

## LCA of Olive Oil using SimaPro 6

### Introduction to SimaPro 6

The software SimaPro 6 (System for Integrated environmental Assessment of PROducts), developed by the Dutch PRé Consultants (PRé, 2005), will be used as the LCA modelling and analysis tool. SimaPro is a well-known, internationally accepted and validated tool and since its development in 1990 has been used in a large number of LCA studies by consultants, research institutes, and universities (Masoni, 1997, Saouter and Van Hoof, 2001, Narayanaswamy *et al.*, 2004, Frazao, and Fernandes, 2004,). The software allows to model and analyse complex life cycles in a systematic and transparent way, following the recommendations of the ISO 14040 (1997) series of standards.

SimaPro 6.0 is available in the "Compact", "Analyst" and "Developer" professional versions and in the "Classroom", "Faculty" and "PhD" educational versions. For this study the "PhD" version will be used which includes Monte Carlo uncertainty analysis.

Included in the software are several inventory databases (libraries) with a range of data on most commonly used materials and processes, such as electricity production, transport and materials such as plastics or metals, which can be used for background data in the study. One of the databases included is the ecoinvent database, developed by the Swiss Centre for Life Cycle Inventories (2005) and includes over 2500 up-to-date processes, covering a broad range of materials and processes with uncertainty data. According to an evaluation of several LCA tools report (Menke *et al.*, 1996) the SimaPro database is one of the more comprehensive ones as all of the embedded data are fully referenced as to their source. Furthermore SimaPro 6 includes several standard impact assessment methods and allows the practitioner to add or edit these methods.

According to a recent LCA software survey (Jönbrink *et al.*, 2000), SimaPro is suitable for cradle to gate and other partial LCA studies and it is suitable for use by LCA experts and environmental engineers as well as by design engineers.

### Olive Oil Life Cycle Modeling in SimaPro

#### Building the Basic Model

As previously discussed, a product system is a collection of unit processes, which are linked to one another by flows of intermediate products and/or waste for treatment (ISO 14041). SimaPro distinguishes five process types (materials, energy, transport, processing, use, waste scenario and waste treatment) each of which can be either a unit process, i.e. describing a single operation or a process system describing a set of unit processes as if it is one process. Nevertheless, all process types have exactly the same purpose, to quantify the flows of resources,

products and emissions in and out of the system and the main purpose of process classification is to facilitate model building. As a result the way flow and other data are imported into any process is rather similar. With the exception of the waste treatment and waste scenario processes, where the input name is used to identify the record, all other processes are referenced by the products that flow out of the process.

Product stages describe the way a product is produced, used and disposed of and they have links to processes, which contain the flow data. SimaPro by default has five product stages: [1] an assembly, which defines the production stage of the product studied [2] a disposal scenario, which describes the end of life scenario for the product if disassembled or reused, [3] a disassembly scenario, which describes what parts of a product are being disassembled and where the disassembled parts and the remaining parts are going, [4] a reuse stage, which describes the processes needed to reuse a product or a disassembled part and [5] the life cycle stage, which describes the total life cycle and therefore links to the assembly and disposal stages, as well as any processes during the use of the product.

It should be highlighted that stages [2], [3] and [4] refer to disposal, disassembly and reuse of the product of the study and not to waste from intermediate processes. Therefore, as a “cradle to gate” analysis is performed in this study only the assembly and lifecycle stages are relevant. The assembly of olive oil links to the processes, which describe the materials, production, transport and energy processes that are needed to produce the reference flow of olive oil defined in section 3.3.

At this stage the basic model of the olive oil production cycle is built by creating the unit processes identified in section 3.1 and interconnecting them into an assembly network through “known outputs to technosphere (products and co-products)”. Since the software only allows the creation of processes with quantified product output flow, in the absence, at this stage, of quantified flow data a unit of product output is used for each process. It is highlighted that the model is only preliminary and further development will possibly be required during the implementation of the inventory analysis. A list with the processes used in the model is provided in Table 7, whereas the model network created is shown in Figure 11. It is noted that for such a complex system the classification into SimaPro categories is subjective, however as previously discussed, process categories only serve model building and do not have any impact on the results. In this case the classification into categories was based on the unit, with which the product output is defined.

**Table 7 – Unit processes included in basic olive oil model**

No.	Unit Process	SimaPro Process Category	Known output to technosphere
1	Electricity production	Energy	Electricity produced (J)
2	Irrigation water supply	Material	Water supplied for irrigation (m <sup>3</sup> )
3	Irrigation	Material	Irrigated water (m <sup>3</sup> )
4	Fertiliser production	Material	Produced fertilisers (kg)
5	Transportation of fertilisers to farm	Transportation	Transported fertilisers (tonnes*km)
6	Fertiliser application	Material	Applied fertilisers (kg)
7	Pesticide production	Material	Produced pesticides (kg)
8	Transportation of pesticides to farm	Material	Transported pesticides (kg)
9	Pesticide application	Material	Applied pesticides (kg)
10	Herbicide production	Material	Herbicides produced (kg)
11	Transportation of herbicides to farm	Transportation	Transported herbicides (tonnes*km)
12	Herbicide application	Material	Applied herbicides (kg)
13	Soil management	Processing	Soil managed land (m <sup>2</sup> )
14	Olive tree planting	Processing	Olive trees planted (p)
15	Olive Tree cultivation	Processing	Olive trees cultivated (p)
16	Pruning	Processing	Olive trees pruned (p)
17	Olive collection	Material	Olives collected (kg)
18	Transportation: Olive farm to production unit	Transportation	Transported olives (tonnes*km)
19	Water treatment	Material	Water treated (m <sup>3</sup> )
20	Water supply	Material	Water supplied (m <sup>3</sup> )

21	Pre-processing olive storage	Processing	Storage time (hr)
22	Olive purification	Material	Purified olives (kg)
23	Olive grinding	Material	Olive paste produced from grinding (kg)
24	Oil extraction	Material	Olive oil extracted (m <sup>3</sup> )
25	On-site liquid waste treatment	Waste treatment	Liquid waste treated on-site (m <sup>3</sup> )
26	Wastewater supplied through network	Waste treatment	Wastewater supplied through network (m <sup>3</sup> )
27	Wastewater treatment (public)	Waste treatment	Treated wastewater (public) (m <sup>3</sup> )
28	Pomace processing	Waste treatment	Pomace processed (kg)
29	Solid waste treatment	Waste treatment	Solid waste treated (kg)
30	Bulk storage of olive oil	Processing	Storage time (hr)

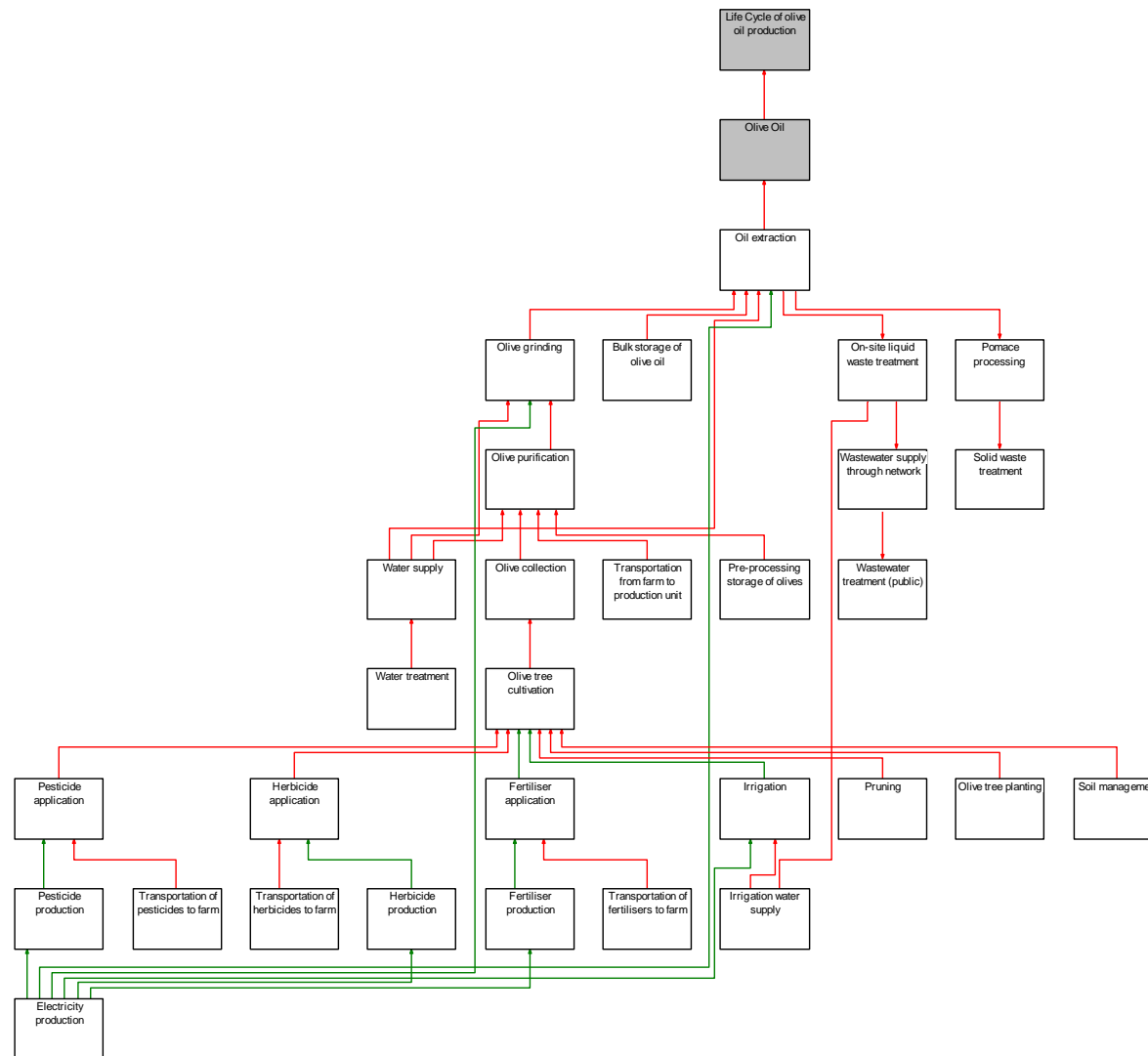


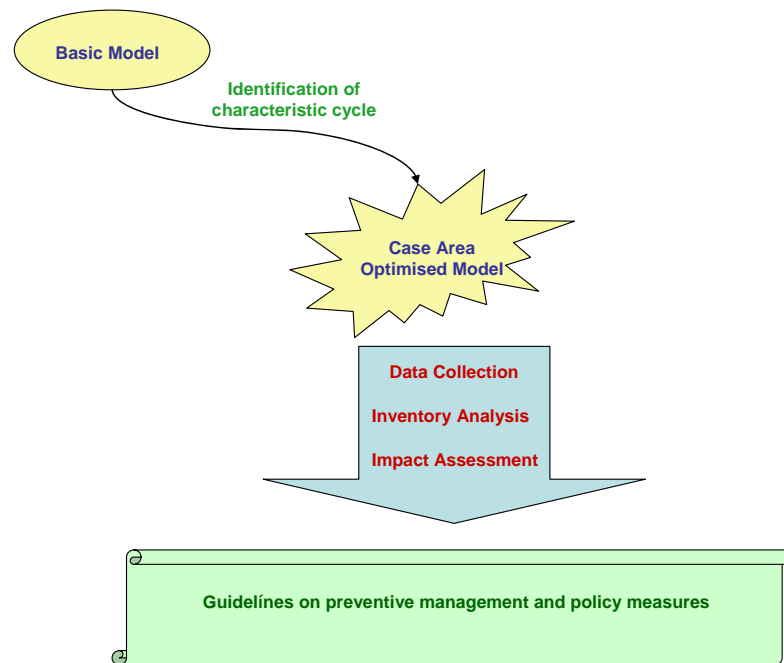
Figure 11 – The basic model of the olive oil life cycle developed with SimaPro 6



## The Way Forward

Having created the basic model to be used in the analysis, this section portrays the next steps in the study.

At a first instance, the characteristic olive oil production life cycle must be identified in each case study area. Through this process, the basic model built will be optimised for each case study area. For example, if two-phase centrifuge oil extraction process is used in a case study area, the Navarra original model will exclude vegetable water related processes. Furthermore, any additional processes not identified in the initial system definition will be included in the optimised models.



**Figure 12 – The way forward**

Subsequently, data will be collected and collated based on the data collection plan defined in section 3.6 and inventory analysis, impact assessment and interpretation of the results will be carried out separately for each case study area, on order to identify the “hot spots” of each cycle and suggest measures for the ecological production of olive oil. Both inventory analysis and impact assessment steps will be undertaken using SimaPro software. The procedure with which these steps will be carried out is described in the following sections of this report.

## Inventory Analysis with SimaPro 6

After data sets on unit processes are collected they will be imported in the model along with their documentation. In SimaPro each process of either category is defined through three main sections. The first section, “documentation” contains various comment fields and the data quality characteristics. The second section,

“input/output” contains all product and elementary flows in and out of the process. Finally, the third section, “system descriptions” contains references to detailed descriptions of the process system and should be used for transparency when a process system is used instead of a unit process.

In the first section each new process gets a reference string when it is created, whereas a process from the libraries (databases) supplied with SimaPro will have the reference string of the library developer. The reference serves purely traceability purposes. An important input field of the first section is the Data Quality Indicators (DQI), in which the applicable characteristic is selected from nine different fields and these will be later used to check to what extent a process suits the Data Quality Indicator criteria set for the study in section 3.6.3. This feature is particularly important for background processes collected from databases. Furthermore, the software allows the user to define miscellaneous information regarding the particular process, for traceability and transparency of the data. Such information includes the name of the person collecting the data, a description of how the data has been collected, a brief description of the operations that have been performed to make the data suited for this application, the literature references used, the name of the person and entering the data to the software.

In the second section, data on input and output flows must be imported. For all inputs and outputs, except the process definition, uncertainty can be defined, which can be used for Monte Carlo uncertainty analysis.

There are three types of inputs. The first type, inputs from nature, refers to inputs that are extracted from natural resources. It is highlighted that this is just referring to the fact that a resource is used, thus the emissions and other environmental impacts to extract the resource should be included in the process. The second input type, inputs from technosphere (materials /fuel) refers to materials and mass flows respectively supplied by other unit processes, whereas the third type, inputs from technosphere electricity/heat refers to non-mass flows including transport and energy supplied by other unit processes. It is highlighted that the only reason SimaPro separates mass and non-mass flows is to allow easier mass balance checks.

In regards to outputs, for each process, product and by-product outputs as well as waste to be sent to further treatment must be quantified. In addition, data on five elementary output flows must be imported: emissions to air, water and soil as well as final waste flows and non-material emissions such as noise. These elementary data together with inputs from nature will be used in inventory analysis of the product system.

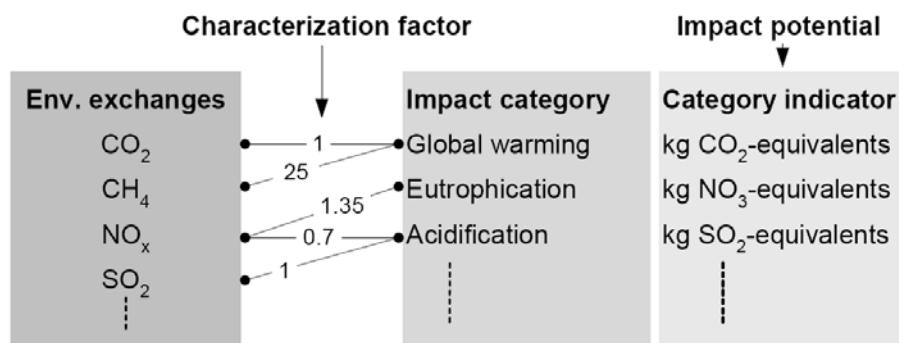
All elementary flow substances can be selected from a default list included in SimaPro. It is also possible to import a new substance; however the Swiss Centre for Life Cycle Inventories (2004) identifies that when linking the elementary flows with impact assessment methods, there are some methodological problems, which the practitioner must take carefully into account. For example, in some cases substance names of elementary flows in the impact assessment method and in the

database may not match. Furthermore some elementary flows in the database may not be considered by the method applied or factors in the method may not have a corresponding flow in the database.

Using the “analyse” function, the software internally, through a reduced matrix, calculates the system inventory by building the process trees and tracing all the references from one process record or product stage to another, thus integrating resource and emission substances as well as final waste flows per reference flow (i.e. 5.4 litres of olive oil). The inventory result screen shows all emissions and raw material consumption as a single list that is sorted alphabetically by substance name. These results can be split into the contributing processes. The aim is to understand the contribution of different product stages or processes to the total environmental load, as well as the contribution of raw materials and emissions. During calculation SimaPro performs a check and lists substances which are not taken into account by the impact assessment method selected. These must be carefully checked to see if important substances are not included in the impact assessment method. This may be the case for user defined substances. In addition a check on materials for which a waste type has not been defined is performed.

## Impact Assessment with SimaPro 6

As previously discussed, the standard methodology for the assessment of impacts comprises of: [1] the definition of impacts to be assessed (category definition), [2] the classification of inventory input and output into the defined impacts and the consideration of their relative contribution to the impact (characterisation) resulting to an impact potential indicator for each category, as shown in Figure 13, [3] the normalisation of each impact assessed to a reference unit for the assessment of the importance of each and [4] the weighting of the “importance” of each impact based on political and/ or ethical values. According to ISO 14042 (2000a) steps [3] and [4] are optional in the impact assessment methodology.

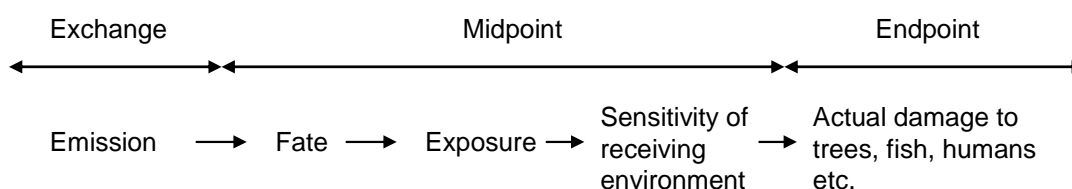


**Figure 13 – Example of classification, characterisation and category indicator (Thrane and Schmidt, 2004)**



It is important to highlight that we only consider potentials impacts. Whether the potentials materialises, will depend on a long series of other factors such as precise fate, exposure, background concentrations and sensitivity of the receiving environment (ecosystems, humans etc.) in the area affected.

As shown in Figure 14, the impact chain describes the environmental mechanism from “exchanges” to “endpoints”. An “endpoint” is something that we want to protect (a value item) such as trees, crops, rivers and human health. A “midpoint” in the other hand, refers to all elements in an environmental mechanism of an impact category that fall between environmental exchanges and endpoints (Udo de Haes *et al.*, 2002b). An example of an exchange is the emission of CFC gases, which causes a depletion of the ozone layer in the stratosphere (mid-point), which results in increased levels of radiation (mid-point) that eventually cause a certain number of people to die from skin cancer (end-point) depending on exposure and sensitivity on receiving environment (dark versus light skin colour, amount of sun block etc.).



**Figure 14 - The impact chain for an emission of a given substance (Hauschild, 2003)**

Based on this chain, impact assessment methods can follow one of two main approaches. The first group, known as problem-oriented methods use a “midpoint” approach as these methods stop somewhere in the environmental mechanism between environmental exchanges and endpoints. The other group, known as damage-oriented methods use a so-called “end-point” approach as they model the potential damage on value items such as trees etc.

SimaPro 6 software includes a number of standard methods as listed in Table 8. These methods have been primarily prepared for the assessment of a product or service and through a number of alterations but with minimum changes to the principal models they have been introduced to the software (PRé Consultants, 2004). Additional changes to the methods are made throughout the years according to new findings on the environment, processes etc.

**Table 8 - Standard impact assessment methods available in SimaPro 6**

Methodology	Developer
CML 1992	Centre for Environmental Studies, University of Leiden part of Dutch Guide to LCA
Eco-indicator 95	PRé Consultants part of Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment
Ecopoints 97	Swiss Ministry of the Environment part of Ecoipoint System
Eco-indicator 99	PRé Consultants part of Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment
CML 2 baseline 2000	Centre for Environmental Studies, University of Leiden part of Dutch Guide to LCA
EPS 2000	Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning for Environmental Priority Strategies in product design
EDIP	Danish UMIP for Environmental Design of Industrial Products
IPCC 2001 GWP	Intergovernmental Panel on Climate Change (IPCC)
Cumulative Energy Demand	PRé Consultants

### CML 1992

The CML 1992 method is based on a method published by the Centre for Environmental Studies of the University of Leiden in 1992 and is a problem-oriented method (PRé Consultants, 2004).

The impacts considered are abiotic and biotic resource use, greenhouse effect, ozone layer depletion, human toxicity, ecotoxicity, smog, acidification, eutrophication and solids emissions. It does not include noise, land use and fine particle matter. These impacts are grouped into two broad categories: exhaustion of raw materials and energy (abiotic and biotic resource use) and pollution (the rest of the above impacts). Abiotic exhaustion is associated to energy sources and scarce metals, whereas the biotic term is for rare animals and plants, whereas the biotic term has not yet been used since is still at a very elementary stage. The main disadvantage of this grouping strategy is the fact that by summing up impacts which could have considerable variations of terms of environmental impact, the reliability of the results can be reduced.

The method uses 100-years Global Warming Potential (GWP). The reference substance for the determination of GWP is CFC. CFCs are distinguished into hard

and soft (values of CFC-12 and HCFC-22 respectively). In regards to the Ozone Depletion Potential (ODP) the reference is the value for CFC-11. Human toxicity is a combination score for emissions to air, water and soil.

The majority of substances have been assigned with Human-toxicological classification value for air (HCA), water (HCW) and soil (HCS) values. Although the parameter for soil has not been included in the SimaPro adoption, it is assumed that emissions entering the soil penetrate to groundwater, thus emissions to soil can be included into the emissions to water. Ecotoxicity is handled in the same manner as human toxicity.

For the assessment of smog, "Potential capacity of a volatile organic substance to produce ozone" (POCP) values are used, with  $\text{NO}_x$  being omitted from the method. In regards to Acidification Potential (AP), the reference substance is  $\text{SO}_2$  while  $\text{SO}_x$  are also included by equating them to  $\text{SO}_2$ . Solids emission has been added through the adaptation for SimaPro as it was considered an environmental problem of high importance (PRé Consultants, 2004).

The normalisation sets used are [1] based on Dutch territory with all emissions registered emitted within the Netherlands and all raw materials consumed by the Dutch economy, [2] based on Dutch consumption, by adding the effect of imports and subtracting the effect of exports and [3] based on European territory with the energy consumption taken as basis for the extrapolation. The method does not include a weighting step.

### Eco-Indicator 95

Eco-indicator 95 was developed by PRé Consultants (Netherlands), as part of the Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment (PRé Consultants, 2004) and is a "damage oriented" method.

The impact categories assessed in Eco-indicator 95 are ozone layer depletion, heavy metals, carcinogenics, summer smog, winter smog, pesticides, greenhouse effect, acidification, eutrophication, depletion of energy resources and solid waste.

Characterisation in Eco-indicator 95 generally follows the methodology used in CML 1992. The difference is that scores of ecotoxicity and human toxicity effect have been replaced by summer smog, winter smog, carcinogens, heavy metals to air and water, and pesticides. The method does not include land use, noise and fossil fuel depletion.

Values used for normalisation are based on average European data from different sources (excluding the former USSR). In several cases, data was extrapolated on the basis of energy consumption of the country, from one or more countries to the European level. Figures were divided by the population of Europe (497 million) (PRé Consultants, 2004).

Weighting factors were calculated based on the distance-to-target principle. The seriousness of an impact was judged by the difference of the current and target

level. At the targets set, 1 excess death per million per year is caused; less than 5 per cent of the ecosystems in Europe are disrupted; and the occurrence of smog periods is extremely unlikely.

### Ecopoints 97

The methodology was developed as part of the Ecopoint System of the Swiss Ministry of the Environment. Ecopoints 97 is a problem-oriented method.

No classification and hence no characterisation is used. The impacts are assessed on an individual emission basis. This gives the advantage of a detailed and very substance specific method but only for a few substances. Normalisation is based on person equivalents. (Hauschild and Wenzel, 1998). For the calculation of weighting factors, the required data is [1] quantified impacts of the product; [2] total environmental load in a certain geographical area per impact type; and finally [3] the maximum environmental load that a particular area can handle in each geographical area.

### Eco-Indicator 99

This methodology has been developed by Pré Consultants, as part of the Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM). Eco-indicator 99 is a “damage oriented method”, and is the successor of Eco-indicator 95. The Eco-indicator 99 method comes in three versions, Egalitarian, Individualist and the Hierarchist (default) version (PRé Consultants, 2004).

Impacts assessed in Eco-indicator 99 are: carcinogens, resp. organics, resp. inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels. These impacts are grouped into three damage categories: [1] damage to human health, [2] damage to ecosystem quality and [3] damage to mineral and fossil resources. The bracket after each impact shows the group they belong to. This procedure can also be interpreted as grouping (Pre Consultants, 2005).

At the damage assessment step the impact category indicator results that are calculated in the characterisation step are added to form damage categories. Addition without weighting is justified here because all impact categories that refer to the same damage type (like human health) have the same unit, Disability Adjusted Life Years (DALYs). This method is also used by WHO and World Bank. Damage models were developed for respiratory and carcinogenic effects, effects of climate change, ozone layer depletion and ionizing radiation.

The eco-system quality is expressed as percentage of species disappeared in a certain area, due to the environmental load (Potentially Disappeared Fraction or PDF). The PDF is then multiplied by the area size and the time period to obtain the damage. The damage category ecosystem quality is not as homogeneous as the

definition of human health. It consists of ecotoxicity, acidification and eutrophication, land use and land transformation. Ecotoxicity is expressed as the percentage of all species present in the environment living under toxic stress (Potentially Affected Fraction or PAF). This is not an observable damage, a rather simple conversion factor is used to translate toxic stress into real observable damage, i.e. convert PAF into PDF. Acidification and eutrophication are treated as one single impact category. Damage to target species (vascular plants) in natural areas is modelled. This model is not suitable to model phosphates. Land use and land transformation are based on empirical data of occurrence of vascular plants as a function of land use types and area size. Both local damage on occupied or transformed area and regional damage on ecosystems are taken into account.

Damages to resources (minerals and fossil fuels) are expressed as surplus energy for the future mining of resources.

For dealing with subjective choices, leading to model uncertainties, three different perspectives of the damage models were developed for the characterisation part; hierarchist (H), individualist (I) and egalitarian (E). The Hierarchist version is the version being used by default. Table 9 summarises the main characteristics and differences of the three versions.

**Table 9 - Characteristics of modelling perspectives of Eco-indicator 99 (PRé Consultants, 2001)**

Version	Time view	Manageability	Level of evidence
Hierarchist	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus
Individualist	Short time	Technology can avoid many problems	Only proven effects
Egalitarian	Very long term	Problems can lead to catastrophe	All possible effects

Normalisation is undertaken on the damage category level. The data is calculated on European level at a “damage-caused by 1 European per year” basis. Normalisation sets are mainly based on 1993 data but some of the important emissions have been updated. Weighting is also undertaken at damage category level and is undertaken by a panel for each of the three damage categories. A specific weighting set is developed for each perspective and is the average result of the panel.

### CML 2 Baseline 2000

CML 2 baseline 2000 is an update of CLM 1992, developed by the Centre for Environmental Studies, University of Leiden as part of the Dutch Guide to LCA and is a problem-oriented method.

The main impacts assessed are abiotic depletion, global warming, ozone layer depletion, human toxicity, water ecotoxicity, acidification and eutrophication (Da Silva and Kulay, 2003).

During the characterisation step, similarly with CML 1992, the method uses 100-years Global Warming Potential (GWP). However, the reference substance (category indicator) for the determination of GWP is CO<sub>2</sub>, while in regards to the Ozone Depletion Potential (ODP), CFC-11 is still the category indicator. Human toxicity potentials are expressed as 1,4-dichlorobenzene equivalents, while for abiotic depletion kg antimony equivalents are used.

Normalisation scores for each baseline indicator are calculated for the reference situations according to the available data; i.e. 1990 world, 1995 Europe and 1997 Netherlands. Weighting is not available in CML 2 baseline 2000 method used in SimaPro (PRé Consultants, 2004).

### EPS 2000

The 2000 version of Environmental Priority Strategies (EPS) in product design was developed by the Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology, Technical Environmental Planning (PRé Consultants, 2004). It is a damage oriented method.

The impact categories considered comprise of the five safe guard subjects of human health, ecosystem production capacity, abiotic stock resource and biodiversity. The method also considers cultural and recreational values, however these, have not been included in the SimaPro adoption.

During classification, impact categories are coupled with emissions and resources according to the likely exposure. Characterisation is performed by application of empirical, equivalency and mechanistic models. The outcome is default characterisation values.

Weighting factors are representing willingness to pay. The unit of the indicator is Environmental Load Unit (ELU).

### EDIP

EDIP (Environmental Design of Industrial Products) was first developed by the Danish UMIP in 1996. It is a problem-oriented approach. Categories considered in the method are global warming, stratospheric ozone depletion, smog, acidification, ecotoxicity, human toxicity, eutrophication and wastes.

Global warming is based on the IPCC 1994 Status report. In SimaPro GWP-100 is used. Stratospheric ozone depletion potentials are based on the status reports (1992/1995) of the Global Ozone Research Project (infinite time period used in SimaPro). Photochemical ozone creation potential values depend on the background concentration of NO<sub>x</sub>, whereas acidification is based on the number of hydrogen ions that can be released. Eutrophication potential is based on N and P content in organisms, while ecotoxicity and human toxicity potentials are based on chemical hazard screening methods, which looks at toxicity, persistency and bioconcentration. Finally, waste streams are divided into 4 categories: bulk non-hazardous, hazardous, radioactive and slag and ashes and all reported on a mass-basis (PRé Consultants, 2004).

The values used for normalisation are based on person equivalents for 1990. Normalisation is set to zero for resources, since it has already been included in the characterisation factor. The weighting factors are set to the politically set target emissions per person in the year 2000. The weighted results are expressed per person in 1990, except for resources which are based on the proven reserves. The weighing is set to zero for resources, since it has already been included in the characterisation factor.

#### IPCC 2001 GWP

IPCC 2001 GWP was developed by the Intergovernmental Panel on Climate Change (IPCC). This method focuses solely on Global Warming Potential (GWP), thus it is a problem-oriented approach.

Characterisation factors are for direct global warming potential of air emissions. These do not include indirect formation of dinitrogen monoxide from nitrogen emissions but do include CO<sub>2</sub> formation from CO emissions. Radiative forcing due to emissions of NO<sub>x</sub>, water, sulphate, etc. in the lower stratosphere and upper troposphere is not accounted. The range of indirect effects given by IPCC is not being considered. Biogenic CO<sub>2</sub> uptake is considered to be negative impact. Normalisation and weighting steps are not included in IPCC 2001 GWP (PRé Consultants, 2004).

#### Cumulative Energy Demand

This impact assessment method is based on a method published by ecoinvent version 1.01, further developed by PRé Consultants and focuses on calculating cumulative energy demand (CED).

The energy types considered are non-renewable, fossil; non-renewable, nuclear; renewable, biomass; renewable, wind, solar, geothermal; renewable, water. Normalisation is not included in the method. For weighting, each impact category is assigned with weighting factor of 1 (to get the total energy demand) (PRé Consultants, 2004).



### Selection of Method(s) for this study

According to Thrane, M and J Schmidt (2004) LCA practitioners often choose a method for impact assessment, which is developed in the country where the LCA is carried out. However, when none of the available methods was developed locally, as is the case in this study, it can be an advantage to use several methods for verification purposes since more impact categories will be covered, as different methods tend to include different impact categories. The matrix in Figure 15 shows the impacts covered by the methods described above. Therefore one of the parameters to be taken into account is the coverage of more impact categories in relation to the specific impact categories identified in the preliminary investigation in section 3.5.1 are also taken into account.

In regards to the approach followed by each method, the majority of the methods use the problem-oriented (mid-point) approach as opposed to the damage-oriented (end-point) approach. According to Udo de Haes (2002b), it is often argued that the mid-point approach provides more reliable results, while the results from end-point methods are easier to understand and use for decision making. Thus the application of two fundamentally different approaches will obviously provide a greater certainty in the assessment. This is the second parameter taken into account in the selection.

A third issue that must be taken into account when selecting an impact assessment method is how long ago the method was developed. The assessment of environmental impacts is a dynamic field where new information is made available every day. Thus, a method which is developed based on the best information available ten years ago might be not too applicable today. Therefore, the third parameter taken into account in the selection is the “age” of each method.



METHOD	Approach	IMPACTS												
		Abiotic Resource exhaustion	Biotic Resource exhaustion	Greenhouse Effect/ Global warming	Ecotoxicological impacts	Human toxicological impacts	Ozone Layer Depletion	Photochemical oxidant formation	Acidification	Eutrophication	Land use	Solid waste	Heavy metals	Other
CML 1992	Problem-oriented	■		■	■	■	■	■	■	■		■		
Eco-indicator 95	Damage-oriented			■		■	■	■	■	■		■	■	■
Ecopoints 97	Problem-oriented													■
Eco-indicator 99	Damage-oriented (Human Health, Ecosystem Quality, Resources)	■		■	■	■	■		■	■	■			■
CML 2 baseline 2000	Problem-oriented	■		■	■	■	■	■	■	■				
EPS 2000	Damage-oriented (Human Health, Ecosystem Production Capacity, Abiotic Stock Resource, Biodiversity)	■	■						■					■
EDIP	Problem-oriented			■	■	■	■	■	■	■		■		
IPCC 2001 GWP	Problem-oriented			■										
CED	Problem-oriented	■												

Figure 15 - Impacts assessed by methods available in SimaPro 6

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Brentrup *et al.* (2000a) reports that the 'Eco-indicator 95' method has proven to be applicable to analyse the environmental impact of agricultural systems as it gives a comparative analysis of the systems under investigation related to global warming, acidification, eutrophication and summer smog. However, his investigation shows that the Eco-indicator 95 method has some constraints when applied on an agricultural production system, because not all relevant information listed in the Life Cycle Inventory is considered in the impact assessment. Some important environmental issues are not covered by the Eco-indicator 95 (e.g. use of land and resources) others are included in an inconsistent way (pesticides, winter smog).

Based on all these considerations, the Eco-Indicator 99, which is the successor of Eco-indicator 95 and the CML 2 baseline 2000 methods were chosen for application in this study. It is noted that these methods do not cover the exhaustion of biotic resources, which has been identified as a relevant impact associated with olive oil production, however, as Narayanaswamy *et al.* (2003) notes, for this impact category "there are neither well-developed impact assessment models nor characterisation factors for use in the LCA case studies". Therefore the impacts to be considered in this study are: abiotic resource exhaustion, global warming, ecotoxicological and human toxicological impacts, ozone layer depletion, photochemical oxidant formation, acidification, eutrophication and land use.