Scope of the Study

According to ISO 14040 (1997), the scope of an LCA study should be sufficiently well defined in order to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal. However, it must be highlighted that the LCA is an iterative technique. Hence, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

The Product System and the System Boundaries

The Product

Olive oil has been one of the staples of the Mediterranean diet for thousands of years and its popularity is also growing rapidly in other parts of the world. The oil extracted from the olive fruit can be classified as: [1] virgin, [2] refined and [3] olive-pomace. Virgin oil is the olive oil produced solely by mechanical or other physical means and no treatment other than washing, decantation, centrifugation and filtration (Council, 1998). Refined means that the oil has been chemically treated to neutralise strong tastes and the acid content, whereas olive-pomace oil means oil extracted from the pomace using chemical solvents, mostly hexane and by heat. Refined and olive-pomace oils are commonly regarded as lower quality oils than virgin oil.

Virgin olive oils are classified by relevant Council Regulations (1966, 1998) based on both their acidity and their organoleptic quality, i.e. their taste. The oil's acidity, defined as the percent, measured by weight of free oleic acid in it is determined by quantitative analytical methods. In order to classify olive oils fit for consumption by taste, the oil is subjectively judged by a panel of professional tasters in a blind taste test.

Table 1 – Virgin Olive Oil Grades (Council, 1966, 1998)

Grade	Acidity	Organoleptic Quality
Extra-virgin olive oil	< 0.8% expressed as oleic acid	Absolutely perfect flavour
(Fine) virgin olive oil	< 2% expressed as oleic acid	Absolutely perfect flavour
Ordinary virgin olive oil	< 3.3% expressed as oleic acid	Good flavour
Lampante virgin olive oil	> 3.3% expressed as oleic acid	Off-flavour

Extra virgin is considered as the olive oil with the finest quality and it accounts for the largest portion of the olive oil production in Voukolies, Lythrodontas and Navarra. Therefore, this LCA study will concentrate on this particular product as defined by the relevant regulations (Council, 1966, 1998). In order to simplify the analysis, no other distinction will be made in regards to colour and aroma.

The System

According to ISO 14041 (1998), a product system is a collection of unit processes, processes, each representing one or several activities, linked to one another by flows of intermediate products and/or waste for treatment. The product system can also be connected to other product systems via product flows across the system boundaries (either into the system or out of the system).

The unit processes are linked to the environment by elementary flows, which are "any material or energy entering the system being studied, which has been drawn from the environment without previous human transformation or leaving the system being studied and discarded into the environment without subsequent human transformation" (ISO, 1997). Examples of such flows entering unit processes are clay and coal, while various emissions of chemical substances or parameters such as CO_2 to air, Biochemical Oxygen Demand (BOD) to water respectively are typical examples of elementary flows leaving unit processes (ISO, 1998). The aggregation of these flows will determine the total extractions from and emissions to the environment. *Hence, the quantification of elementary flows is probably the most resource-intensive aspect of the study.* This is further discussed in section 3.6 of this report.

Finally it has to be stressed out that because the system is a physical system, each unit process should theoretically obey the laws of conservation of mass and energy. Hence, mass and energy balances could provide a useful check on the validity of a unit process description (ISO, 1998). However, in practice the mass balance is not correct, for a number of reasons. For example, emissions like water vapour and the use of oxygen in incineration are usually not specified, whereas some sum parameters like BOD have a mass unit, but do not really reflect the mass of the emission. Furthermore, inputs and outputs can also be specified as volume or energy content, while inputs and outputs of lesser importance are neglected, depending on the cut-off criteria set during data collection (see section 3.6.1).

Prior to setting the boundaries of this study the examination of the full "cradle to grave" cycle of olive oil was considered necessary. A brief description of the typical olive oil life cycle begins with the production of pre-farm inputs and the cultivation of trees up to the acquisition of the raw material required for the product (olives) through agricultural farming. The olives are then processed into olive oil through a series of processing steps. Next, the produced olive oil is possibly stored for some time in suitable conditions in the processing unit prior to its transportation to a packaging unit, where it is packaged, usually in plastic or glass bottles and aluminium bulk containers. Packaged olive oil is usually stored for certain time prior to its distribution to the consumers where it is used. What remains from the product after use, mainly the packaging, is treated as municipal waste.

Therefore, the olive oil life cycle can be separated into five main stages: [1] agriculture (comprising of pre-farm activities and farm activities), [2] processing, [3] packaging [4] storage and distribution, [5] use and end-of-life. A graphical analysis of the main material and product flows for each stage of this life cycle is provided in Figures 2-6.

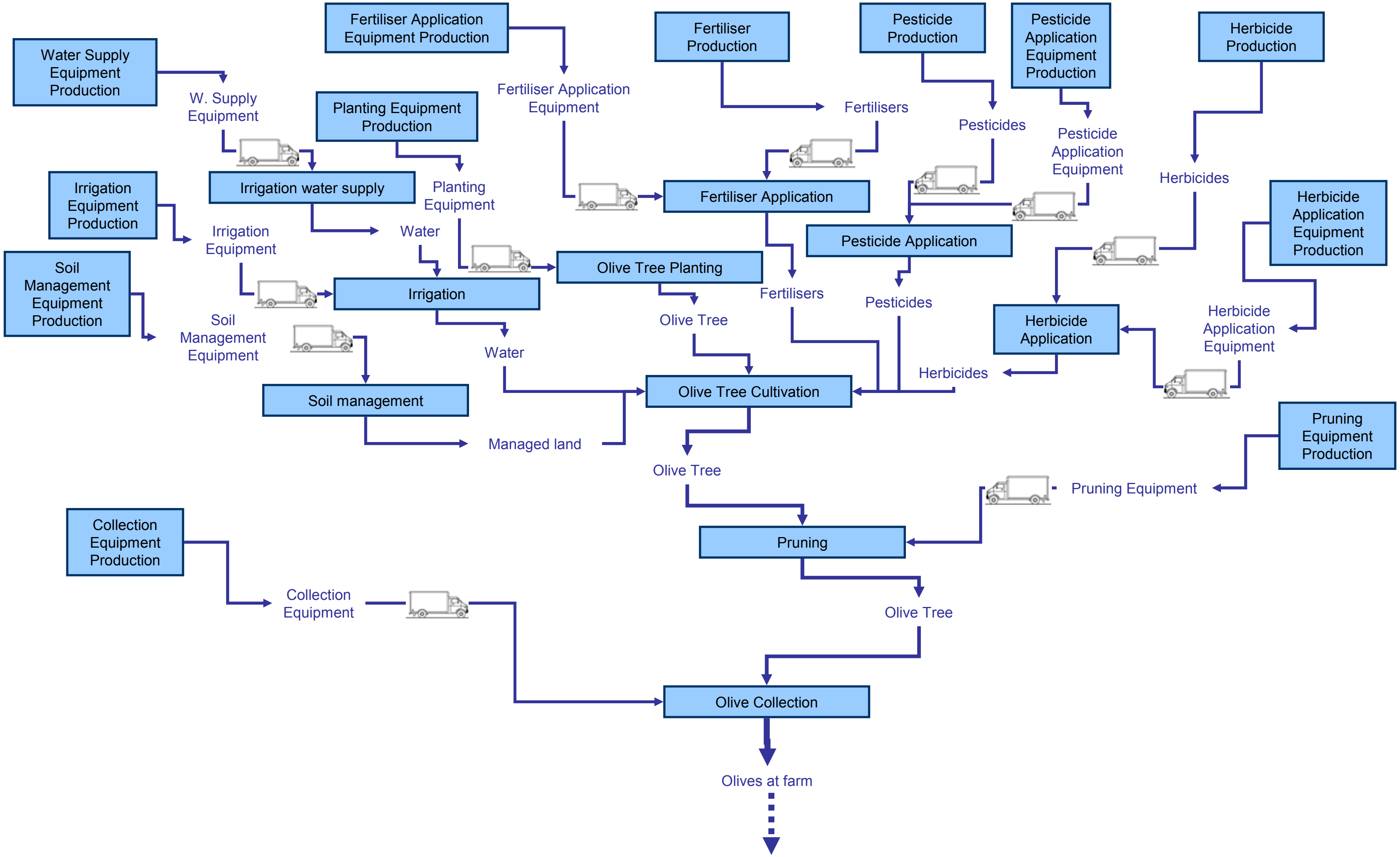

Figure 2 - Process Flowchart (Agriculture)

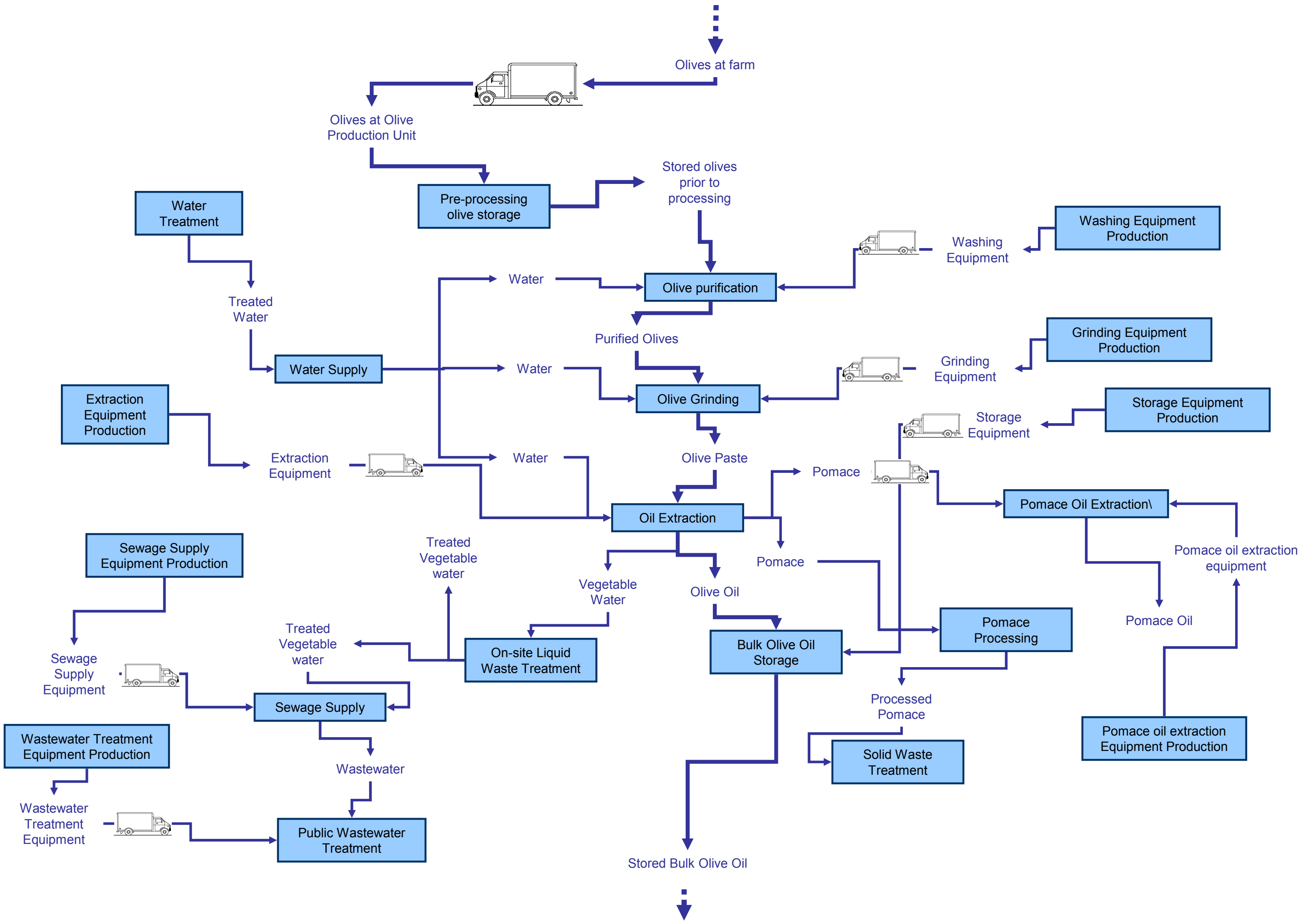

Figure 3 - Process Flowchart (Processing)

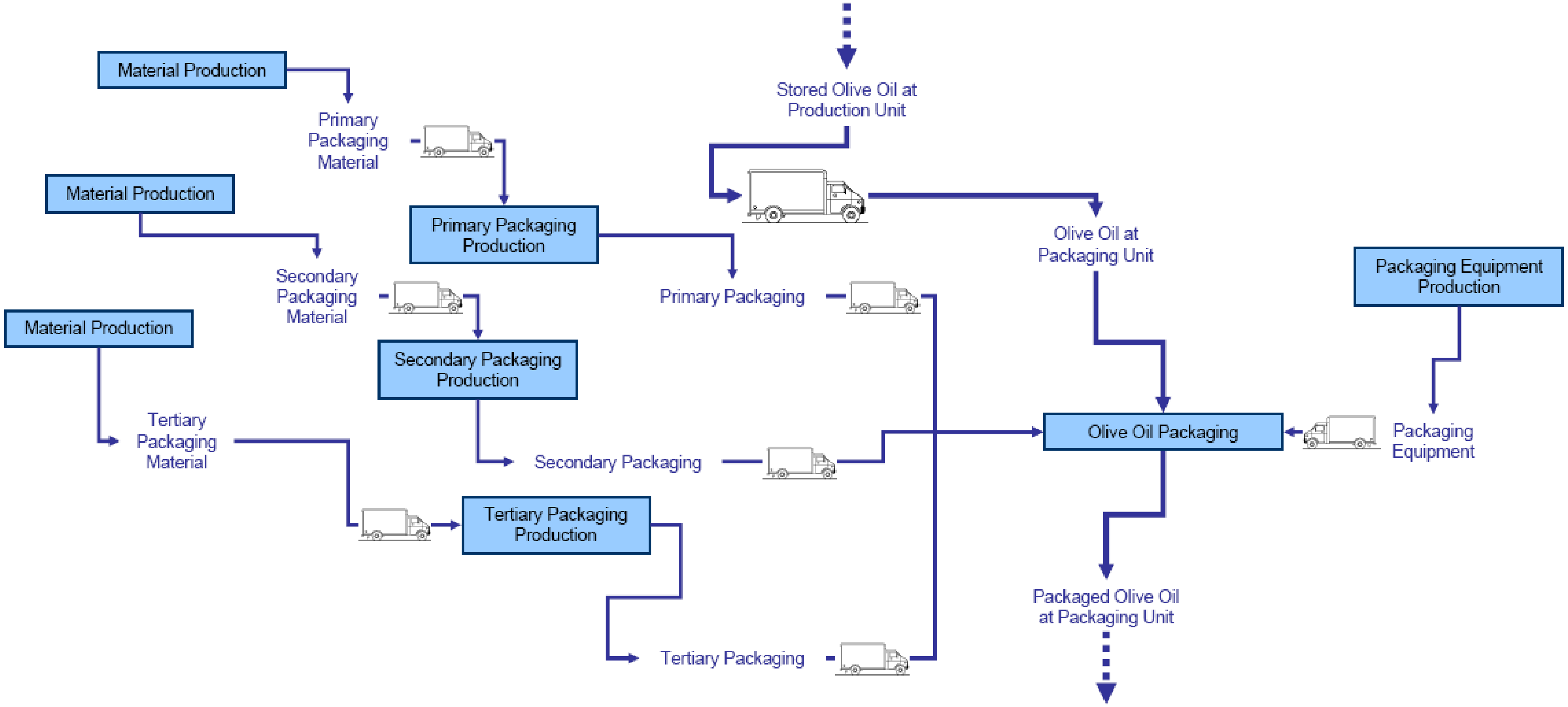

Figure 4 - Process Flowchart (Packaging)

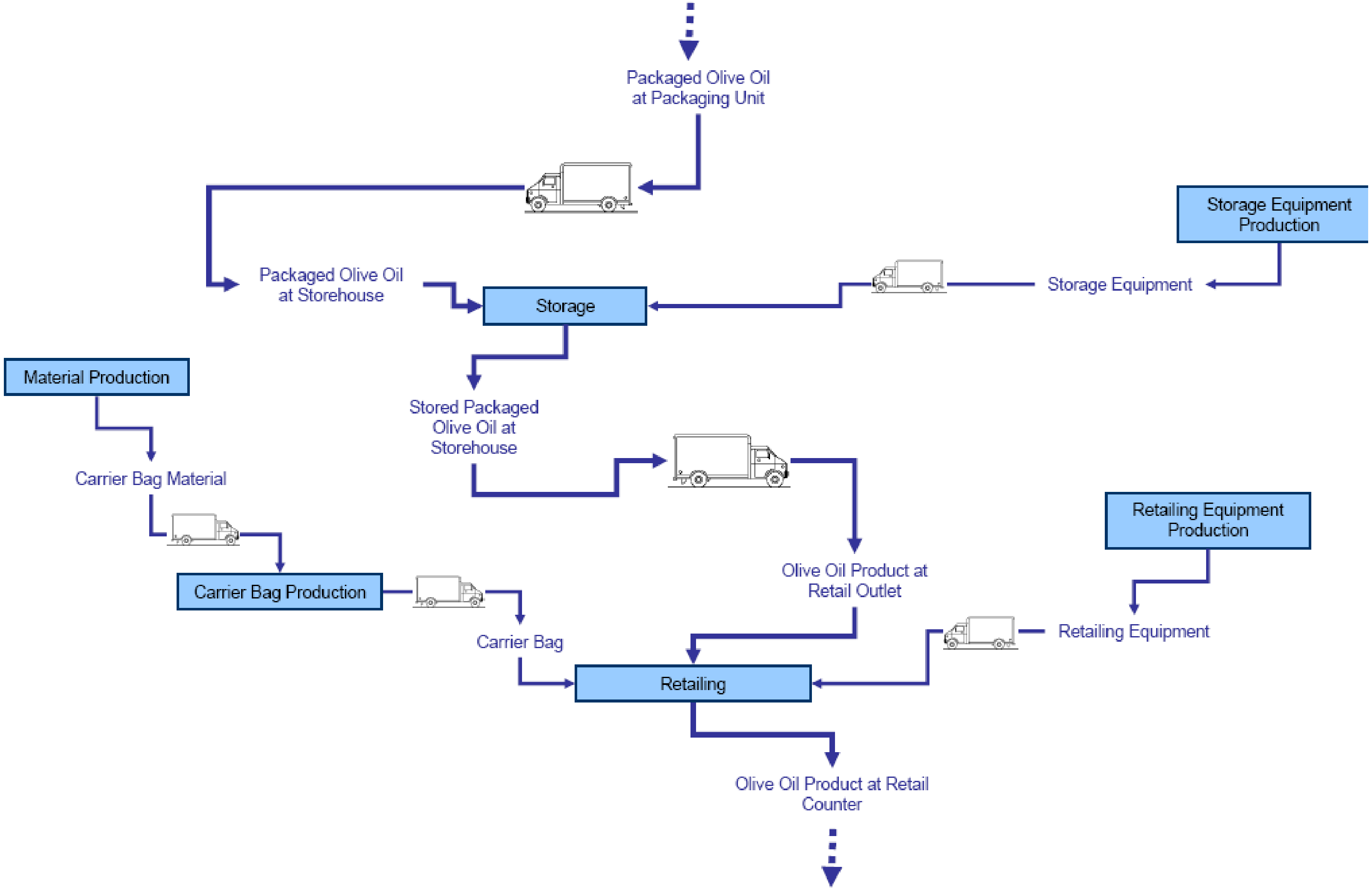

Figure 5 - Process Flowchart (Storage and Distribution)

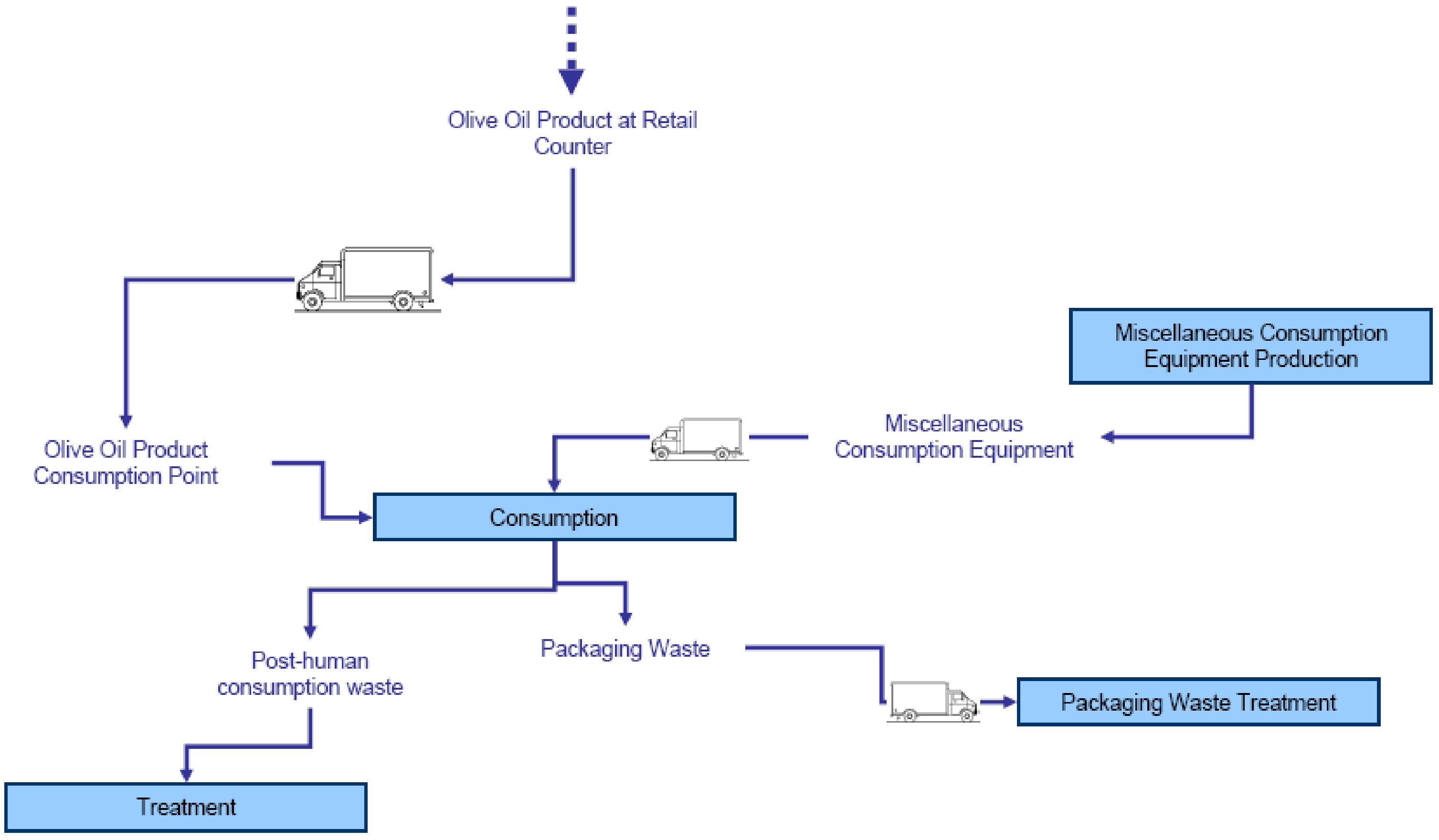

Figure 6 - Process Flowchart (Use and End-of-Life)

The Boundaries

The system boundaries determine which unit processes shall be included within the LCA and therefore separate the system from the rest of the world. According to VROM, CML (2001) there are three types of boundaries: [1] the boundary between the product system and the environment, [2] the boundary between processes that are relevant and irrelevant to the product system and [3] the boundary between the product system under consideration and other product systems.

The first boundary condition that needs to be defined at this stage is the boundary of the olive tree agricultural system with nature. The agricultural system can be either considered as part of the part of the natural system i.e. within the ecosphere or as part of the production system i.e. within in the technosphere. In the first case, CO_2 consumed by growing olive trees must not be accounted and the whole input of fertilisers, pesticides and herbicides, for example, must be accounted as an emission since by applying the fertiliser into the farming ground it is introduced into the ecosphere. This approach can be valid where a plantation is naturally occurring, e.g. a natural forest where every intervention on the forest should be considered as an intervention to the environment. However, in the vast majority of olive plantations, olive trees do not simply occur in nature, but are planted and cultivated strictly for the purpose of olive oil production or possibly for the production of olives intended for table consumption. Hence, in this study the olive tree agricultural system is considered as part of the olive oil production system. As a result, the absorption of CO_2 from the atmosphere by the plantations must be accounted in the inventory as a negative emission and the land used for the agricultural system must also be accounted as resource consumption. Furthermore planting of olive trees should also be included as a unit process. On the other hand, fertilizers, pesticides, herbicides and possibly other chemical inputs on agricultural soils should not be counted as emissions into nature as a whole, but only those substances and quantities that leach into deeper soil and water or evaporate in the atmosphere.

In regards to the second and third boundary conditions, all processes are considered as relevant unless one of the exclusion criteria set for this study applies. These exclusion criteria are: [1] processes preliminarily judged to have insignificant contribution to the overall environmental load, [2] processes for which the collection of representative data is practically impossible, [3] processes which can clearly be specified as part of a separate product system and [4] processes which are not relevant with the goal of this study.

According to Andersson *et al*. (1998), a complete LCA study for a food product should include agricultural production, industrial refining, storage and distribution, packaging, consumption and waste management, all of which together comprise a large and complex system. The inclusion of all these stages in the assessment, i.e. a “cradle to grave analysis”, according to VROM and CML (2001) avoids problem shifting, as it is important in eco-design not to solve one environmental problem merely by shifting it to another stage of the product’s life cycle. For example, the inclusion of olive oil packaging stage in the study without including the waste management of the packaging waste could potentially lead to a selection of packaging type A, as the production is less damaging to the environment than packaging type B. However the management of packaging type A waste might be by far environmentally inferior to that of packaging waste type B and overall packaging type B should be the choice.

Nevertheless, in some cases LCA studies can only include selected life cycle stages such as the stages from raw material extraction to final processing. In this case the perspective would be "cradle to gate" but the analysis is still termed an LCA, even though it is somewhat amputated. Nevertheless, any decisions to omit life cycle stages must be clearly stated and justified (ISO, 1998) and attuned to the ultimate goal of the study (VROM, CML, 2001).

The goal of this study, as defined in this report, is to identify the stages of the olive oil production cycle that have significant contribution to the overall environmental load so that the conclusions drawn can be used by all actors involved in the production of olive oil as an integrated Decision Support Tool (DST) on the selection of particular processes such as adoption of proper olive tree cultivation processes, olive fruit transportation, olive oil milling process and olive oil mill waste management.

Subsequent stages of the cycle, such as packaging, packed olive oil storage, distribution, use and end-of-life are therefore excluded from the system boundary in order to focus on the relative environmental load from production stage unit processes. The inclusion of subsequent stages of the cycle would offer little value in regards to olive oil specifically, as these processes, excluding use, are similar for a number of different products and in such a perspective should be analysed. The consumption (use) stage, although is directly related to the specific product, is a matter of personal choice, for which representative data are difficult to obtain and process optimisation would possibly interfere with the product's original function.

The exclusion of those stages from the study, thus the analysis of a "cradle to gate" cycle for olive oil instead of the full "cradle to grave" life cycle is not expected to shift any environmental problems to a later stage of the product life cycle.

Fossil-based energy use, water use and the production, supply and application of other pre-farm inputs for the cultivation of olive trees such as fertilisers, pesticides and herbicides are relevant environmental considerations, thus are included within the system boundary. Olive milling and processing steps consume water, electricity, heat energy and generate gases, wastewater, and solid wastes. They are all included and will be accounted in the LCA as well as their waste treatment processes where applied.

The electricity used in any activity is being generated at a power station for which fossil fuels are consumed and emissions and waste generated. The generation of electricity used by any process within the boundary is therefore included. The electrical energy flows are traced from mining and extraction of fossil fuels, processing, production and distribution to the grid at the points of use.

Similarly, the transportation of the various material inputs, is a significant resource consuming and pollutant emitting process that needs to be accounted, thus transportation of consumable materials taking place during the agriculture (fertilisers, pesticides, etc.) and processing stages (olives) is included. However neither transport of personnel to their workplaces nor the burdens from labour at farm and the processing unit are included since it will be practically impossible to collect representative data and their inclusion would give rise to complicated allocation issues.

Olive oil extraction results to the co-production of pomace and vegetable water (three-phase centrifuge only) as well as to the production of olive oil of lower quality than the product of this study. Pomace and vegetable water can sometimes be utilised through further treatment. Pomace, can be treated further for production of pomace-oil, a product not accounted in this study as previously discussed. Therefore pomace-oil extraction is considered as part of a different system and thus excluded from the boundaries of this system (third boundary condition), whereas pomace, which is not to be utilised further is considered as waste of our system and therefore its treatment is included within the system boundary. Similarly further processing of lower quality olive oil is also regarded as part of a different system and thus excluded from the boundary. The same applies for further processing of olives collected for utilisation into products other than the product of this study.

The second potential by-product of olive oil extraction, vegetable water can also be utilised by on-site treatment and use for irrigation of olive groves. This close-loop recycling system is included in the boundary. At the same time, vegetable water not utilised by the system but sent to further treatment in public wastewater works is also included in the boundary along with its downstream treatment. The reasons for the inclusion of pomace (waste) and vegetable water treatment processes within the system boundary is further discussed in section 3.4.2 of this report.

In LCA studies of agricultural products comparable with olive oil, the production of capital goods such as machinery, buildings, tools and transportation vehicles was excluded from the system boundary. Narayanaswamy *et al*. (2004) in an LCA study for grain-produced products reports that their exclusion was mainly due to non-availability of reliable LCI data. Nevertheless, several other LCA studies have shown that the environmental load from the production of capital goods is insignificant when compared to their operation, therefore the exclusion is justifiable. In particular, PA Consulting Group (1992), in a life cycle assessment study on washing machines demonstrated that the energy consumption of a washing machine is approximately 23 times higher during the use phase compared to the production phase. In a different LCA study on trucks 90 per cent of the total environmental burden originated from their use phase (Volvo, 2001), while a life cycle assessment on forestry harvesting machines in 2001 showed that the fossil energy consumption, and hence the global warming potential, associated with the production phase constituted approximately 2-3 per cent of the consumption during the whole life cycle (EA, 2005). Therefore the production of capital goods required for processes within the boundary, is excluded from the boundaries of this system.

Similarly, although the maintenance and replacement processes of capital equipment can be rather significant in regards to cost, their contribution to the overall environmental loading of the cycle is judged as insignificant, thus they are excluded from the system boundaries.

A matrix of the processes considered for the system along with the deciding criteria for their inclusion or exclusion is provided in Figure 7, whereas, a schematic presentation of the system boundaries is shown in Figure 8. Finally, Table 2 lists the main unit processes within the system boundaries. For each unit process, the starting and ending point of the process as well as the nature of transformations taking place are defined in line with the requirements of ISO (1998). All within the system boundary will be taken up for in-depth data collection and evaluation.

Process Category	Included	Exclusion Criteria			
		Low environmental significance	Impossible to obtain representative data	Part of a different system	Not directly relevant to goal of the study
Production, maintenance and replacement of capital equipment		■			
Transportation of capital goods		■			
Production of agricultural inputs (fertilisers, pesticides, herbicides etc)	■				
Transportation of agricultural inputs	■				
Water treatment and supply	■				
Transportation of personnel			■		
Labour activities			■		
Main agricultural activities (application of agricultural inputs, irrigation, soil management, cultivation, pruning, olive collection)	■				
Processing of low quality olives				■	
Main processing activities (storage, purification, grinding, oil extraction, bulk oil storage)	■				
Processing stage waste management activities	■				
Pomace oil extraction				■	
Low quality olive processing				■	
Packaging stage processes					■
Packed oil storage and distribution stages processes					■
Use and end-of-life stages processes					■
Electricity generation	■				

Figure 7 – System Boundary Definition Criteria

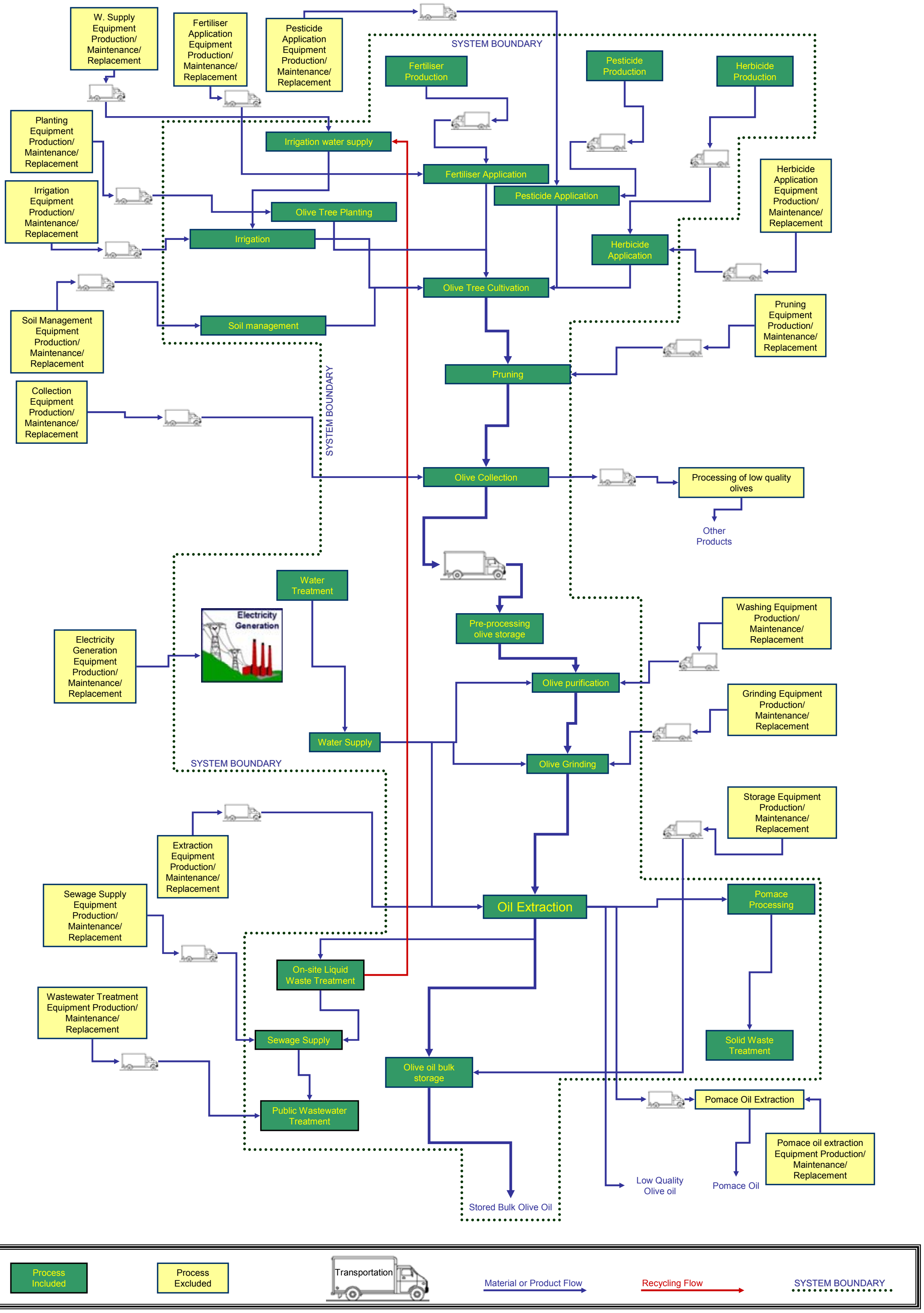

Figure 8 - System Boundaries

Table 2 – Olive Oil Product System

No.	Unit Process	Process Start	Nature of Transformations	Process Ends
1	Electricity production	Mining and extraction of fossil fuels	Energy conversion	Distribution to the grid at the points of use
2	Irrigation water supply	Water in aquifers or surface waters or treated wastewater lagoons	Physical	Water at farm
3	Irrigation	Water at farm	Physical	Water applied at olive tree root
4	Fertiliser production	Acquisition of raw materials	Chemical processing	Fertilisers at the production unit gate
5	Transportation of fertilisers to farm (may include intermediate storage and retailing)	Collection of fertilisers from production unit gate	Physical	Delivery of fertilisers to farm gate
6	Fertiliser application (including unpacking and incorporation into soil)	Fertiliser stored at farm	Physical	Fertiliser into agricultural soil (part of technosphere)
7	Pesticide production	Acquisition of raw materials	Chemical processing	Pesticides at the production unit gate
8	Transportation of pesticides to farm (may include intermediate storage and retailing)	Collection of pesticides from production unit gate	Physical	Delivery of pesticides to farm gate

9	Pesticide application (including unpacking)	Pesticide stored at farm	Physical	Pesticide applied to olive groves
10	Herbicide production	Acquisition of raw materials	Chemical processing	Herbicides at the production unit gate
11	Transportation of herbicides to farm (may include intermediate storage and retailing)	Collection of herbicides from production unit gate	Physical	Delivery of herbicides to farm gate
12	Herbicide application (including unpacking)	Herbicide stored at farm	Physical	Herbicide applied to agricultural soil (part of technosphere)
13	Soil management	Soil at its natural state	Physical	Physically managed soil
14	Olive tree planting	Acquisition of olive trees	Physical	Planted olive grove
15	Olive Tree cultivation	Planted olive grove	Biological	Mature olive grove
16	Pruning (may include burning or chopping)	Olive grove not pruned	Physical	Olive trees pruned
17	Olive collection	Olive fruits on olive trees	Physical	Olive fruits detached from trees and packed
18	Transportation of olives from farm to processing unit	Collection of olives from farm gate	Physical	Delivery of olives to processing unit gate
19	Water treatment	Extraction of water from acquifers or surface waters	Physical, chemical and	Potable water at water works gate

			biological processing	
20	Water supply	Potable water at water works gate	Physical	Water at olive oil processing unit gate
21	Pre-processing olive storage	Olives after collection	Physical processing	Olives before processing
22	Olive purification (includes washing and removal of leaves and other materials from olives)	Olives as collected from farm	Physical processing	Olives without any foreign matter
23	Olive grinding	Olives without any foreign matter	Physical processing	Olive paste
24	Oil extraction	Olive paste	Physical processing	Olive oil, (vegetable water) and pomace
25	On-site liquid waste treatment	Vegetable water	Biological processing	Treated vegetable water
26	Wastewater supply through network	Treated vegetable water at processing unit	Physical	Treated vegetable water at public wastewater treatment works
27	Wastewater treatment (public)	Treated vegetable water at public wastewater treatment works	Physical, chemical and biological processing	Treated wastewater

28	Pomace processing	Pomace with high water content	Physical processing	Dried pomace
29	Solid waste treatment (may include transportation)	Dried pomace	Biological processing (landfill or composting)	Compost
30	Bulk storage of olive oil (kept under suitable physical conditions)	Olive oil ready	Physical processing	Olive oil at the production unit gate

The Functions of the Product System

According to ISO 14049 (2000c), the starting point for identifying the function of the product may be the specific product to be studied, i.e. extra virgin olive oil or it may be the final need or goal, which in some cases may be fulfilled by several distinct products. Olive oil due to its high nutritional value is mainly used in cooking where it is regarded as a healthful dietary oil because of its high content of monounsaturated fat. For this reason it is one of the most versatile cooking oils and an excellent alternative to butter or margarine as a condiment or for use in food preparation. Furthermore, olive oil is used in cosmetics and soaps and traditionally used by Eastern Orthodox Christians as a fuel for their traditional oil (vigil) lamps.

The Functional Unit and Reference Flows

During the analysis, all inputs and outputs have to be related to a common reference (unit). This allows normalisation, in a mathematical sense, of all extractions and emissions for a single product or between products. This reference must relate to the function of the product, for this reason it is termed as functional unit. Functional unit is defined by ISO 14040 (1997) defines as “the quantified performance of a product system for use as a reference unit in a life cycle assessment study”. ISO 14041 (1998) clearly states that comparisons between systems shall be made on the basis of the same function, quantified by the same functional unit in the form of their reference flows, i.e. the quantity of product which is necessary to fulfil the function quantified by the functional unit.

ISO 14049 (2000c) describes and provides examples of a methodology for the selection of the functional unit for an LCA study. A more detailed methodology for the selection of the functional unit was recently published by the Danish Environmental Protection Agency (2004). In this section the functional unit of this study is defined following the methodology of the ISO standards.

The purpose of the functional unit is to quantify the service delivered by the product system. The first step is thus to identify the purpose served by the product system, i.e. its functions (ISO, 2000c). As discussed in the previous section, olive oils functions include its use in: food preparation, cosmetics and as fuel. However, not all functions may be relevant for a particular LCA. Thus, out of all possible functions, the relevant ones must be identified. The goal of the study, as already defined is to identify those stages of the olive oil production cycle that have significant contribution to the overall environmental load and should ideally be optimised or redesigned. Hence we are solely concerned with this particular product and therefore the functions of olive oil, which can be fulfilled by other products, are considered irrelevant. The relevant function of the system considered is to provide olive oil for use in food preparation.

Following the ISO methodology the functional unit shall be defined based on the relevant function of the product. Therefore an appropriate functional unit for this study would be “olive oil to fulfil the food preparation needs of one person for one year”.

According to statistics of the International Olive Oil Council for the year 2002, the average per capita consumption of olive oil in the European Union was 5.4 litres. Hence, based on this functional unit, a reference flow of 5.4 litres should be used. Nevertheless, purely for practicality reasons, the practitioner team decided the use of a reference flow of *1 litre*, which corresponds to a functional unit of *“olive oil to fulfilling the food preparation needs of one person for 68 days”.*

Allocation Procedures

Methods to deal with allocation

According to ISO 14040 (1997) allocation is the “partitioning of input or output flows of a unit process to the product system under study”. This is particularly difficult when dealing with processes fulfilling more than one function (Ekvall and Tillman, 1997) and some of the multiple products involved are crossing the system boundaries. Apart from multi-product or multi-function processes, allocation issues arise also in cases of open- or close-loop recycling. In all those cases materials and energy flows as well as associated environmental releases must be allocated to the different product streams according to clearly stated procedures, which shall be documented and justified (ISO, 1997). This is not an easy task “because of (the) arbitrary definition of product and by-products and the changing destination for (re)use of by-products” (Krozer, 1998). The main procedures developed to deal with allocation are to avoid allocation by [1] subdivision and [2] system expansion or to allocate environmental loads based on [3] physical and [4] other relationships.

Through the first approach, allocation can be avoided by subdivision of data. This means that a process is broken down into sub-processes and data for the subdivisions is required instead of data for the overall process. By dividing a unit process into two or more sub-processes each having one only product, input and output data related to the particular sub-processes can be collected and allocated to the single product. However, according to Ekvall and Finnveden (2001) this type of approach can be successful only if the sub-processes are physically separate in time or space.

The second approach used to avoid allocation, is the expansion of the system boundaries to include the additional functions related to the co-products (Rebitzer, *et al*., 2003). However, care must be taken, since avoiding allocation by expanding the system boundaries bears the risk of making the system too complex (EEA, 1997). Consequently, data collection, impact assessment and interpretation can then become too expensive and unrealistic in time and money.

The third and fourth procedures is to allocate inputs and outputs based on physical relationships of by-products, such as their mass or volume or to allocate inputs and outputs based on other relationships such as their economic value respectively. Although such a relationship can make allocation even more contentious because of the changing market prices (Krozer, 1998), it has been found that it is more appropriate for the LCA of agricultural systems (Sleeswijk *et al*., 1996).

Allocation issues in this study

A preliminary review of the system for potential allocation issues has revealed that the olive oil extraction process is a multifunction process. Firstly, apart from olive oil, vegetable water (in three phase centrifuge) as well as pomace are produced. If those effluents are treated as final waste flows then no allocation would be necessary. However, since further on-site and off-site treatment and partial re-utilisation follows they should be treated as by-products and an allocation issue occurs. Secondly, not the whole of the quantity of olive oil extracted may satisfy the quality standards set in order to be classified as extra virgin olive oil, i.e. the product of the study. In a similar way, if the quantity of olive oil falling outside the quality standards is utilised, then allocation procedures must be applied.

In regards to vegetable water, this was dealt by expansion of the system boundary to include its on-site treatment. However a further allocation issue occurs at that process. This is because, the vegetable water after negligible treatment may be reutilised for irrigation of olive trees (olive trees are resistant to high salinity and BOD waters), giving rise to close-loop recycling in the system. This issue was dealt again through boundary expansion and in particular by substitution allocation, i.e. the environmental load corresponding to the mass of water recycled is subtracted from the environmental load of the water supply for irrigation unit process as that mass of water is avoided.

In regards to the production of pomace during oil extraction, system boundary expansion was also undertaken to include its on-site treatment. However, as previously mentioned, pomace may also be utilised for extraction of pomace oil. This is however considered as a different consumer product, therefore it was to decided that it should not be included within the boundary of this study. Its exclusion, however, means that allocation is not avoided and therefore a different approach must be used in order to de-assign the portion of extractions and emissions corresponding to pomace exiting the system from the olive oil extraction process. The method selected was allocation based on the economic value of the by-products. This approach is the most appropriate in this case since the production of the most valuable product (olive oil) is the reason for production in the first place and has been used in the past for similar issues (Berlin, 2002 and Narayanaswamy *et al*., 2004).

The same procedure, i.e. allocation of process inputs and outputs based on the product's economic value, will also be used for the lower quality olive oil produced in the oil extraction process.

A similar allocation issue arises during the olive collection process, where a certain portion of olives may be of low quality, therefore unsuitable for processing into extra virgin olive oil. In this case, olives which are unsuitable for further utilisation into any product other product will be treated as final waste flows. If further processing takes place prior to their disposal the system boundary will be expanded to include this processing. In the other hand, for olives which are suitable for utilisation into a product other than extra virgin olive oil, allocation of olive collection inputs and outputs will be based again on the economic value of the products.

Table 3 summarises the method, with which allocation issues encountered in this study are dealt. It is highlighted that allocation percentages will be derived after data collection, in the next stage of this project.

Table 3 - Allocation issues and procedures to be used in this study

Unit Process	Issue	Method
Olive oil extraction	Production of vegetable water by-product	System boundary expansion
On-site liquid waste treatment	Part of treated liquid is sent to further treatment and part is recycled in a close-loop system through irrigation	Substitution allocation, avoided product for irrigation water supply
Olive oil extraction	Production of pomace by-product (to further treatment)	System boundary expansion
Olive oil extraction	Production of pomace by-product (for pomace oil extraction)	Allocation based on economic value
Olive oil extraction	Production of lower quality olive oil (not extra virgin)	Allocation based on economic value
Olive collection	Collection of olives unsuitable for utilisation neither into the product of the study nor into any other useful product	System boundary expansion
Olive collection	Collection of olives unsuitable for utilisation into the product of the study but suitable for utilisation into a defferent	Allocation based on economic value

product

Types of Impact and Methodology of Impact Assessment

Types of Impact

According to a study of the Institute for European Environmental Policy, IEEP (2002), environmental impacts arise as a result of farming activities of many kinds. The most important issues include the loss of biodiversity and decline in important habitats and species, loss of landscape diversity and quality, water pollution and excessive abstraction levels, soil erosion, air pollution by ammonia and greenhouse gases and the use of toxic substances. Agriculture in general contributed about 11 per cent of total EU greenhouse gas emissions in 1990-1997. Its share of carbon dioxide emissions was only about 2 per cent but it accounted for more than half of total nitrous oxides and nearly 45 per cent of methane emissions (OECD, 2001).

The agriculture stage of the olive oil cycle in particular, is highly associated with emissions to the ground, water and air from pesticides, herbicides and fertilisers. Fertilisation is a proven cause of eutrophication (nitrates, nitrites, ammonium salts, phosphorus, potassium etc.), whereas the persistent compounds used for handling weeds, pests and diseases are associated with toxicity (Jain *et al.*, 2002). Furthermore frequent tillage and heavy pesticide use also result in a considerable reduction in the diversity and total numbers of flora and fauna, including beneficial insect species (Cino, 1997 and Heller *et al.*, 2000)

Topsoil erosion by wind and water and also due to the fact that many oil tree plantations are often located on slopes is another common problem. This is further worsened by the common practice of short types of vegetation being removed and the low precipitation levels in the area of Mediterranean. Furthermore, salinity and soil acidification are relevant environmental impacts which need to be accounted.

Apart from the emissions, irrigation of olive vines, which is nowadays expanding rapidly, is contributing to water over-exploitation, putting heavy pressure on aquifers in several regions (IEEP, 2002).

Furthermore, olive tree farming is a process consuming electrical and chemical (fuel) energy, especially in cases where the olive vine is irrigated but also due to the use of machinery for soil management, pruning, olive collection etc. Energy production/consumption apart from the resource point of view has also a pollution point of view as it leads to emissions of pollutants and greenhouse gases to the atmosphere. Similarly diesel use in the transportation vehicles causes winter smog and releases carbon dioxide whereas the atmosphere can also be affected by the burning of pruning residues and other invasive scrub. The latter also contributes to the generation of solid waste.

Moving on the next stage in the life cycle, olive oil processing can also have a range of environmental impacts. These are mainly associated with the solid, liquid and air emissions of milling process. The types and amounts differ according to the process used. In Cyprus, Greece and Spain, two-phase or three-phase centrifuge process is used for oil extraction. The major waste streams associated with these processes are: liquid waste from the centrifuging decanters which separate the oil from other liquids, sludge settling at the liquid wastes evaporation tanks, sludge originating from the decanter and leaves from the defoliation. These wastes can potentially be associated with eutrophication and other impacts.

Electricity used in any activity is being generated at a power station for which fossil fuels are consumed, and emissions and wastes generated.

Transportation processes in the cycle, are mainly associated with abiotic resource use and emissions (carbon dioxide, NOx, VOCs, etc.). Furthermore, noise pollution from the vehicles is a significant impact of these processes.

An impact matrix associated with the life cycle of olive oil is shown in Figure 9. It is noted that this matrix is only preliminary and non-exhaustive and aims to assist to the selection of an appropriate impact assessment method in section 4.4 of this report. The relative magnitude of environmental impacts associated with the production of olive oil will be examined in detail in the analytical impact assessment stage of this study, the methodology of which follows.

	IMPACTS												
CAUSE	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
Use of fertilisers	■	■	■	■	■			■	■				
Use of pesticides/ herbicides	■	■	■	■	■			■					
Irrigation	■		■										
Burning of pruning residues			■								■		
Soil management	■		■							■			
Olive collection	■		■										
Waste from milling process									■		■		
Energy requirements	■		■				■						
Transportation	■		■				■					■	■

Figure 9 – Preliminary impact identification matrix

Methodology of Impact Assessment

According to ISO 14042 (1998), impacts associated with a product should be methodically assessed in four steps: [1] category definition, [2] classification/ characterisation, [3] normalisation and [4] weighting. It should be noted that steps 1 and 2 are mandatory whereas 3 and 4 are optional (ISO, 1998).

In category definition, impact categories, which cover the potential impacts associated with the product or product system considered, are selected for the study. Based on the findings of the previous section, the impact categories to be considered for this project should ideally include abiotic and biotic resource exhaustion, global warming, ecotoxicological and human toxicological impacts, photochemical oxidant formation, acidification, eutrophication, land use and solid waste.

During classification, the inventory input and output data is assigned to potential environmental impacts i.e. impact categories. In cases where outputs contribute to two or more different impact categories, they have to be mentioned as many times. The resulting double (or more) counting is acceptable if the effects are independent to each other.

Relative contribution of each input and output to the selected impact categories is assigned by characterisation. The potential contribution of each input and output to the environmental impacts has to be estimated. For some environmental impact categories there is consensus about equivalency factors to be used in the estimation of the total impact (e.g. global warming potentials, ozone depletion potentials etc.). For other environmental impacts, equivalence factors are not available at consensus level (e.g. biotic resources, land use etc.).

During normalisation, the magnitude of each environmental impact category is examined for the analysed system. Taking global warming as an example, normalisation is carried out by dividing the global warming potential of the system under investigation by the total global warming potential in Europe (Brentrup *et al*, 2000b). In order to keep the figures manageable, the total extent of the different environmental problems in Europe is expressed as environmental effects caused by one person per year. However, the normalised and dimensionless data do not allow any conclusion about the potential of the different effects to harm the environment. Therefore, an additional weighting step is required to consider the different significance level of the environmental effects. Weighting is not necessarily based on natural science but commonly on political or ethical values, and is a qualitative or quantitative step. Several methods for weighing have been developed by different institutions based on different principles such as “Proxy approach”, “Technology abatement approach”, “Monetarisation” etc (Lindeijer, 1996).

Data Collection Plan

Data Categories

The most resource-consuming steps of the implementation of this LCA study will be the collection and collation of data in order to build a life cycle inventory for olive oil. For each unit process, within the system boundary defined, quantified data on inputs and outputs must be collected. The flow types for which data is required for each unit process within the system boundaries are shown in Figure 10 using the olive oil extraction unit process as example. Inputs are material or energy that enters a unit process, whereas outputs are material or energy that leaves a unit process. A unit process is the smallest portion of a product system for which data are collected when performing a life cycle assessment (ISO, 1997). It must be emphasised that the input and output exchanges include non-flow related impacts such as land use or aspects of occupational health. Some authors choose to use the word “interventions” instead of “exchanges” to emphasise that non-flow related aspects are included.

The categories of data e.g. energy, occupied land, CO_2 emissions etc. that must be targeted during data collection must correlate to the impact categories and characterisation factors included in the impact assessment method to be used. It is highlighted that the data collected for flows can have various units. Furthermore, indicator parameters e.g. biochemical oxygen demand (BOD) may also be used. According to VROM and CML (2001), it is important to distinguish the emissions into the compartment they are released, i.e. air, soil, water and possibly in a more detailed manner, i.e. freshwater, seawater, agricultural soil, industrial soil etc.

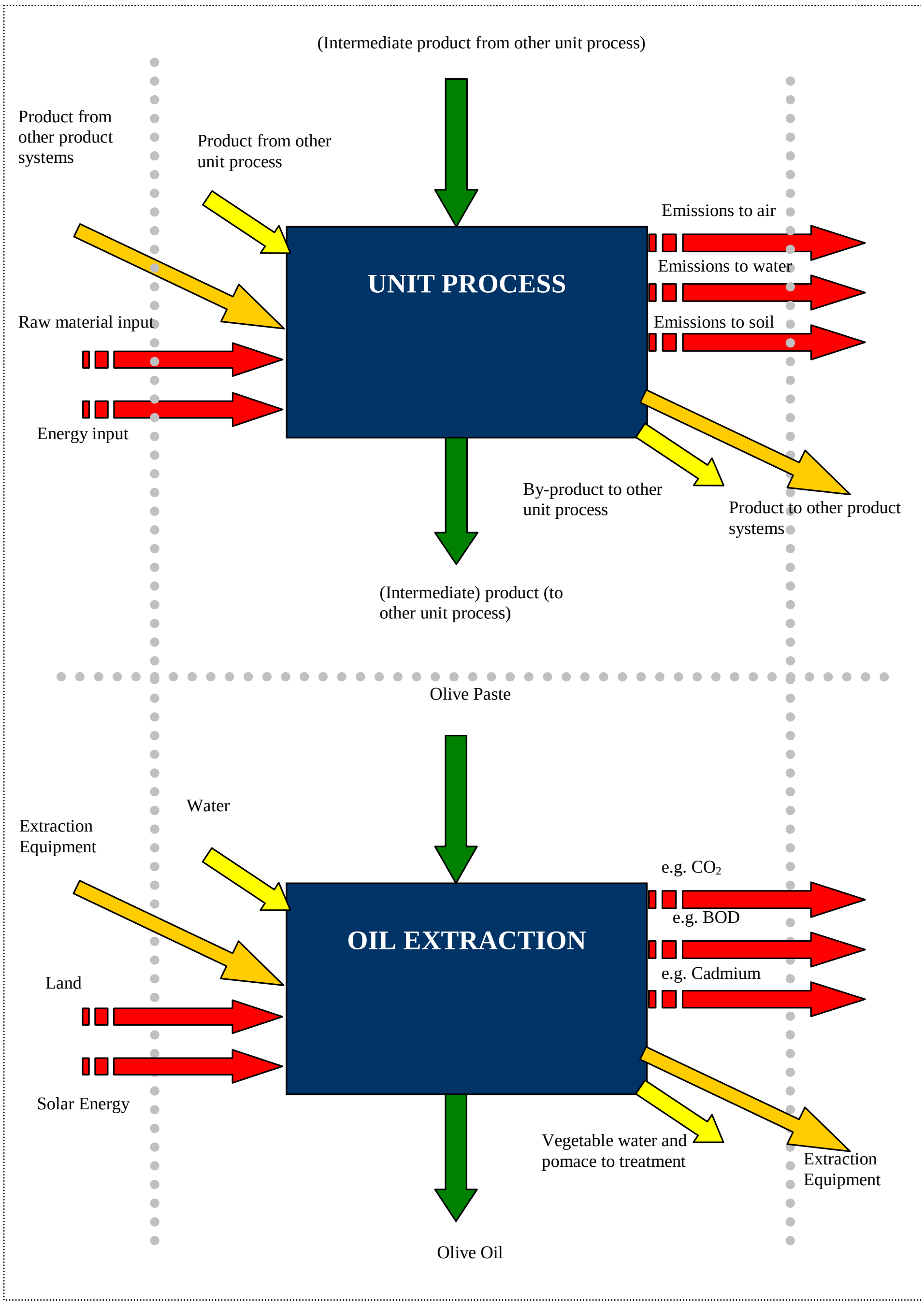

Figure 10 – Flow Data Required

The use of a transparent format is essential for quality assurance purposes. According to ISO 14049 (2000c), the data collected for each unit process should ideally include: [1] a reference unit, based on one or more incoming or outgoing material or energy flow, [2] a description of what the data includes, i.e. where the process begins and ends and which sub-processes are included, [3] the geographical source of the data and [4] the applied technology. Furthermore, for every single input or output, the period during which data has been collected and how data has been collected and how representative they are should be documented. Finally the name and affiliation of the person responsible for the data collection as well as the validation procedure used must be available for every single set of data used in this study.

If possible, the input and output data must be given with indication of uncertainty, preferably with information such as standard deviation and type of distribution for statistical analysis such as Monte Carlo analysis during the interpretation stage of this study.

A distinction can be made between foreground and background processes. Foreground processes are those unit processes for which case-specific primary data must be used, while background processes are those unit processes for which more general information can be used. It is important to remember that the larger the number of the unit processes treated as foreground, the more the detail and accuracy of the study but at the same time the more resource consuming. A preliminary classification of unit processes included within the system boundary into foreground and background processes is provided in Table 4.

Table 4 – Preliminary classification of unit processes for data collection

No.	Unit Process	Classification
1	Electricity production	Background
2	Irrigation water supply	Background
3	Irrigation	Foreground
4	Fertiliser production	Background
5	Transportation of fertilisers to farm	Background
6	Fertiliser application	Foreground
7	Pesticide production	Background
8	Transportation of pesticides to farm	Background
9	Pesticide application	Foreground
10	Herbicide production	Background
11	Transportation of herbicides to farm	Background
12	Herbicide application	Foreground
13	Soil management	Foreground

14	Olive tree planting	Foreground
15	Olive Tree cultivation	Foreground
16	Pruning	Foreground
17	Olive collection	Foreground
18	Transportation: Olive farm to production unit	Background
19	Water treatment	Background
20	Water supply	Background
21	Olive purification	Foreground
22	Olive grinding	Foreground
23	Oil extraction	Foreground
24	On-site liquid waste treatment	Foreground
25	Wastewater supply through network	Background
26	Wastewater treatment (public)	Background
27	Pomace processing	Foreground
28	Solid waste treatment	Background
29	Storage of olive oil	Foreground

Each unit process includes several flows of different inputs and outputs. The collection of all data is extremely time-consuming and difficult, if not impossible. For this reason certain criteria can be used to decide which inputs and outputs to include in the study. These criteria are known as “cut-off” criteria and can be distinguished into: [1] based on environmental relevance, where all inputs/outputs that contribute less than a certain percentage are neglected, [2] based on physical parameters, usually mass, where all inputs/outputs which contribute less than a defined percentage to the mass input/output respectively of the product system being modelled are neglected and [3] criteria based on socioeconomic parameters, usually the cost. The disadvantage of the last two types of cut-off criteria is that even small amounts of material flows and flows with low value can also have high environmental impacts. The first approach would be the most appropriate, however, its main disadvantage is that one cannot determine the environmental relevance before data is collected; hence no data collection avoidance is achieved. In this study a mass-based threshold limit of 1 per cent of inputs only is used.

Finally an important issue that must be considered when collecting data is to keep a consistent nomenclature of flows and other environmental exchanges. This must be compatible with the nomenclature used by SimaPro software and the standard impact assessment methods to be used.

Sources of Data

Apart from the definition of data categories, the identification of sources of data is important at this stage of the study as it will reduce the time required to actually collect the data at the inventory stage which follows.

The majority of data for foreground processes will be collected and collated directly from grain growers and processors, agricultural and environmental experts and olive oil farming associations. The data collection methods will include circulating data sheets and paying site visits to farms and factories in the case study areas. More specifically, data will be collected from meter readings from equipment and equipment operating logs in the olive groves and the olive oil processing units. In addition, telephone discussions and face-to-face interviews will be held with agricultural and LCA experts to verify the reliability of collected data. It is our intent to use as much site-specific information as possible.

For background processes, secondary data sources will be used to collect, obtain and calculate the datasets from published sources such as industry data reports, validated life cycle inventory databases, laboratory test results, government documents and reports, reference books, previous life cycle inventory studies, equipment and process specifications. The use of the best engineering judgement is essential throughout the data collection. SimaPro 6.0 educational version (PRé Consultants, 2004) software with the Ecoinvent database (Swiss Centre for Life Cycle Inventories, 2005) incorporated will also be used. When collecting data for background processes it is essential to remember that these may significantly influence the outcome of the study. Furthermore, the choice of background data from databases may limit the opportunities for choosing different allocation rules or cut-off criteria and conducting sensitivity and uncertainty analyses. It is very important to justify that each data source selected for background processes is representative with respect to the specification of the goal and scope of the study.

Data Quality Goals

Data quality is of paramount importance for the validity of this study as it will have a major influence on results. Prior to the collection of the data, specific quality goals must be defined to enable the goal and scope of the LCA study to be met. The data quality goals should ideally address: [1] time-related coverage, [2] geographical coverage, [3] technology coverage, [4] precision, [5] completeness, [6] representativeness of data, [7] consistency and [8] reproducibility. No pre-defined list of data quality goals exists for all LCA projects. The number and nature of data quality goals necessarily depends on the level of accuracy required to inform the decision-makers involved in the process. Data quality indicators are benchmarks to which the collected data can be measured to determine if data quality goals have been met.

Since the goal of this study is to identify the processes which contribute most to the overall environmental load (“hot spots”), the most suitable data would be average data that reflect the types of technologies used in case study region, originate from the case study region and are not too old. These requirements must dictate the choice of data in this study.

A list with data quality goals defined for this study and the associated indicators, where applicable, is given in Table 5. It is highlighted that different, less strict indicators have been defined for background data compared to foreground data. This is mainly due to the fact that background data will primarily be collected from databases and other generic sources, thus the definition of very high quality indicators would impose difficulties in regards to data availability. As foreground data will be collected specifically for this study the collection will follow the goals defined. Nevertheless, background processes are not expected to affect the results to a high extent.

Table 5 – Data Quality Goals and Indicators

Parameter	Goal	Indicator
Time-related coverage	Data used are dated and are not too old.	Foreground data: collected within the last year Background data: collected within the last 10 years
Geographical coverage	The geographical origin of data is specified. Data originate from study region.	Foreground data: Voukolies or Lythrodontas or Navarra Background data: Europe
Technology coverage	The study considers the actual technology used in case study regions. Abnormal conditions during measurements having an influence on data sets are reported.	Average technology
Precision	Variance of data sets is reported	Not defined
Completeness	Data sets quantify all significant flows	1% mass based input threshold
Representativeness of data	Data sets are case study representative	66% of locations (from the potential number in existence) reporting foreground data Average from processes with similar outputs in case study regions

Consistency	Apply uniform methodology for all three case study regions	Not defined
Reproducibility	With permission of the ECOIL research team	Not defined

Furthermore, all data sources should be clearly identified and referenced. If possible, conversion of the data should be minimised and, if necessary, clearly documented. Any inconsistencies from the data goals above should be noted.

Validation of the data process collected will be undertaken in this study. Various tools are available for this purpose, including mass balances, energy balances and comparison with data from other sources (VROM, CML, 2001, EEA, 1997). Any data found to be inadequate during the validation process should be replaced. Similarly at this stage, missing data should be identified and a decision on how these gaps will be filled should be made.

Limitations and Assumptions

The LCA technique in general has a number of limitations by default, which naturally will affect this study. Firstly, the technique focuses on environmental and some human health impacts, but does not address economic, social or other aspects. These aspects are significant parameters since often what is regarded as ecological can be at the same time expensive or socially unacceptable.

Secondly, any LCA involves a number of technical assumptions. This study, for example, considers extra virgin olive oil only, which makes up the majority of production in the three case study regions and for simplicity of the analysis no other distinction in regards to the product´s colour or aroma is made. In addition, the characteristic production chain is considered for each case study region, therefore alternative olive oil products, practices and processes used to a lesser extend are not accounted. Furthermore, it is assumed that olive groves have been planted specifically for the production of olive oil thus, as discussed during the definition of the system boundaries, they are considered as industrial systems and not as parts of the environment. Furthermore, the environmental exchanges are typically assumed to be linearly related to one of the product flows of the unit process, a rather simplifying but not strictly correct assumption.

In addition to the technical assumptions that had to be made there are also some “value choices”. For the selection of impact categories assessed, for example, although particular attention was paid in identifying the most important impacts resulting from olive oil production and selecting the most appropriate standard environmental impact assessment methods accordingly, the selection of the impacts, which the study deals with, is still subjective.

Bennett (2004), reports that it is important that such assumptions and choices are transparent with justification as to their use. In this study, every effort was made to ensure that such assumptions and choices are thoroughly justified.

Thirdly, as with any analysis, there are data limitations. Guinee (2002) notes that, for any LCA, "in practice, data are frequently obsolete, incomparable or of unknown quality". Although databases are being developed in many central and northern European countries, databases including data from southern Europe are not readily available. Moreover, the Ecoinvent database, which is one of the most widely used LCA databases and is included in SimaPro 6.0 software, although includes agricultural processes of many varieties it does not include olive tree cultivation, therefore there is no validation basis for those data sets, which will be collected from the sites.

A fourth limitation of this study and every other LCA study is the fact that environmental impacts are not specified in time and space and are related to an arbitrarily defined functional unit. However, this will not inhibit the achievement of the goal of the study which is not the exact quantification and specification of impacts but the identification of the environmentally undesirable processes in relative terms.

Type and Format of the Final Report

The ISO standard outlines the requirements of how the results of an LCA should be documented:

> "The results of the LCA shall be fairly, completely and accurately reported to the inteded audience... The results data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA-study. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study." (ISO, 1997)

According to VROM, CML (2001), reporting is a crucial issue in LCA. A technically excellent LCA without a transparent and unambiguous report will be of limited value. Thus the basic requirement of the report is transparency. The reader of the report should be able to understand what has been analysed, how allocations issues were handled, and what data was used. In this study, the results will also be communicated to third parties i.e. interested parties other than the commissioner or the practitioner of the study. Hence, in accordance with ISO 14040 (1997) a third-party report shall be prepared. According to the same standard, the third-party report must cover: [1] General aspects, [2] the definition of goal and scope of the study, [3] analysis of the life cycle inventory, [4] Life Cycle impact assessment and where applicable [5] critical review.

A non-exhaustive list of what must be included in the final report of this study is provided in Table 6.

Table 6 – Format of final report

Chapter	Subchapters	Contents
Front Page	-	Title of project Course number Date Group number - Authors and affiliations
Executive Summary	-	- A non-technical summary statement designed to provide a quick overview of the full-length report
1. Introduction	-	A statement that the study has been conducted according to the requirements of International Standard ISO 14040 (1997) - Background of the problem
2. Goal and Scope of the Study	2.1 Goal of the Study	Reasons for carrying out the study Intended application - Practitioner, intended audience and interested parties
	2.2 Scope of the study	Description of the Product System Definition of system boundaries Description of the functions of the product system Definition of the functional unit and reference flows Allocation procedures Types of impacts considered in the model and impact assessment method used Data collection plan - Limitations and assumptions

3. Life Cycle Inventory Analysis	3.1 Process Flowchart	Flowchart including processes that are included in the modelled product system - Processes related to the system that have been excluded
	3.2 Data	Documentation of the data, assumptions, allocation procedures, and data gaps related to each process of the product system Description of the data used Documentation of foreground data obtained for this study with source, assumptions, and calculations Documentation of data from databases in SimaPro with complete reference to the database and the process name - Documentation of data from other LCA sources with complete reference.
4. Life Cycle Impact Assessment	4.1 Impact categories	- Description of the impact categories assessed and common sources of such impacts
	4.2 Classification	- Documentation of classification of resource consumption and emissions to impact categories
	4.3 Characterisation	- Documentation of characterisation factors used
	4.4 Normalisation and Weighting (if applied)	- Documentation of normalisation and weighting method used
	4.5 Results	Presentation and analysis of results Identify significant impacts and significant life cycle stages Explain the cause (source and emission) of main impacts - Explain important differences between alternatives.
5. Life Cycle Interpretation	5.1 Data Quality Assessment	Data quality assessment Consistency check Contribution analysis

	Anomality assessment Notes on validity of choices in goal and scope definition Notes on appropriateness of impact assessment methods - Notes on major uncertainties in the data and model
Conclusions and Recommendations	Provide conclusions in regards to the stages of the olive oil production cycle that have significant impact to the environment - Based on the results of the study provide guidelines on the selection of particular processes to reduce the environmental impacts
References	- Complete list of references, ordered in alphabetical order

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^3)
3	Irrigation	Material	Irrigated water (m^3)
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^2)
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^3)
20	Water supply	Material	Water supplied (m^3)
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^3)
25	On-site liquid waste treatment	Waste treatment	Liquid waste treated on-site (m^3)
26	Wastewater supplied through network	Waste treatment	Wastewater supplied through network (m^3)
27	Wastewater treatment (public)	Waste treatment	Treated wastewater (public) (m^3)
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)

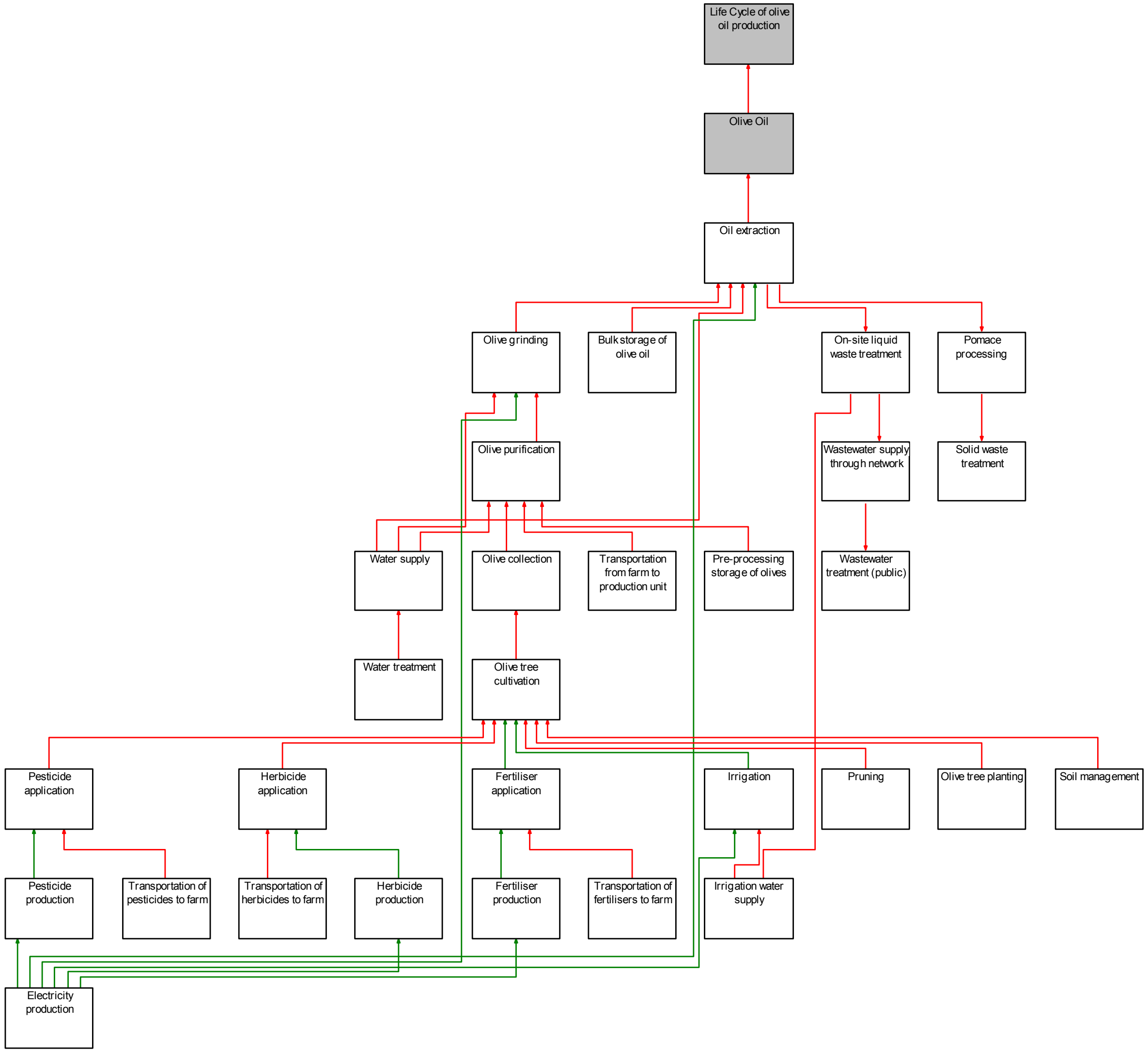

Figure 11 – The basic model of the olive oil life cycle developed with SimaPro 6

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.

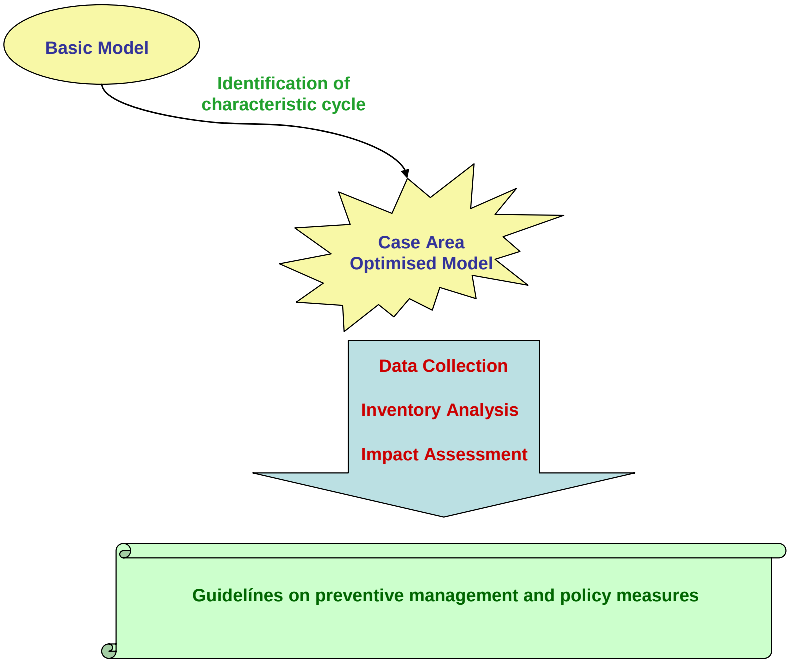

Figure 12 – The way forward

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 extend 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 Invetories (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.

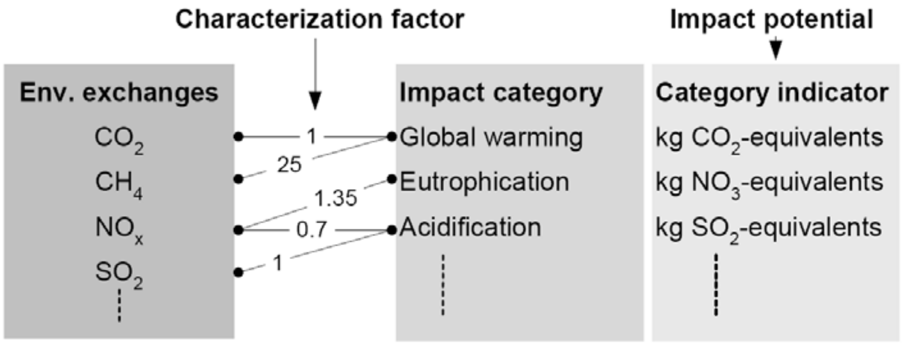

Figure 13 – Example of classification, characterisation and category indicator (Thrane and Schmidt, 2004)

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.).

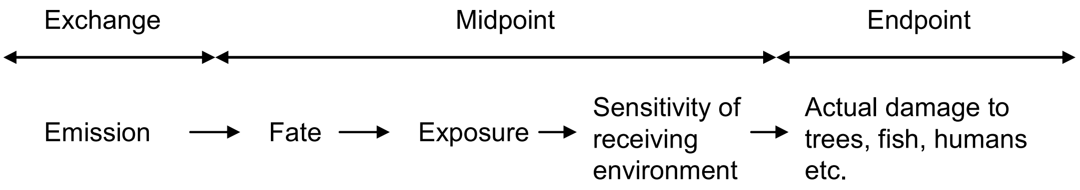

Figure 14 - The impact chain for an emission of a given substance (Hauschild, 2003)

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 emmissions. 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 NO_x being omitted from the method. In regards to Acidification Potential (AP), the reference substance is SO_2 while SO_x are also included by equating them to 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 emmission 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 are 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_2, 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 NOx, 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_2 formation from CO emissions. Radiative forcing due to emissions of NOx, 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 CO2 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

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.