Lifecycle analysis aspects of biofuels

What can be learned from a practical case of inland waterways transport?

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Abstract: An experiment done in Geneva on the river Rhône with a push boat gave the practical frame of a comparative study between 3 fuels: diesel, biodiesel and vegetable oil. Further more in this concrete case the VO used, came from frying oil waste constitutes an interesting illustration of industrial ecology.

The asset of this study on environmental impacts analysis done here is to have used practical measurements of emissions from an engine in function on the push boat in complement to bibliographic sources and Data Base.

Investigating the sensibility of such analysis shows that there are still questions to be answered and that this field is still subject for research.

Finally, it confirms that the environmental gains of biofuels scenarios are not as important as expected, if their vegetable raw material is produced uniquely for energy as in the transport function. They are much more interesting when used in an industrial ecology context where a first cooking function allows dispatching of the production's impacts.

Keywords: industrial ecology, environmental impacts analysis, LCA, biofuels, diesel, biodiesel, vegetable oil

1 Introduction

Biofuels play an important role in R&D of renewable energy. The use of biodiesel or the appropriate mixture of diesel oil with vegetable oil as fuel for diesel engines has the advantage of needing little or no modification of an existing engine.

An experiment done by the SIG (Services Industriels de Genève) at Geneva, consisting in the use of a mixture of diesel oil / vegetable oil in a propelled push boat, used to push barges of waste on the river Rhône gave the practical frame of a comparative study between 3 fuels: diesel, biodiesel and vegetable oil (SVO). Further more in this concrete case the VO used, came from frying oil waste (WVO), which constitutes an interesting illustration of industrial ecology.

It is quite important here to point out that in the frame of Agenda 21, the state of Geneva introduced in 2001 a law [1] that encouraged initiatives of industrial ecology. In that perspective, it is important to find opportunities to exchange material waste or energy through a network of industrial partners and to put this in practice.

2 Environmental Analysis of the push boats

The study was done in two steps: in the first, the cooking function of VO was not considered, so the results of LCA of fluvial transport using this kind of push boat became as if VO was produced directly to be used as fuel (SVO), which is often the case.

In the second step the cooking function was taken in to consideration as well as the sensibility check.

2.1 Definition of the system limits

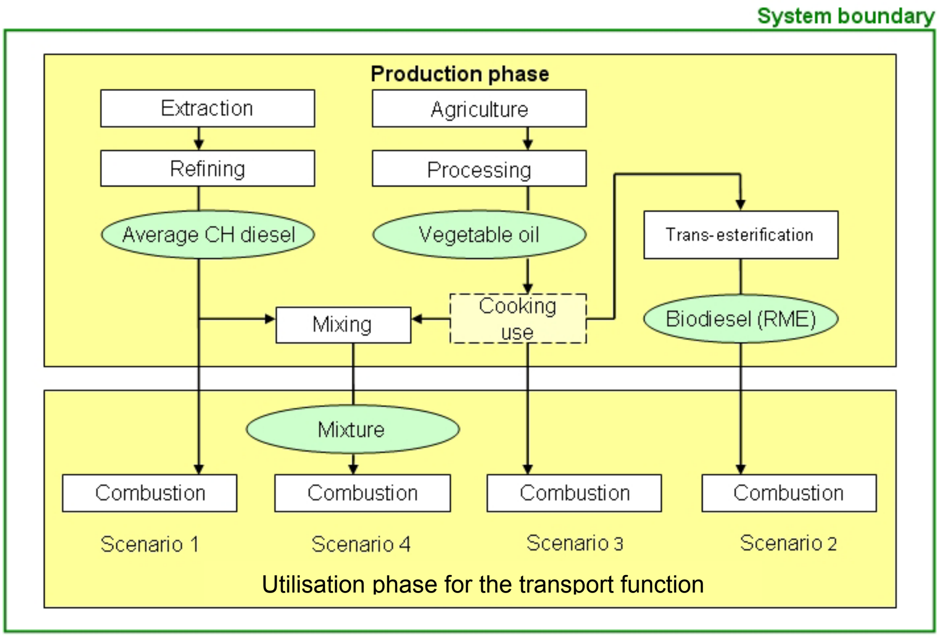
The push boat has two 6 cylinder engines of 242 kW (325 bhp) at 1800 rpm, direct injection, without neither catalyser nor particles filter.

Each barge (or convoy) has a maximum capacity of 170 t.

The system boundary covers the fuels production (transport included) and the fuels usage (combustions and emissions).

The impacts link to the construction, maintenance, and end of life of the push boat and the fluvial infrastructure were not taken in account in this study.

Figure 1 System boundaries



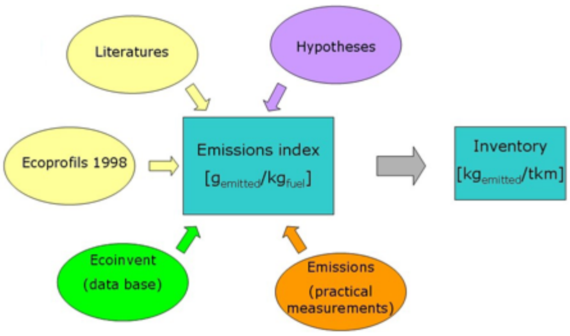
2.2 *Inventory*

The asset of this study on environmental impacts analysis done here is to have used practical measurements of emissions from an engine in function on the push boat, fed with diesel fuel and a mixture of diesel-VO, and with complementary data research from bibliographic sources and data base (Ecoprofils [2] and ecoinvent [3]).

The practical benchmark measurements were made at the laboratory of control of exhausting gases from the University of Applied Sciences of Bienne, Switzerland.

All data on emission collected, were reported in the emissions index, and then to the inventory in accordance to the chosen functional unit (FU), which was the ton kilometer "tkm" (one ton moved on one kilometer).

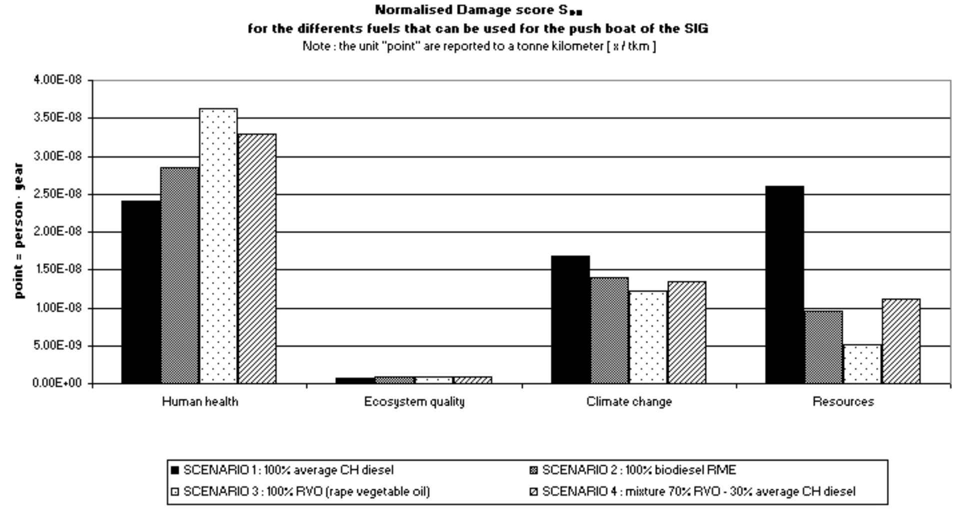
Figure 2 Data sources for the inventory



2.3 *Impacts*

The method use to evaluate impacts is Imapct2002+ V2.1, is a life cycle impact assessment methodology that propose a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories a method developed by the EPFL, Switzerland [4].

Figure 3 Results - Normalised Damage Score S_{DN} (production + use)



Note: “points” are equal to “pers·yr”. A “point” represents the average impact in a specific category “caused” by one person during one year in Europe

2.3.1 Interpretations

As we can see (fig. 3), the RVO as the highest damage score in the human health category, principally due to the respiratory effects from high level of NOx and PM in exhaust gas during the utilisation phase for the transport function (combustion).

On the climate change, biofuels have lower impact than diesel, but not as much as we could have expected, that is mainly due to the production phase where the agriculture plays a major role, due to the use of mineral fertilizer (nitrogen, N) that partially become N_2O (nitrous oxide) [5], where 1 kg $N_2O \equiv 156$ $kg_{eq}CO_2$ [6].

The resources category, represents the non renewable energy needed, to realise the function (move a ton of waste for a kilometer), as we can see on the figure 3 above, the use of biofuels (RME, RVO, mixture) clearly diminished the need for non renewable energy, this major environmental benefit is largely in favor of biofuels compared to fossil fuels.

The higher impact of biodiesel RME compared with RVO, is due to the use of methanol from fossil origin, that is used in the reaction of trans-esterification in the production phase.

A solution to overcome the impact on human health (respiratory effects) and still benefit from the low consumption of non-renewable energy (NRE) from biofuels could be to use a particle filter.

2.3.2 Sensibility: What is the importance of agriculture?

We choose to lead a sensibility test in the resource impact category (which express the NRE demand), because the variation between scenarios are great. We also have well detailed information on each step of production of biodiesel RME and RVO.

We look at the relative importance of NRE consumption used to produce 1 kg of biodiesel RME versus RVO.

Figure 4 Parts of non-renewable energy needed to produce biodiesel RME

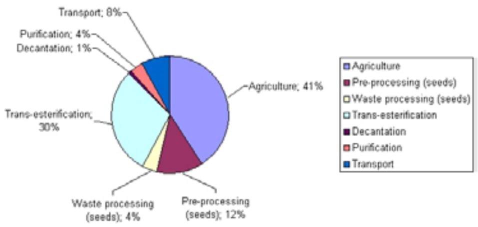


Figure 5 Parts of non-renewable energy needed to produce RVO

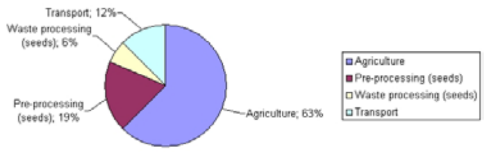
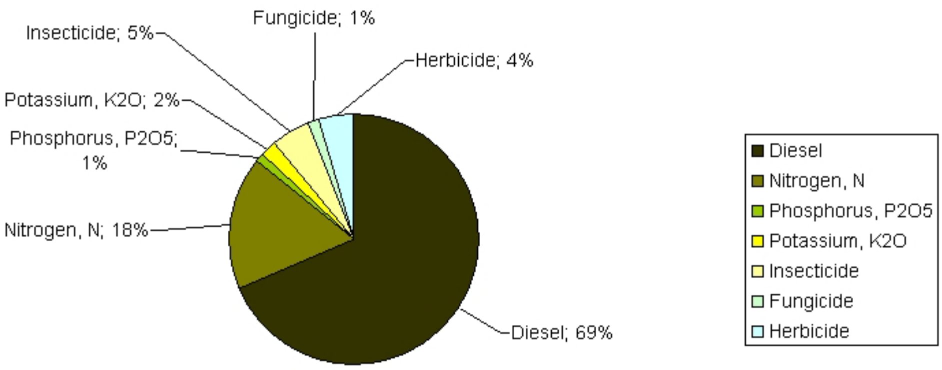


Figure 6 Parts of non-renewable energy needed for the agriculture step in the production of RVO



As fig. 4 and 6 show the main part of NRE is used in agriculture, respectively 41% for biodiesel RME and 69% for RVO, then if we look inside the agriculture phase we see (fig.6) that the use of diesel (fuel for field work) and mineral fertilizer (nitrogen) are the two main contributors to the consumption of NRE, respectively 69% and 18%.

2.3.3 Sensibility: What about considering the cooking function?

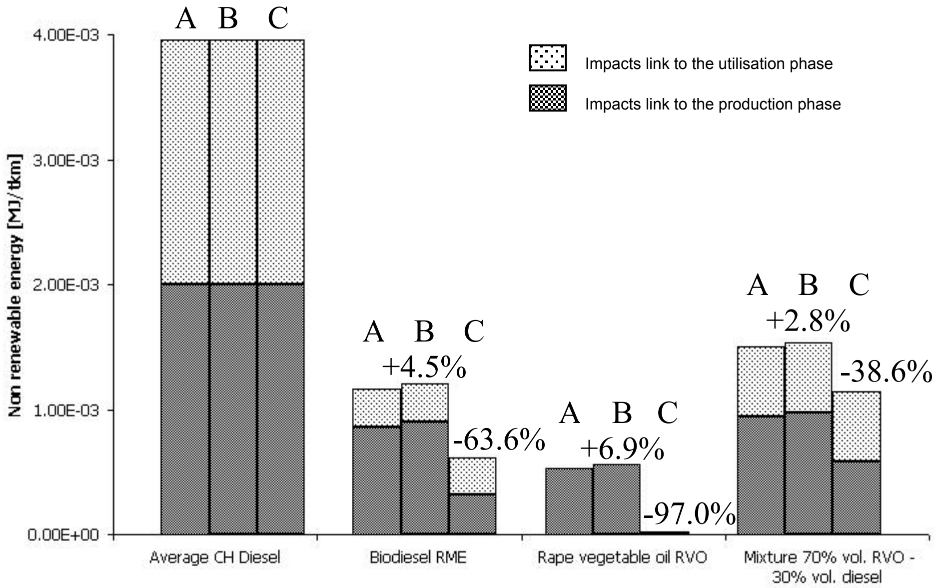
To test the sensibility we modified:

A) Standard case, VO directly produced for energy use (no modifications).

B) The type of agriculture, the hypothesis is: adding +20% of fertilizer, +20% pesticide involving +7% diesel in consumption for fieldwork.

C) The financial allocation of impact. According to WVO supplier information, we considered that the WVO has a cost to get rid off, so we dispatched them between the first "cooking function" and the second "transport function", the impacts from agriculture, pre-processing (seeds), waste processing (seeds) is then allocated to the first function.

Figure 7 Non-renewable energy impacts / Results sensibility on agriculture and allocation



The variation of impacts of case B: agriculture (+20% fertilizer, +20% pesticide, 7% diesel) compare to the impacts of the standard case are very small, almost negligible, but if doses and/or transport are increased it may lead to much higher variations, this is of some concern when the vegetable oil comes from plants other than rape (e.g. peanuts oil).

The important variations between standard case A and the case C is due to allocation : part of the impact is reported to the "cooking function" and so disappears from the "transport function". The way you chose to allocate is predominant.

In our case the WVO costs restaurants to get rid off, so we have to attribute the impact due to production (agriculture, seeds pre-processing, seeds waste processing) to the cooking function (case C); but if the WVO had a value, we should attribute a part of those impacts to the transport function.

But the concern is that the cost of waste can fluctuate depending on the demand, so the impact changes according to the value of WVO, that does not represent the global reality: that is impact stay the same (it is not changing with the cost or price), but they are just dispatch differently between the cooking function and the transport function.

So financial allocation has to be considered with caution.

Conclusion

The innovativeness of this study is to have mixed some literature data with some practical measurements of the gas emission coming out of the engine as basis of the life cycle inventory for the environmental impacts analysis. This study has also shown that allocation is a major concern when considering impacts.

This study has been focused on RVO and RME, the evaluation of the sensibility of the environmental impact has shown the importance of the agriculture phase. This will be important when considering VO if coming from other plants, and it shows that research still has to be done in this area.

We also see that using WVO as fuel should be considered in the perspective of industrial ecology: VO after use in the cooking function (as frying oil) is considered as waste, but it is considered as raw material (resource) for the transport function. In this case there is a problem of concept: how to measure impacts of successive functions? Should the impacts of the production of VO be attributed uniquely to cooking function or should they be dispatched between the two successive functions? The technique of allocations allows solving the problem in a more or less satisfying way; it is a difficult question which disserves discussion and that this case study can enlighten.

The so-called “financial allocation” reports the impacts due to production on the cooking function and in consequence the transport function impacts decrease (price could depend on demand, tax, etc.) This means that some impacts disappear from transport function and appear on the cooking function – is this very fair? This involves the splitting of the VO life cycle, in our case the question of the CO_2 should be treated in particular way: it is absorbed on the 1^{st} part of the cycle and restituted in the 2^{nd} part of the cycle. So this splitting in two of the cycle is uncomfortable – in this situation of industrial ecology, we clearly have one cycle with 2 functions that should not ignore each other. The kind of environmental benefit that appears on the 2^{nd} part of the cycle is in fact the benefit of industrial ecology.

Finally this study allows us to confirm that the environmental gains of biofuels scenarios are not as important as we first thought, if their vegetable raw material is produced uniquely for fuel use. They are of much more interest when used in an industrial ecology context where a first cooking function allows dispatching of the impacts due to production.

Acknowledgment

Mr. Charles Burckhardt (SIG, fluvial transport department chief)

Mr. Raymon Moser (SIG, push boat driver)

Mr. Dominique Stämplfli-Lugrin (SCPA, air emission department chief)

Mr. Yves Lützelschwab (SCPA, inspector in environment)

Mr. Vincent Perret (STIPI, scientific adviser)

Mr. Yves Loerincik (ECOINTESYS S.A.)

Mr. Donald Buchet (D-Solutions S.A., WVO supplier)

Mr. Yvan Abbatiallo (Biocarb S.A., engineer)

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4 Annexes

4.1 Glossary

CH	Confoederatio Helvetica, means Swiss Confederation or Switzerland.
CO_2	Carbon dioxide.
EPFL	École Polytechnique Fédérale de Lausanne (EPFL) is the Swiss Federal Institute of Technology.
eq.	Equivalent (e.g. 1 kg $N_2O \equiv 156\ kg_{eq.}CO_2$).
FU	Functional unit.
LCA	Life Cycle Assessment, sometime call ecobilan
N_2O	Nitrous oxide.
NOx	Nitrogen oxide (e.g. NO, NO_2).
NRE	Non-renewable energy.
PM	Particles matter, in this study particles PM10 (particles with aerodynamic diameter less than 10 µm) and PM2.5 (less than 2.5 µm) have been taken in account.
point	"points" are equal to "pers·yr". A "point" represents the average impact in a specific category "caused" by one person during one year in EU.
R&D	Research and development.
RME	Rape methyl ester, biodiesel made from rape oil
RVO	Rape vegetable oil.
SIG	Services Industriels de Genève, semi-public company which provide (e.g. water, electricity, waste disposal).
SVO	Straight vegetable oil.
VO	Vegetable oil.
vol.	Volume.
WVO	Waste vegetable oil.