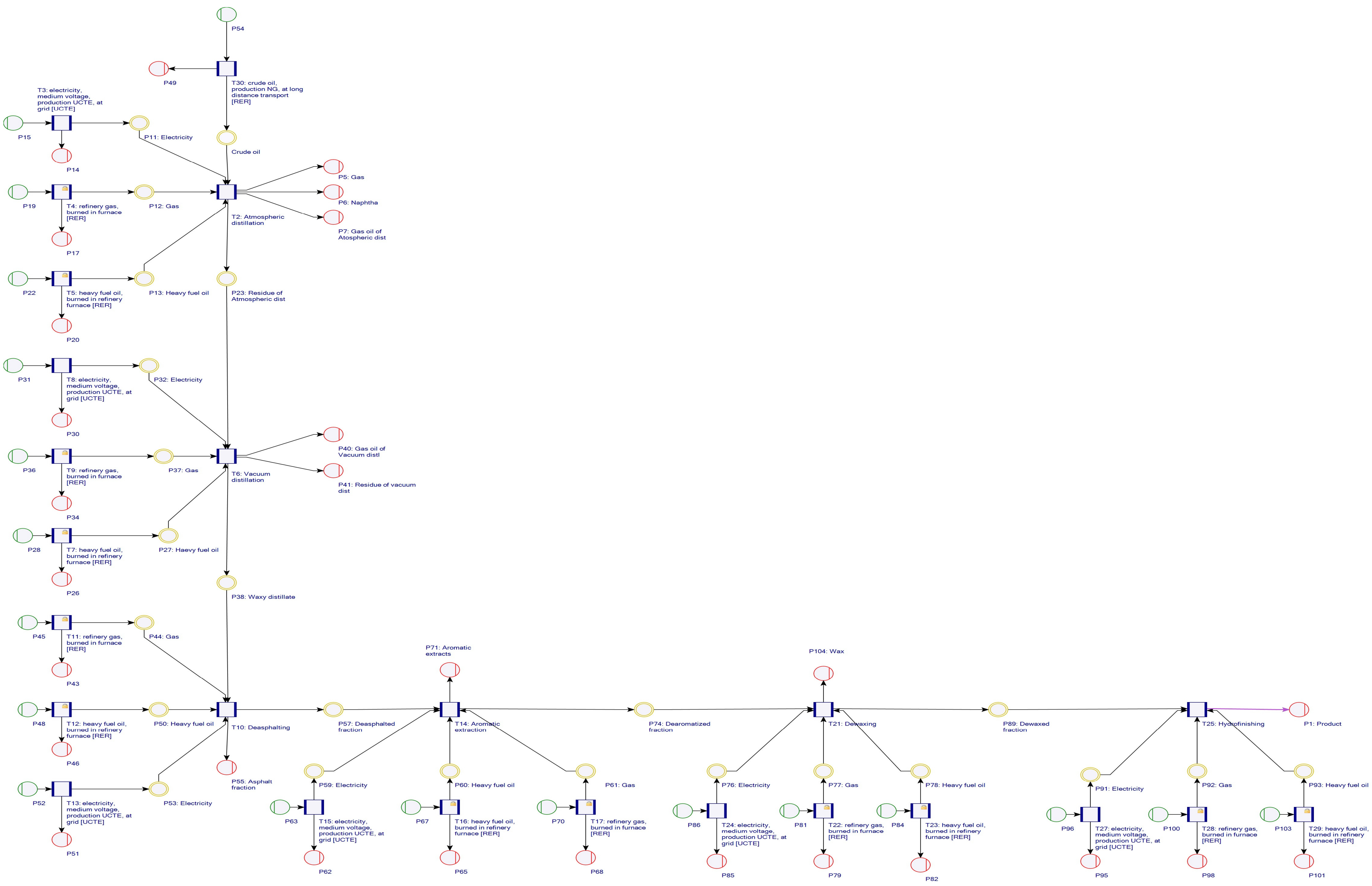

FIG. Nº 23.Base mineral base oil production scenario

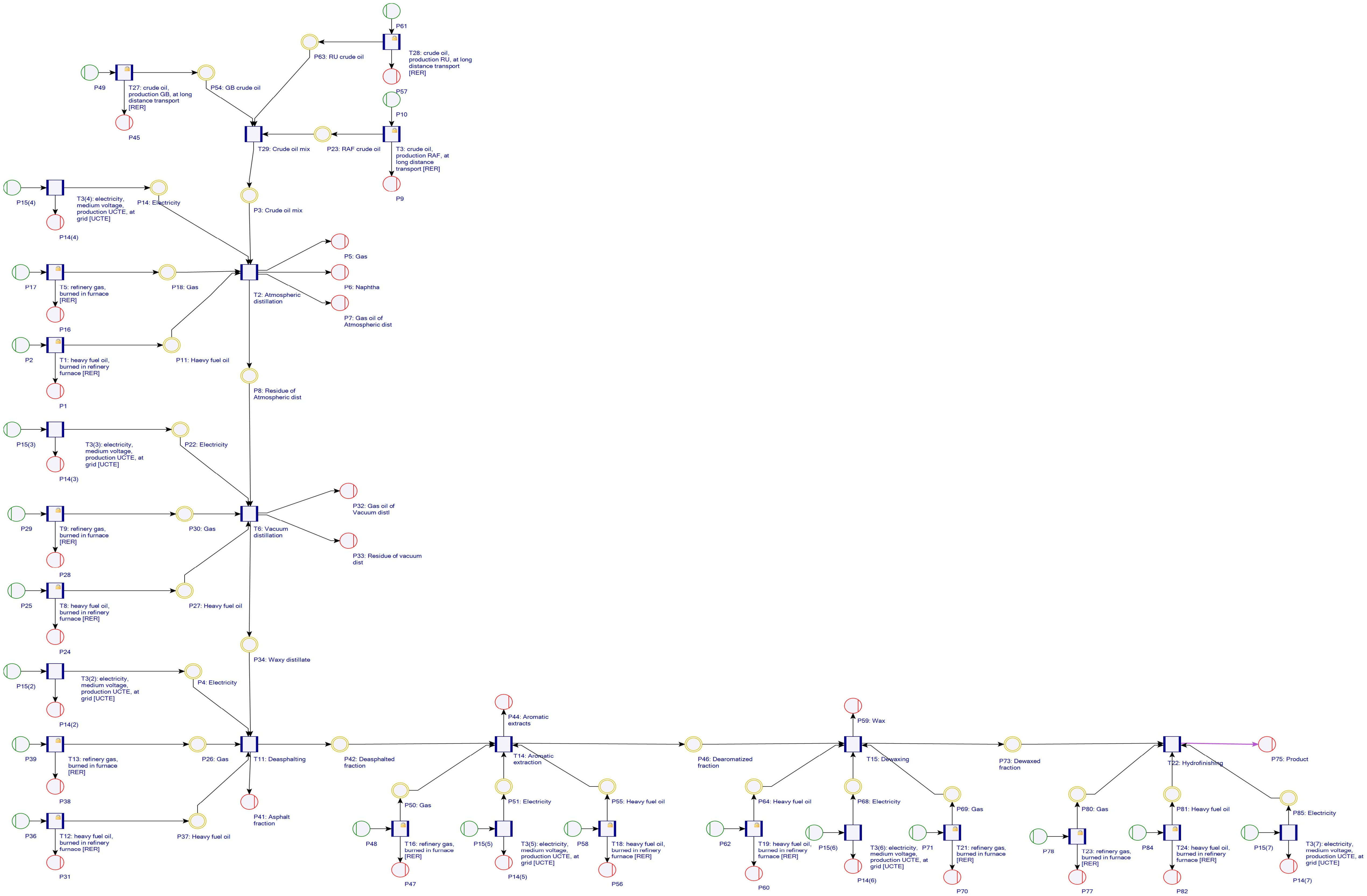

FIG. Nº 24. Alternative mineral base oil production scenario

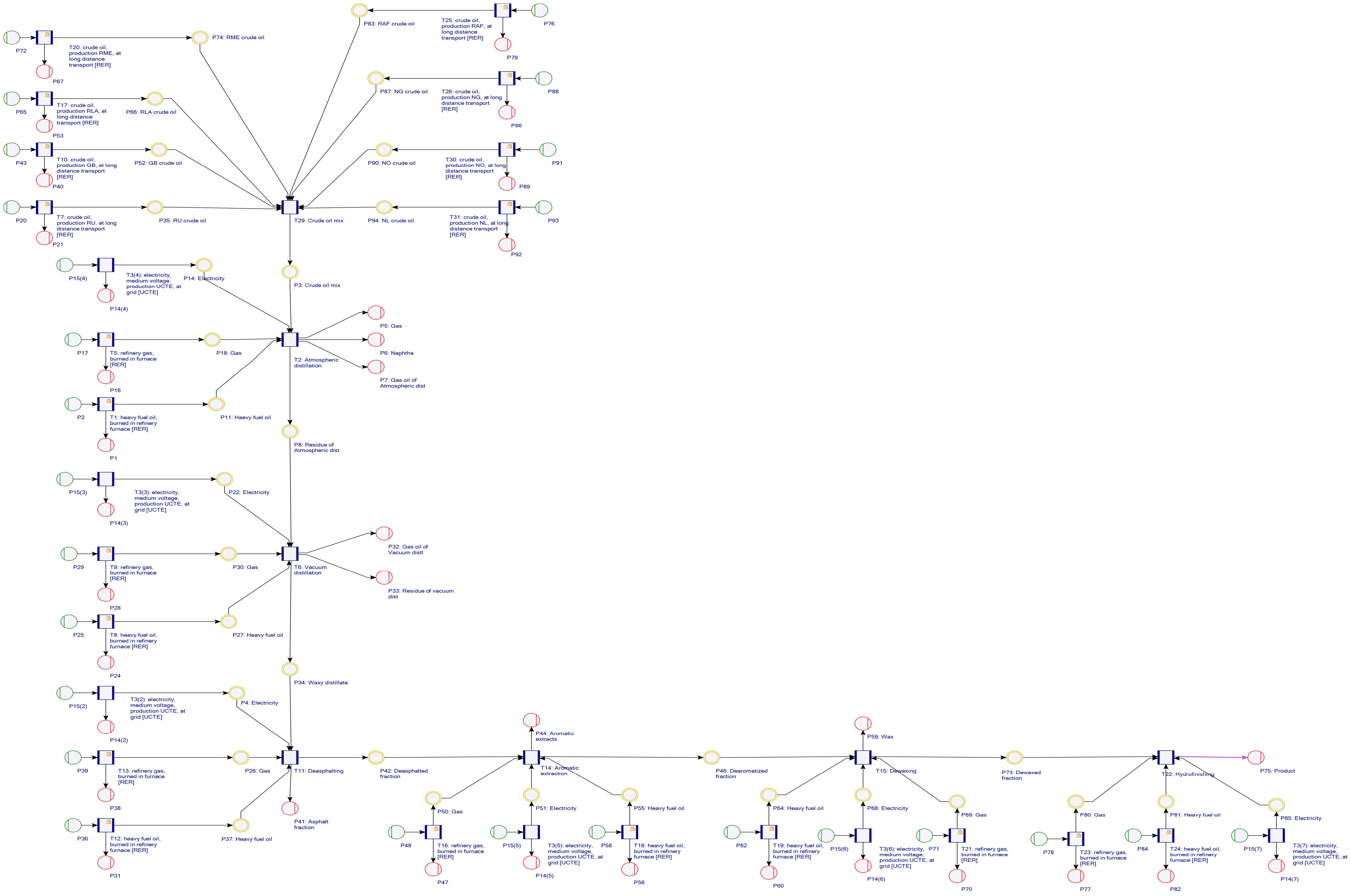

FIG. Nº 25. Alternative mineral base oil production scenario whit RER oil mix

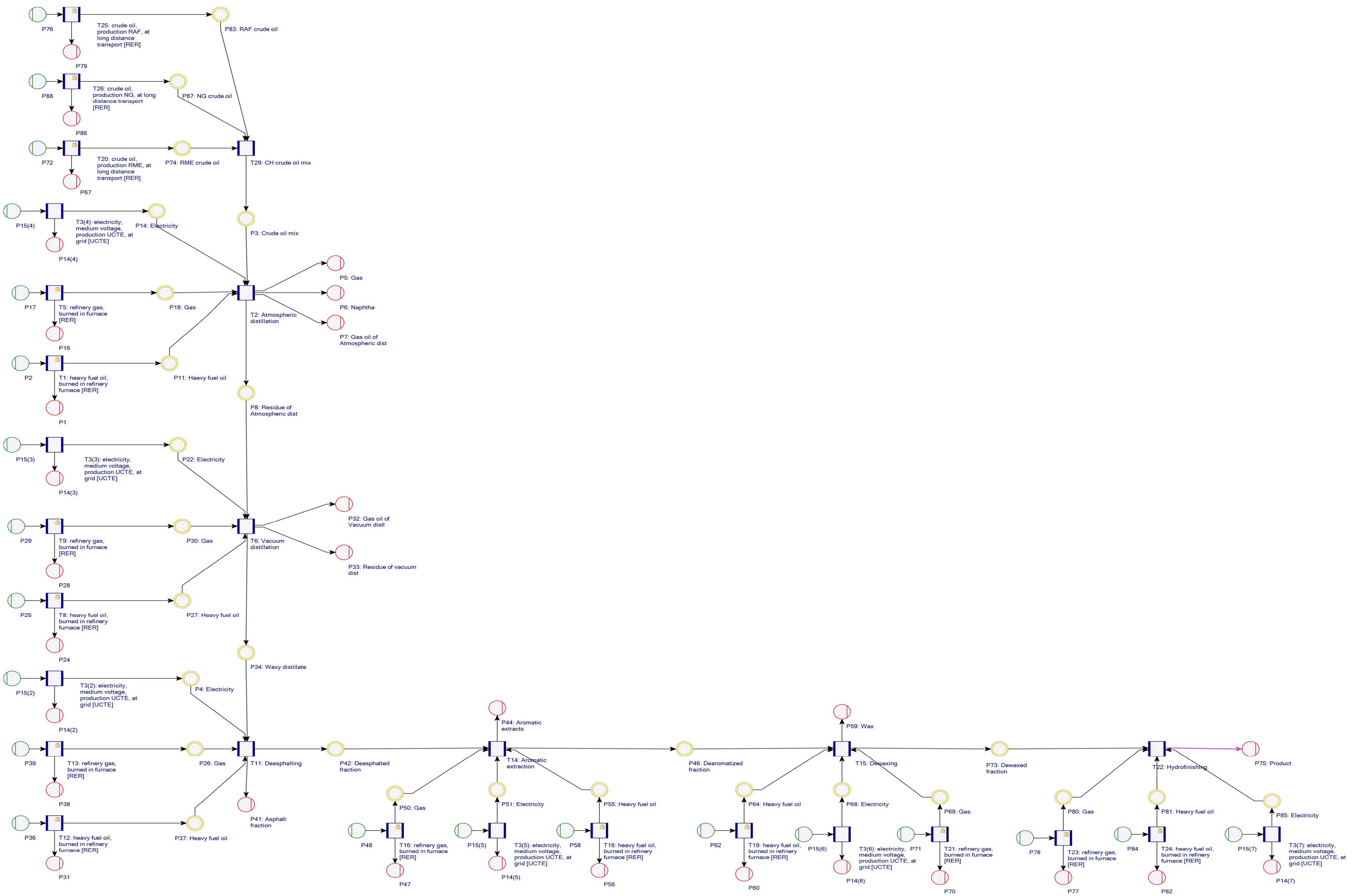

FIG. Nº 26.Alternative mineral base oil production scenario with CH oil mix

Global warming potential of the Jatropha oil production scenarios

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Base jatropha oil production scenario	Jatropha cultivation	Capsules	1,30	Ammonium nitrate as N	0,97
				Potassium sulphate as K2O	0,18
				Ammonium nitrate phosphate as P2O5	0,06
				Diesel	0,06
				Irrigation	0,03
	Dehusking	Seeds	1,36	Electricity	0,06
		Husks	--		
	Screw press	Raw oil	1,94	Electricity	0,58
		Cake	--		
	Transportation	Raw oil transportation	2,01	Transport, transoceanic freigth ship	0,07
	Refining	Refined oil	2,02	Electricity	3,13E-04
				Alkali	5,83E-03
	Transesterification	Base oil	2,27	KOH	0,06
		Glycerin	--	Ethanol	0,19
				Electricity	9,89E-03

TABLE N° 27 Global warming potential of the base jatropha oil production scenario

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Alternative Jatropha oil production scenario without allocation of glycerin	Jatropha cultivation	Capsules	1,30	Ammonium nitrate as N	0,97
				Potassium sulphate as K2O	0,18
				Ammonium nitrate phosphate as P2O5	0,06
				Diesel	0,06
				Irrigation	0,03
	Dehusking	Seeds	0,85	Electricity	0,06
		Husks	0,51		
	Screw press	Raw oil	0,41	Electricity	0,58
		Cake	1,03		
	Transportation	Raw oil transportation	0,48	Transport, transoceanic freigth ship	0,07
	Refining	Refined oil	0,49	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	0,96	KOH	0,06
		Glycerin	--	Ethanol	0,19
				Electricity	0,22

TABLE Nº 28 Global warming potential of the alternative Jatropha oil production scenario without allocation of the glycerin

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Alternative Jatropha oil production scenario without allocation of husks and cake	Jatropha cultivation	Capsules	1,30	Ammonium nitrate as N	0,97
				Potassium sulphate as K2O	0,18
				Ammonium nitrate phosphate as P2O5	0,06
				Diesel	0,06
				Irrigation	0,03
	Dehusking	Seeds	1,36	Electricity	0,06
		Husks	--		
	Screw press	Raw oil	1,94	Electricity	0,58
		Cake	--		
	Transportation	Raw oil transportation	2,01	Transport, transoceanic freigth ship	0,07
	Refining	Refined oil	2,03	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	2,27	KOH	0,06
		Glycerin	0,23	Ethanol	0,19
				Electricity	0,22

TABLE N° 29 Global warming potential of the alternative Jatropha oil production scenario without allocation of the husks and cake

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Alternative Jatropha oil production scenario with ammonium sulphate as N	Jatropha cultivation	Capsules	0,64	Ammonium sulphate as N	0,31
				Potassium sulphate as K2O	0,18
				Ammonium nitrate phosphate as P2O5	0,06
				Diesel	0,06
				Irrigation	0,03
	Dehusking	Seeds	0,43	Electricity	0,06
		Husks	0,26		
	Screw press	Raw oil	0,29	Electricity	0,58
		Cake	0,73		
	Transportation	Raw oil transportation	0,36	Transport, transoceanic freigth ship	0,07
	Refining	Refined oil	0,37	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	0,76	KOH	0,06
		Glycerin	0,08	Ethanol	0,19
				Electricity	0,22

TABLE N° 30 Global warming potential of the base Jatropha oil production scenario with ammonium sulphate as N

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Alternative Jatropha oil production scenario with potassium chloride as K2O	Jatropha cultivation	Capsules	1,18	Ammonium nitrate as N	0,97
				Potassium chloride as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,06
				Diesel	0,06
				Irrigation	0,03
	Dehusking	Seeds	0,77	Electricity	0,06
		Husks	0,46		
	Screw press	Raw oil	0,39	Electricity	0,58
		Cake	0,97		
	Transportation	Raw oil transportation	0,46	Transport, transoceanic freigth ship	0,07
	Refining	Refined oil	0,47	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	0,85	KOH	0,06
		Glycerin	0,08	Ethanol	0,19
				Electricity	0,22

TABLE N° 31 Global warming potential of the alternative Jatropha oil production scenario with potassium chloride as K2O

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Alternative Jatropha oil production scenario without infrastructure on the background systems	Jatropha cultivation	Capsules	1,19	Ammonium nitrate as N	0,93
				Potassium sulphate as K2O	0,14
				Ammonium nitrate phosphate as P2O5	0,05
				Diesel	0,05
				Irrigation	0,02
	Dehusking	Seeds	0,78	Electricity	0,06
		Husks	0,47		
	Screw press	Raw oil	0,44	Electricity	0,58
		Cake	0,97		
	Transportation	Raw oil transportation	0,44	Transport, transoceanic freigth ship	0,06
	Refining	Refined oil	0,46	Electricity	6,97E-03
				Alkali	5,39E-03
	Transesterification	Base oil	0,83	KOH	0,05
		Glycerin	0,08	Ethanol	0,18
				Electricity	0,22

TABLE Nº 32 Global warming potential of the alternative Jatropha oil production scenario without infrastructure on the background systems

Scenario	Process	Contribution kg CO2-Eq		Background systems	Contribution kg CO2-Eq
Best Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	1,07	Ammonium nitrate as N	0,83
				Potassium sulphate as K2O	0,14
				Ammonium nitrate phosphate as P2O5	0,05
				Diesel	0,05
				Irrigation	8,86E-03
	Dehusking	Seeds	0,76	Electricity	0,05
		Husks	0,36		
	Screw press	Raw oil	0,40	Electricity	0,53
		Cake	0,89		
	Transportation	Raw oil transportation	0,47	Transport, transoceanic freight ship	0,07
	Refining	Refined oil	0,48	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	1,33	KOH	0,57
		Glycerin	0,13	Ethanol	0,19
				Electricity	0,22

TABLE N° 33 Global warming potential of the best Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg CO2-Eq		Background process	Contribution kg CO2-Eq
Best Jatropha oil production scenario without allocation of the co-products	Jatropha cultivation	Capsules	1,07	Ammonium nitrate as N	0,83
				Potassium sulphate as K2O	0,14
				Ammonium nitrate phosphate as P2O5	0,05
				Diesel	0,05
				Irrigation	8,86E-03
	Dehusking	Seeds	1,12	Electricity	0,05
		Husks	--		
	Screw press	Raw oil	1,65	Electricity	0,53
		Cake	--		
	Transportation	Raw oil transportation	1,72	Transport, transoceanic freight ship	0,07
	Refining	Refined oil	1,74	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	2,72	KOH	0,57
		Glycerin	--	Ethanol	0,19
				Electricity	0,22

TABLE N° 34 Global warming potential of the best Jatropha oil production scenario without allocation of the co-products

Fossil depletion potential of the Jatropha oil production scenarios

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Base Jatropha oil production scenario	Jatropha cultivation	Capsules	0,38	Ammonium nitrate as N	0,15
				Potassium sulphate as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,39	Electricity	0,02
		Husks	--		
	Screw press	Raw oil	0,55	Electricity	0,16
		Cake	--		
	Transportation	Raw oil transportation	0,58	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,58	Electricity	9,19E-05
				Alkali	1,68E-03
	Transesterification	Base oil	0,77	KOH	0,02
		Glycerin	--	Ethanol	0,16
				Electricity	2,90E-03

TABLE N° 35 Fossil depletion potential of the base Jatropha oil production scenario

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario whit allocation of the co-products	Jatropha cultivation	Capsules	0,83	Ammonium nitrate as N	0,15
				Potassium sulphate as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,25	Electricity	0,02
		Husks	0,15		
	Screw press	Raw oil	0,11	Electricity	0,16
		Cake	0,29		
	Transportation	Raw oil transportation	0,14	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,14	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,35	KOH	0,02
		Glycerin	0,04	Ethanol	0,16
				Electricity	0,06

TABLE Nº 36 Fossil depletion potential of the alternative Jatropha production scenario with allocation of the co-products

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario without allocation of glycerin	Jatropha cultivation	Capsules	0,38	Ammonium nitrate as N	0,15
				Potassium sulphate as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,25	Electricity	0,02
		Husks	0,15		
	Screw press	Raw oil	0,11	Electricity	0,16
		Cake	0,29		
	Transportation	Raw oil transportation	0,14	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,14	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,39	KOH	0,02
		Glycerin	--	Ethanol	0,16
				Electricity	0,06

TABLE Nº 37 Fossil depletion potential of the alternative Jatropha production scenario without allocation of glycerin

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario without allocation of husks and cake	Jatropha cultivation	Capsules	0,38	Ammonium nitrate as N	0,15
				Potassium sulphate as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,39	Electricity	0,02
		Husks	--		
	Screw press	Raw oil	0,55	Electricity	0,16
		Cake	--		
	Transportation	Raw oil transportation	0,58	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,58	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,75	KOH	0,02
		Glycerin	0,08	Ethanol	0,16
				Electricity	0,06

TABLE Nº 38 Fossil depletion potential of the alternative Jatropha oil production scenario without allocation of husks and cake

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario with ammonium sulphate as N	Jatropha cultivation	Capsules	0,34	Ammonium sulphate as N	0,11
				Potassium sulphate as K2O	0,06
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,22	Electricity	0,02
		Husks	0,13		
	Screw press	Raw oil	0,11	Electricity	0,16
		Cake	0,27		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,14	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,35	KOH	0,02
		Glycerin	0,03	Ethanol	0,16
				Electricity	0,06

TABLE N° 39 Fossil depletion potential of the alternative Jatropha oil production scenario with ammonium sulphate as N

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario with potassium chloride as K2O	Jatropha cultivation	Capsules	0,34	Ammonium nitrate as N	0,15
				Potassium chloride as K2O	0,02
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	0,01
	Dehusking	Seeds	0,22	Electricity	0,02
		Husks	0,13		
	Screw press	Raw oil	0,11	Electricity	0,16
		Cake	0,27		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,14	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,35	KOH	0,02
		Glycerin	0,03	Ethanol	0,16
				Electricity	0,06

TABLE Nº 40 Fossil depletion potential of the alternative Jatropha oil production scenario with potassium chloride as K2O

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Alternative Jatropha oil production scenario without infrastructure in the background systems	Jatropha cultivation	Capsules	0,34	Ammonium nitrate as N	0,14
				Potassium sulphate as K2O	0,05
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,13
				Irrigation	8,63E-03
	Dehusking	Seeds	0,22	Electricity	0,02
		Husks	0,13		
	Screw press	Raw oil	0,11	Electricity	0,16
		Cake	0,27		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freight ship	0,02
	Refining	Refined oil	0,13	Electricity	2,02E-03
				Alkali	1,55E-03
	Transesterification	Base oil	0,34	KOH	0,02
		Glycerin	0,03	Ethanol	0,16
				Electricity	0,06

TABLE N° 41 Fossil depletion potential of the alternative Jatropha oil production scenario without infrastructure in the background systems

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Best Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	0,30	Ammonium nitrate as N	0,13
				Potassium sulphate as K2O	0,05
				Ammonium nitrate phosphate as P2O5	0,02
				Diesel	0,10
				Irrigation	3,49E-03
	Dehusking	Seeds	0,21	Electricity	0,01
		Husks	0,10		
	Screw press	Raw oil	0,11	Electricity	0,14
		Cake	0,24		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freigth ship	0,02
	Refining	Refined oil	0,14	Electricity	2,05E-03
				Alkali	1,68E-03
	Transesterification	Base oil	0,50	KOH	0,19
		Glycerin	0,05	Ethanol	0,16
				Electricity	0,06

TABLE N° 42 Fossil depletion potential of the best Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg Oil-Eq		Background systems	Contribution kg Oil-Eq
Best Jatropha oil production scenario without allocation of co-products	Jatropha cultivation	Capsules	1,07	Ammonium nitrate as N	0,83
				Potassium sulphate as K2O	0,14
				Ammonium nitrate phosphate as P2O5	0,05
				Diesel	0,05
				Irrigation	8,86E-03
	Dehusking	Seeds	1,12	Electricity	0,05
		Husks	--		
	Screw press	Raw oil	1,65	Electricity	0,53
		Cake	--		
	Transportation	Raw oil transportation	1,72	Transport, transoceanic freight ship	0,02
	Refining	Refined oil	1,74	Electricity	7,06E-03
				Alkali	5,83E-03
	Transesterification	Base oil	2,72	KOH	0,57
		Glycerin	--	Ethanol	0,19
				Electricity	0,22

TABLE N° 43 Fossil depletion potential of the best Jatropha oil production scenario with allocation of the co-products

Human toxicity potential of the Jatropha oil production scenarios

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Base Jatropha oil production scenario	Jatropha cultivation	Capsules	0,09	Ammonium nitrate as N	0,04
				Potassium sulphate as K2O	0,03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,09	Electricity	3,63E-03
		Husks	--		
	Screw press	Raw oil	0,13	Electricity	0,04
		Cake	--		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,13	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,14	KOH	3,24E-03
		Glycerin	--	Ethanol	4,50E-03
				Electricity	1,46E-03

TABLE N° 44 Human toxicity potential of the base Jatropha oil production scenario

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	0,09	Ammonium nitrate as N	0,04
				Potassium sulphate as K2O	0,03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,06	Electricity	3,63E-03
		Husks	0,03		
	Screw press	Raw oil	0,03	Electricity	0,04
		Cake	0,07		
	Transportation	Raw oil transportation	0,03	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,03	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,04	KOH	0,03
		Glycerin	4,36E-03	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE Nº 45 Human toxicity potential of the alternative Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario without allocation of the glycerin	Jatropha cultivation	Capsules	0,09	Ammonium nitrate as N	0,04
				Potassium sulphate as K2O	0,03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,06	Electricity	3,63E-03
		Husks	0,03		
	Screw press	Raw oil	0,03	Electricity	0,04
		Cake	0,07		
	Transportation	Raw oil transportation	0,03	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,03	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,05	KOH	3,24E-03
		Glycerin	--	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE N° 46 Human toxicity potential of the alternative Jatropha oil production scenario without allocation of the glycerin

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario without allocation of the husks and cake	Jatropha cultivation	Capsules	0,09	Ammonium nitrate as N	0,04
				Potassium sulphate as K2O	0,03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,09	Electricity	3,63E-03
		Husks	--		
	Screw press	Raw oil	0,13	Electricity	0,04
		Cake	--		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,13	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,14	KOH	3,24E-03
		Glycerin	0,01	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE Nº 47 Human toxicity potential of the alternative Jatropha oil production scenario without allocation of the husks and cake

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario with ammonium sulphate as N	Jatropha cultivation	Capsules	0,07	Ammonium sulphate as N	0,02
				Potassium sulphate as K2O	0,03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,05	Electricity	3,63E-03
		Husks	0,03		
	Screw press	Raw oil	0,02	Electricity	0,04
		Cake	0,06		
	Transportation	Raw oil transportation	0,03	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,03	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,04	KOH	3,24E-03
		Glycerin	4,12E-03	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE Nº 48 Human toxicity potential of the alternative Jatropha oil production scenario with ammonium sulphate as N

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario with potassium chloride as K2O	Jatropha cultivation	Capsules	0,07	Ammonium nitrate as N	0,04
				Potassium chloride as K2O	6,18E-03
				Ammonium nitrate phosphate as P2O5	0,01
				Diesel	4,31E-03
				Irrigation	4,09E-03
	Dehusking	Seeds	0,04	Electricity	3,63E-03
		Husks	0,03		
	Screw press	Raw oil	0,02	Electricity	0,04
		Cake	0,06		
	Transportation	Raw oil transportation	0,03	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,03	Electricity	2,89E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,04	KOH	3,24E-03
		Glycerin	4,03E-03	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE Nº 49 Human toxicity potential of the alternative Jatropha oil production scenario with potassium chloride as K2O

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative Jatropha oil production scenario without infrastructure	Jatropha cultivation	Capsules	0,05	Ammonium nitrate as N	0,02
				Potassium sulphate as K2O	0,01
				Ammonium nitrate phosphate as P2O5	9,11E-03
				Diesel	3,12E-03
				Irrigation	1,30E-03
	Dehusking	Seeds	0,03	Electricity	3,47E-03
		Husks	0,02		
	Screw press	Raw oil	0,02	Electricity	0,04
		Cake	0,05		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	1,10E-03
	Refining	Refined oil	0,02	Electricity	2,48E-04
				Alkali	1,83E-03
	Transesterification	Base oil	0,03	KOH	1,56E-03
		Glycerin	3,02E-03	Ethanol	1,81E-03
				Electricity	7,83E-03

TABLE N° 50 Human toxicity potential of the alternative Jatropha oil production scenario without infrastructure

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background systems	Contribution kg 1,4-DCB-Eq
Best Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	0,07	Ammonium nitrate as N	0,03
				Potassium sulphate as K2O	0,02
				Ammonium nitrate phosphate as P2O5	9,67E-03
				Diesel	3,22E-03
				Irrigation	1,19E-03
	Dehusking	Seeds	0,05	Electricity	3,06E-03
		Husks	0,02		
	Screw press	Raw oil	0,03	Electricity	0,03
		Cake	0,06		
	Transportation	Raw oil transportation	0,03	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,03	Electricity	2,98E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,07	KOH	0,03
		Glycerin	6,93E-03	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE N° 51 Human toxicity potential of the best Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Best Jatropha oil production scenario without allocation of the co-products	Jatropha cultivation	Capsules	0,07	Ammonium nitrate as N	0,03
				Potassium sulphate as K2O	0,02
				Ammonium nitrate phosphate as P2O5	9,67E-03
				Diesel	3,22E-03
				Irrigation	1,19E-03
	Dehusking	Seeds	0,07	Electricity	3,06E-03
		Husks	--		
	Screw press	Raw oil	0,11	Electricity	0,03
		Cake	--		
	Transportation	Raw oil transportation	0,11	Transport, transoceanic freight ship	2,18E-03
	Refining	Refined oil	0,11	Electricity	2,98E-04
				Alkali	2,03E-03
	Transesterification	Base oil	0,16	KOH	0,03
		Glycerin	--	Ethanol	4,50E-03
				Electricity	9,13E-03

TABLE N° 52 Human toxicity potential of the best Jatropha oil production scenario without allocation of the co-products

Freshwater eutrophication potential of the Jatropha oil production scenarios

<table>
<tr><th>Scenario</th><th>Process</th><th colspan="2">Contribution kg U235-Eq</th><th>Background system</th><th>Contribution kg U235-Eq</th></tr>
<tr><td rowspan="16">Base Jatropha oil production scenario</td><td rowspan="5">Jatropha cultivation</td><td rowspan="5">Capsules</td><td rowspan="5">5,86E-05</td><td>Ammonium nitrate as N</td><td>1,95E-05</td></tr>
<tr><td>Potassium sulphate as K2O</td><td>1,59E-05</td></tr>
<tr><td>Ammonium nitrate phosphate as P2O5</td><td>1,88E-05</td></tr>
<tr><td>Diesel</td><td>1,19E-06</td></tr>
<tr><td>Irrigation</td><td>3,16E-06</td></tr>
<tr><td rowspan="2">Dehusking</td><td>Seeds</td><td>6,50E-05</td><td rowspan="2">Electricity</td><td rowspan="2">6,45E-06</td></tr>
<tr><td>Husks</td><td>--</td></tr>
<tr><td rowspan="2">Screw press</td><td>Raw oil</td><td>1,32E-04</td><td rowspan="2">Electricity</td><td rowspan="2">6,71E-05</td></tr>
<tr><td>Cake</td><td>--</td></tr>
<tr><td>Transportation</td><td>Raw oil transportation</td><td>1,34E-04</td><td>Transport, transoceanic freight ship</td><td>1,38E-06</td></tr>
<tr><td rowspan="2">Refining</td><td rowspan="2">Refined oil</td><td rowspan="2">1,35E-04</td><td>Electricity</td><td>7,65E-07</td></tr>
<tr><td>Alkali</td><td>7,46E07</td></tr>
<tr><td rowspan="3">Transesterification</td><td>Base oil</td><td>2,22E-04</td><td>KOH</td><td>7,75E-06</td></tr>
<tr><td rowspan="2">Glycerin</td><td rowspan="2">--</td><td>Ethanol</td><td>5,76E-05</td></tr>
<tr><td>Electricity</td><td>2,41E05</td></tr>
</table>

TABLE N° 53 Freshwater eutrophication potential of the base Jatropha oil production scenario

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	5,86E-05	Ammonium nitrate as N	1,95E-05
				Potassium sulphate as K2O	1,95E-05
				Ammonium nitrate phosphate as P2O5	1,88E-05
				Diesel	1,19E-06
				Irrigation	3,16E-06
	Dehusking	Seeds	4,06E-05	Electricity	6,45E-05
		Husks	2,44E-05		
	Screw press	Raw oil	3,05E-05	Electricity	6,71E-05
		Cake	7,73E-05		
	Transportation	Raw oil transportation	3,19E-05	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	3,43E-05	Electricity	7,46E-07
				Alkali	7,46E-07
	Transesterification	Base oil	1,09E-04	KOH	4,75E-06
		Glycerin	1,09E-05	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE N° 54 Freshwater eutrophication potential of the alternative Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario without allocation of glycerin	Jatropha cultivation	Capsules	5,86E-05	Ammonium nitrate as N	1,95E-05
				Potassium sulphate as K2O	1,59E-05
				Ammonium nitrate phosphate as P2O5	1,88E-05
				Diesel	1,19E-06
				Irrigation	3,16E-06
	Dehusking	Seeds	4,06E-05	Electricity	6,45E-06
		Husks	2,44E-05		
	Screw press	Raw oil	3,05E-05	Electricity	6,71E-05
		Cake	7,73E-05		
	Transportation	Raw oil transportation	3,19E-05	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	3,34E-05	Electricity	7,46E-07
				Alkali	7,46E-07
	Transesterification	Base oil	1,20E-04	KOH	4,75E-06
		Glycerin	--	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE Nº 55 Freshwater eutrophication potential of the alternative Jatropha oil production scenario without allocation of glycerin

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario without allocation of husks and cake	Jatropha cultivation	Capsules	5,86E-05	Ammonium nitrate as N	1,95E-05
				Potassium sulphate as K2O	159E-05
				Ammonium nitrate phosphate as P2O5	1,88E-05
				Diesel	1,19E-06
				Irrigation	3,16E-06
	Dehusking	Seeds	6,50E-05	Electricity	6,45E-06
		Husks	--		
	Screw press	Raw oil	1,32E-04	Electricity	6,71E-05
		Cake	--		
	Transportation	Raw oil transportation	1,34E-04	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	1,35E-04	Electricity	7,64E-07
				Alkali	7,46E-07
	Transesterification	Base oil	0,12	KOH	4,75E-06
		Glycerin	0,01	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE N° 56 Freshwater eutrophication potential of the alternative Jatropha oil production scenario without allocation of the husks and cake

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario with ammonium sulphate as N	Jatropha cultivation	Capsules	5,49E-05	Ammonium sulphate as N	1,59E-05
				Potassium sulphate as K2O	1,59E-05
				Ammonium nitrate phosphate as P2O5	1,88E-05
				Diesel	1,19E-06
				Irrigation	3,16E-06
	Dehusking	Seeds	3,84E-05	Electricity	6,45E-06
		Husks	2,30E-05		
	Screw press	Raw oil	2,99E-05	Electricity	2,86E-03
		Cake	7,56E-05		
	Transportation	Raw oil transportation	3,13E-05	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	2,28E-05	Electricity	7,64E-07
				Alkali	7,46E-07
	Transesterification	Base oil	1,08E-04	KOH	4,75E-06
		Glycerin	1,08E-05	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE N° 57 Freshwater eutrophication potential of the alternative Jatropha oil production scenario with ammonium sulphate as N

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario with potassium chloride as K2O	Jatropha cultivation	Capsules	4,85E-05	Ammonium nitrate as N	1,95E-05
				Potassium chloride as K2O	5,79E-06
				Ammonium nitrate phosphate as P2O5	1,88E-05
				Diesel	1,19E-06
				Irrigation	3,16E-06
	Dehusking	Seeds	3,43E-05	Electricity	6,45E-06
		Husks	2,06E-05		
	Screw press	Raw oil	2,87E-05	Electricity	6,71E-05
		Cake	7,27E-05		
	Transportation	Raw oil transportation	3,01E-05	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	3,16E-05	Electricity	7,64E-07
				Alkali	7,46E-07
	Transesterification	Base oil	1,07E-04	KOH	4,74E-06
		Glycerin	1,07E-05	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE N° 58 Freshwater eutrophication potential of the alternative Jatropha oil production scenario with potassium chloride as K2O

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative Jatropha oil production scenario without infrastructure in the background system	Jatropha cultivation	Capsules	2,35E-05	Ammonium nitrate as N	2,20E-06
				Potassium sulphate as K2O	2,32E-06
				Ammonium nitrate phosphate as P2O5	1,72E-05
				Diesel	5,40E-07
				Irrigation	1,24E-06
	Dehusking	Seeds	1,87E-05	Electricity	6,34E-06
		Husks	1,12E-05		
	Screw press	Raw oil	2,40E-05	Electricity	6,61E-05
		Cake	6,07E-05		
	Transportation	Raw oil transportation	2,41E-05	Transport, transoceanic freight ship	9,55E-08
	Refining	Refined oil	2,54E-05	Electricity	7,36E-07
				Alkali	5,61E-07
	Transesterification	Base oil	9,75E-05	KOH	3,30E-06
		Glycerin	9,75E-06	Ethanol	5,53E-05
				Electricity	2,32E-05

TABLE Nº 59 Freshwater eutrophication potential of the alternative Jatropha oil production scenario without infrastructure on the background system

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Best Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	4,68E-05	Ammonium nitrate as N	1,67E-05
				Potassium sulphate as K2O	1,21E-05
				Ammonium nitrate phosphate as P2O5	1,61E-05
				Diesel	8,89E-07
				Irrigation	9,20E-07
	Dehusking	Seeds	3,52E-05	Electricity	5,43E-06
		Husks	1,70E-05		
	Screw press	Raw oil	3,00E-05	Electricity	6,11E-05
		Cake	6,64E-05		
	Transportation	Raw oil transportation	3,14E-05	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	3,29E-05	Electricity	7,64E-07
				Alkali	7,46E-07
	Transesterification	Base oil	1,47E-04	KOH	4,75E-05
		Glycerin	1,47E-05	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE Nº 60 Freshwater eutrophication potential of the best Jatropha oil production scenario with allocation of the co-products

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Best Jatropha oil production scenario without allocation of the co-products	Jatropha cultivation	Capsules	4,68E-05	Ammonium nitrate as N	1,67E-05
				Potassium sulphate as K2O	1,21E-05
				Ammonium nitrate phosphate as P2O5	1,61E-05
				Diesel	8,89E-07
				Irrigation	9,20E-07
	Dehusking	Seeds	5,22E-05	Electricity	5,43E-06
		Husks	--		
	Screw press	Raw oil	1,13E-04	Electricity	6,11E-05
		Cake	--		
	Transportation	Raw oil transportation	1,15E-04	Transport, transoceanic freight ship	1,38E-06
	Refining	Refined oil	1,16E-04	Electricity	7,64E-07
				Alkali	7,46E-07
	Transesterification	Base oil	2,45E-04	KOH	4,75E-05
		Glycerin	--	Ethanol	5,76E-05
				Electricity	2,41E-05

TABLE N° 61 Freshwater eutrophication potential of the best Jatropha oil production scenario without allocation of the co-products

Water depletion potential of the Jatropha oil production scenarios

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Base Jatropha oil production scenario	Jatropha cultivation	Capsules	0,13	Ammonium nitrate as N	1,54E-03
				Potassium sulphate as K2O	8,34E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,13	Electricity	2,10E-04
		Husks	--		
	Screw press	Raw oil	0,13	Electricity	2,19E-03
		Cake	--		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,01	Electricity	4,88E-05
				Alkali	1,46E-03
	Transesterification	Base oil	0,13	KOH	4,55E-04
		Glycerin	--	Ethanol	4,65E-04
				Electricity	1,54

TABLE Nº 62 Water depletion potential of the base Jatropha oil production scenario

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative Jatropha oil production scenario whit allocation of the co-products	Jatropha cultivation	Capsules	0,13	Ammonium nitrate as N	1,54E-03
				Potassium sulphate as K2O	8,34E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,08	Electricity	2,10E-04
		Husks	0,05		
	Screw press	Raw oil	0,02	Electricity	2,19E-03
		Cake	0,06		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,02	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,02	KOH	4,55E-04
		Glycerin	2,42E-03	Ethanol	4,65E-04
				Electricity	1,81E-03

TABLE Nº 63 Alternative Jatropha oil production scenario whit allocation of the co-products

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative Jatropha oil production scenario without allocation of glycerin	Jatropha cultivation	Capsules	0,13	Ammonium nitrate as N	1,54E-03
				Potassium sulphate as K2O	8,34E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,08	Electricity	2,10E-04
		Husks	0,05		
	Screw press	Raw oil	0,02	Electricity	2,19E-03
		Cake	0,06		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	1,66E04
	Refining	Refined oil	0,02	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,03	KOH	4,55E-04
		Glycerin	--	Ethanol	4,65E-04
				Electricity	1,81E-03

TABLE N° 64 Water depletion potential of the alternative Jatropha oil production scenario without allocation of glycerin

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative Jatropha oil production scenario without allocation of husks and cake	Jatropha cultivation	Capsules	0,13	Ammonium nitrate as N	1,54E-03
				Potassium sulphate as K2O	8,34E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,13	Electricity	2,10E-04
		Husks	--		
	Screw press	Raw oil	0,13	Electricity	2,19E-03
		Cake	--		
	Transportation	Raw oil transportation	0,13	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,13	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,12	KOH	4,55E-04
		Glycerin	0,01	Ethanol	4,65E-04
				Electricity	1,81E-03

TABLE N° 65 Water depletion potential of the alternative Jatropha oil production scenario without allocation of husks and cake

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative jatropha oil production scenario with ammonium sulphate as N	Jatropha cultivation	Capsules	0,13	Ammonium sulphate as N	7,12E-04
				Potassium sulphate as K2O	8,34E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,08	Electricity	2,10E-04
		Husks	0,05		
	Screw press	Raw oil	0,02	Electricity	2,19E-03
		Cake	0,06		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,02	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,02	KOH	4,55E-04
		Glycerin	2,41E-03	Ethanol	4,65E-04
				Electricity	1,81E-03

TABLE N° 66 Water depletion potential of the alternative Jatropha oil production scenario with ammonium sulphate as N

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative Jatropha oil production scenario with potassium chloride as K2O	Jatropha cultivation	Capsules	0,12	Ammonium nitrate as N	1,54E-03
				Potassium chloride as K2O	8,85E-04
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	4,66E-04
				Irrigation	0,12
	Dehusking	Seeds	0,08	Electricity	2,10E-04
		Husks	0,05		
	Screw press	Raw oil	0,02	Electricity	2,19E-03
		Cake	0,06		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,02	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,02	KOH	4,55E-04
		Glycerin	2,30E-03	Ethanol	4,65E-04
				Electricity	1,81E-03

TABLE Nº 67 Water depletion potential of the alternative Jatropha oil production scenario with potassium chloride as K2O

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Alternative Jatropha oil production scenario without infrastructure on the background system	Jatropha cultivation	Capsules	0,13	Ammonium nitrate as N	9,00E-04
				Potassium sulphate as K2O	7,65E-03
				Ammonium nitrate phosphate as P2O5	4,62E-04
				Diesel	3,52E-04
				Irrigation	0,12
	Dehusking	Seeds	0,08	Electricity	2,06E-04
		Husks	0,05		
	Screw press	Raw oil	0,02	Electricity	2,14E-03
		Cake	0,06		
	Transportation	Raw oil transportation	0,02	Transport, transoceanic freight ship	5,11E-05
	Refining	Refined oil	0,02	Electricity	5,62E-05
				Alkali	6,91E-05
	Transesterification	Base oil	0,02	KOH	3,97E-04
		Glycerin	2,36E-03	Ethanol	3,64E-04
				Electricity	1,77E-03

TABLE Nº 68 Water depletion potential of the alternative Jatropha oil production scenario without infrastructure on the background system

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Best Jatropha oil production scenario with allocation of the co-products	Jatropha cultivation	Capsules	0,04	Ammonium nitrate as N	1,32E-03
				Potassium sulphate as K2O	6,37E-03
				Ammonium nitrate phosphate as P2O5	3,96E-04
				Diesel	3,48E-04
				Irrigation	0,03
	Dehusking	Seeds	0,03	Electricity	1,77E-04
		Husks	0,01		
	Screw press	Raw oil	9,69E-03	Electricity	2,00E-03
		Cake	0,02		
	Transportation	Raw oil transportation	9,85E-03	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	9,99E-03	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,02	KOH	4,55E-03
		Glycerin	1,53E-'3	Ethanol	4,65E-04
				Electricity	1,82E-03

TABLE Nº 69 Water depletion potential of the best Jatropha oil production scenario with allocation of co-products

Scenario	Process	Contribution m3		Background system	Contribution kg m3
Best Jatropha oil production scenario without allocation of the co-products	Jatropha cultivation	Capsules	0,04	Ammonium nitrate as N	1,32E-03
				Potassium sulphate as K2O	6,37E-03
				Ammonium nitrate phosphate as P2O5	3,96E-04
				Diesel	3,48E-04
				Irrigation	0,03
	Dehusking	Seeds	0,05	Electricity	1,77E-04
		Husks	--		
	Screw press	Raw oil	0,05	Electricity	2,00E-03
		Cake	--		
	Transportation	Raw oil transportation	0,05	Transport, transoceanic freight ship	1,66E-04
	Refining	Refined oil	0,05	Electricity	5,73E-05
				Alkali	7,54E-05
	Transesterification	Base oil	0,05	KOH	4,55E-03
		Glycerin	--	Ethanol	4,65E-04
				Electricity	1,82E-03

TABLE Nº 70 Water depletion potential of the best Jatropha oil production scenario without allocation of co-products

Global warming potential of the mineral oil production scenarios

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Base mineral oil production	Crude oil production NG at long distance transport	Crude oil	9,52	--	--
	Atmospheric distillation	Gas	0,20	Electricity	0,09
		Naphtha	2,13		
		Gas oil of Atmos. distillation	3,65	Gas	0,50
		Residue of Atmos. distillation	4,16	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,18	Electricity	0,04
		Residue of Vacuum distillation	1,76	Gas	0,20
		Waxy distillate	2,47	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,87	Electricity	0,02
		Deasphalted fraction	2,03	Gas	0,03
				Heavy fuel oil	0,38
	Aromatic extraction	Aromatic extracts	0,77	Electricity	5,96E-03
		Dearomatized fract.	1,42	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,35	Electricity	0,07
		Dewaxed fraction	1,41	Gas	0,09
				Heavy fuel oil	0,18
	Hydrofinishing	Base oil	1,48	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE Nº 71 Global warming potential of the base mineral oil production scenario

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Alternative mineral oil production scenario	Crude oil production GB, RU and RAF at long distance transport	Crude oil	4,87	--	--
	Atmospheric distillation	Gas	0,13	Electricity	0,09
		Naphtha	1,16		
		Gas oil of Atmos. distillation	1,97	Gas	0,50
		Residue of Atmos. distillation	2,24	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,11	Electricity	0,04
		Residue of Vacuum distillation	0,99	Gas	0,20
		Waxy distillate	1,39	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,55	Electricity	0,02
		Deasphalted fraction	1,27	Gas	0,03
				Heavy fuel oil	0,38
	Aromatic extraction	Aromatic extracts	0,50	Electricity	5,96E-03
		Dearomatized fract.	0,93	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,27	Electricity	0,07
		Dewaxed fraction	0,99	Gas	0,09
				Heavy fuel oil	0,18
	Hydrofinishing	Base oil	1,06	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE N° 72 Global warming potential of the alternative mineral oil production

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Alternative mineral oil production scenario without allocation of aromatic extracts	Crude oil production NG at long distance transport	Crude oil	9,52	--	--
	Atmospheric distillation	Gas	0,20	Electricity	0,09
		Naphtha	2,13		
		Gas oil of Atmos. distillation	3,65	Gas	0,50
		Residue of Atmos. distillation	4,16	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,18	Electricity	0,04
		Residue of Vacuum distillation	1,76	Gas	0,20
		Waxy distillate	2,47	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,87	Electricity	0,02
		Deasphalted fraction	2,03	Gas	0,03
				Heavy fuel oil	0,38
	Aromatic extraction	Aromatic extracts	--	Electricity	5,96E-03
		Dearomatized fract.	2,19	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,51	Electricity	0,07
		Dewaxed fraction	2,02	Gas	0,09
				Heavy fuel oil	0,18
	Hydrofinishing	Base oil	2,10	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE N° 73 Global warming potential of the alternative mineral oil production scenario without allocation of aromatic extracts

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Alternative mineral oil production scenario with CH oil mix	Crude oil production NG, RAF and RME at long distance transport	Crude oil	6,04	--	--
	Atmospheric distillation	Gas	0,15	Electricity	0,09
		Naphtha	1,40		
		Gas oil of Atmos. distillation	2,39	Gas	0,50
		Residue of Atmos. distillation	2,71	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,13	Electricity	0,04
		Residue of Vacuum distillation	1,18	Gas	0,20
		Waxy distillate	1,65	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,63	Electricity	0,02
		Deasphalted fraction	1,45	Gas	0,03
				Heavy fuel oil	0,38
	Aromatic extraction	Aromatic extracts	0,57	Electricity	5,96E-03
		Dearomatized fract.	1,05	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,30	Electricity	0,07
		Dewaxed fraction	1,09	Gas	0,09
				Heavy fuel oil	0,18
	Hydrofinishing	Base oil	1,16	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE Nº 74 Global warming potential of the alternative mineral oil production scenario with CH oil mix

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Alternative mineral oil production scenario with RER oil mix	Crude oil production GB, RLA, RU, RAF, RME, NG, NO and NL at long distance transport	Crude oil	3,13	--	--
	Atmospheric distillation	Gas	0,10	Electricity	0,09
		Naphtha	0,79		
		Gas oil of Atmos. distillation	1,34	Gas	0,50
		Residue of Atmos. distillation	1,52	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,08	Electricity	0,04
		Residue of Vacuum distillation	0,71	Gas	0,20
		Waxy distillate	0,98	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,43	Electricity	0,02
		Deasphalted fraction	0,99	Gas	0,03
				Heavy fuel oil	0,38
	Aromatic extraction	Aromatic extracts	0,40	Electricity	5,96E-03
		Dearomatized fract.	0,74	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,24	Electricity	0,07
		Dewaxed fraction	0,84	Gas	0,09
				Heavy fuel oil	0,18
	Hydrofinishing	Base oil	0,92	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE N° 75 Global warming potential of the alternative mineral oil production scenario with RER oil mix

Scenario	Process	Contribution kg CO2-Eq		Background system	Contribution kg CO2-Eq
Alternative mineral oil production scenario without infrastructure on the background system	Crude oil production NG at long distance transport	Crude oil	9,23	--	--
	Atmospheric distillation	Gas	0,20	Electricity	0,09
		Naphtha	2,06		
		Gas oil of Atmos. distillation	3,54	Gas	0,49
		Residue of Atmos. distillation	4,03	Heavy fuel oil	0,03
	Vacuum distillation	Gas oil of Vacuum distillation	0,17	Electricity	0,04
		Residue of Vacuum distillation	1,71	Gas	0,20
		Waxy distillate	2,40	Heavy fuel oil	0,01
	Deasphalting	Asphalt fraction	0,74	Electricity	0,02
		Deasphalted fraction	1,38	Gas	0,03
				Heavy fuel oil	0,37
	Aromatic extraction	Aromatic extracts	0,77	Electricity	5,88E-03
		Dearomatized fract.	1,42	Gas	0,12
				Heavy fuel oil	0,03
	Dewaxing	Wax	0,34	Electricity	0,07
		Dewaxed fraction	1,37	Gas	0,09
				Heavy fuel oil	0,17
	Hydrofinishing	Base oil	1,45	Electricity	0,02
				Gas	0,03
				Heavy fuel oil	0,03

TABLE Nº 76 Global warming potential of the alternative mineral oil production scenario without infrastructure on the background system

Fossil depletion potential of the mineral oil production scenarios

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Base mineral oil production	Crude oil production NG, transportation at long distance	Crude oil	15,36	--	--
	Atmospheric distillation	Gas	0,31	Electricity	0,03
		Naphtha	3,27		
		Gas oil of Atmos. distillation	5,61	Gas	0,19
		Residue of Atmos. distillation	6,39	Heavy fuel oil	9,48E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,26	Electricity	0,01
		Residue of Vacuum distillation	2,59	Gas	0,08
		Waxy distillate	3,63	Heavy fuel oil	3,88E-03
	Deasphalting	Asphalt fraction	1,13	Electricity	7,95E-03
		Deasphalted fraction	2,65	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	0,95	Electricity	1,73E-03
		Dearomatized fract.	1,76	Gas	0,05
				Heavy fuel oil	0,01
	Dewaxing	Wax	0,38	Electricity	0,02
		Dewaxed fraction	1,50	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	1,53	Electricity	5,00E-03
				Gas	9,94E-03
				Heavy fuel oil	0,01

TABLE Nº 77 Fossil depletion potential of the base mineral oil production scenario

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Alternative mineral oil production	Crude oil production GB, RAF and RU, transportation at long distance	Crude oil	14,80	--	--
	Atmospheric distillation	Gas	0,31	Electricity	0,03
		Naphtha	3,16		
		Gas oil of Atmos. distillation	5,41	Gas	0,19
		Residue of Atmos. distillation	6,16	Heavy fuel oil	9,48E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,25	Electricity	0,01
		Residue of Vacuum distillation	2,50	Gas	0,08
		Waxy destillate	3,50	Heavy fuel oil	3,88E-03
	Deasphalting	Asphalt fraction	1,10	Electricity	7,05E-03
		Deasphalted fraction	2,55	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	0,91	Electricity	1,73E-03
		Dearomatized fract.	1,70	Gas	0,04
				Heavy fuel oil	0,05
	Dewaxing	Wax	0,37	Electricity	0,02
		Dewaxed fraction	1,45	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	1,47	Electricity	5,00E-03
				Gas	9,94E-03
				Heavy fuel oil	0,01

TABLE N° 78 Fossil depletion potential of the alternative mineral oil production scenario

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Alternative mineral oil production scenario without allocation of aromatic extracts	Crude oil production NG, transportation at long distance	Crude oil	15,36	--	--
	Atmospheric distillation	Gas	0,31	Electricity	0,03
		Naphtha	3,27		
		Gas oil of Atmos. distillation	5,61	Gas	0,19
		Residue of Atmos. distillation	6,39	Heavy fuel oil	9,48E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,26	Electricity	0,01
		Residue of Vacuum distillation	2,59	Gas	0,08
		Waxy distillate	3,63	Heavy fuel oil	3,88E-03
	Deasphalting	Asphalt fraction	1,13	Electricity	7,05E-03
		Deasphalted fraction	2,65	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	--	Electricity	1,73E-03
		Dearomatized fract.	2,71	Gas	0,05
				Heavy fuel oil	0,01
	Dewaxing	Wax	0,56	Electricity	0,02
		Dewaxed fraction	2,26	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	2,29	Electricity	5,00E-03
				Gas	9,94E-03
				Heavy fuel oil	0,01

TABLE N° 79 Fossil depletion potential of the alternative mineral oil production scenario without allocation of aromatic extracts

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Alternative mineral oil production scenario with CH oil mix	Crude oil production RAF, NG and RME, transportation at long distance	Crude oil	14,66	--	--
	Atmospheric distillation	Gas	0,30	Electricity	0,03
		Naphtha	3,13		
		Gas oil of Atmos. distillation	5,36	Gas	0,19
		Residue of Atmos. distillation	6,10	Heavy fuel oil	9,48E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,25	Electricity	0,01
		Residue of Vacuum distillation	2,48	Gas	0,08
		Waxy distillate	3,47	Heavy fuel oil	3,88E-03
	Deasphalting	Asphalt fraction	1,09	Electricity	7,05E-03
		Deasphalted fraction	2,53	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	0,91	Electricity	1,73E-03
		Dearomatized fract.	1,68	Gas	0,05
				Heavy fuel oil	0,01
	Dewaxing	Wax	0,37	Electricity	0,02
		Dewaxed fraction	1,43	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	1,46	Electricity	5,00E-03
				Gas	9,94E-03
				Heavy fuel oil	0,01

TABLE N° 80 Fossil depletion potential of the alternative mineral oil production scenario with CH oil mix

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Alternative mineral oil production scenario with RER oil mix	Crude oil production RAF, NG RME, RU, RLA, NL, NO, GB, transportation at long distance	Crude oil	14,13	--	--
	Atmospheric distillation	Gas	0,29	Electricity	0,03
		Naphtha	3,02		
		Gas oil of Atmos. distillation	5,17	Gas	0,19
		Residue of Atmos. distillation	5,88	Heavy fuel oil	9,48E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,24	Electricity	0,01
		Residue of Vacuum distillation	2,39	Gas	0,08
		Waxy distillate	3,34	Heavy fuel oil	3,88E-03
	Deasphalting	Asphalt fraction	1,05	Electricity	7,05E-03
		Deasphalted fraction	2,45	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	0,88	Electricity	1,73E-03
		Dearomatized fract.	1,63	Gas	0,05
				Heavy fuel oil	0,01
	Dewaxing	Wax	0,36	Electricity	0,02
		Dewaxed fraction	1,39	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	1,42	Electricity	5,00E-03
				Gas	9,94E-03
				Heavy fuel oil	0,01

TABLE N° 81 Fossil depletion potential of the alternative mineral oil production scenario with RER oil mix

Scenario	Process	Contribution kg Oil-Eq		Background system	Contribution kg Oil-Eq
Alternative mineral oil production scenario without infrastructure on the background system	Crude oil production NG, transportation at long distance	Crude oil	15,27	--	--
	Atmospheric distillation	Gas	0,31	Electricity	0,03
		Naphtha	3,25		
		Gas oil of Atmos. distillation	5,58	Gas	0,19
		Residue of Atmos. distillation	6,35	Heavy fuel oil	9,29E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,26	Electricity	0,01
		Residue of Vacuum distillation	2,58	Gas	0,08
		Waxy distillate	3,61	Heavy fuel oil	3,81E-03
	Deasphalting	Asphalt fraction	1,13	Electricity	6,95E-03
		Deasphalted fraction	2,63	Gas	0,01
				Heavy fuel oil	0,13
	Aromatic extraction	Aromatic extracts	0,94	Electricity	1,70E-03
		Dearomatized fract.	1,75	Gas	0,04
				Heavy fuel oil	0,01
	Dewaxing	Wax	0,37	Electricity	0,02
		Dewaxed fraction	1,49	Gas	0,03
				Heavy fuel oil	0,06
	Hydrofinishing	Base oil	1,52	Electricity	4,93E-03
				Gas	9,75E-03
				Heavy fuel oil	0,01

TABLE N° 82 Fossil depletion potential of the alternative mineral oil base production scenario without infrastructure on the background system

Human toxicity potential of the mineral oil production scenarios

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Base mineral oil production scenario	Crude oil production NG, transportation at long distance	Crude oil	0,27	--	--
	Atmospheric distillation	Gas	5,86E-03	Electricity	3,78E-03
		Naphtha	0,06		
		Gas oil of Atmos. distillation	0,11	Gas	0,01
		Residue of Atmos. distillation	0,12	Heavy fuel oil	2,76E-03
	Vacuum distillation	Gas oil of Vacuum distillation	5,11E-03	Electricity	1,55E-03
		Residue of Vacuum distillation	0,05	Gas	4,98E-03
		Waxy distillate	0,07	Heavy fuel oil	1,13E-03
	Deasphalting	Asphalt fraction	0,03	Electricity	9,96E-04
		Deasphalted fraction	0,08	Gas	7,23E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	0,03	Electricity	2,44E-04
		Dearomatized fract.	0,06	Gas	2,90E-03
				Heavy fuel oil	3,29E-03
	Dewaxing	Wax	0,02	Electricity	2,99E-03
		Dewaxed fraction	0,06	Gas	2,14E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,07	Electricity	7,07E-04
				Gas	6,34E-04
				Heavy fuel oil	3,30E-03

TABLE Nº 83 Human toxicity potential of the base mineral oil production scenario

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative mineral oil production scenario	Crude oil production GB, RAF and RU, at long distance transport	Crude oil	0,72	--	--
	Atmospheric distillation	Gas	0,02	Electricity	3,78E-03
		Naphtha	0,15		
		Gas oil of Atmos. distillation	0,26	Gas	0,01
		Residue of Atmos. distillation	0,30	Heavy fuel oil	2,76E-03
	Vacuum distillation	Gas oil of Vacuum distillation	0,01	Electricity	1,55E-03
		Residue of Vacuum distillation	0,12	Gas	4,98E-03
		Waxy distillate	0,17	Heavy fuel oil	1,13E-03
	Deasphalting	Asphalt fraction	0,06	Electricity	9,96E-04
		Deasphalted fraction	0,15	Gas	7,23E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	0,05	Electricity	2,44E-04
		Dearomatized fract.	0,10	Gas	2,90E-03
				Heavy fuel oil	3,29E-03
	Dewaxing	Wax	0,03	Electricity	2,99E-03
		Dewaxed fraction	0,10	Gas	2,14E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,10	Electricity	7,04E-04
				Gas	6,34E-03
				Heavy fuel oil	3,30E-03

TABLE Nº 84 Human toxicity potential of the alternative mineral oil production scenario

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative mineral oil production scenario with out allocation of aromatic extracts	Crude oil production NG, transportation at long distance	Crude oil	0,27	--	--
	Atmospheric distillation	Gas	5,86E-03	Electricity	3,78E-03
		Naphtha	0,06		
		Gas oil of Atmos. distillation	0,11	Gas	0,01
		Residue of Atmos. distillation	0,12	Heavy fuel oil	2,76E-03
	Vacuum distillation	Gas oil of Vacuum distillation	5,11E-03	Electricity	1,55E-03
		Residue of Vacuum distillation	0,05	Gas	4,98E-03
		Waxy distillate	0,07	Heavy fuel oil	1,13E-03
	Deasphalting	Asphalt fraction	0,03	Electricity	9,96E-04
		Deasphalted fraction	0,08	Gas	7,23E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	--	Electricity	2,44E-04
		Dearomatized fract.	0,08	Gas	2,90E-03
				Heavy fuel oil	3,29E-03
	Dewaxing	Wax	0,02	Electricity	2,99E-03
		Dewaxed fraction	0,09	Gas	2,14E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,09	Electricity	7,07E-04
				Gas	6,34E-04
				Heavy fuel oil	3,30E-03

TABLE N° 85 Human toxicity potential of the alternative mineral oil production scenario without allocation of aromatic extracts

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative mineral oil production scenario with CH oil mix	Crude oil production RAF, NG and RME, transportation at long distance	Crude oil	0,31	--	--
	Atmospheric distillation	Gas	7,51E-03	Electricity	3,78E-03
		Naphtha	0,07		
		Gas oil of Atmos. distillation	0,12	Gas	0,01
		Residue of Atmos. distillation	0,14	Heavy fuel oil	2,76E-03
	Vacuum distillation	Gas oil of Vacuum distillation	6,19E-03	Electricity	1,55E-03
		Residue of Vacuum distillation	0,06	Gas	4,98E-03
		Waxy distillate	0,08	Heavy fuel oil	1,13E-03
	Deasphalting	Asphalt fraction	0,04	Electricity	9,96E-04
		Deasphalted fraction	0,08	Gas	7,23E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	0,03	Electricity	2,44E-04
		Dearomatized fract.	0,06	Gas	2,90E-03
				Heavy fuel oil	3,29E-03
	Dewaxing	Wax	0,02	Electricity	2,99E-03
		Dewaxed fraction	0,06	Gas	2,14E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,07	Electricity	7,07E-04
				Gas	6,34E-04
				Heavy fuel oil	3,30E-03

TABLE N° 86 Human toxicity potential of the alternative mineral oil production scenario with CH oil mix

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative mineral oil production scenario with RER oil mix	Crude oil production RAF, NG RME, RU, RLA, NL, NO, GB, transportation at long distance	Crude oil	0,37	--	--
	Atmospheric distillation	Gas	8,68E-03	Electricity	3,78E-03
		Naphtha	0,08		
		Gas oil of Atmos. distillation	0,14	Gas	0,01
		Residue of Atmos. distillation	0,16	Heavy fuel oil	2,76E-03
	Vacuum distillation	Gas oil of Vacuum distillation	7,14E-03	Electricity	1,55E-03
		Residue of Vacuum distillation	0,07	Gas	4,98E-03
		Waxy distillate	0,09	Heavy fuel oil	1,13E-03
	Deasphalting	Asphalt fraction	0,04	Electricity	9,96E-04
		Deasphalted fraction	0,09	Gas	7,23E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	0,03	Electricity	2,44E-04
		Dearomatized fract.	0,06	Gas	2,90E-03
				Heavy fuel oil	3,29E-03
	Dewaxing	Wax	0,02	Electricity	2,99E-03
		Dewaxed fraction	0,07	Gas	2,14E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,07	Electricity	7,07E-04
				Gas	6,34E-04
				Heavy fuel oil	3,30E-03

TABLE N° 87 Human toxicity potential of the alternative mineral oil production scenario with RER oil mix

Scenario	Process	Contribution kg 1,4-DCB-Eq		Background system	Contribution kg 1,4-DCB-Eq
Alternative mineral oil production scenario without infrastructure on the background system	Crude oil production NG, transportation at long distance	Crude oil	0,23	--	--
	Atmospheric distillation	Gas	4,97E-03	Electricity	3,24E-03
		Naphtha	0,05		
		Gas oil of Atmos. distillation	0,09	Gas	0,01
		Residue of Atmos. distillation	0,10	Heavy fuel oil	2,68E-03
	Vacuum distillation	Gas oil of Vacuum distillation	4,35E-03	Electricity	1,33E-03
		Residue of Vacuum distillation	0,04	Gas	4,29E-03
		Waxy distillate	0,06	Heavy fuel oil	1,10E-03
	Deasphalting	Asphalt fraction	0,03	Electricity	8,54E-04
		Deasphalted fraction	0,08	Gas	6,22E-04
				Heavy fuel oil	0,04
	Aromatic extraction	Aromatic extracts	0,03	Electricity	2,09E-04
		Dearomatized fract.	0,05	Gas	2,50E-03
				Heavy fuel oil	3,19E-03
	Dewaxing	Wax	0,01	Electricity	2,56E-03
		Dewaxed fraction	0,06	Gas	1,84E-03
				Heavy fuel oil	0,02
	Hydrofinishing	Base oil	0,06	Electricity	6,06E-04
				Gas	5,46E-04
				Heavy fuel oil	3,20E-03

TABLE Nº 88 Human toxicity potential of the alternative mineral oil production scenario without infrastructure on the background system

Freshwater depletion potential of the mineral oil production scenarios

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Base mineral oil production scenario	Crude oil production NG, transportation at long distance	Crude oil	2,89E-05	--	--
	Atmospheric distillation	Gas	8,15E-07	Electricity	9,98E-06
		Naphtha	8,55E-06		
		Gas oil of Atmos. distillation	1,67E-05	Gas	1,79E-06
		Residue of Atmos. distillation	0,03	Heavy fuel oil	8,62E-08
	Vacuum distillation	Gas oil of Vacuum distillation	8,62E-07	Electricity	4,09E-06
		Residue of Vacuum distillation	8,62E-06	Gas	3,54E-08
		Waxy distillate	1,21E-05	Heavy fuel oil	6,56E-05
	Deasphalting	Asphalt fraction	1,12E-05	Electricity	2,63E-06
		Deasphalted fraction	4,81E-06	Gas	1,06E-07
				Heavy fuel oil	1,21E-06
	Aromatic extraction	Aromatic extracts	4,34E-06	Electricity	6,44E-07
		Dearomatized fract.	8,05E-06	Gas	4,28E-07
				Heavy fuel oil	1,03E-07
	Dewaxing	Wax	3,37E-06	Electricity	7,90E-06
		Dewaxed fraction	1,35E-05	Gas	3,15E-07
				Heavy fuel oil	5,67E-07
	Hydrofinishing	Base oil	1,55E-05	Electricity	1,87E-06
				Gas	9,33E-08
				Heavy fuel oil	1,03E-07

TABLE Nº 89 Freshwater depletion potential of the base mineral oil production scenario

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative mineral oil production scenario	Crude oil production RAF, RU and GB, transportation at long distance	Crude oil	2,20E-04	--	--
	Atmospheric distillation	Gas	6,94E-06	Electricity	9,98E-06
		Naphtha	4,92E-05		
		Gas oil of Atmos. distillation	8,25E-05	Gas	1,79E-06
		Residue of Atmos. distillation	9,36E-05	Heavy fuel oil	8,62E-08
	Vacuum distillation	Gas oil of Vacuum distillation	5,14E-06	Electricity	4,09E-06
		Residue of Vacuum distillation	3,91E-05	Gas	3,54E-08
		Waxy distillate	5,42E-05	Heavy fuel oil	6,56E-05
	Deasphalting	Asphalt fraction	1,80E-05	Electricity	2,63E-06
		Deasphalted fraction	4,02E-05	Gas	1,06E-07
				Heavy fuel oil	21,21E-06
	Aromatic extraction	Aromatic extracts	1,46E-05	Electricity	6,44E-07
		Dearomatized fract.	2,68E-05	Gas	4,28E-07
				Heavy fuel oil	1,03E-07
	Dewaxing	Wax	9,48E-06	Electricity	7,90E-06
		Dewaxed fraction	2,61E-05	Gas	3,15E-07
				Heavy fuel oil	5,67E-07
	Hydrofinishing	Base oil	2,81E-05	Electricity	1,87E-06
				Gas	9,33E-08
				Heavy fuel oil	1,03E-07

TABLE N° 90 Freshwater depletion potential of the alternative mineral oil production scenario

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative mineral oil production scenario without allocation of aromatic extracts	Crude oil production NG, transportation at long distance	Crude oil	2,89E-05	--	--
	Atmospheric distillation	Gas	8,15E-07	Electricity	9,98E-06
		Naphtha	8,55E-06		
		Gas oil of Atmos. distillation	1,47E-05	Gas	1,79E-06
		Residue of Atmos. distillation	1,67E-05	Heavy fuel oil	8,63E-08
	Vacuum distillation	Gas oil of Vacuum distillation	8,62E-07	Electricity	4,09E-06
		Residue of Vacuum distillation	8,62E-06	Gas	7,34E-07
		Waxy distillate	1,21E-05	Heavy fuel oil	3,54E-08
	Deasphalting	Asphalt fraction	4,81E-05	Electricity	2,63E-06
		Deasphalted fraction	1,12E-05	Gas	1,06E-07
				Heavy fuel oil	1,21E-06
	Aromatic extraction	Aromatic extracts	--	Electricity	6,44E-07
		Dearomatized fract.	1,24E-05	Gas	4,28E-07
				Heavy fuel oil	1,03E-07
	Dewaxing	Wax	4,23E-06	Electricity	7,90E-06
		Dewaxed fraction	1,69E-05	Gas	3,15E-07
				Heavy fuel oil	5,67E-07
	Hydrofinishing	Base oil	1,90E-05	Electricity	1,87E-06
				Gas	9,33E-08
				Heavy fuel oil	1,03E-07

TABLE N° 91 Freshwater depletion potential of the alternative mineral oil production scenario without allocation of aromatic extracts

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative mineral oil production scenario with CH oil mix	Crude oil production RAF, NG and RME, transportation at long distance	Crude oil	7,05E-05	--	--
	Atmospheric distillation	Gas	3,94E-06	Electricity	9,98E-06
		Naphtha	1,77E-05		
		Gas oil of Atmos. distillation	2,86E-05	Gas	1,79E-06
		Residue of Atmos. distillation	3,22E-05	Heavy fuel oil	8,62E-08
	Vacuum distillation	Gas oil of Vacuum distillation	2,68E-06	Electricity	4,09-E06
		Residue of Vacuum distillation	1,45E-05	Gas	7,34E-07
		Waxy distillate	1,98E-05	Heavy fuel oil	3,54E-08
	Deasphalting	Asphalt fraction	0,02	Electricity	2,63E-06
		Deasphalted fraction	1,61E-05	Gas	1,06E-07
				Heavy fuel oil	1,21E-06
	Aromatic extraction	Aromatic extracts	6,14E-06	Electricity	6,44E-07
		Dearomatized fract.	1,11E-05	Gas	4,28E-07
				Heavy fuel oil	1,03E-07
	Dewaxing	Wax	6,35E-06	Electricity	7,90E-06
		Dewaxed fraction	1,36E-05	Gas	3,15E-07
				Heavy fuel oil	5,67E-07
	Hydrofinishing	Base oil	1,56E-05	Electricity	1,87E-06
				Gas	9,33E-08
				Heavy fuel oil	1,03E-07

TABLE N° 92 Freshwater depletion potential of the alternative mineral oil production scenario with CH oil mix

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative mineral oil production scenario with RER oil mix	Crude oil production RAF, NG RME, RU, RLA, NL, NO, GB, transportation at long distance	Crude oil	1,00E-04	--	--
	Atmospheric distillation	Gas	4,54E-06	Electricity	9,98E-06
		Naphtha	2,39E-05		
		Gas oil of Atmos. distillation	3,93E-05	Gas	1,79E-06
		Residue of Atmos. distillation	3,92E-05	Heavy fuel oil	8,62E-08
	Vacuum distillation	Gas oil of Vacuum distillation	3,17E-06	Electricity	4,09E-06
		Residue of Vacuum distillation	1,94E-05	Gas	7,34E-07
		Waxy distillate	2,66E-05	Heavy fuel oil	3,54E-08
	Deasphalting	Asphalt fraction	9,69E-06	Electricity	2,63E-06
		Deasphalted fraction	2,09E-05	Gas	1,06E-07
				Heavy fuel oil	1,21E-06
	Aromatic extraction	Aromatic extracts	7,71E-06	Electricity	6,44E-07
		Dearomatized fract.	1,43E-05	Gas	4,28E-07
				Heavy fuel oil	1,03E-07
	Dewaxing	Wax	6,99E-06	Electricity	7,90E-06
		Dewaxed fraction	1,61E-05	Gas	3,15E-07
				Heavy fuel oil	5,67E-07
	Hydrofinishing	Base oil	1,82E-05	Electricity	1,87E-06
				Gas	9,33E-08
				Heavy fuel oil	1,03E-07

TABLE N° 93 Freshwater depletion potential of the alternative mineral oil production scenario with RER oil mix

Scenario	Process	Contribution kg U235-Eq		Background system	Contribution kg U235-Eq
Alternative mineral oil production scenario without infrastructure on the background system	Crude oil production NG, transportation at long distance	Crude oil	2,13E-06	--	--
	Atmospheric distillation	Gas	2,51E-07	Electricity	9,62E-06
		Naphtha	2,63E-06		
		Gas oil of Atmos. distillation	4,52E-06	Gas	7,60E-07
		Residue of Atmos. distillation	5,14E-06	Heavy fuel oil	3,56E-08
	Vacuum distillation	Gas oil of Vacuum distillation	3,77E-07	Electricity	3,94E-06
		Residue of Vacuum distillation	3,77E-06	Gas	3,12E-07
		Waxy distillate	5,27E-06	Heavy fuel oil	1,46E-08
	Deasphalting	Asphalt fraction	2,51E-06	Electricity	2,53E-06
		Deasphalted fraction	5,85E-06	Gas	4,52E-08
				Heavy fuel oil	4,99E-07
	Aromatic extraction	Aromatic extracts	2,34E-06	Electricity	6,21E-07
		Dearomatized fract.	4,36E-06	Gas	1,82E-07
				Heavy fuel oil	4,24E-08
	Dewaxing	Wax	2,47E-06	Electricity	7,61E-06
		Dewaxed fraction	9,86E-06	Gas	1,35E-07
				Heavy fuel oil	2,34E-07
	Hydrofinishing	Base oil	1,17E-05	Electricity	1,80E-06
				Gas	3,96E-08
				Heavy fuel oil	4,26E-08

TABLE N° 94 Freshwater depletion potential of the alternative mineral oil production scenario without infrastructure on the background system

Water depletion potential of the mineral oil production scenarios

Scenario	Process	Contribution m3		Background system	Contribution m3
Base mineral oil production scenario	Crude oil production NG, transportation at long distance	Crude oil	4,86E-03	--	--
	Atmospheric distillation	Gas	1,26E-04	Electricity	7,49E-04
		Naphtha	1,32E-03		
		Gas oil of Atmos. distillation	2,26E-03	Gas	6,39E-03
		Residue of Atmos. distillation	2,57E-03	Heavy fuel oil	3,16E-05
	Vacuum distillation	Gas oil of Vacuum distillation	1,26E-04	Electricity	3,07E-04
		Residue of Vacuum distillation	1,26E-03	Gas	2,62E-04
		Waxy distillate	1,77E-03	Heavy fuel oil	1,30E-05
	Deasphalting	Asphalt fraction	7,34E-04	Electricity	1,97E-04
		Deasphalted fraction	1,71E-03	Gas	3,80E-05
				Heavy fuel oil	4,43E-04
	Aromatic extraction	Aromatic extracts	6,83E-04	Electricity	4,83E-05
		Dearomatized fract.	1,27E-03	Gas	1,53E-04
				Heavy fuel oil	3,77E-05
	Dewaxing	Wax	4,36E-04	Electricity	5,92E-04
		Dewaxed fraction	1,74E-03	Gas	1,13E-04
				Heavy fuel oil	2,08E-04
	Hydrofinishing	Base oil	1,96E-03	Electricity	1,40E-04
				Gas	3,33E-05
				Heavy fuel oil	3,79E-05

TABLE N° 95 Water depletion potential of the base mineral oil production scenario

Scenario	Process	Contribution m3		Background system	Contribution m3
Alternative mineral oil production scenario	Crude oil production GB, RAF and RU, at long distance transport	Crude oil	0,05	--	--
	Atmospheric distillation	Gas	1,30E-03	Electricity	7,49E-04
		Naphtha	0,01		
		Gas oil of Atmos. distillation	0,02	Gas	6,39E-04
		Residue of Atmos. distillation	0,02	Heavy fuel oil	3,16E-05
	Vacuum distillation	Gas oil of Vacuum distillation	1,03E-03	Electricity	3,07E-04
		Residue of Vacuum distillation	9,39E-03	Gas	2,62E-04
		Waxy distillate	0,01	Heavy fuel oil	1,30E-05
	Deasphalting	Asphalt fraction	4,18E-03	Electricity	1,97E-04
		Deasphalted fraction	9,61E-03	Gas	3,80E-05
				Heavy fuel oil	4,43E-04
	Aromatic extraction	Aromatic extracts	3,45E-03	Electricity	4,83E-05
		Dearomatized fract.	6,40E-03	Gas	1,53E-04
				Heavy fuel oil	3,77E-05
	Dewaxing	Wax	1,64E-03	Electricity	5,92E-04
		Dewaxed fraction	5,67E-03	Gas	1,13E-04
				Heavy fuel oil	2,08E-04
	Hydrofinishing	Base oil	5,88E-03	Electricity	1,40E-04
				Gas	3,33E-05
				Heavy fuel oil	3,79E-05

TABLE N^{o} 96 Water depletion potential of the alternative mineral oil production

Scenario	Process	Contribution m3		Background system	Contribution m3
Alternative mineral oil production scenario without allocation of aromatic extracts	Crude oil production NG, transportation at long distance	Crude oil	4,86E-03	--	--
	Atmospheric distillation	Gas	1,26E-04	Electricity	7,49E-04
		Naphtha	1,32E-03		
		Gas oil of Atmos. distillation	2,26E-03	Gas	6,39E-03
		Residue of Atmos. distillation	2,57E-03	Heavy fuel oil	3,16E-05
	Vacuum distillation	Gas oil of Vacuum distillation	1,26E-04	Electricity	3,07E-04
		Residue of Vacuum distillation	1,26E-03	Gas	2,62E-04
		Waxy distillate	1,77E-03	Heavy fuel oil	1,30E-05
	Deasphalting	Asphalt fraction	7,34E-04	Electricity	1,97E-04
		Deasphalted fraction	1,71E-03	Gas	3,80E-05
				Heavy fuel oil	4,43E-04
	Aromatic extraction	Aromatic extracts	--	Electricity	4,83E-05
		Dearomatized fract.	1,95E-03	Gas	1,53E-04
				Heavy fuel oil	3,77E-05
	Dewaxing	Wax	5,73E-04	Electricity	5,92E-04
		Dewaxed fraction	2,29E-03	Gas	1,13E-04
				Heavy fuel oil	2,08E-04
	Hydrofinishing	Base oil	2,50E-03	Electricity	1,40E-04
				Gas	3,33E-05
				Heavy fuel oil	3,79E-05

TABLE N° 97 Water depletion potential of the alternative mineral oil production scenario without allocation of aromatic extracts

Scenario	Process	Contribution m3		Background system	Contribution m3
Alternative mineral oil production scenario with CH oil mix	Crude oil production RAF, NG and RME, transportation at long distance	Crude oil	0,04	--	--
	Atmospheric distillation	Gas	9,73E-04	Electricity	7,49E-04
		Naphtha	8,44E-03		
		Gas oil of Atmos. distillation	0,01	Gas	6,39E-04
		Residue of Atmos. distillation	0,02	Heavy fuel oil	3,16E-05
	Vacuum distillation	Gas oil of Vacuum distillation	7,65E-04	Electricity	3,07E-04
		Residue of Vacuum distillation	6,73E-03	Gas	2,62E-04
		Waxy distillate	9,01E-03	Heavy fuel oil	1,30E-05
	Deasphalting	Asphalt fraction	2,94E-04	Electricity	1,97E-04
		Deasphalted fraction	6,74E-03	Gas	3,80E-05
				Heavy fuel oil	4,43E-04
	Aromatic extraction	Aromatic extracts	2,44E-03	Electricity	4,83E-05
		Dearomatized fract.	4,54E-03	Gas	1,53E-04
				Heavy fuel oil	3,77E-05
	Dewaxing	Wax	1,27E-03	Electricity	5,92E-04
		Dewaxed fraction	4,18E-03	Gas	1,13E-04
				Heavy fuel oil	2,08E-04
	Hydrofinishing	Base oil	4,39E-03	Electricity	1,40E-04
				Gas	3,33E-05
				Heavy fuel oil	3,79E-05

TABLE N° 98 Water depletion potential of the alternative mineral oil production scenario with CH oil mix

Scenario	Process	Contribution m3		Background system	Contribution m3
Alternative mineral oil production scenario with RER oil mix	Crude oil production RAF, NG RME, RU, RLA, NL, NO, GB, transportation at long distance	Crude oil	0,04	--	--
	Atmospheric distillation	Gas	9,40E-03	Electricity	7,49E-04
		Naphtha	8,09E-03		
		Gas oil of Atmos. distillation	0,01	Gas	6,39E-04
		Residue of Atmos. distillation	0,02	Heavy fuel oil	3,16E-05
	Vacuum distillation	Gas oil of Vacuum distillation	7,38E-04	Electricity	3,07E-04
		Residue of Vacuum distillation	6,46E-03	Gas	2,62E-04
		Waxy distillate	9,38E-03	Heavy fuel oil	1,30E-05
	Deasphalting	Asphalt fraction	3,06E-03	Electricity	1,97E-04
		Deasphalted fraction	7,00E-03	Gas	3,80E-05
				Heavy fuel oil	4,43E-04
	Aromatic extraction	Aromatic extracts	2,54E-03	Electricity	4,83E-05
		Dearomatized fract.	4,70E-03	Gas	1,53E-04
				Heavy fuel oil	3,77E-05
	Dewaxing	Wax	1,30E-03	Electricity	5,92E-04
		Dewaxed fraction	4,31E-03	Gas	1,13E-04
				Heavy fuel oil	2,08E-04
	Hydrofinishing	Base oil	4,52E-03	Electricity	1,40E-04
				Gas	3,33E-05
				Heavy fuel oil	3,79E-05

TABLE N° 99 Water depletion potential of the alternative mineral oil production scenario with RER oil mix

Scenario	Process	Contribution m3		Background system	Contribution m3
Alternative mineral oil production scenario without infrastructure on the background system	Crude oil production NG, transportation at long distance	Crude oil	5,33E-04	--	--
	Atmospheric distillation	Gas	3,50E-05	Electricity	7,34E-03
		Naphtha	3,68E-04		
		Gas oil of Atmos. distillation	6,30E-04	Gas	4,61E-04
		Residue of Atmos. distillation	7,18E-04	Heavy fuel oil	2,28E-05
	Vacuum distillation	Gas oil of Vacuum distillation	4,87E-05	Electricity	3,01E-04
		Residue of Vacuum distillation	4,87E-04	Gas	1,89E-04
		Waxy distillate	6,82E-04	Heavy fuel oil	6,82E-04
	Deasphalting	Asphalt fraction	3,67E-04	Electricity	1,93E-04
		Deasphalted fraction	8,55E-04	Gas	2,74E-05
				Heavy fuel oil	3,19E-04
	Aromatic extraction	Aromatic extracts	6,76E-04	Electricity	4,74E-05
		Dearomatized fract.	6,76E-04	Gas	1,10E-04
				Heavy fuel oil	2,71E-05
	Dewaxing	Wax	2,98E-04	Electricity	5,81E-04
		Dewaxed fraction	1,19E-03	Gas	8,11E-05
				Heavy fuel oil	1,50E-04
	Hydrofinishing	Base oil	1,38E-03	Electricity	1,37E-04
				Gas	2,40E-05
				Heavy fuel oil	2,73E-05

TABLE N° 100 Water depletion potential of the alternative mineral oil production scenario without infrastructure on the background system