"Life Cycle Assessment (LCA) as a Decision Support Tool (DST) for the ecoproduction of olive oil"

TASK 4.1

Life Cycle Environmental Impact Assessment

Lythrodontas Region

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LIFE-Environment

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1 Developing a DST for Olive Oil Production

During the preceding third task of this project a Life Cycle Inventory Analysis of the production of olive oil in the three case study regions, was implemented (Avraamides *et al.*, 2006). This resulted to a quantitative list of resources consumed and emissions released from the production of olive oil. The third step in the LCA methodology as defined by the relevant standards (ISO, 1997) and as prescribed in the framework definition of this study (Avraamides *et al.*, 2005) is the assessment of the impacts arising from the system under study (Figure 1).

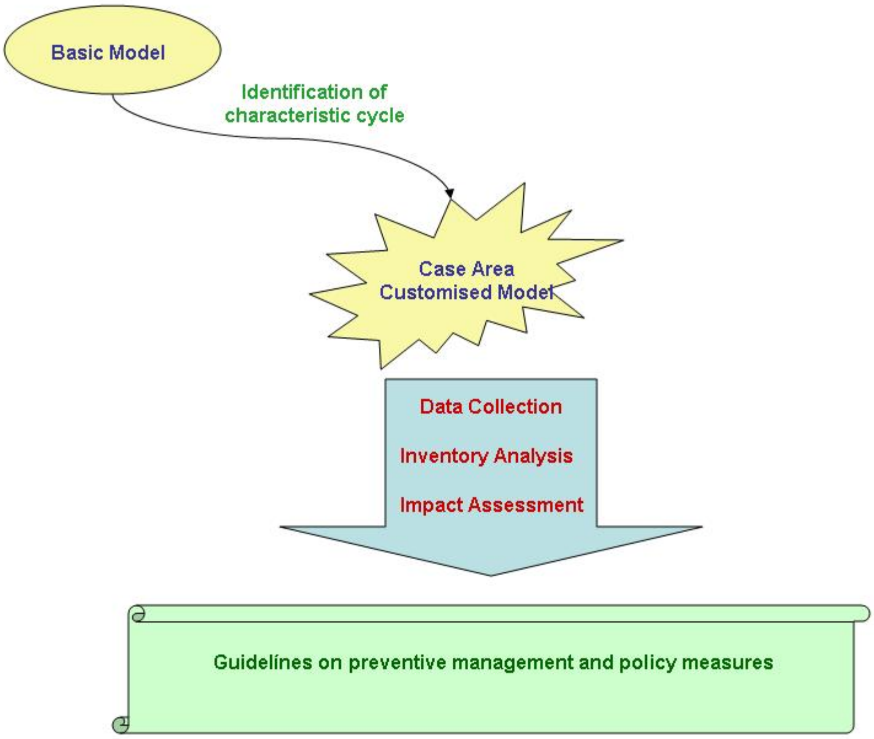

Figure 1 – The implementation plan foreseen during the development of the LCA framework (Avraamides et al., 2005)

This report presents the results of the impact assessment step of the olive oil production system life cycle in Lythrodontas and draws conclusions on the system processes that need to be reconsidered in order to enhance the environmental profile of the production of olive oil.

2 Life cycle impact assessment

2.1 General

The purpose of the life cycle impact assessment (LCIA) is to assess a product system's life cycle inventory (LCI) results in order to better understand their environmental significance (ISO, 2000). It is a complex procedure, for which the scientific community is often in disagreement both on the methodology to be used (Rebitzer *et al.*, 2001) and also on the interpretation of the results obtained using different approaches (Finnveden, 2000). This complexity lies in the cause-effect chains, linking inventory emissions and resource depletion to the consequences.

As shown in Figure 2, 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.*, 2002a). An example of an exchange is the emission of CFC gases, which causes 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.).

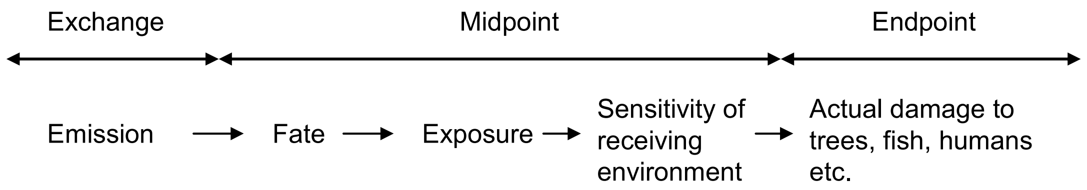

Figure 2 - The impact chain for an emission of a given substance (Hauschild, 2003)

Due to the intricacy of evaluating the cause-effect chain of each environmental problem, many LCIA methods have been published and used by LCA practicioners. Based on the impact chain, these 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 the so-called "end-point" approach as they model the potential damage on value items such ecosystem quality, human health etc.

According to Thrane and 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.

In regards to the approach followed by each method, the majority of methods developed 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 of the impact assessment methods to be used in this study. Based on these considerations, as discussed in previous reports (Avraamides *et al.*, 2005), the CML 2 baseline 2000 and Eco-Indicator 99 methods were chosen for application in this study.

The LCIA phase models selected environmental issues, called impact categories, and uses category indicators to condense and explain the LCI results. Category indicators are intended to reflect the aggregate emissions or resource use of each impact category. However, it is important to highlight that we only consider potentials impacts. Whether the potentials materialise, 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. The results of the LCIA step can be used to identify product system improvement opportunities and assist in their prioritisation and this is exactly our aim in this study.

2.2 Methodology

ISO 14042 (2000) defines a standard methodology for the assessment of impacts comprises, as shown in Figure 3.

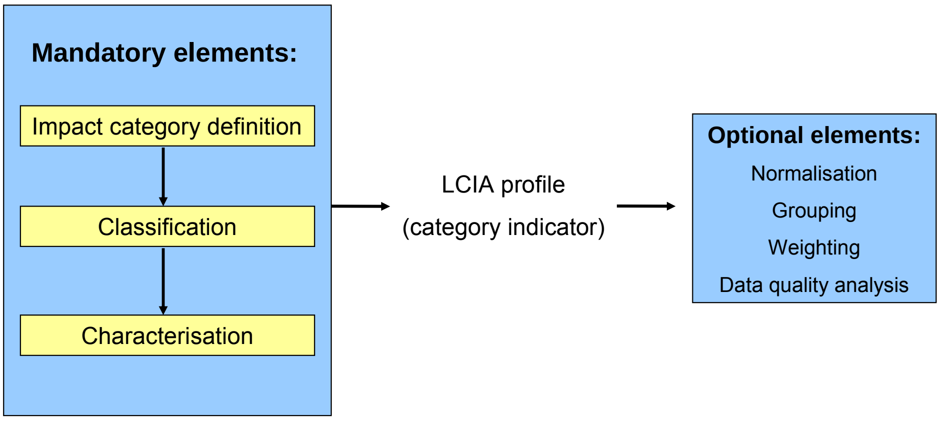

Figure 3 – Life Cycle Impact Assessment according to ISO 14042

According to this methodology, LCIA comprises of: [1] the definition of impacts to be assessed (category definition), [2] the classification of inventory input and output into the defined impacts, [3] the consideration of their relative contribution to the impact (characterisation), resulting to an impact potential indicator for each category, as shown in Figure 4, [4] the normalisation of each impact assessed to a reference unit for the assessment of the importance of each and [5] the weighting of the "importance" of each impact based on political and/ or ethical values. According to ISO 14042 (2000) steps [4] and [5] are optional in the impact assessment methodology.

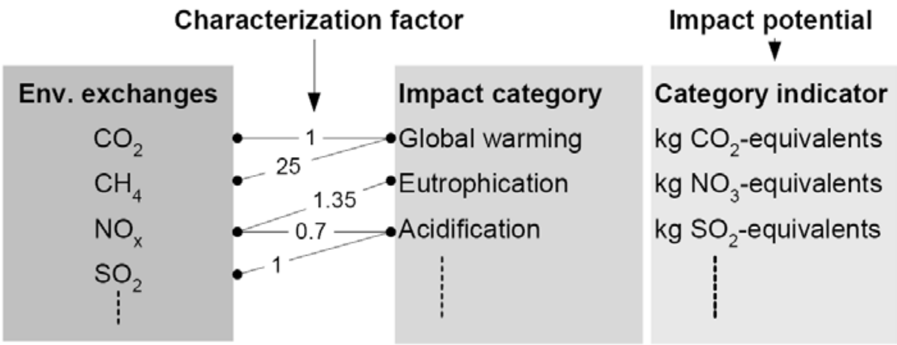

Figure 4– Example of classification, characterisation and category indicator (Thrane and Schmidt, 2004)

3 CML 2 baseline 2000

3.1 General

The methodology of the Centre for Environmental Studies (CML) of the University of Leiden was originally published in 1992 (CML, 1992) as part of the Dutch guide to LCA and formed the basis for the development of the majority of other LCIA procedures, including the Society of Environmental Toxicology and Chemistry (SETAC) LCA code of practice (Consoli *et al*., 1993). The methodology was updated in 2000 (CML 2 baseline 2000). It is compatible with the ISO standard (ISO, 2000) and indicates explicitly where it goes beyond the standard. It is a problem-oriented method.

The classified impact categories for the characterisation step of the procedure are abiotic depletion, global warming, ozone layer depletion, human toxicity, water ecotoxicity, photochemical oxidation, acidification and eutrophication (Da Silva and Kulay, 2003) and are based on up-to-date scientific principles, as developed within the scientific community of SETAC and its working groups.

During the characterisation step, similarly with CML 1992, CML 2 baseline 2000 uses 100-years Global Warming Potential (GWP). 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 the category indicator used. Human toxicity potentials are expressed as 1.4-dichlorobenzene equivalents, while for abiotic depletion kg antimony equivalents are used, as shown in Table 1.

Table 1 – Characteristics of the CML LCIA methodology (Guinee et al., 2001)

Impact categories	Units of measurement	Normalisation and weighting
Eutrophication	kg of PO_4^{3-} equivalence of substances	Normalisation
Ozone depletion	kg of CFC-11 equivalence of substances	Choice of normalised values
Eco-toxicity	kg of 1, 4-dichlorobenzene equivalence	given for:
Greenhouse gases	kg of CO_2 equivalence of substances	• World population (1990)
Acidification	kg of SO_2 equivalence of substances	• The Netherlands (1997)
Photo-oxidant formation	kg of C_2H_4 equivalence of substances	• Western Europe (1995)
Human toxicity	kg of 1, 4-dichlorobenzene equivalence	
Energy use	MJ or kg of fuel per MJ	Weighting
Solid waste	kg of waste	No weighting procedure included
Abiotic resource depletion	kg of Sb equivalence	or recommended.
Land use	m^2.yr (increase of land competition)	

As shown in Table 1, sets of normalisation data are derived for three separate regions, i.e. the Netherlands (1997), Western Europe (1995) and the World (1990). CML indicates that a uniform set of regionally specified reference values is lacking and additional data sets are required for the different temporal scales, especially global data, based on empirical measurements and derived statistics. A certain level of uncertainty therefore exists with regards to the proposed normalisation data (Huijbregts *et al.*, 2003). In this study, Western European normalisation data have been used (Table 2) as the most representative set of the case study region analysed.

Table 2 – Annualised factors for normalisation for different reference regions (Huijbregts et al., 2003)

Impact categories	Units of measurement	The Netherlands (1997)	Western Europe (1995)	The World (1990)
Abiotic resource depletion	kg (Sb eq.).yr^{-1}	1.71×10^{9}	1.06×10^{10}	1.58×10^{11}
Climate change	kg (CO_2 eq.).yr^{-1}	2.51×10^{11}	4.73×10^{12}	4.45×10^{13}
Ozone depletion	kg (CFC-11 eq.).yr^{-1}	9.77×10^{5}	8.03×10^{7}	1.14×10^{9}
Human toxicity	kg (1,4-DCB eq.).yr^{-1}	1.88×10^{11}	7.57×10^{12}	5.71×10^{13}
Eco-toxicity				
Freshwater aquatic	kg (1,4-DCB eq.).yr^{-1}	7.54×10^{9}	5.05×10^{11}	1.98×10^{12}
Marine aquatic		4.26×10^{12}	1.14×10^{14}	9.11×10^{13}
Photo-oxidant formation	kg (C_2H_4 eq.).yr^{-1}	1.82×10^{8}	8.24×10^{9}	1.07×10^{11}
Acidification	kg (SO_4 eq.).yr^{-1}	6.69×10^{8}	2.74×10^{10}	3.13×10^{11}
Eutrophication	kg (PO_4^{3-} eq.).yr^{-1}	5.02×10^{8}	1.25×10^{10}	1.32×10^{11}

Weighting is not available in CML 2 baseline 2000 method used in SimaPro (PRé Consultants, 2004).

As a problem-oriented method, CML methodology does not take into account the consequences or resulting damages of environmental interventions. The published documentation stipulates a comprehensive list of classified impact categories. However, quantified characterisation procedures for all these categories have not been proposed and the key impact category, especially for olive oil production, of water as resource has been excluded, although the impact on water quality is taken into account in terms of freshwater and marine aquatic eco-toxicity.

3.2 Characterisation results

The LCIA results, using the CML 2 baseline 2000 method (Figure 5), show that the olive agriculture stage is the predominant contributor in all impact category indicators. Its contribution ranges from 64.9% in the "terrestrial ecotoxicity" impact indicator to 99.6% in the "photochemical oxidation".

The contribution of the agricultural stage in the “terrestrial ecotoxicity” impact indicator is 66.4%, whereas in “eutrophication”, “ozone layer depletion “ and “marine aquatic ecotoxicity” impact indicators the contribution is 87.8%, 88.3% and 88.9% respectively. In the “abiotic depletion”, “human toxicity”, “global warming” and “acidification” impact indicators the contribution of the agricultural stage is 92.5%, 96.4%, 96.8% and 97% respectively.

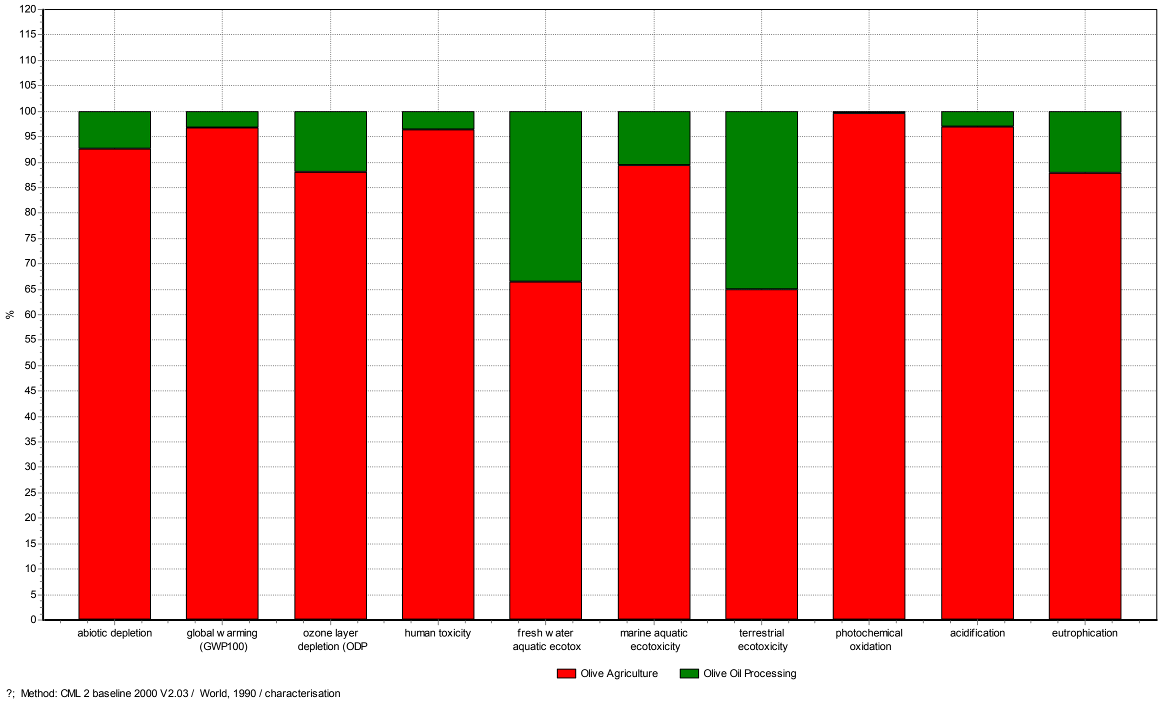

Figure 5 – Olive oil production characterisation results (CML 2 baseline 2000)

3.2.1 Abiotic depletion

According to the analysis, the system of olive oil production in Lythrodontas is responsible for the aviotic depletion of 0.0173 kg antimony (Sb) equivalents, from which 0.016 kg in the agricultural stage (Figure 6).

Over half (50.2%) of the abiotic resources consumed are related to fertilisers (mainly their production processes, 46.2%), whereas the production and use of pesticides contributes another 19.9% to the overall resource depletion. Within the agricultural stage, soil management (9.2%) and irrigation (6.9%) are also considered significant stages in terms of abiotic resource depletion, mainly due to the consumption of oil and associated fuels for the operation of tractors and the extraction of water from wells.

In the processing stage, which overall contributes a total of 7.5% of the system´s resource depletion, the generation of electricity required for the operation of the olive oil processing plant is the dominant contributor (7.3%).

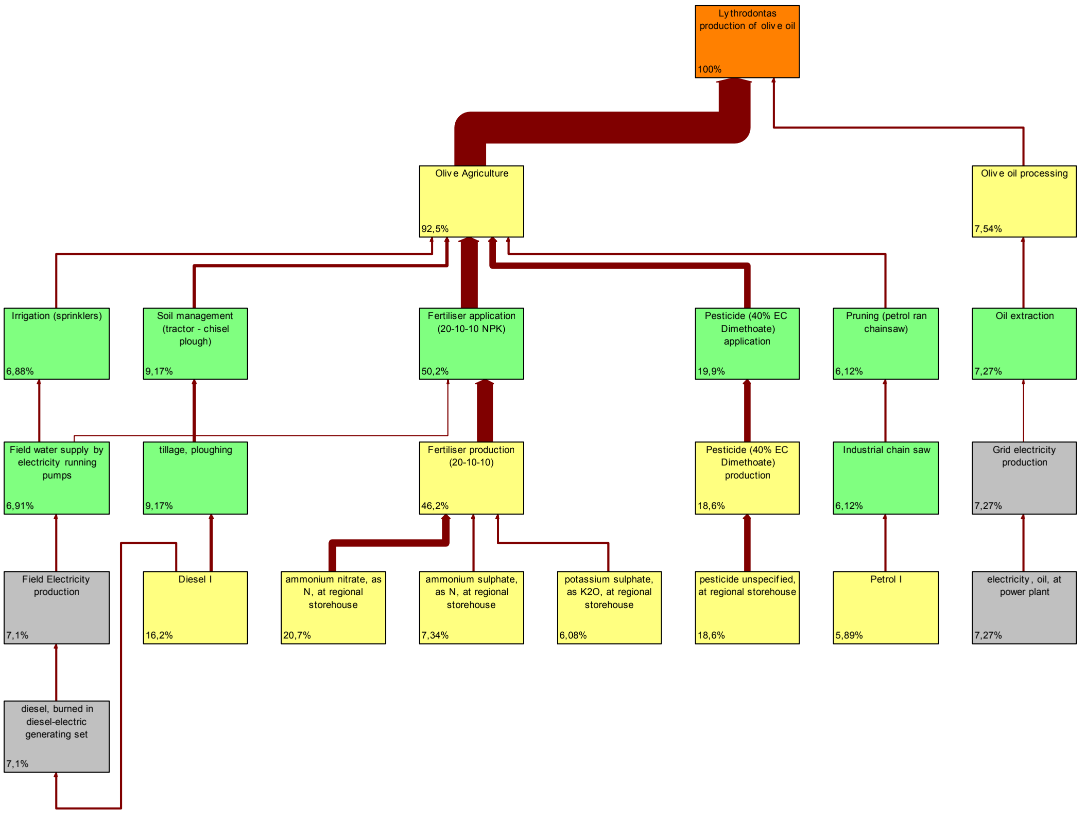

Figure 6 – Process contribution in abiotic resource depletion (4% cut-off)

The main abiotic resource depleted by the system is crude oil. The consumption of crude oil is equivalent to 0.00995 kg Sb eq. (57.5%), followed by natural gas (35.8%) and coal (6.6%) as shown in Figure 7.

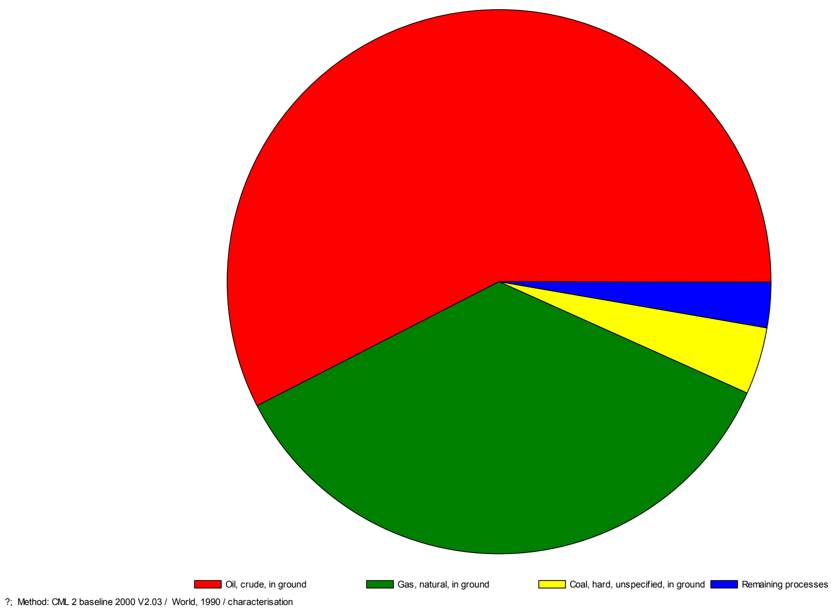

Figure 7 – Abiotic resource depletion of olive oil production by substance

3.2.2 Global Warming

According to the analysis, the system of olive oil production in Lythrodontas is responsible for the emissions of 7.9 kg CO_2 equivalents, from which 7.65 kg (96.8%) are emitted from agricultural stage processes, as shown in Figure 8.

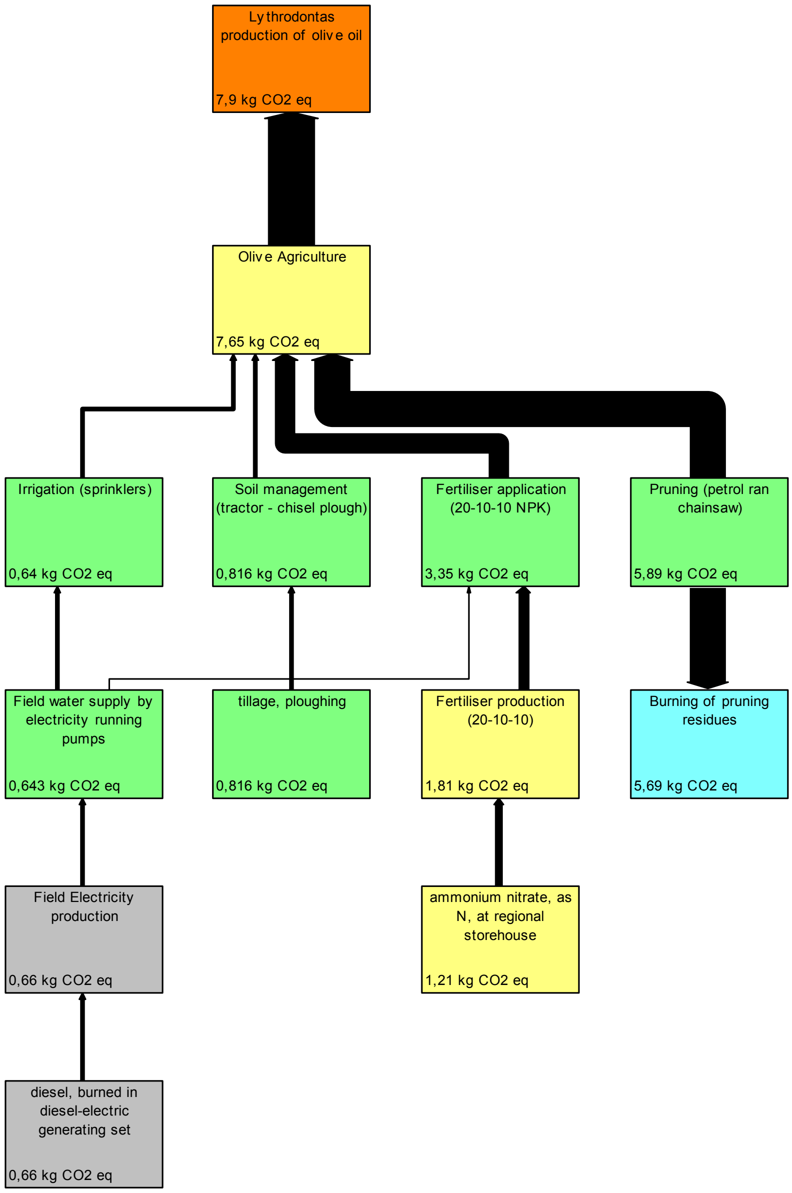

Figure 8 – Process contribution in global warming impact category (4% cut-off)

Pruning is the main contributor to greenhouse gas emissions (5.89kg CO_2 eq.), mainly due to the emissions from burning the pruning residue (5.69kg CO_2 eq.), whereas the use of fertilisers (production and application) is responsible for the emissions of 3.35kg CO_2 equivalents. Soil management (tractor operation) and irrigation (field electricity generation) are also significant contributors.

In the other hand, the absorption of carbon dioxide from the olive tree groves is beneficial in the reduction of greenhouse gas emissions by 3.4 kg CO_2 equiv., as shown in Figure 9. Nevertheless the system is a net contributor to global warming.

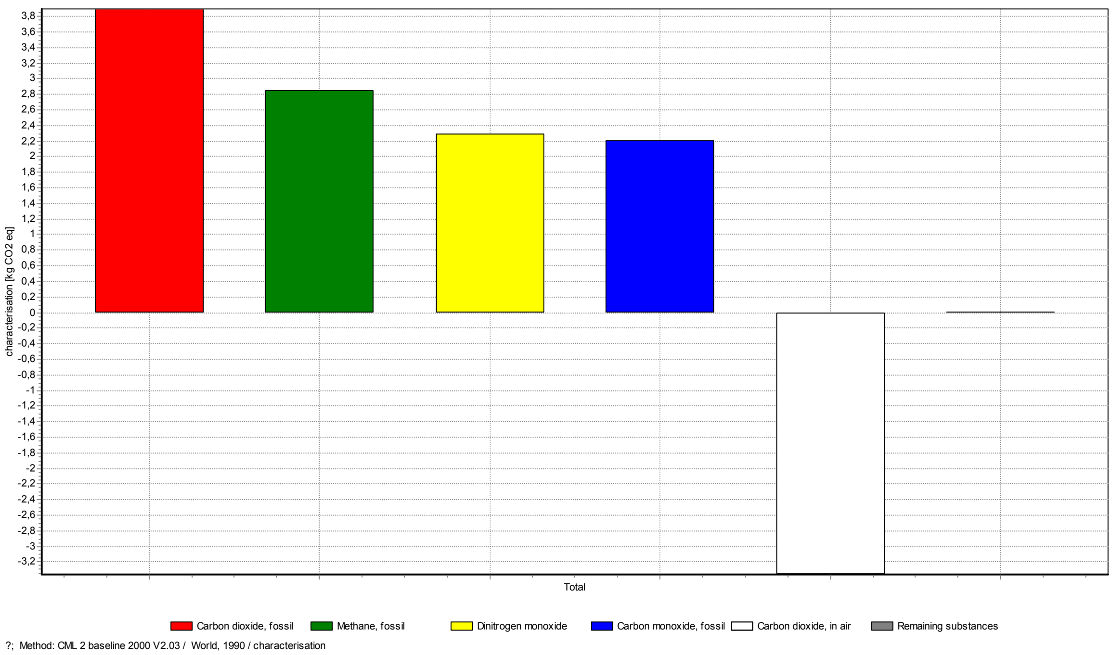

Figure 9 – Global warming from olive oil production by substance

In regards to the specific emission substances, the main greenhouse gases released are: carbon dioxide (3.9kg CO_2 eq.), methane (2.85kg CO_2 eq.), dinitrogen monoxide (2.3kg CO_2 eq.) and carbon monoxide (2.2kg CO_2 eq.).

3.2.3 Ozone layer depletion

The analysis has shown that, the system of olive oil production in Lythrodontas is responsible for the emissions of 2.14×10^{-7} kg CFC-11 eq., from which 1.89×10^{-7} kg CFC-11 eq (88.1%) are emitted from agricultural stage processes, as shown in Figure 10.

Processes which contribute most in this category are: the production of fertilisers (57.6%), the production of pesticides (24.2%) and electricity generation required for the operation of olive oil processing plant (11.5%) (Figure 10).

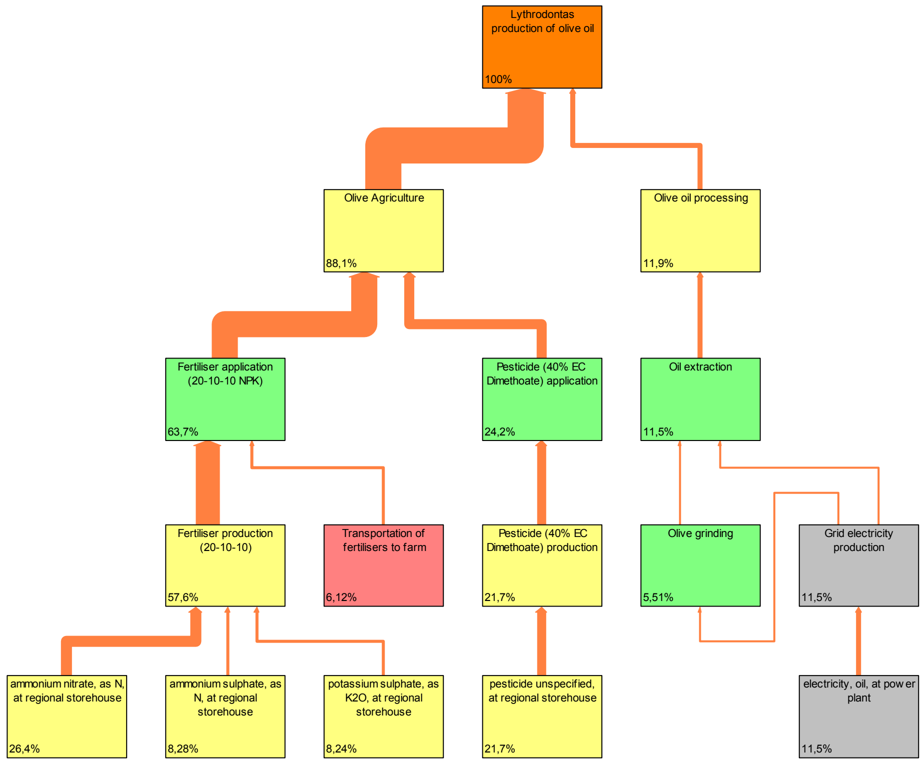

Figure 10 – Process contribution in ozone layer depletion impact category (5% cut-off)

In regards to ozone depleting substances released, these comprise of methane, bromotrifluro- (Halon 1301) sunstances (61.2%) and methane, bromochlorodifluro- (Halon 1211) substances (36.8%) (Figure 11).

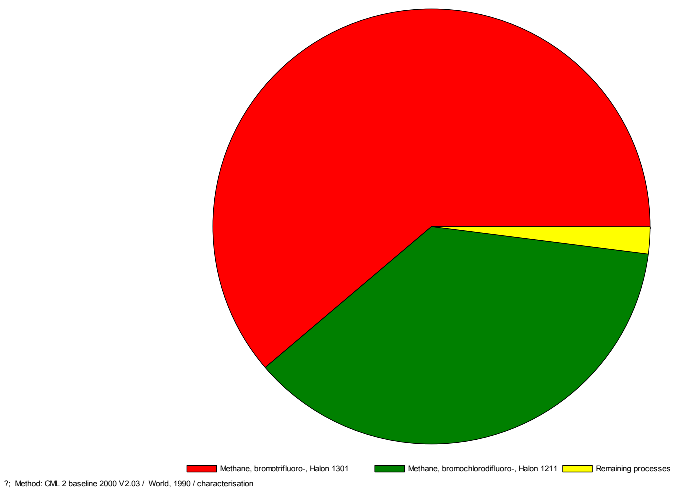

Figure 11 – Ozone layer depletion substances released from olive oil production

3.2.4 Human toxicity

The application of CML 2 baseline 2000 LCIA method has shown that 30.9 kg 1,4-DB eq. are released by the olive oil production system under study, from which 96.4% in agricultural related processes.

As shown in Figure 12, burning of the pruning residues in open fires is the dominant contributor to human toxicity with 89.3%. Other processes which affect the overall human toxicity load of the system, although to a minor extent, are: the application of pesticides (4.2%) and the disposal of liquid waste in evaporation ponds (3.14%).

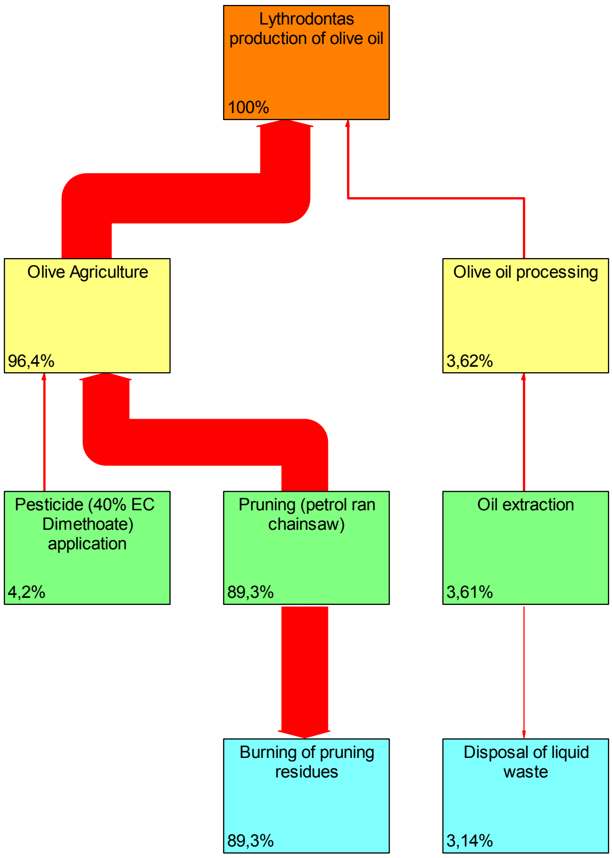

Figure 12 – Process contribution in human toxicity impact category (3% cut-off)

In regards to the toxic substances released by the system (Figure 13), these mainly comprise of benzene (27.3 kg 1,4-DB eq, 88.3%.) and dimethoate, which is the active substance of the characteristic pesticides used in the region of Lythrodontas (1.2 kg 1,4-DB eq., 3.9%).

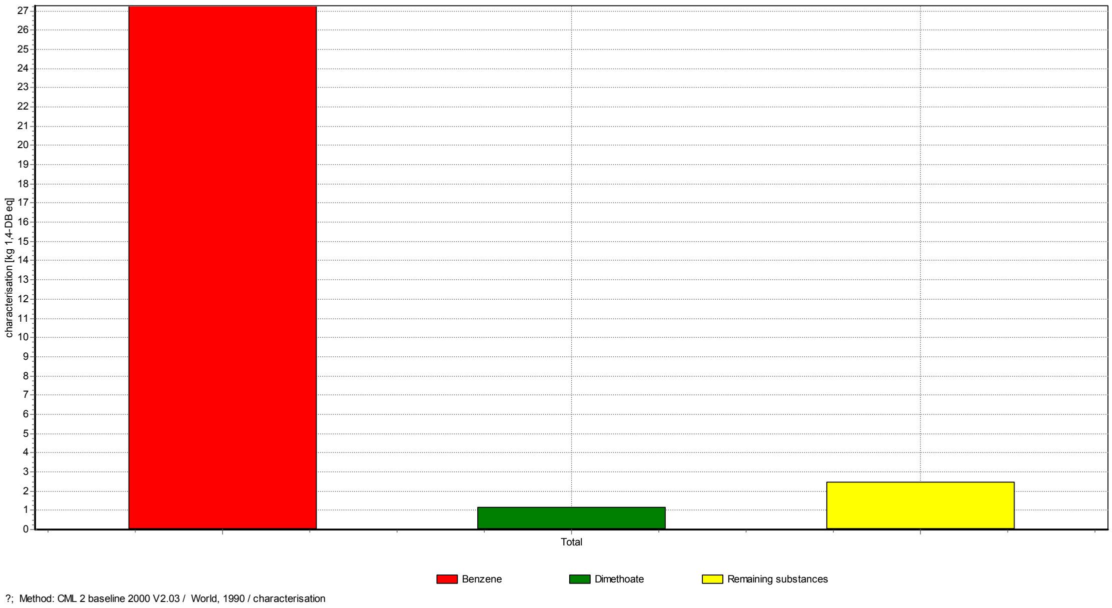

Figure 13 –Human toxicity of olive oil production system by substance

3.2.5 Fresh water, marine aquatic and terrestrial ecotoxicity

The analysis shows that the fresh water aquatic, marine aquatic and terrestrial life ecotoxicity caused by the production of 1 litre of olive oil in Lythrodontas is 0.69, 1170 and 0.05 kg 1,4-DB eq. respectively. In all impact categories, the agricultural stage is the main stage responsible with 66.4%, 88.9% and 64.9% respectively.

In the fresh water ecotoxicity category (Figure 14), over half of the load originates from the application of pesticides to olive groves (50.8%), whereas liquid waste from olive mills disposed to evaporation ponds contributes a further 33.6%. Other processes affecting the magnitude of the fresh water ecotoxicity load are the burning of pruning residue (9.1%) and the production of fertilisers (6.3%).

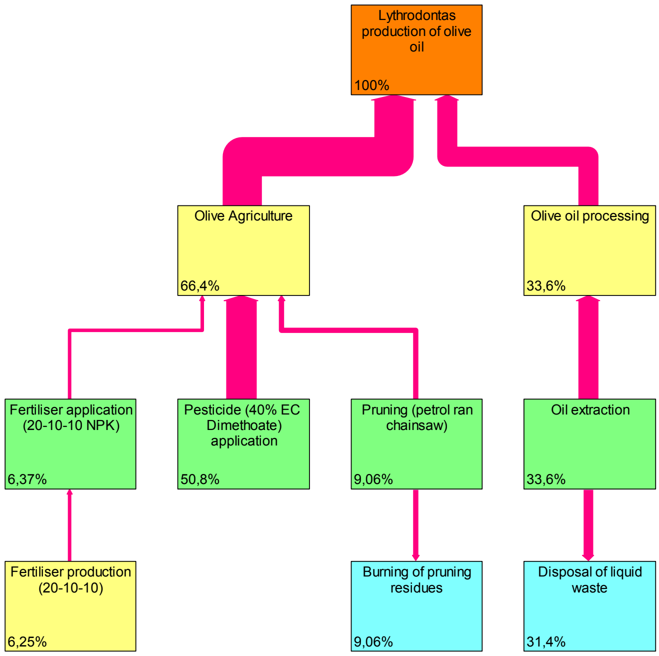

Figure 14 – Process contribution in fresh water ecotoxicity impact category (5% cut-off)

The main substances, which are released by the system and contribute to the fresh water ecotoxicity impact category are: dimethoate (active ingredient of pesticide used), phenols, vanadium, nickel and cadmium, as shown in Figure 15.

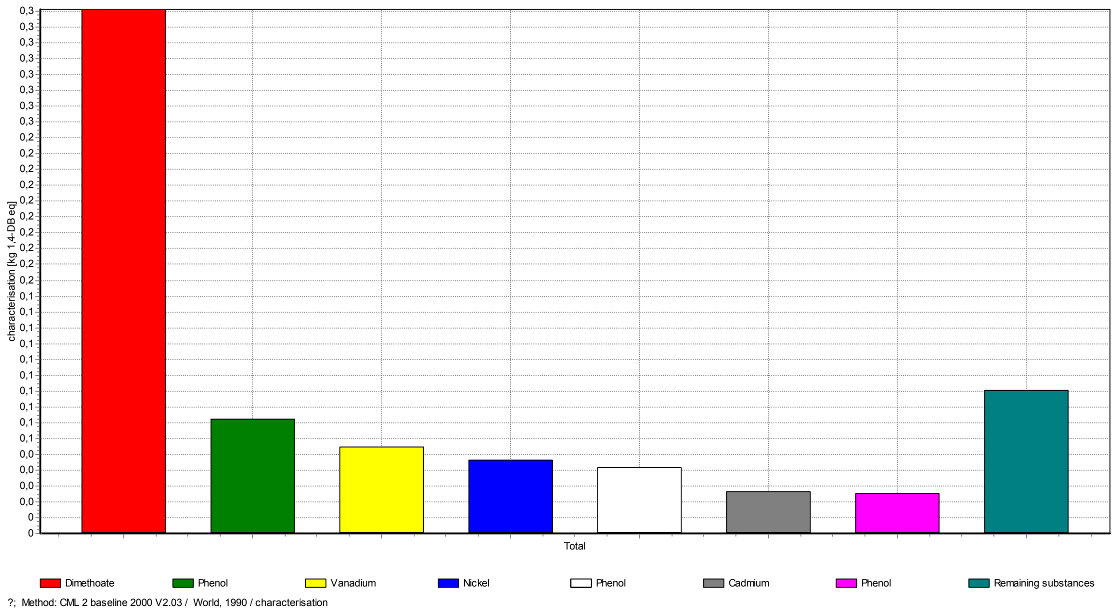

Figure 15 –Fresh water ecotoxicity of olive oil production system by substance

In the marine aquatic ecotoxicity category (Figure 16), the production of fertilisers is by far the most significant contributor (62.5%), followed by the burning of pruning residues (15.3%) and the production of pesticides (11.4%).

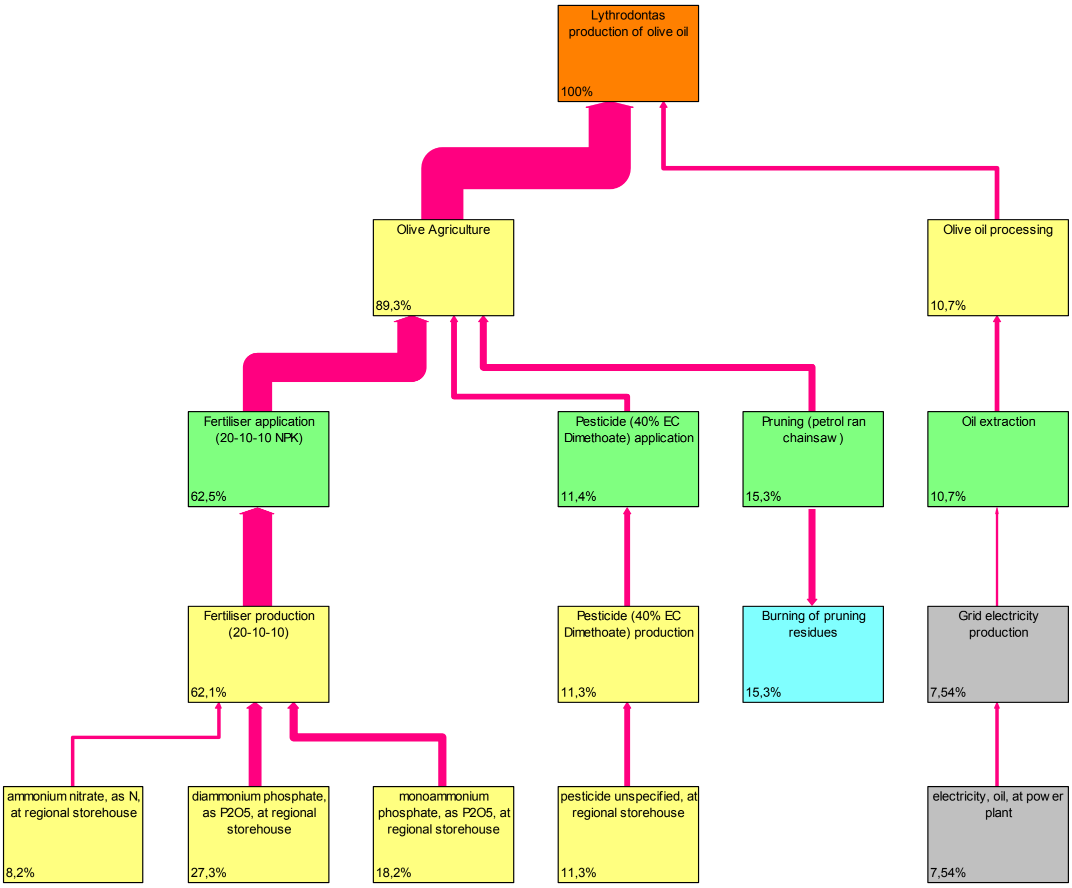

Figure 16 – Process contribution in marine aquatic ecotoxicity impact category (5% cut-off)

The main substances, which are released by the system and contribute to the marine aquatic ecotoxicity impact category, are: hydrogen fluoride, vanadium and nickel ion, as shown in Figure 17.

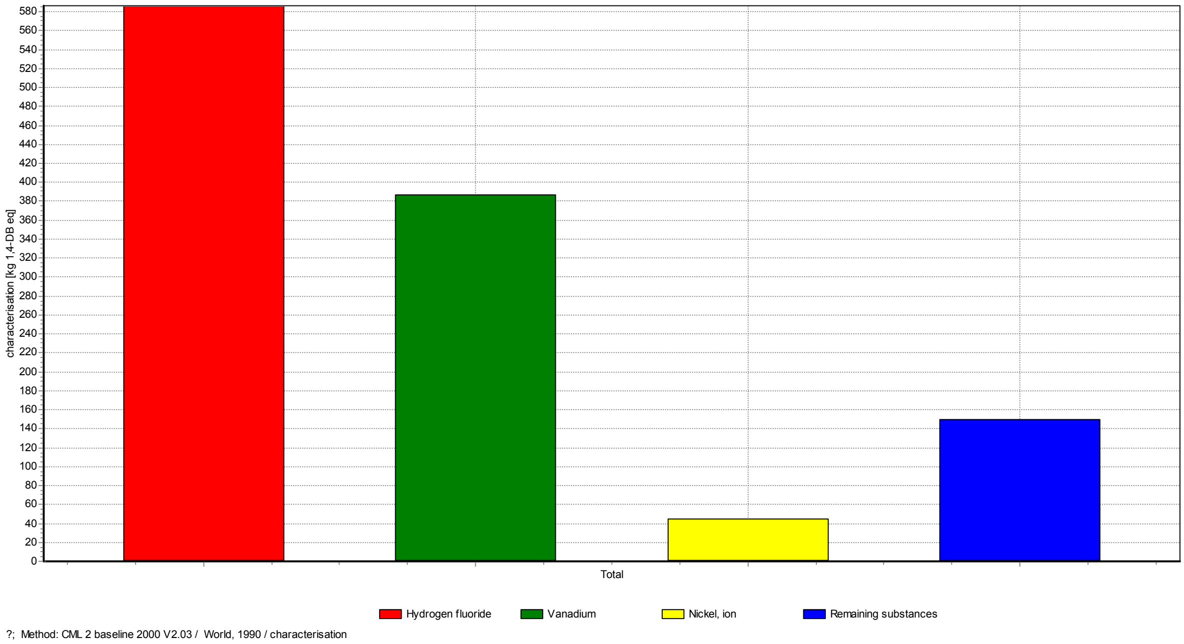

Figure 17 –Marine aquatic ecotoxicity of olive oil production system by substance

In the terrestrial ecotoxicity impact category, contribution is more evenly distributed between liquid waste disposal (26.8%), burning of pruning residues (26.6%), pesticide application (21.9%) and fertiliser production (15.1%).

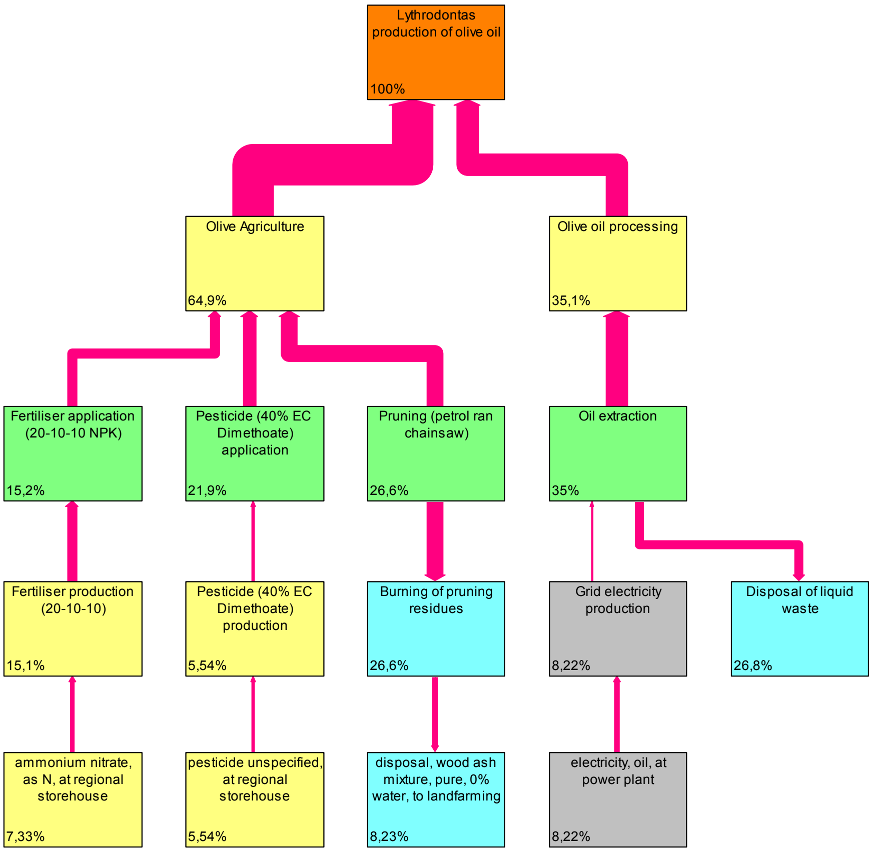

Figure 18 – Process contribution in terrestrial ecotoxicity impact category (5% cut-off)

The main substances, which are released by the system and contribute to this impact category are: vanadium, dimethoate, nickel, cadmium and zinc, as shown in Figure 19.

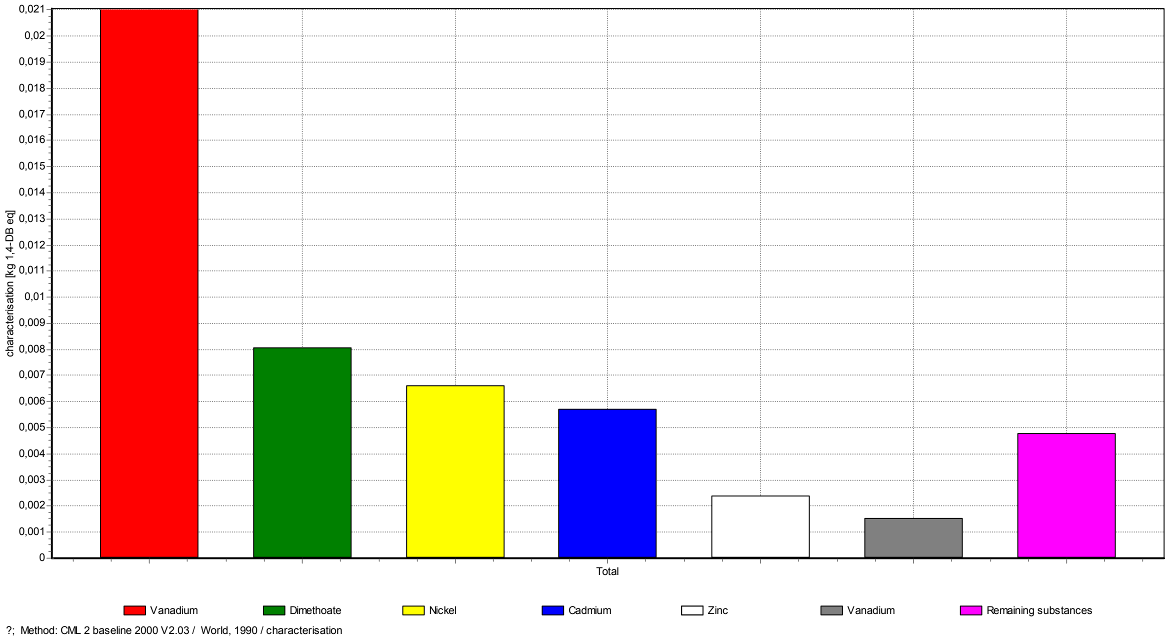

Figure 19 – Terrestrial ecotoxicity of olive oil production system by substance

3.2.6 Photochemical oxidation

The application of CML 2 baseline 2000 LCIA method has shown that 0.0471 kg C_2H_4 eq. are released by the olive oil production system under study, almost entirely (99.6%) from the olive agriculture stage. This is attributed to the large emissions of carbon monoxide, during the burning of pruning residue, which is the main substance contributing to the formation of photo-oxidants within the system (Figure 20).

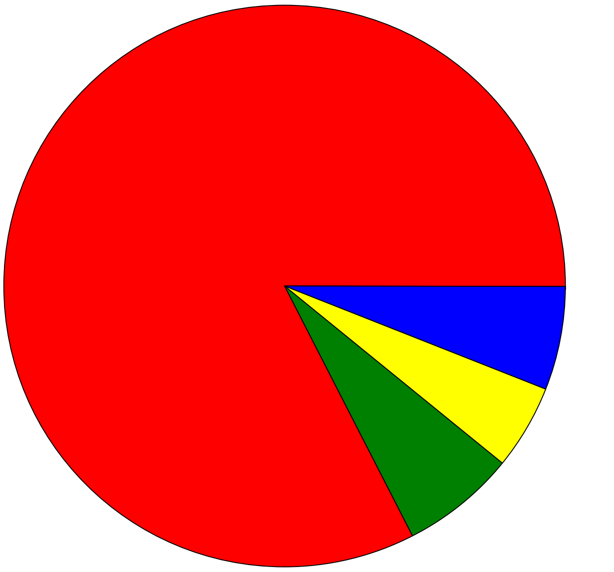

Figure 20 – Photochemical oxidation from olive oil production system by substance

3.2.7 Acidification

The analysis shows that the LCA system under study releases 0.0664 kg SO_2 eq. of substances with an acidification potential. From these 97% are released from agricultural stage processes.

As shown in Figure 21, the use of fertilisers in the orchards contributes 70.3% of this load (19.6% from fertiliser production while the rest from fertiliser application). The field electricity generation contributes a further 10%, whereas the contribution of soil management and pruning in this impact category is 8.3% and 5.2%, respectively.

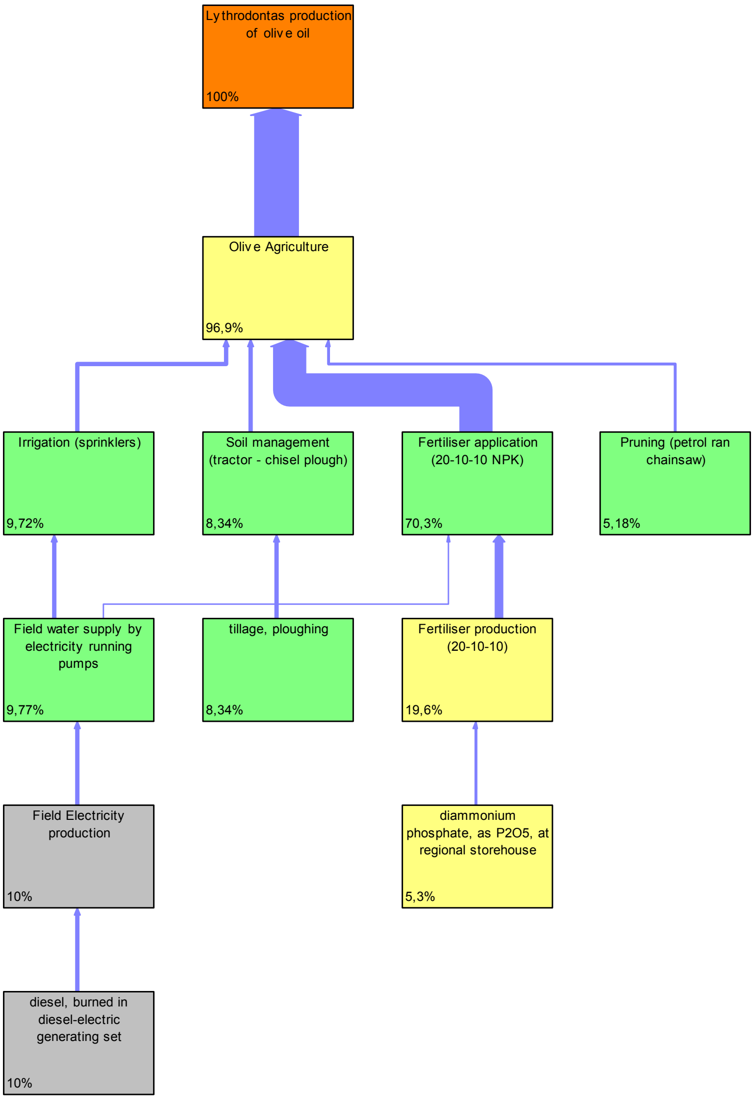

Figure 21 – Process contribution in acidification impact category (5% cut-off)

The main substances contributing to this impact category are ammonia (0.034 kg SO_2 eq.), sulphur dioxide (0.016 kg SO_2 eq.) and nitrogen oxides (0.016 kg SO_2 eq.) (Figure 22).

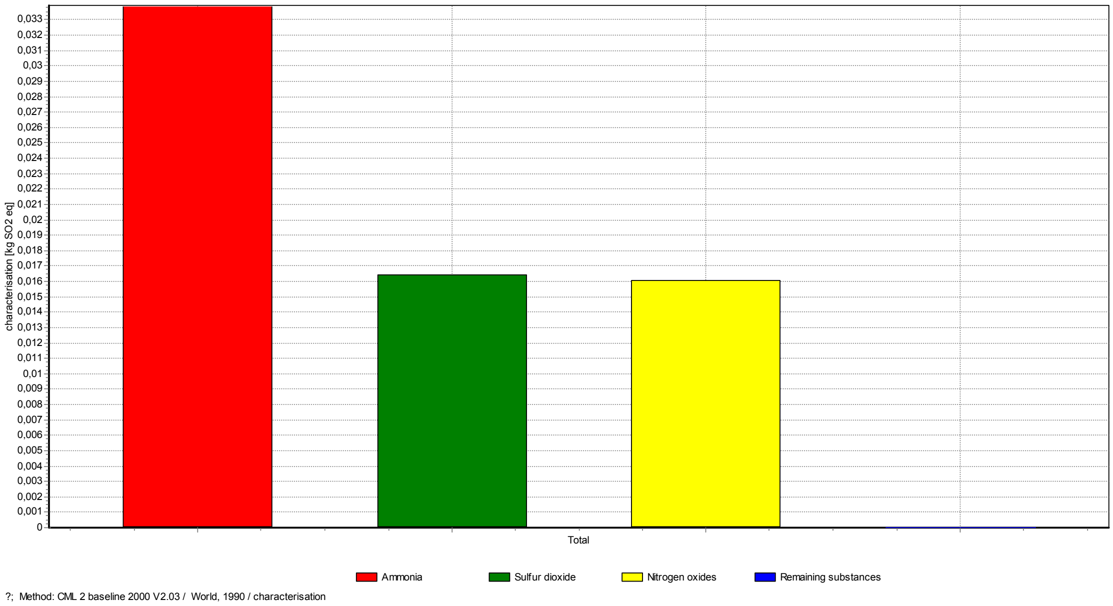

Figure 22 – Acidification from olive oil production system by substance

3.2.8 Eutrophication

0.0523 kg PO_4 eq. of eutrophication triggering substances are released in the environment from the production of 1 litre of olive oil in Lythrodontas. Again the main portion of this load (87.8%) is released in the agriculture stage.

As expected, fertilisers are responsible for most of this load. Their application to the fields releases 64.1% of the overall load, whereas along with their production, the contribution of fertilisers to eutrophication effects of the olive oil production system reaches 79.5%.

Other processes, which have an effect in this impact category are: liquid waste disposal (11.9%), field electricity production (2.95%), pruning (2.53%) and soil management (2.52%) (Figure 23).

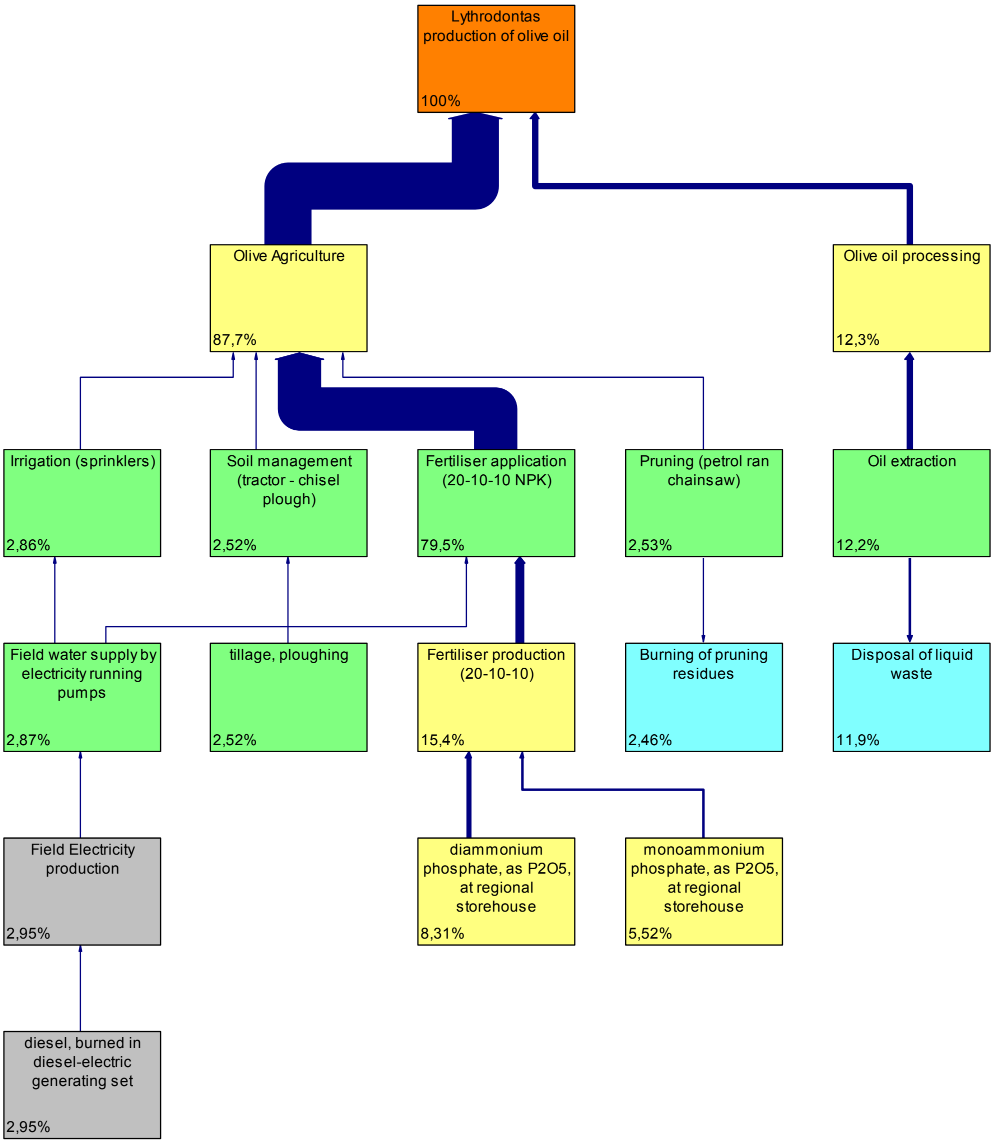

Figure 23 – Process contribution in eutrophication impact category (2% cut-off)

The substances which have the most significant contribution in this impact category are: nitrates (34.4%), phosphates (29.3%), ammonia (14.2%), phosphorus (12.1%) and nitrogen oxides (8.0%), as shown in Figure 24.

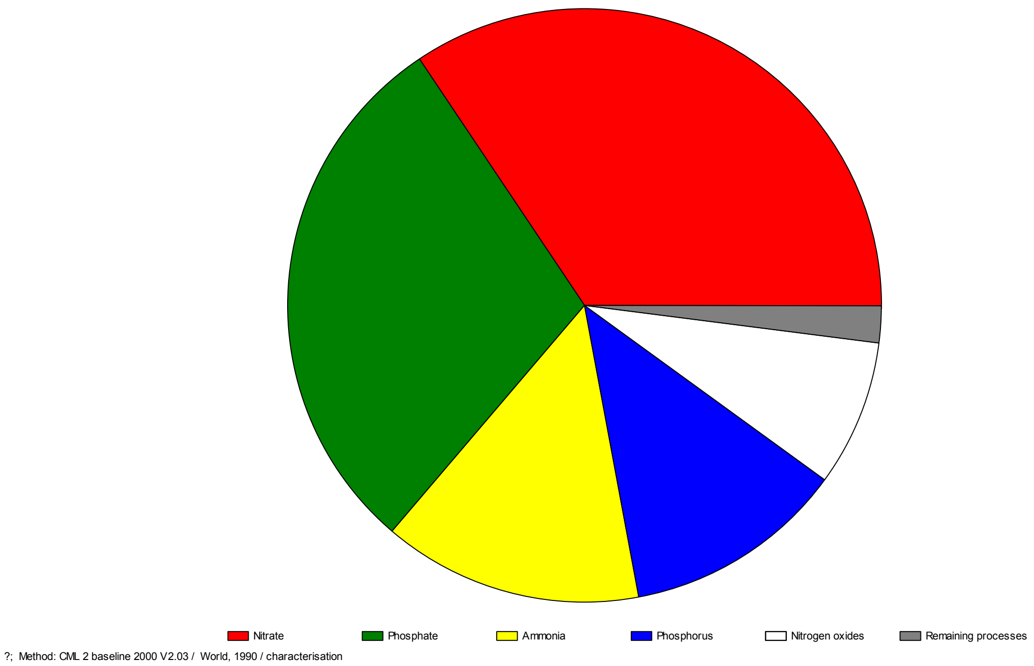

Figure 24 – Eutrophication from olive oil production system by substance

3.3 Normalisation results

As previously discussed, the Western European normalisation set was chosen for application in this study. Thus, characterisation results are multiplied with the normalisation factors shown in Table 3.

Table 3 – Normalisation factors used in this study

Impact Category	Factor
abiotic depletion	6.74E-11
global warming (GWP100)	2.08E-13
ozone layer depletion (ODP)	0.000000012
human toxicity	1.32E-13
fresh water aquatic ecotox.	1.98E-12
marine aquatic ecotoxicity	8.81E-15
terrestrial ecotoxicity	2.12E-11
photochemical oxidation	1.21E-10
acidification	3.66E-11
eutrophication	8.02E-11

The normalised results, as shown in Figure 25, show that "marine aquatic ecotoxicity" is the most serious impact arising from the olive oil productions system. Based on the characterisation results, previously discussed, the process of the olive oil production cycle, which mostly contributes to this impact category, is the production of fertilisers.

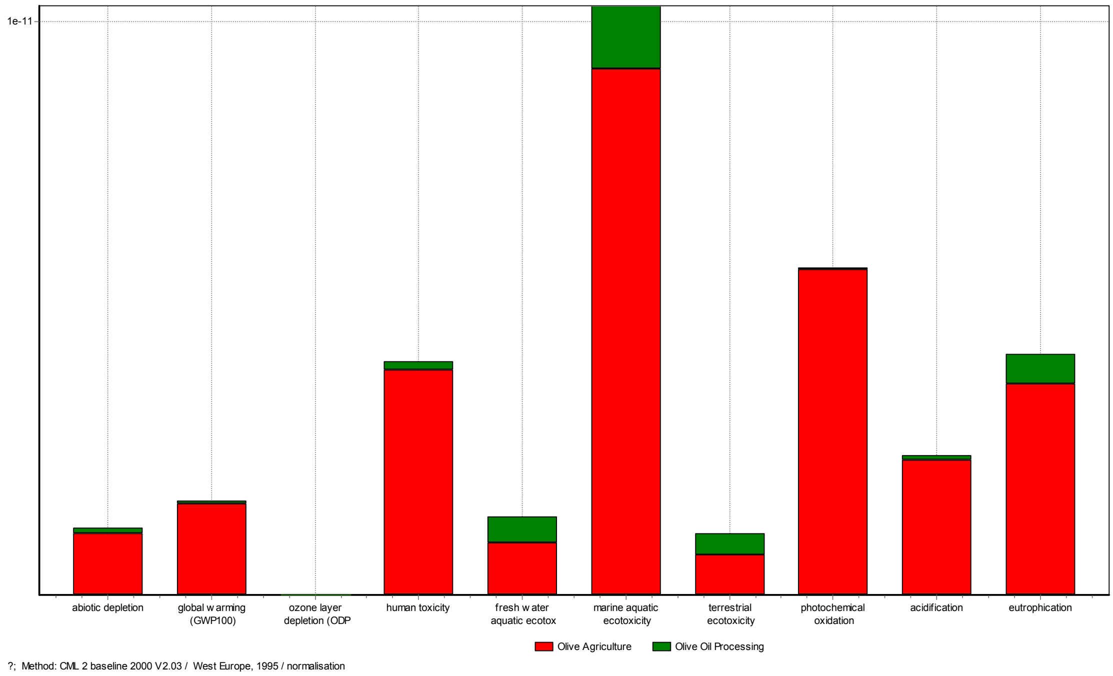

Figure 25 – Normalisation results (CML 2 baseline 2000)

The second most important impact caused by the olive oil production system in Lythrodontas, based on the normalisation data, is photochemical oxidation, of which burning of pruning residue is the main cause.

Other important impacts are eutrophication and human toxicity, of which the most significant contributors are, as previously discussed, the application of fertilisers and burning of pruning residues respectively.

Therefore, based on the normalisation data, the burning of pruning residue (photochemical oxidation and human toxicity) and the production and application of fertilisers (marine aquatic ecotoxicty and eutrophication), are considered the hot spots of the system.

4 Eco-indicator 99

4.1 General

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. Eco-indicator 99 is a “damage-oriented method”, and is the successor of Eco-indicator 95. The primary differences of the Eco-indicator 99 method, compared to the previous version, lie in the characterisation and the weighting steps. The effects (impact category indicators) in the characterisation step (carcinogens, resp. organics, resp. inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/ eutrophication, land use, minerals and fossil fuels) are allocated to three endpoint (damage) categories: [1] damage to human health, [2] damage to ecosystem quality and [3] damage to mineral and fossil resources, with units of measurements directly indicating the damage to these endpoints, as shown in Table 4.

The contributions of effects to the three endpoint-categories are the result of extensive modelling to connect damages to life cycle inventory results.

Human health modelling is expressed in the Disability Adjusted Life Years (DALYs) scale, which was developed for the World Health Organisation and the World Bank (Murray *et al.*, 1996) and consists of the following steps (Goedkoop *et al.*, 2000): [1] fate analysis (linking an emission to a temporary change in ambient concentration), [2] exposure analysis (linking the ambient concentration to a dose intake), [3] effects analysis (linking the dose to a number of health effects) and [4] damage analysis (linking health effects to DALYs).

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.

The resource damage category is expressed as surplus energy, which is the expected increase of energy required per kilogram of extracted material after a period when the amount of material that has been extracted is equal to five times the cumulative extracted material prior to 1990.

Table 4 – Characteristics of the Eco-indicator 99 LCIA methodology (Gedkoop M. et al., 2000)

<table>
<tr><th>Impact categories</th><th>Units of measurement</th><th>Normalisation and weighting</th></tr>
<tr><td><u>Human Health</u>
Carcinogenic emissions
Respiratory organics
Respiratory inorganics
Climate change
Radiation
Ozone layer depletion</td><td>DALYs of substances in sub-categories
A DALY (Disability Adjusted Life Years) is calculated for each emission into air, water and soil in these subcategories.
Links health effect to the number of years lived disables and years of life lost</td><td rowspan="3"><u>Normalisation</u>
Total inventory of mass and energy used (mostly for 1993 as base year) for the whole of western Europe for one year per person (population of 495 million assumed).
Weighting
A choice of four based on responses from a panel of experts placed into three perspectives:
Individualists (higher weight to human health)
Egalitarians (higher weight to ecosystem quality)
Hierarchists (equal weight distribution)</td></tr>
<tr><td><u>Ecosystem quality</u>
Eco-toxicity
Acidification/Eutrophication
Land use</td><td>PDF of substances/cause in sub-categories
Links effects to Potentially Disappeared Fraction (PDF) for plants.</td></tr>
<tr><td><u>Resources</u>
Minerals
Fossil fuels</td><td>MJ surplus of each resource
Links lower concentration to increased efforts to extract resources in future</td></tr>
</table>

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 follows a panel procedure amongst a Swiss LCA interest group, which was requested to rank the three endpoint-categories in order of importance. The response of the panel has been discriminated into three perspectives. Therefore, the Eco-indicator 99 method comes in three versions, Egalitarian, Individualist and the Hierarchist (default) version (PRé Consultants, 2004), which represent the three different perspectives of the damage models. The Hierarchist version (default) is used in this study. Table 5 summarises the main characteristics and differences of the three versions:

Table 5 - Characteristics of modelling perspectives of Eco-indicator 99

Version	Time view	Manageability	Level of evidence	Rounded weighting factors		
				Ecosystem Quality	Human Health	Resources
Hierarchist	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus	40%	30%	30%
Individualist	Short term	Technology can avoid many problems	Only proven effects	25%	55%	20%
Egalitarian	Very long term	Problems can lead to catastrophe	All possible effects	50%	30%	20%

4.2 Characterisation results

The LCIA results, using the Eco-indicator 99 method, show that the olive agriculture stage is the predominant contributor in the impact category indicators. The same conclusion was drawn when CML method was used. The contribution of the agricultural stage ranges from 49.1% in the “ecotoxicity” indicator to 99.99% in the “land use” indicator (Figure 26).

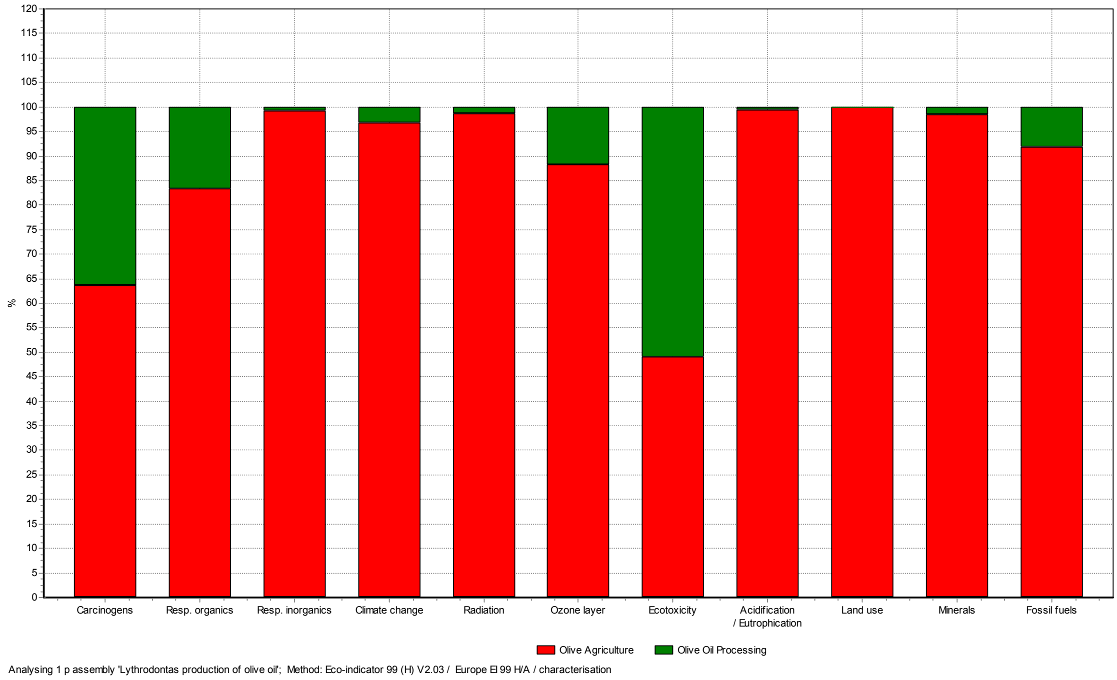

Figure 26 – Olive oil production characterisation results (Eco-indicator 99/H)

4.2.1 Carcinogens

According to the analysis, the system of olive oil production in Lythrodontas is responsible for 0.0002 DALY of carcinogens, from which 0.00013 DALY (63.5%) are released during the agricultural stage, as shown in Figure 27.

63% of the emissions of carcinogens from olive oil production are associated with the burning of pruning residues, whereas the disposal of liquid waste to evaporation ponds contributes another 36.5% to the total impact indicator.

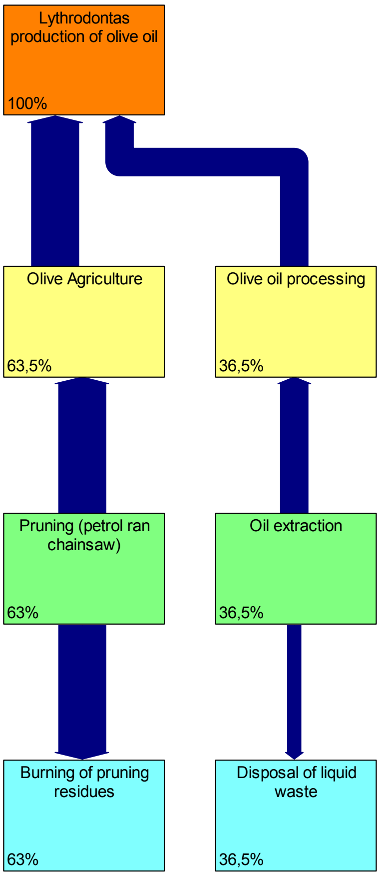

Figure 27 – Process contribution of carcinogens release (4% cut-off)

The main carcinogen substances emitted by the system are dibenzanthracene, and cadmium. Arsenic ions have been identified in small amounts (Figure 28).

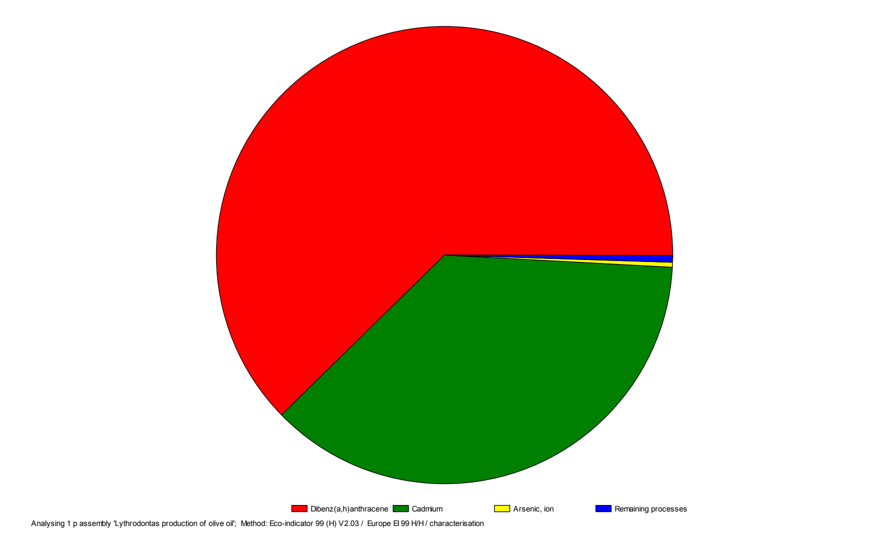

Figure 28 –Carcinogens substances released by olive oil production LCA system

4.2.2 Resp. organics

According to the analysis, the system of olive oil production in Lythrodontas is responsible for a damage of $1.71x10^{-7}$ DALY associated with resp. organics, from which $1.42x10^{-7}$ DALY (88.3%) are released during the agricultural stage, as shown in Figure 29.

68.6% of the damage by emissions of resp. organics in olive oil production are associated to the burning of pruning residues, which along with the use of chain saws, the contribution of pruning is 81.3% of the total load of the impact category indicator. A further 16.6% is contributed by the disposal of liquid effluent.

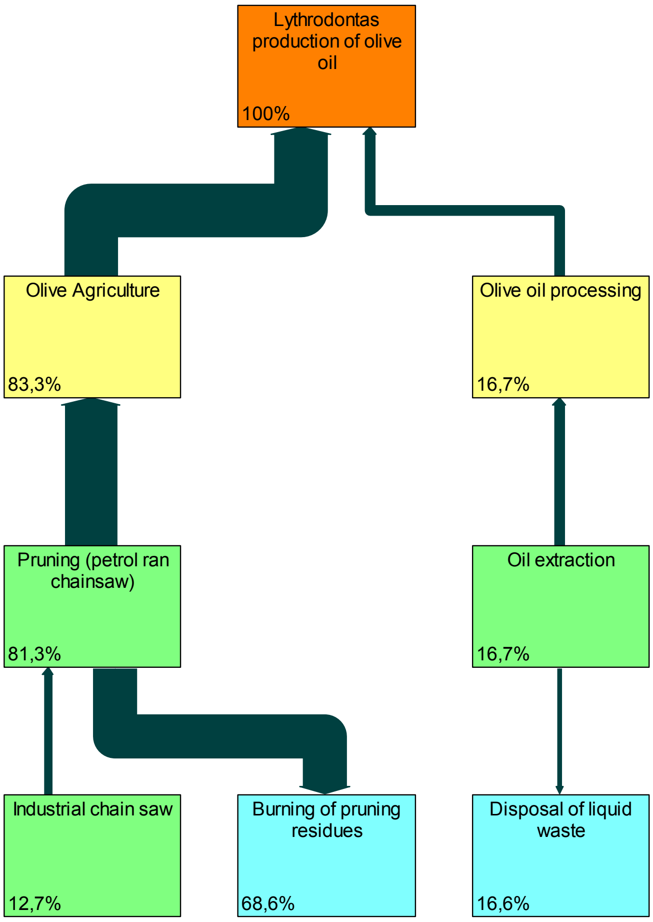

Figure 29 – Process contribution for emissions of resp. organics (1% cut-off)

The main resp. organic species released by the system are shown in Figure 30.

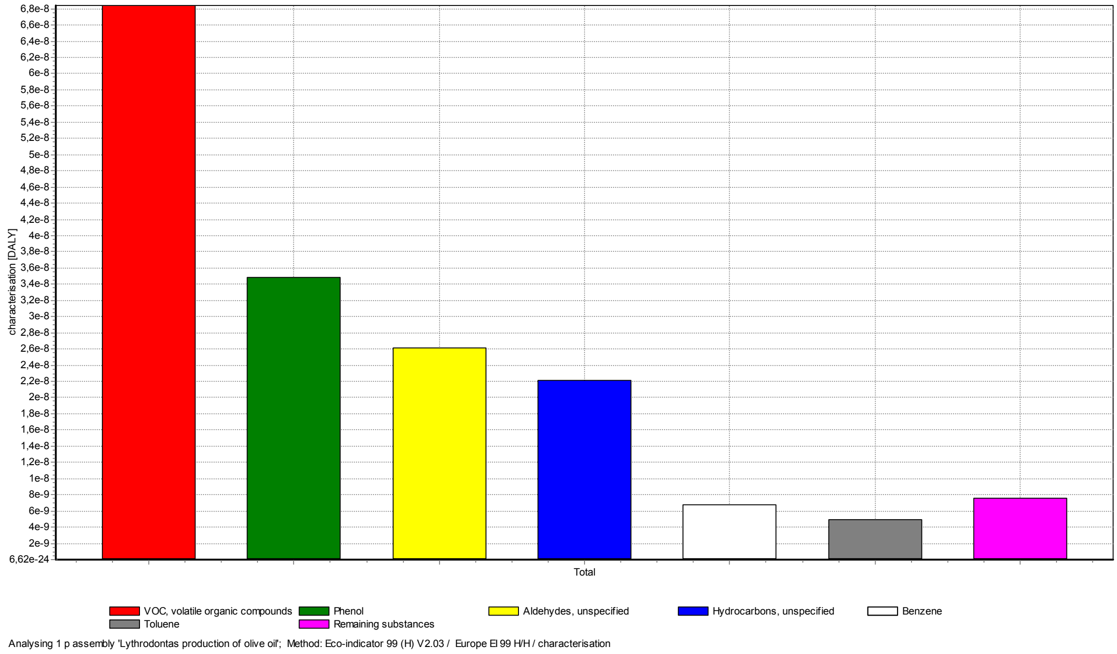

Figure 30 – Resp. organics in olive oil production by type

4.2.3 Resp. inorganics

According to the analysis, the system of olive oil production in Lythrodontas is responsible for a damage of 2.07×10^{-5} DALY by resp. inorganics, from which 2.06×10^{-5} DALY are released during the agricultural stage, as shown in Figure 31.

62.9% of the damage by resp. inorganics in olive oil production are associated to the burning of pruning residues, whereas the application of fertilisers, irrigation and soil management are also significant contributors as they contribute: 16.1%, 9.8% and 8.9% of the total damage respectively.

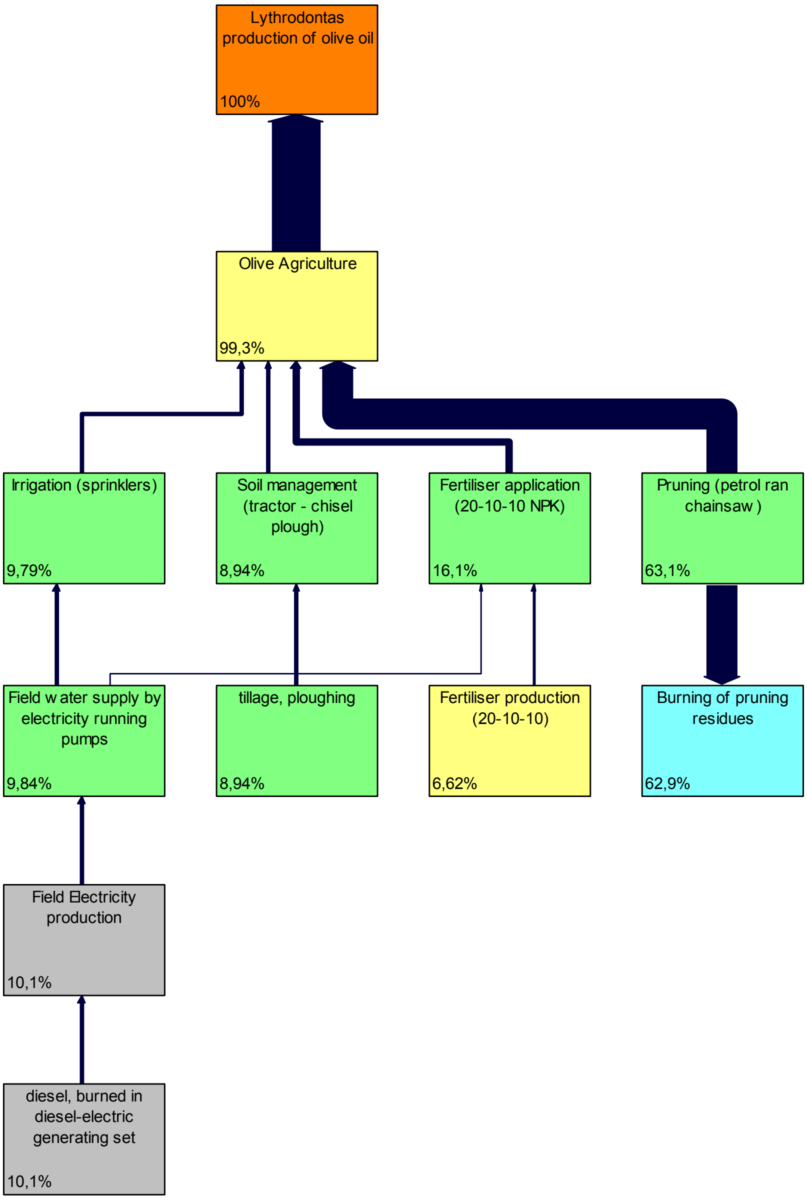

Figure 31 – Process contribution for emissions of resp. inorganics (5% cut-off)

The main resp. inorganic species released by the system are shown in Figure 32.

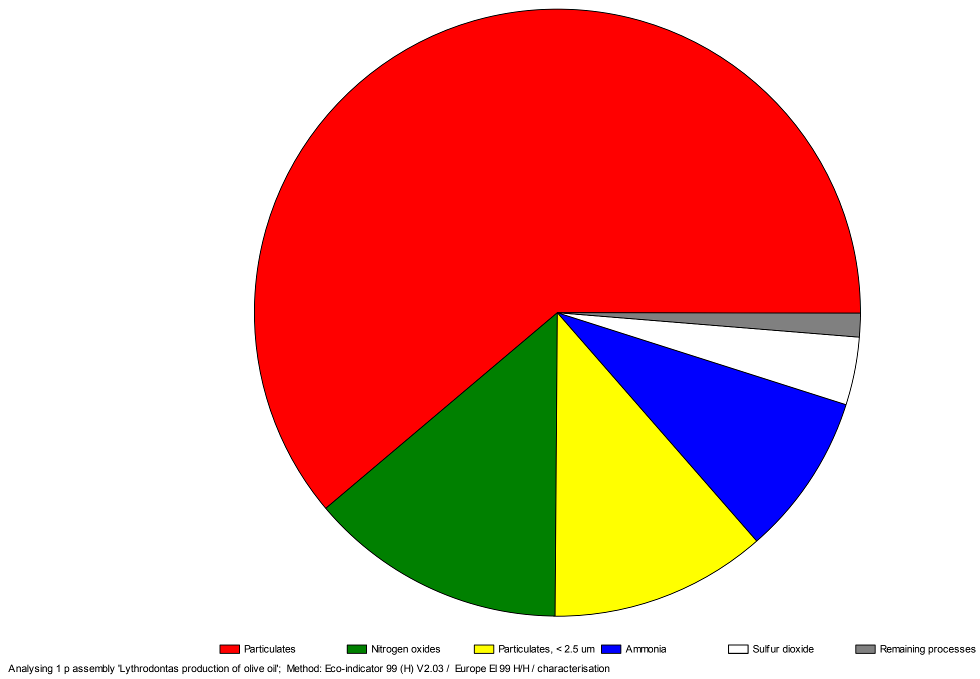

Figure 32 – Resp. inorganics in olive oil production by type

4.2.4 Climate change

According to the analysis, the damage caused by climate change triggered by the system is 1.66x10^{-6} DALY, from which 1.61x10^{-6} DALY (96.8%) is due to the agricultural stage, as shown in Figure 33.

68.9% of the damage associated with climate change originates from burning of pruning residues, whereas the application of fertilisers contributes a further 45.5%. Soil management and irrigation are also significant stages of olive oil production in regards to climate change (10.3% and 8.1% contribution to overall damage respectively).

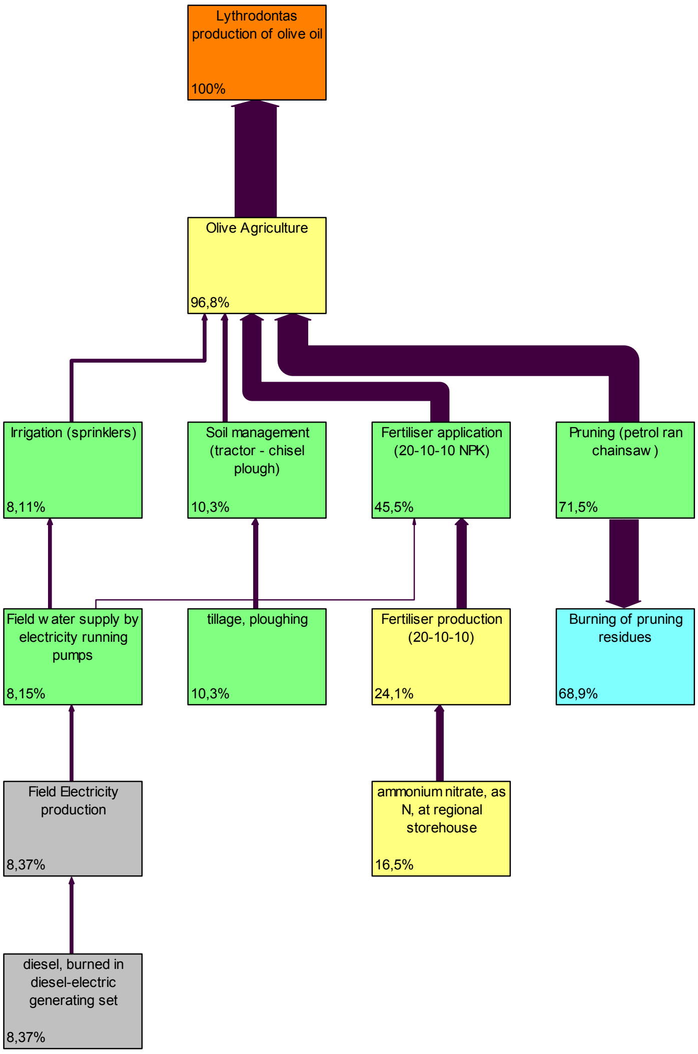

Figure 33 – Process contribution for climate change (4% cut-off)

As shown in Fig. 34, emissions of carbon dioxide are causing the largest portion of the damage, followed by methane, dinitrogen monoxide and carbon monoxide. The natural absorption of carbon dioxide by olive grooves is reducing the damage significantly.

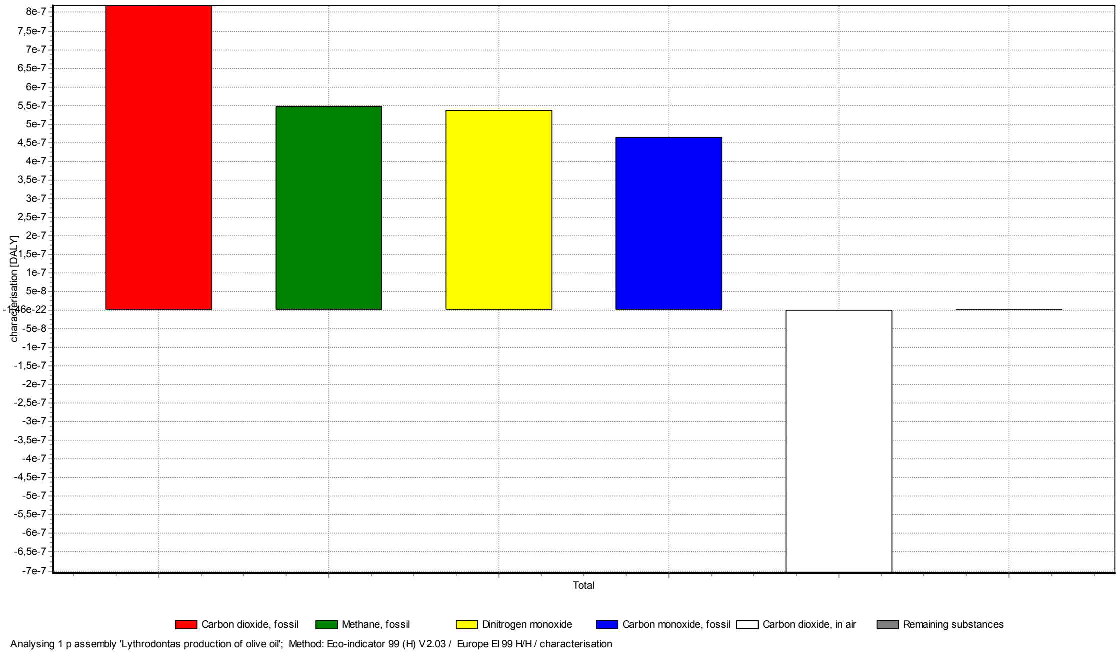

Figure 34 – Substances in olive oil production system associated with climate change

4.2.5 Radiation

According to the analysis, the damage caused by radiation associated with the system is $4.23x10^{-9}$ DALY, from which $4.18x10^{-9}$ DALY (98.7%) during the agricultural stage, as shown in Figure 35.

51% of the radiation load is associated to the production of pesticides, whereas the production of fertilisers contributes a further 46.8% to the overall radiation induced damage.

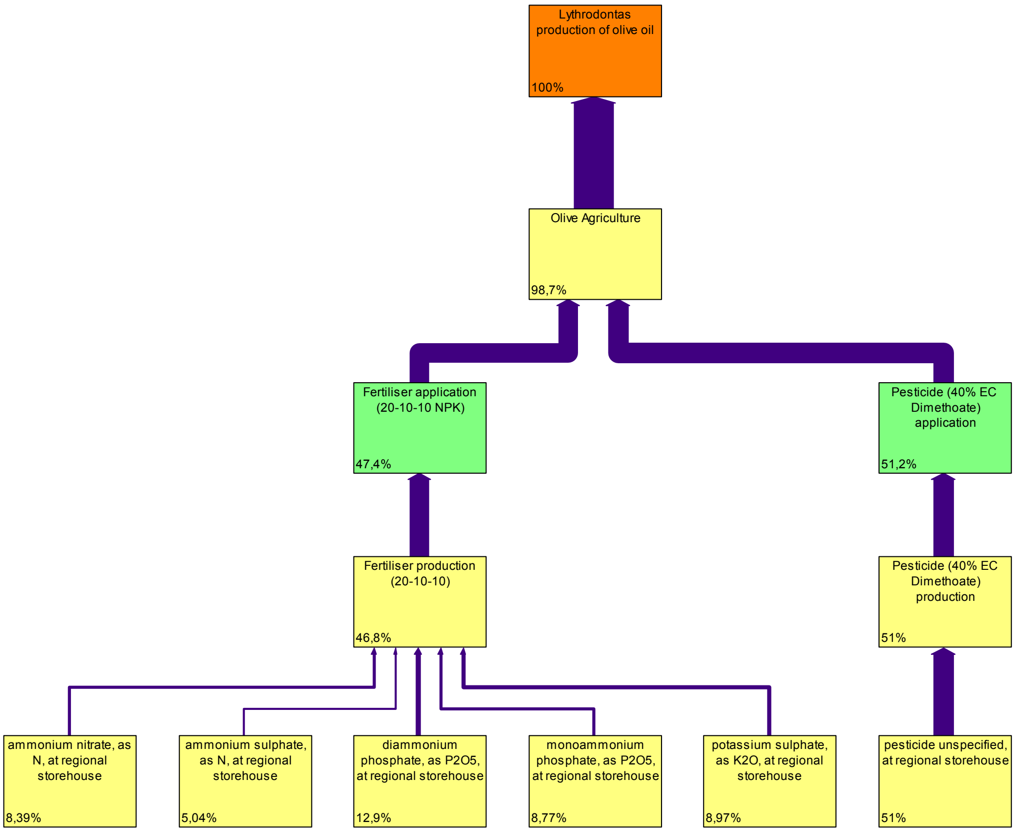

Figure 35 – Process contribution for radiation induced damage (4% cut-off)

4.2.6 Ozone layer depletion

The damage caused by ozone layer depletion associated with the system is 2.25×10^{-10} DALY, from which 1.99×10^{-10} DALY is caused during the agricultural stage, as shown in Figure 36.

57.6% of the damage load associated with ozone layer depletion originates from fertiliser production. Combined with transportation and application, fertilisation is responsible for 63.8% of this damage load. Pesticides contribute a further 24.1% of ozone layer damage load, whereas a significant 11.9% load originates from olive processing, due to the electricity generated.

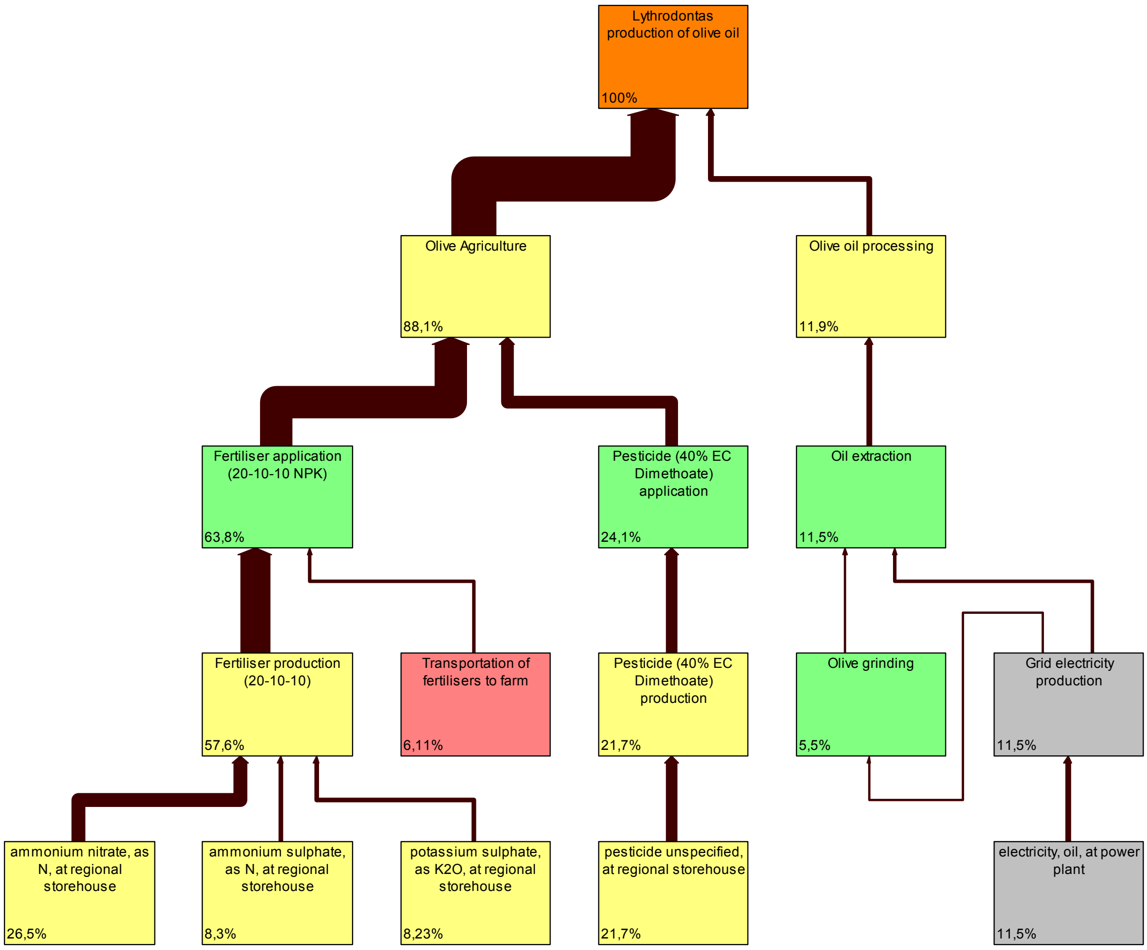

Figure 36 – Process contribution for ozone layer depletion (5% cut-off)

The substances, released by the system, which contribute the most to ozone related damage, are shown in Figure 37.

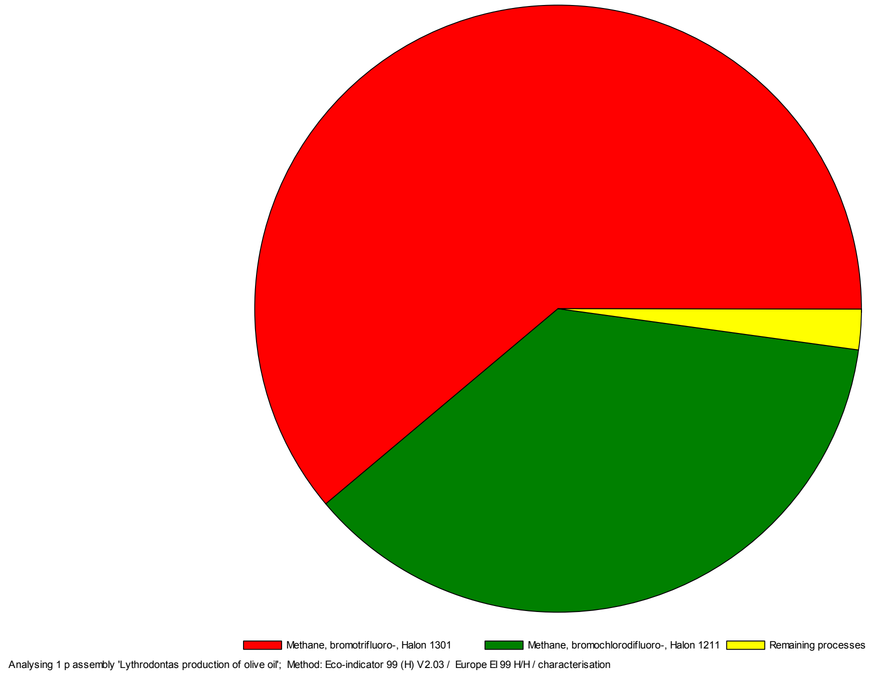

Figure 37 – Substances present in olive oil production system associated with ozone layer depletion

4.2.7 Ecotoxicity

The analysis has show that the ecotoxicity damage caused by the system is 9.3 PAF*m^2yr, from which 4.74 PAF*m^2yr occur during the processing stage, as shown in Figure 38.

49.5% of the damage load associated with ecotoxicity originates from the disposal of liquid waste. Pruning stage (including burning of residue and subsequent disposal of ash) contributes a further 37.8% of ecotoxicity damage load, whereas soil management and fertiliser application contribute a further 6.2% and 3.3% respectively.

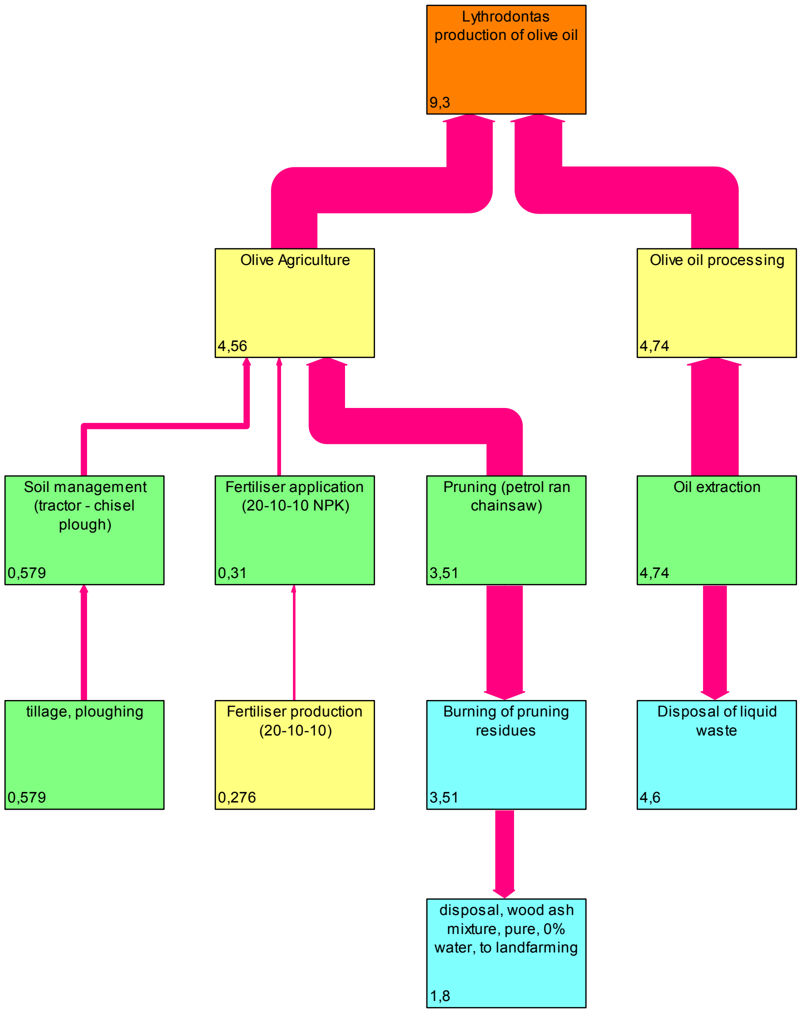

Figure 38 – Process contribution for ecotoxicity damage in PAF*m^{2}yr (2% cut-off)

The contribution of substances released by the system, in ecotoxicity, is shown in Figure 39.

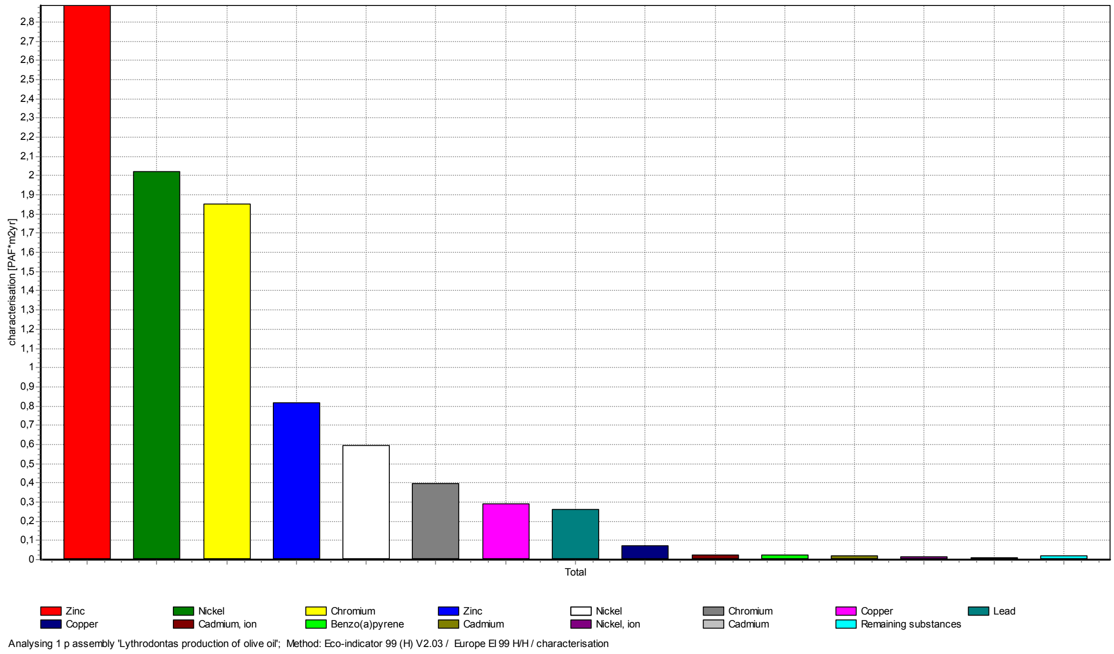

Figure 39 – Substances present in olive oil production system contributing to ecotoxicity

4.2.8 Acidification - Eutrophication

According to the analysis, the damage caused by acidification and eutrophication associated with the system is 0.53 PDF*m^{2}yr, from which 0.527 PDF*m^{2}yr during the agricultural stage, as shown in Figure 40.

70% of the damage load associated with acidification and eutrophication is due to the use of fertilisers (including production of fertilisers). Irrigation (which includes on-site electricity generation for water extraction) contributes a further 12.5% of acidification/eutrophication damage load, whereas soil management and pruning contribute a further 11% and 4.3% respectively.

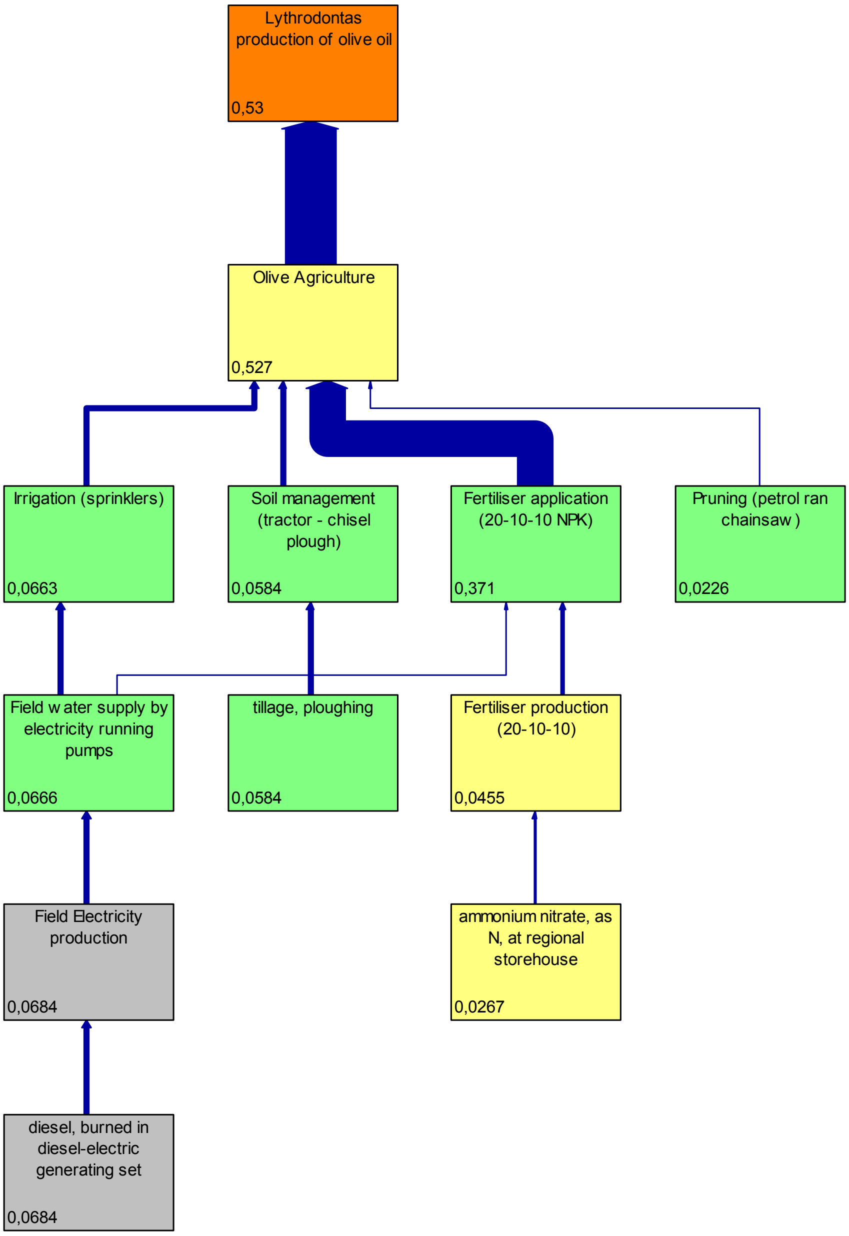

Figure 40 – Process contribution for acidification - eutrophication damage in PDF*m^{2}yr (4% cut-off)

The contribution of substances released by the system, in acidification and eutrophication related damage, is shown in Figure 41.

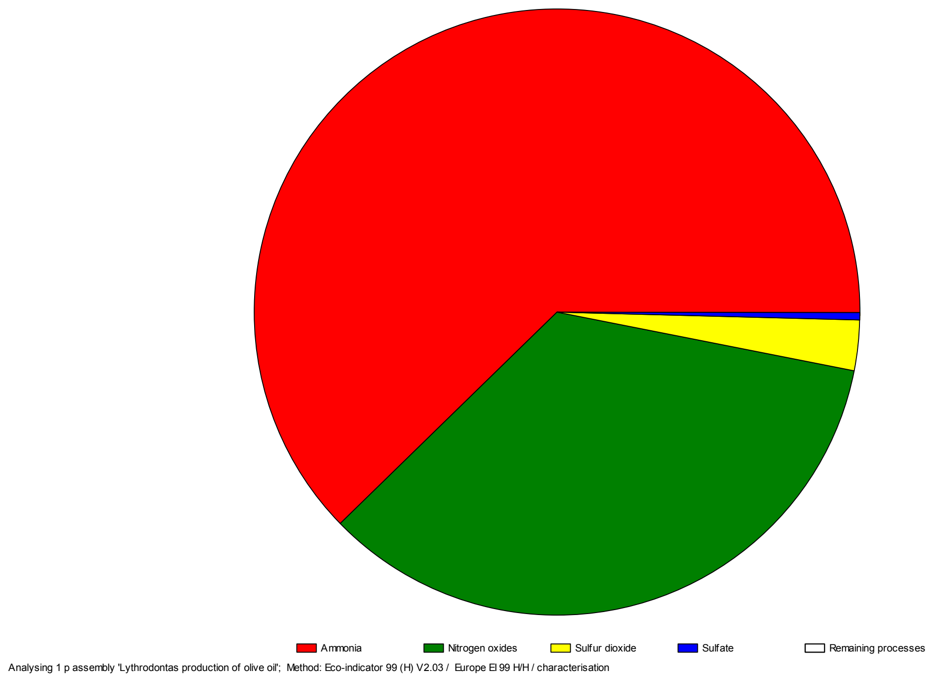

Figure 41 – Substances present in olive oil production system contributing to acidification / eutrophication

4.2.9 Fossil fuels

According to the analysis, the fossil fuels depletion associated with the system is 4.8 MJ surplus, from which 4.4 MJ surplus are depleted during the agricultural stage, as shown in Figure 42.

44.6% and 18% of the fossil fuels depletion is due to the production of fertilisers and pesticides respectively. Soil management, oil extraction, and irrigation (including on-site electricity generation for water extraction) contribute 10.1%, 8% and 7.6% of fossil fuels depletion respectively, whereas pruning by petrol chainsaws contributes a further 6.8%.

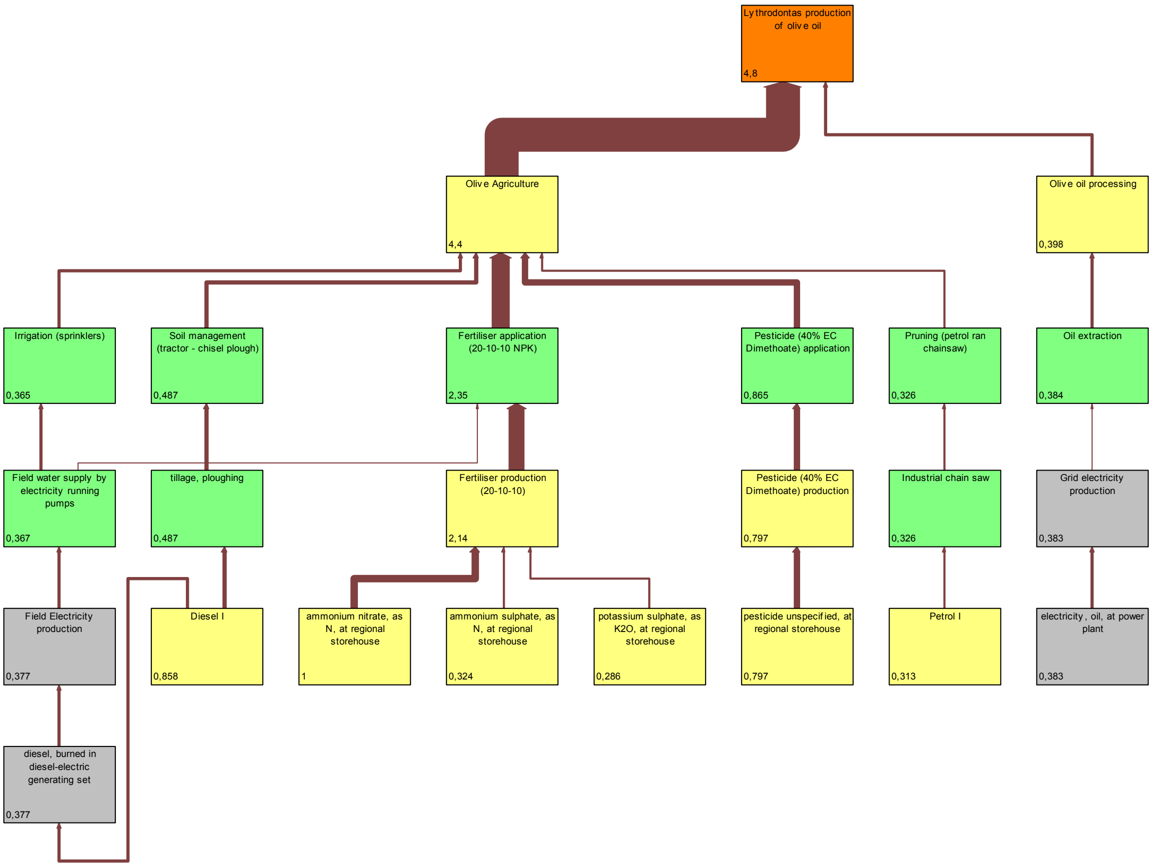

Figure 42 – Process contribution for fossil fuel depletion (5% cut-off)

4.3 Normalisation results

The results, following normalisation, show that “carcinogens” is the most serious impact arising from the olive oil production system (Fig. 43). As previously discussed, the burning of pruning residues and the disposal of liquid wastes to evaporation ponds are the processes within the olive oil production cycle, which mostly contribute to the release of carcinogens. Another significant impact category, according to the normalised results, is land use, which is almost entirely due to the occupation of cultivation land by olive grooves. However, the consideration of land use as an impact in an agricultural system is a matter of dispute and in any case it cannot be considered of the same severity as the rest of the impacts.

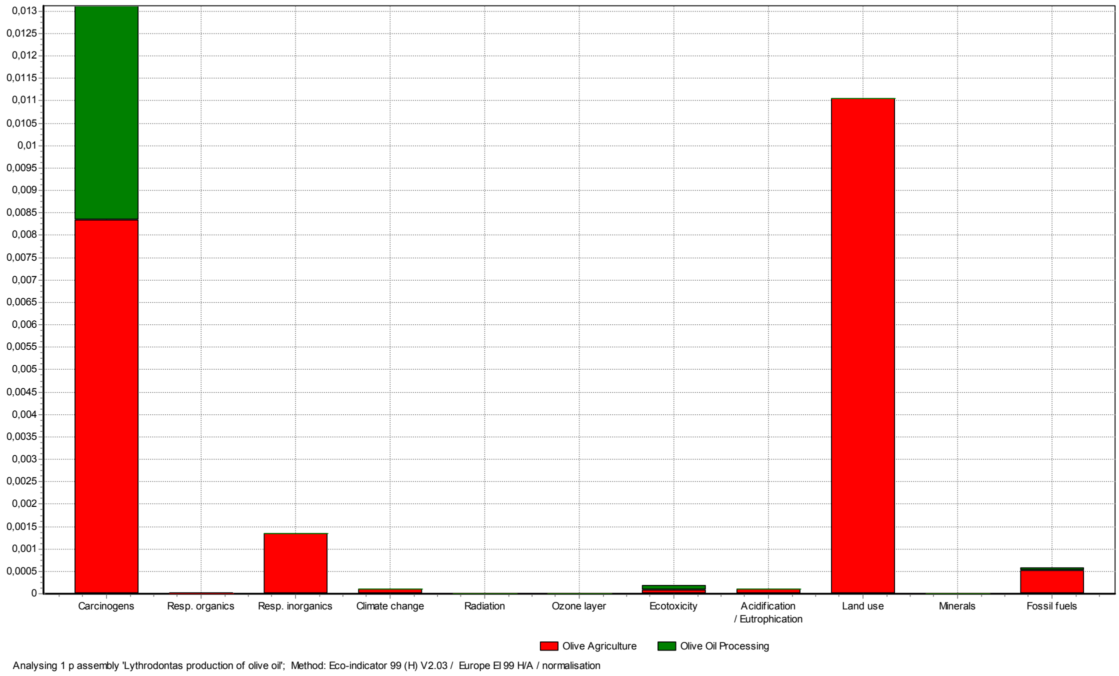

Figure 43 – Normalisation results – impact category indicators (Eco-indicator 99/H)

The normalised damage assessment results (Figure 44) show that damage caused by the olive oil production system primarily concerns human health and secondarily the quality of ecosystem. Damage in respect to resource depletion is minor, as it was expected for an agricultural product.

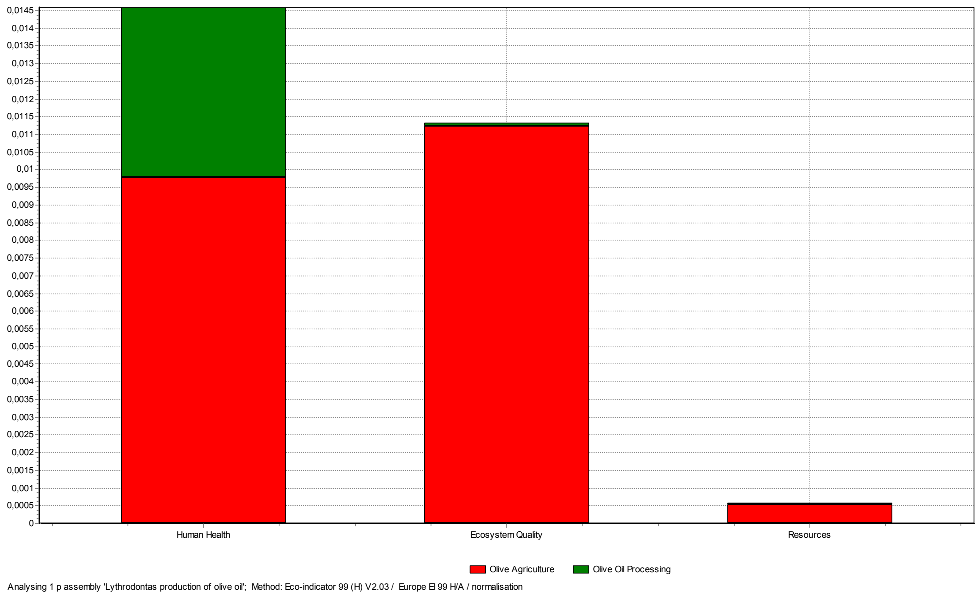

Figure 44 – Normalisation results – damage assessment (Eco-indicator 99/H)

An analysis of the contribution of the various processes to the damage caused to human health by the olive oil production system (Figure 45) shows that burning of pruning residues and disposal of liquid waste from olive mills into evaporation ponds are the main processes responsible. Therefore, based on the normalisation results, the burning of pruning residue and the disposal of liquid wastes to evaporation ponds are considered the hot spots of the system.

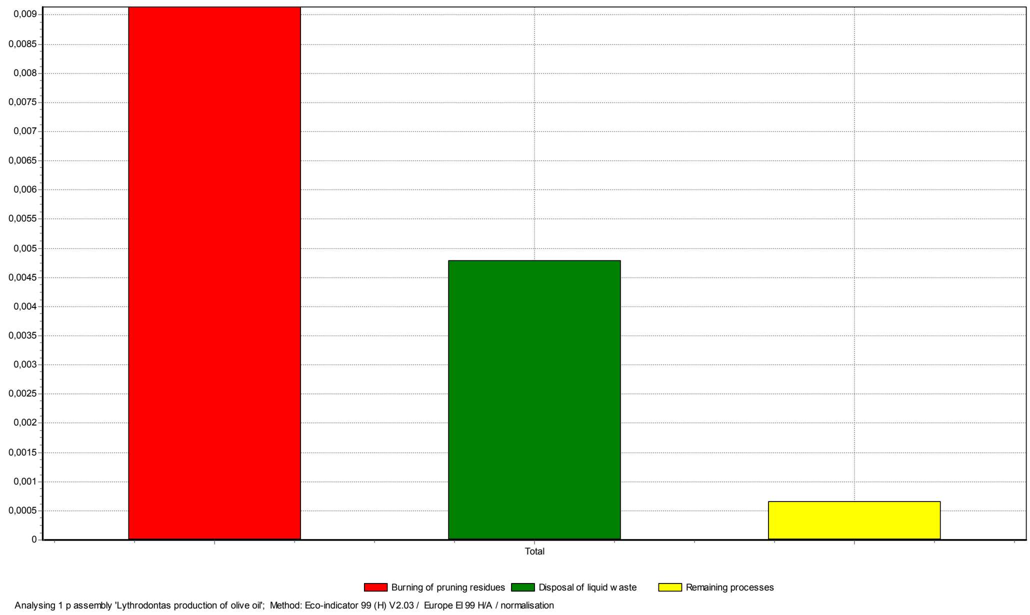

Figure 45 – Process contribution to damage to human health (Eco-indicator 99/H)

5 Conclusions

The results of the life cycle impact assessment step using both CML 2 baseline 2000 (a problem-oriented method) and Eco-indicator 99 (a damage-oriented method), show that overall, the agricultural stage of the production system is more significant in regards to raw material consumption and air pollution, when compared to the processing stage. However, the processing stage is of primary importance when it comes to toxicity effects, mainly due to the particular management practice of liquid wastes from olive mills (disposal to evaporation ponds).

Based on the results of the study (Table 6), individual processes of the overall system were classified in priority categories according to the effect a potential optimisation could have in the environmental improvement of the olive oil production system:

- Tree planting, olive collection and transportation of olives to the processing unit do not raise any concern as their contribution to all environmental impacts and damage categories considered was less than 0.5%. Thus, their optimisation is not considered an effective way of optimising the system. They are classified as priority category 3.
- Irrigation and soil management are classified in priority category 2. Irrigation, apart from the fact that, itself is a major consumer of fresh water in the system, most of environmental impacts arise as a result of the emissions from mechanical extraction of water from wells. Similarly, soil management consumes fossil fuels and causes heavy emissions of pollutants during tractor operation, causing moderate resource depletion and global warming impact problems, respectively.
- The results of this study have shown that the use of fertilisers and pesticides, the particular residue management and the liquid waste management techniques, as used in Lythrodontas, shall be considered as priority-1 processes, since they are the major contributors to most of the environmental impacts and damage categories considered. Preventive management measures should therefore focus on these processes since their optimisation could potentially prove particularly effective in the environmental optimisation of the overall system of olive oil production.

Table 6 – Summary of LCIA results for the production of 1 litre of olive oil in Lythrodontas

Parameter	Impact Assessment Method	Agricultural stage							Processing stage		Totals		
		Tree planting	Irrigation (incl. fuel production, on-site electricity generation, water extraction and supply)	Soil management (incl. fuel production, tractor operation)	Fertilisation (incl. production, transportation and application)	Pest control (incl. production, transportation and application)	Pruning (incl. fuel production, chainsaw operation and pruning residue management)	Olive collection (incl. fuel production, on-site electricity generation and operation of pneumatic combs)	Transportation of olives	Oil extraction (incl. grid electricity generation, water treatment and supply, liquid and solid waste management)	Agricultural stage TOTAL	Processing stage TOTAL	Olive oil production system TOTAL
Abiotic resource depletion (g Sb eq.)	CML 2 baseline 2000	<0.99%	1.19 (6.9%)	1.59 (9.2%)	8.68 (50.2%)	3.45 (19.9%)	1.06 (6.1%)	<0.99%	<0.99%	1.26 (7.3%)	16 (92.5%)	1.3 (7.5%)	17.3 (100%)
Global warming (g CO_2 eq.)		<0.99%	640 (8.1%)	816 (10.3%)	3350 (42.4%)	294 (3.7%)	5890 (74.6%)	<0.99%	<0.99%	245 (3.1%)	7650 (96.8%)	253 (3.2%)	7900 (100%)
Ozone layer depletion (μg CFC-11 eq.)		<0.99%	<0.99%	<0.99%	136 (63.7%)	51.7 (24.2%)	<0.5%	<0.99%	<0.99%	24.6 (11.5%)	189 (88.1%)	25.5 (11.9%)	214 (100%)
Human toxicity (g 1,4-DB eq.)		<0.99%	<0.99%	495 (1.6%)	389 (1.3%)	1300 (4.2%)	27600 (89.3%)	<0.99%	<0.99%	1120 (3.6%)	29800 (96.4%)	1120 (3.6%)	30900 (100%)
Fresh water ecotoxicity (g 1,4-DB eq.)		<0.99%	<0.99%	<0.99%	43.9 (6.4%)	350 (50.8%)	62.4 (9.1%)	<0.99%	<0.99%	231 (33.6%)	457 (66.4%)	231 (33.6%)	688 (100%)
Marine aquatic ecotoxity (kg 1,4-DB eq.)		<0.99%	<0.99%	<0.99%	729 (62.5%)	133 (11.4%)	179 (15.3%)	<0.99%	<0.99%	125 (10.7%)	1040 (89.3%)	125 (10.7%)	1170 (100%)
Terrestrial ecotoxicity (g 1,4-DB eq.)		<0.99%	<0.99%	0.5 (1.0%)	7.6 (15.2%)	11 (21.9%)	13.4 (26.6%)	<0.99%	<0.99%	17.6 (35%)	32.5 (64.9%)	17.6 (35.1%)	50.1 (100%)
Photochemical oxidation (g C_2H_4)		<0.99%	<0.99%	<0.99%	0.5 (1.1%)	<0.99%	46.1 (97.8%)	<0.99%	<0.99%	<0.99%	46.9 (99.6%)	0.2 (0.4%)	47.1 (100%)
Acidification (g SO_2 eq.)		<0.99%	6.5 (9.7%)	5.5 (8.3%)	46.7 (70.3%)	2.0 (3.1%)	3.4 (5.2%)	<0.99%	<0.99%	2.0 (3.0%)	64.4 (96.9%)	2.1 (3.1%)	66.4 (100%)
Eutrophication (g PO_4 eq.)		<0.99%	1.5 (2.9%)	1.3 (2.5%)	41.6 (79.5%)	<0.99%	1.3 (2.5%)	<0.99%	<0.99%	6.4 (12.2%)	45.9 (87.7%)	6.4 (12.3%)	52.3 (100%)
Human health ($x10^{-6}$ DALY)	Ecoindicator 99 (H)	<0.99%	<0.99%	<0.99%	5.1 (2.3%)	<0.99%	140 (63.1%)	<0.99%	<0.99%	73.7 (32.9%)	150 (67.1%)	73.8 (32.9%)	224 (100%)
Ecosystem quality ($PDFm^2yr$)		<0.99%	<0.99%	<0.99%	<0.99%	<0.99%	<0.99%	<0.99%	<0.99%	<0.99%	57.6 (99.2%)	0.5 (0.8%)	58.1 (100%)
Resources (MJ surplus)		<0.99%	0.4 (7.6%)	0.5 (10.1%)	2.4 (49%)	0.9 (18%)	0.3 (6.8%)	<0.99%	<0.99%	0.4 (8.0%)	4.4 (91.7%)	0.4 (8.3%)	4.8 (100%)

	< 0.99%	1 - 9.99%	10 - 19.99%	20 - 29.99%	>30%
Process contribution key	(green)	(light blue)	(yellow)	(orange)	(pink)

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