

# **Comparison of allocation and impact assessment methodologies on the life cycle assessment of rape and sunflower seed oils.**

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## **Abstract**

As part of the DEFRA Funded Sustainable Emulsion Ingredients through Bio-Innovation (SEIBI) project, attributional Life Cycle Assessment (LCA) models of both sunflower and rapeseed oils have been developed to enable the relative environmental burdens within both production systems to be identified, from cultivation through to factory gate, using existing technologies. This paper shows the effect of using two different methodologies for both co-product allocation and life cycle impact assessment (LCIA) when modelling the life cycle inventories of the two product systems. Results obtained showed that changing allocation methodology significantly changed both the relative contributions of the individual process stages and the relative contributions from the impact categories. This change was heightened when changing both LCIA methodologies.

## **1 Introduction**

The SEIBI project (Sustainable Emulsion Ingredients through Bio-Innovation) is a DEFRA funded collaborative and cross disciplinary project incorporating researchers from the Universities of Nottingham and Bath together with a consortium of industrial partners. The project was initiated to investigate novel processing routes for the production of edible oil emulsions for food production, since a significant proportion of edible oils are consumed as emulsions, in products ranging from sauces and drinks to confectionery and spreads.

Current oilseed processing techniques involve extraction and refining of the oil using high temperatures and organic solvents, followed by re-encapsulation of the oil if required using manufactured surfactants, for incorporation into a range of food products. The SEIBI project aims to reduce the number and complexity of processing steps required for this process, with the intention that a simplified process will improve efficiency and reduce the environmental impact of the production.

Life Cycle Assessment (LCA) has been used to build models of both the rape and sunflower seed oil systems in order to i) identify and quantify the relative contributions of each processing step, such that process improvements can be targeted to specific areas and ii) to identify the current environmental loads to be used as a comparison with those generated by the novel process.

Both processes involve the production of not only the product of interest, but also a co-product during both the extraction (meal) and refining (acid-oil co-product) stages. Product systems such as this require the issue of allocation to be considered, to determine the proportion of the environmental impacts that will be attributed to the production of each product. Allocation is defined as '*partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems*' [1]. ISO 14044:2006 [2] states that allocation should be avoided where possible, in favour of system expansion (and the subsequent development of a consequential LCA), however as highlighted in the U.S EPA Guidance document [3], expansion of systems is not possible in all cases and it can be argued that choice of allocation method should be based on what type of LCA is being done [4].

ISO 14044:2006 [2] goes on to state that where allocation cannot be avoided, it should be done in such a way as to reflect the physical relationships between the co-products, although in step 3 of its allocation procedure it acknowledges that this is not always practical [6]. Whilst use of mass as the allocation basis appears to be the preferred approach [5], other methods such as economic value, energy content, volume or even nutritional value (for foodstuffs) can also be used. [5, 6, 7]. From studying a range of published oilseed LCAs it was evident that for rape and sunflower seed oils, the favoured allocation method is generally economic. The basis for this is that oil crops are harvested for their oil, without which, they would not be financially viable to grow (the exception is soy bean oil – which is primarily grown for animal feed from the meal).

The choice of allocation approach can have a profound effect on the results generated [5,8,9] and it is this effect that is examined with specific reference to the rapeseed and sunflower seed oil LCAs within this paper.

Life cycle impact assessment (LCIA) aims to provide additional information to help assess the results of the life cycle inventory (LCI), such that the environmental loads can be better understood [7,2]. There are many LCIA methodologies and the one chosen is largely dictated by the impact categories required within the scope of the study.

This paper will furthermore examine the impact that LCIA methodology has on the effect of differing allocation parameters.

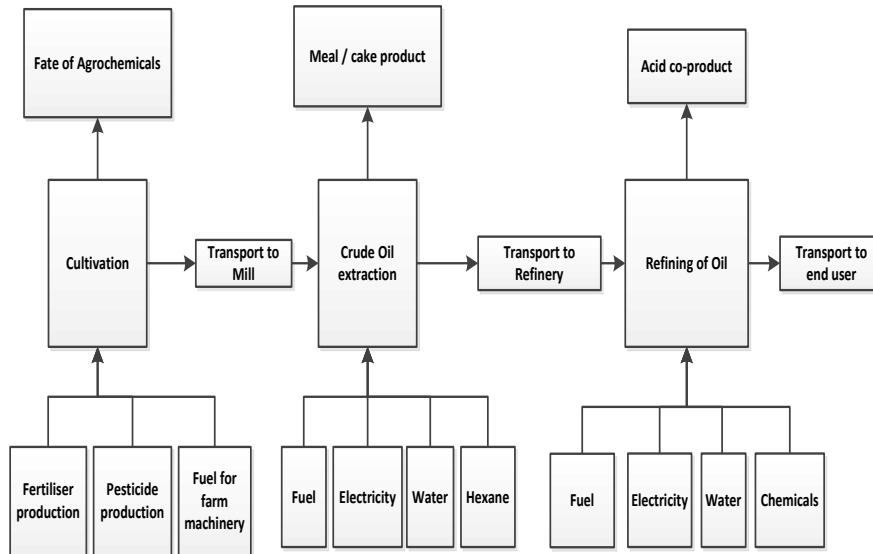
## **2 Methodology**

Attributional LCA models of both product systems were constructed using the SimaPro 7 software system.

### ***2.1 Functional unit and system boundaries***

The functional units of both systems were set as 'receipt of 1 ton of refined oil at food processor' with the system boundary starting at the cultivation stage and finishing at delivery of oil to food processor. The process flow used for both product systems was as depicted in figure 1, with the main process stages being cultivation, extraction and refining. For analysis purposes, transportation was aggregated to form a fourth 'process' step.

Whilst this indicates a relatively simple flow-sheet, creation of the LCA entailed each input being further expanded to include the mass and energy balance around each individual system. The result was a complex process network involving over 2000 process nodes (input values).



**Figure 1. Process flowchart for oilseed processing system.**

## 2.2 Data and sources

Data for all stages of the production sequence was taken from Unilever manufacturing sites and suppliers [10,11] corroborated against data from literature sources [12,13,14,15]. Data for secondary processes such as electricity and steam generation was taken from the EcoInvent database supplied within SimaPro, for the geographical area of the process in question e.g. for generation of electricity used in Rapeseed oil extraction, the Germany power mix was utilised. Table 1 depicts the geographical specificity of the data requirements.

**Table.1: Geographical scope of LCI data**

	Rapeseed oil	Sunflowerseed oil
Cultivation	Germany	South Africa
Extraction	Germany	South Africa
Refining	Netherlands	Netherlands
Transport farm to mill	Road 65km	Road 100 km
Transport mill to refiner	Road 650 km	Sea 12300 km Road 20 km
Transport refiner to factory	Road 50 km	50 km

### ***2.3 Allocation methodologies***

Allocation was performed using both mass and economic methodologies to facilitate a comparison of results.

The economic allocation was based on market prices [16], combined with the mass balance figures and entailed that within the extraction stage, 76.9% and 82.4% of the impacts were allocated to Rapeseed Oil and Sunflower Seed Oil respectively, rather than their meal co-products. When this was changed to mass allocation, the oils both had the reduced figure of 40% allocated to them. Within the refining stage, economic allocation attributed both oils with 66.67% of the load, whereas mass allocation increased this to 96.45%.

### ***2.4 Impact assessment methodologies***

Two LCIA methodologies were chosen for assessment of the system to illustrate the differences that can arise through choice of LCIA method. Eco-Indicator 99 (EI-99) [17] is an endpoint method developed by Pré consultants to supersede their Eco-Indicator 95 method. Within EI-99, the results of the LCI are characterised into 11 impact categories and then aggregated into three damage categories namely 'Human Health', 'Ecosystem quality' and 'Resources'.

ReCiPe 2008 [18] was developed through a collaboration with Radboud University Nijmegen, CML and Pré which was aimed at harmonising the CML midpoint and Pré endpoint methodologies. As such, ReCiPe has 18 midpoint categories and 17 endpoint categories which, like EI-99 can be aggregated into 3 damage categories; Human Health, Ecosystems and resources.

For ease of comparison, the endpoint data only is reviewed in this paper.

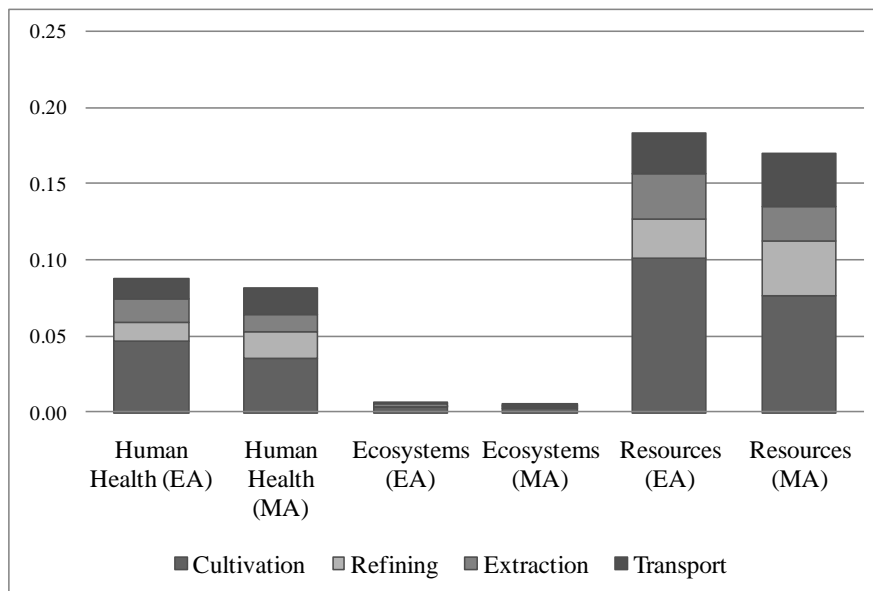
## **3 Results**

The inventories were analysed with the objective of identifying both the relative contributions from each of the process stages and the overall environmental load of both systems. The effect of using the different allocation and impact assessment methodologies was scrutinised on that basis.

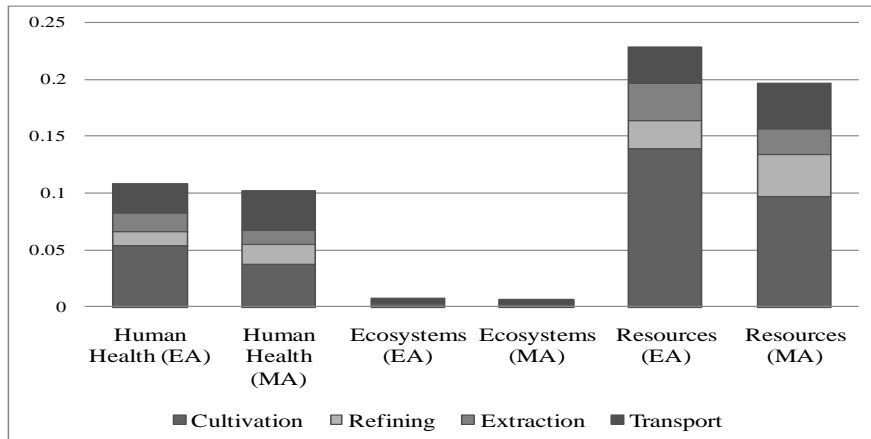
### 3.1 Relative contribution from process stages

From the data presented in figures 2 to 5, it is evident that for both oilseed systems, cultivation contributes the largest impacts within each damage category, regardless of allocation or impact assessment methodology used. However when changing from mass to economic allocation, the environmental burdens of each process stage change significantly. When analysed using ReCiPe 2008, increases of 25% and 30% arise for Rapeseed cultivation and extraction, and decreases of 45% and 27% for refining and transport. This change also takes place within the Sunflower seed system where the environmental loads attributed to cultivation and extraction both increase by 30%, with the loads from refining and transport decreasing by 45% and 26% respectively.

Significantly, these changes lead to a modified order of relative contribution within the system. Both systems retain cultivation and transport as the stages with the greatest contribution, but moving from mass to economic allocation reverses the order of the remaining two, with extraction having a reduced environmental load compared to refining.

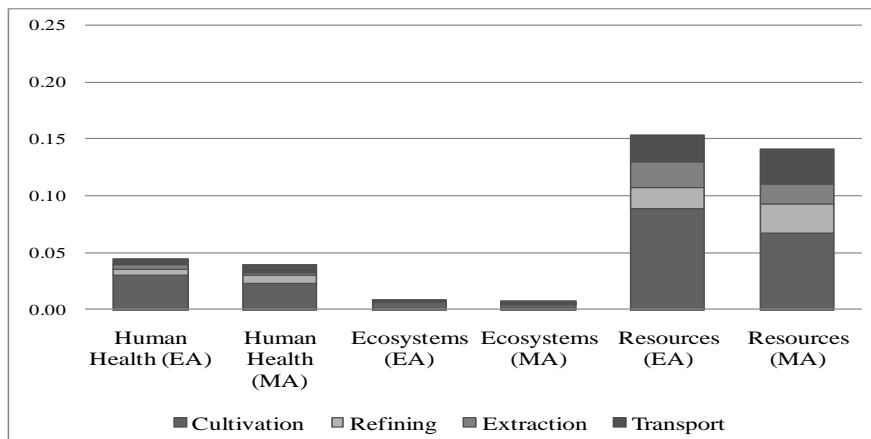


**Fig.2:** Changes in relative contributions for normalised endpoint data (rapeseed oil system, ReCiPe LCIA methodology)

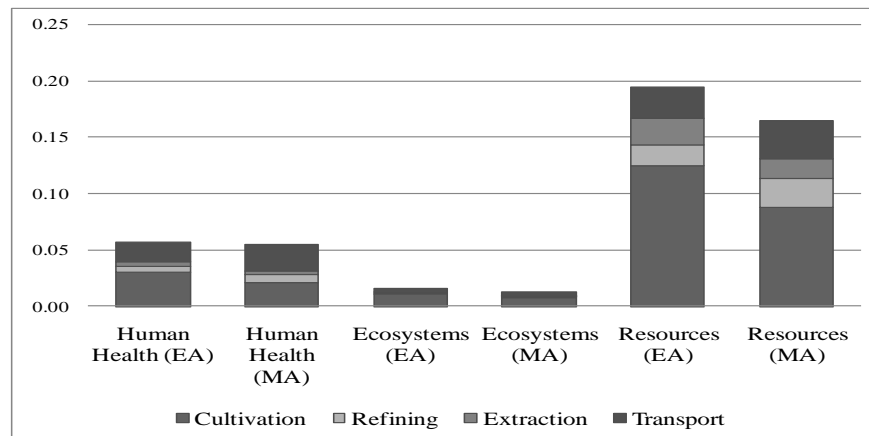


**Fig.3: Changes in relative contributions for normalised endpoint data (sunflowerseed oil system, ReCiPe LCIA methodology)**

This same effect is observed when using EI-99 as the LCIA method, as shown in figures 4 and 5. Here, within the Rapeseed oil system a move from mass to economic allocation produces increases of 25% and 25% for the cultivation and extraction stages, and decreases of 45% and 31% for the refining and transport stages. Again, for the Sunflowerseed oil system, the same change causes an increase in the environmental load of 30% from both the cultivation and extraction stages, with decreases of 45% for cultivation and 26% for transport. As previously, the order of relative contribution within the system is changed, with cultivation and transport being the largest two regardless of allocation, but extraction moving to third when economic allocation is applied.



**Fig.4: Changes in relative contributions for normalised endpoint data (rapeseed oil system, EI-99 LCIA methodology)**



**Fig.5: Changes in relative contributions for normalised endpoint data (sunflowerseed oil system, EI-99 LCIA methodology)**

### ***3.2 Relative contribution from impact categories***

Both oilseed systems were analysed to ascertain which of the impact categories were most prominent, and whether that was affected by the use of allocation method. Figure 6 shows the percentage change to characterised impact categories that arise from a change from mass to economic allocation, when using ReCiPe 2008 as the LCIA method.

For the Rapeseed oil system, within certain impact categories, the change in allocation method has a large effect, with changes of over 20% occurring. However, when the percentage changes are shown for the 4 impact categories that have the largest impact (when comparing normalised data) these changes whilst still significant are more modest, at 5.8% for 'Climate Change Human Health', 8.2% for 'Human toxicity', 8.7% for 'Particulate Matter Formation' and 7.2% for 'Fossil depletion'.

The changes are more striking within the Sunflowerseed oil system, where both positive and negative changes are found. Here the top 4 impact categories have relative changes of 9.9% for 'Climate Change Human Health', 11.6% for 'Human toxicity', -5.4% for 'Particulate Matter Formation' and 13.7% for 'Fossil depletion'.



Despite these changes however, the relative contribution of the impact categories remain unchanged and allocation method does not affect the order, with Fossil Fuels being the largest contributing category, followed by Respiratory Organics, Carcinogens and Climate Change.

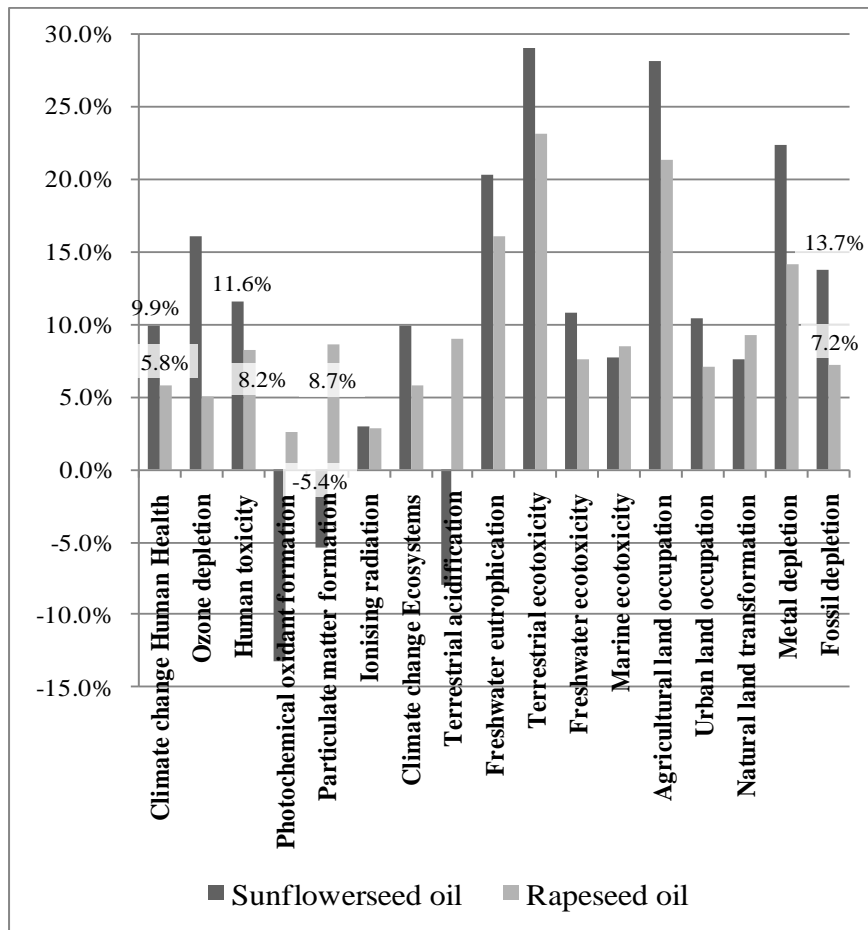
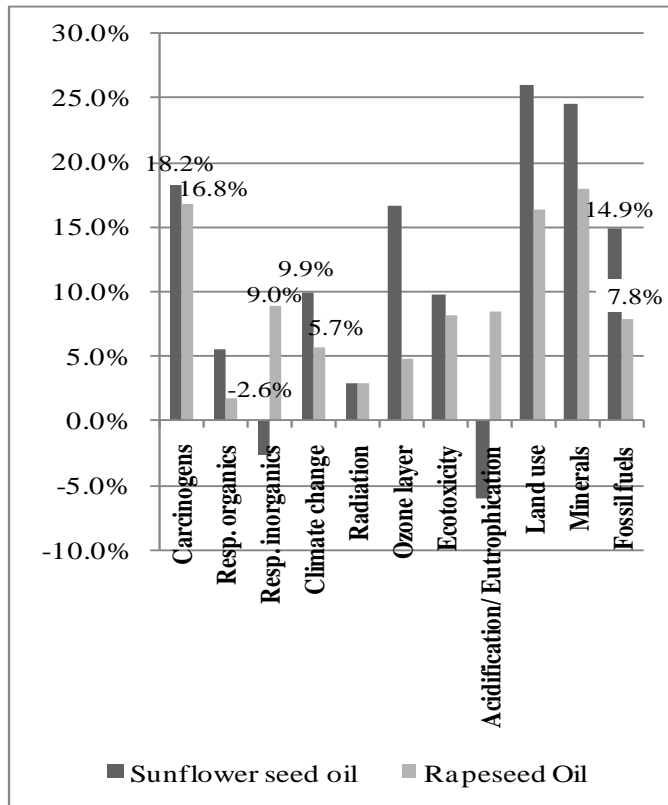


Fig.6: Percentage change in characterised impact category through changing from mass to economic allocation (ReCiPe LCIA methodology)

The changes are even more significant when using the EI-99 method. Here in terms of percentage change in impact category, there are large changes up to 26% for the sunflower seed oil systems and 18% for the rapeseed oil system as depicted in figure 7. When the top 4 categories are scrutinised however, the percentage changes are again more modest, but higher than those observed when using ReCiPe.

For the rapeseed oil system, the 'Carcinogens' category has the largest change of the four, at 16.8%, followed by 'Respiratory inorganics' at 9.0%, 'Fossil fuels' at 7.8% and 'Climate change' at 5.7%. Within the sunflower seed oil system, of the 4 most significant categories, 'Carcinogens' has the highest relative change at 18.2%, with Fossil fuels at 14.9%, 'Climate change' at 9.9% and 'Respiratory inorganics' at -2.6%.



**Fig.7: Percentage change in impact category through changing from mass to economic allocation (EI-99 LCIA methodology)**

## 4 Conclusions

Where system expansion is not possible or feasible, allocation of environmental impacts must take place within multi-output systems. Several sources acknowledge that choice of allocation approach can have a significant effect on the results generated [5,8,9]; this is consistent with our findings, reported in this paper, from the analysis of the rapeseed oil and sunflower seed oil systems, using both mass and economic allocation.

The results of the paper have further shown that the size of the effect is also affected by choice of LCIA methodology, with the relative changes to environmental impact categories for the four most significant impact categories (based on normalised endpoint data), being greater when Eco-Indicator 99 was used, rather than ReCiPe 2008.

One of the purposes of the LCA determination within the SEIBI project is to identify and quantify the relative contributions of each processing step, such that process improvements can be targeted to specific areas. It is evident from the results presented here, that choice of allocation parameter will be an important consideration for this project (and others with similar scopes) and must certainly be transparent to enable effective decisions to be made based on the LCA results.

## 5 References

- [1] ISO 14040:2006; Environmental management - Life cycle assessment - Principles and Framework, BSI, London
- [2] ISO 14044:2006; Environmental management - Life cycle assessment - Requirements and guidelines, BSI, London
- [3] Environmental Protection Agency, Life Cycle Assessment: Principles and Practice; EPA/600/R-06/060: Washington DC, 2006
- [4] Baumann. H and Tillman. A, *The Hitch Hiker's Guide to LCA - An orientation in life cycle assessment methodology and application*; 1st Ed, Studentlitteratur, 2004
- [5] Curran. M.A, Studying the effect on system preference by varying co-product allocation in creating life-cycle inventory, *Environmental Science & Technology*, Vol 41, No 20, 2007, pp7145 – 7151
- [6] Guinée. J.B, Heijungs. R, and Huppes. G. Economic Allocation: Examples and Derived Decision Tree, *International journal of Life Cycle Assessment*, Vol 9, No. 1, 2004, pp 23 - 33

- [7] Finnveden. G, Hauschild. M.Z, Ekvall. T, Guinée. J, Heijungs. R, Hellweg. S, Koehler. A, Pennington. D, Suh. S. Recent Developments in Life Cycle Assessment, *Journal of Environmental management*, Vol 91, 2009, pp 1 - 21
- [8] Halleux. H, Lassaux. S, Renzoni. R, Germain. A, Comparative Life Cycle assessment of Two Biofuels. Ethanol from Sugar Beet and Rapeseed Methyl Ester. *International Journal of Life Cycle Assessment*, Vol 13, No. 3, 2008, pp 184 - 190
- [9] Morais. S, Martins. A. A, and Mata. T.M. Comparison of allocation approaches in soybean biodiesel life cycle assessment, *Journal of the Institute of Energy*, Vol 83, No.1, 2010, pp 48-55
- [10] Shonfield. P.K.A and Dumelin. E, A life cycle assessment of spreads and margarines, *Lipid Technology*, Vol 17, No. 9, 2005, pp 199 – 203
- [11] Nilsson. K, Flysjö. A, Davis. J, Sim. S, Unger. N, Bell. S, Comparative life cycle assessment of margarine and butter consumed in the UK, Germany and France, *International Journal of Life Cycle Assessment*, Vol 15, No. 9, 2010, pp 916 - 926
- [12] Schmidt J H (2007), PhD Thesis, Life Cycle Assessment of Rapeseed oil and palm oil, Department of Development and Planning, Aalborg University, Denmark
- [13] <http://www.eastagri.org/downloads/ae375e00.pdf>, (accessed 25/11/2010)
- [14] McManus. M.C, PhD Thesis, Life Cycle Assessment of Rapeseed and Mineral Oil Based Fluid Power Systems, The University of Bath, 2001
- [15] McManus. M.C, Hammond. G.P, and Burrows. C.R, Life Cycle Assessment of Mineral and Rapeseed Oil in Mobile Hydraulic Systems, *Journal of Industrial Ecology*, Vol 7, No. 3-4, pp 163 - 177
- [16] [www.imf.org/external/np/res/commod/index.asp](http://www.imf.org/external/np/res/commod/index.asp) (accessed 25/11/2010)
- [17] Goedkoop M, Oele M, de Schryver A and, Vieira M (2008), SimaPro Database Manual Methods Library. <http://www.pre.nl/download/manuals/DatabaseManualMethods.pdf> (accessed 26.08. 2010)
- [18] Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J and van Zelm R (2009), ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First edition, Report I: Characterisation, Ministry of Housing, Spatial Planning and the Environment (VROM), The Netherlands.