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Life cycle thinking as a decision tool for waste management policy

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Abstract – The European Waste Framework Directive (2008/98/EC) explicitly specifies the hierarchy for waste management: prevention, preparation for re-use, recycling, other recovery actions, disposal. When selecting waste management options, this waste hierarchy should be followed. A deviation can only be justified by Life Cycle Thinking (LCT) on the overall impacts. The application of this principle in the Flemish waste management practice triggered the need for evaluation of treatment options for several waste streams. Alternative treatments were evaluated for waste batteries, used frying oils and waste oil. The evaluation methodology combined life cycle assessment with technical and economical viability criteria. These cases show that LCT does not allow to establish a "general priority order". In each case reasons for deviation from the standard waste hierarchy could be given, but also none of the evaluated options can be considered as the best. The evaluation showed that the priority is largely dependent on location-specific characteristics of inputs, outputs, processes and installations and that the establishment of local and global environmental priorities always implies a value choice. In this presentation, we will present the results of the three cases and provide a methodological framework for life cycle thinking in waste management policy.

1 Introduction

1.1 Challenging the waste hierarchy

The European Waste Framework Directive (2008/98/EC), in its article 4, explicitly specifies a hierarchy for waste management: prevention, preparation for re-use, recycling, other recovery actions, disposal. When selecting waste management options, this waste hierarchy should be followed. Nevertheless, to achieve the best overall environmental outcome it might be required to depart from the hierarchy when this can be justified by life-cycle thinking on the overall impacts of the generation and management of such waste. Life Cycle Thinking (LCT) seeks to identify possible improvements to goods and services in the form of lower environmental impacts and reduced use of resources across all life cycle stages. Most importantly, Life Cycle Thinking should help to avoid resolving one environmental problem while creating another, the so-called *shifting of burdens* (ILCD Handbook, 2010) [1].

Article 4 of the Waste Framework Directive in addition requires to take into account the general environmental protection principles of precaution and sustainability, technical feasibility and economic viability, protection of resources as well as the overall environmental, human health, economic and social impacts.

1.2 Research objectives

The translation into policy and practice of the life cycle thinking concept by environmental administrations entails a deeper and wider assimilation of technical, economic and social concerns in what used to be purely environment-oriented decision-making processes. At the other hand, the growing economic and social relevance of recycling industries targeting very specific waste streams, derives in the need for evaluation of treatment options for those streams. In a global economic and environmental context, such evaluation cannot longer be

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based on criteria that only consider local and environmental impacts. With a growing number of parameters to be taken in account, not only will the complexity of the assessment increase, but also the probability to obtain unambiguous conclusions regarding the overall performance of treatments for specific waste streams will diminish accordingly.

In separate studies, alternative treatment technologies were evaluated for waste batteries, used frying oils and waste oil, in the Flemish context of waste management practices. Treatments situated on different levels of the waste hierarchy were included. The objective was to draw conclusions from the comparison of the overall environmental impact of each treatment, with the conviction that the environmentally more desirable treatments could be distinguished in view of eventual adjustments of the existing waste policies.

Through evaluation and comparison of the three cases, some general conclusions on the outcome and usefulness of LCT can be drawn. Such conclusions will allow to make specific recommendations regarding the methodological framework for life cycle thinking in waste management policy.

2 Methodology for calculating and comparing the environmental performance of alternative waste treatments

2.1 Life Cycle Thinking (LCT)

The current trend is to strive to a full assessment of goods and services within the context of sustainable development (SD). The combination of Life Cycle Thinking (LCT) which includes the so-called three "pillars of sustainable development" (economic, environmental and social), aims at getting such global picture of societal impacts associated to goods and services.

Different approaches can be used to assess the sustainability of products or services: in a mono-pillar approach, each one of the three dimensions of sustainability is analyzed separately. However it is possible to carry out the analysis of different pillars in a parallel manner so that the results can be combined into a single sustainability analysis. This approach led to a new concept that should allow a methodical and structured approach of life-cycle thinking, namely the assessment of the life cycle sustainability (Life Cycle Sustainability Assessment, LCSA) [2].

At the present, no formal procedures have been developed yet to integrate the three different above-mentioned mono-pillar tools. Nevertheless, multi-pillar assessments can be, and actually are performed by deploying complementary procedural and analytical tools and methods.

The guidelines for supporting environmentally sound decisions in waste management of the European Commission's Joint Research Center [3] affirm that Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) can be applied to legislation and waste management planning, leading to the identification (and ultimately choice) of the most preferable environmental option.

The JRC states that an LCA can be conducted with different levels of detail and therefore should be tailored to the problem. Whether a very detailed LCA is necessary, or a simplified approach is sufficient, depends on the relevance and impact of the decision at stake. For the studied cases, the decisions that might be taken based on the results of the assessment were at that moment not expected nor intended to be linked with high costs, technology lock-in nor the need for infrastructure. For this reason, it was decided not to perform detailed and peer-reviewed LCAs to assess the differences in environmental impacts of the selected options. Nonetheless, for each of the analyzed waste streams, stakeholder groups that included companies and authorities participated actively in each of the consecutive steps of the analyses, particularly in the inventory building and to corroborate product and market related information.

All LCAs were performed following the ISO 14040:2006 principles[1], and the analyses were complemented where necessary with straightforward criteria and data derived from the available experience and

[1] ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA).

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knowledge gained from previous successful applications of LCA in comparable waste management contexts.

2.2 Attributional and consequential Life Cycle Assessment (LCA)

For the analysis of the different cases, an attributional and differential approach was applied. The expression *attributional* refers to the fact that for every analyzed treatment of a well-defined waste stream the environmentally relevant physical flows attributable to that particular treatment are described separately. This, as opposed to *consequential* where only the changes in relevant flows, in response to possible decisions, would be modeled for analysis. A consequential approach focuses on the environmental effects that are a consequence of e.g. applying a lower incineration fee for waste oil, by taking into account the effects of a decrease of the amount of waste oil supplied to alternative treatments.

As the objective of the case studies was to compare environmental effects of different End-of-Life (EoL) treatments, a differential approach was applied by not including the environmental benefits and burdens associated to shared life cycle stages or process steps (e.g. production and use phases that generate the specific waste stream, or common waste collection activities).

2.3 Dealing with multifunctionality

The functional unit of the LCAs always corresponds to the treatment of one unit of a specific waste type, whatever secondary product or material results from the treatment. The case studies thus do not aim to analyze the environmental impacts of producing one unit of treatment output (e.g. biodiesel or base oil). Furthermore, alternative treatments of a single waste stream can lead to the generation of different and multifunctional by-products. To fully attribute the resulting impacts to the functional unit and make them comparable, it is thus necessary to allocate for all resulting secondary products.

Different methods exist to allocate the recycling impacts at product EoL, and the choice of the method is known to have implications, e.g. on the values of cumulative environmental impact for a material that is recycled from the product [4]. As the performed analysis aimed to assess EoL life cycle stages only (in case of the frying oil the recycled product reuse phase was included), allocation methods that account for the recycled content of the primary product, like the cut-off (or recycled content) method or the 50/50 method, were not applied. Instead, the substitution method, also known as the EoL or avoided burden method, that assigns all recycling benefits to the EoL phase, was used. The application of the EoL method requires that the recycled products have sufficient demand, which here, as existing recycling activities are concerned, is assumed to be the case [5].

System expansion was applied by substituting the environmental effects of the useful recycling or recovery process outputs, by the effects of the production of equivalent products in an average primary production process. The life cycle inventory of the other system is subtracted from the analyzed system.

2.4 Selecting the best treatment

Under the EoL allocation method, the net environmental impact of recycling processes typically will be determined mainly by the benefits that are a consequence of avoiding production processes that convert primary materials into products that provide the same functionality as the secondary products from the recycling activity. This requires a thorough investigation and good knowledge of the functionalities of the recycling outputs and their degree of correspondence with not only the substituted primary products but also with the input characteristics. The latter might be highly variable and/or determined by local parameters as the type of collection system, local or national regulations, agreements on End-of-Waste criteria, etcetera.

Under an attributional LCA approach it is suggested to use average flow figures that correspond to average process flows, allowing for conclusions on the process' environmental performance that are generally valid in average conditions. Nevertheless, it was

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observed that the processes that are performed to recycle the very specific waste streams with typical (Flemish) characteristics, take place in a limited number of highly specialized plants in a restrained geographical area. This situation entails the risk that in the end an assessment is made of the environmental impact of an individual plant in a specific context, rather than of a general treatment applied to a waste stream with a fairly unique Flemish composition.

It will thus be a very complicated task to provide recommendations to policymakers who request decisive results from objective comparisons of the environmental performance of alternative treatments of specific waste streams, as will be shown in the analyzed case studies.

3 The impacts of waste treatments compared: the case studies

3.1 Treatment of animal fat and recycled used edible fats and oils (UEFO) [6]

The studied waste materials correspond to rendered animal fat from the pig and poultry processing industry, and used edible animal fats and vegetable oils (UEFO) from the food industry, the catering sector and households. UEFO are melted, filtered and/or blended to produce standard quality secondary intermediate products for specific end-uses. This intermediate is referred to as recycled UEFO.

The compared treatment scenarios were:

1. Electricity production in a CHP facility: animal fat or recycled UEFO are used in a combined heat and power facility to generate electricity to be fed into the grid. 50% of the residual heat is used in internal processes.
2. Steam production in an industrial furnace: animal fat or recycled UEFO is used directly in an industrial furnace for the production of process steam. The steam is used in a rendering process or by a recycler of UEFO.
3. Use in the compound feed industry: animal fat is traditionally used as an additive for the production of compound feeds. The material can be used directly, without any pre-treatment.
4. Production of oleochemicals: in general, the production of oleochemicals from animal fats and vegetable oils either starts with hydrolysis or with transesterification. In this study, both variants are evaluated. The end-products of the hydrolysis and transesterification are processed into a wide range of oleochemical end-products through a number of typical oleochemical processes. These end-products are used as basic compounds for detergents, paints, plastics, etcetera.
5. Production and use of biodiesel: a specific pre-treatment is needed to remove the free fatty acids. Then, biodiesel is produced from the animal fat or recycled UEFO through a conventional biodiesel production process. By transesterification of the fat/oil in the presence of methanol and a basic catalyst, a methyl ester (=biodiesel) is produced. Biodiesel from recycled UEFO needs to be purified by distillation in order to meet the European product standards. Standardised biodiesel is blended with petroleum diesel for use in all diesel-engine cars. Biodiesel can substitute alternative biodiesels (5a) or fossil diesel (5b). In the latter case, it is not a perfect substitute for diesel, as the emissions resulting from internal combustion have proven to be different. The corresponding differences in environmental impacts were therefore taken into account.

The potential damages were estimated for the following impact categories, by using the EcoIndicator 99 Life Cycle Impact Assessment (LCIA) method[2]: emissions of carcinogens, respiratory effects caused by emissions of organic components, respiratory effects caused by emissions of inorganic components, climate change, toxic stress, eutrophication and acidification, land use, use of minerals and fossil fuels.

A first conclusion of the study was that no significant differences regarding the process impacts were found between using animal fat or recycled UEFO. Actually, it were the avoided processes rather than the

[2] The study was performed in 2007.

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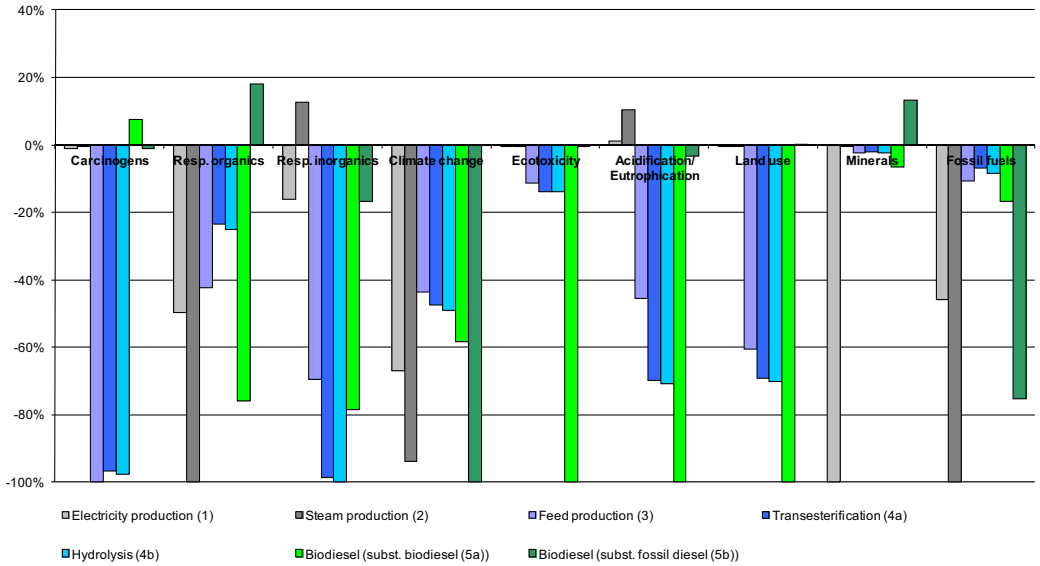


Fig. 1. Relative impacts for different animal fat treatment options.

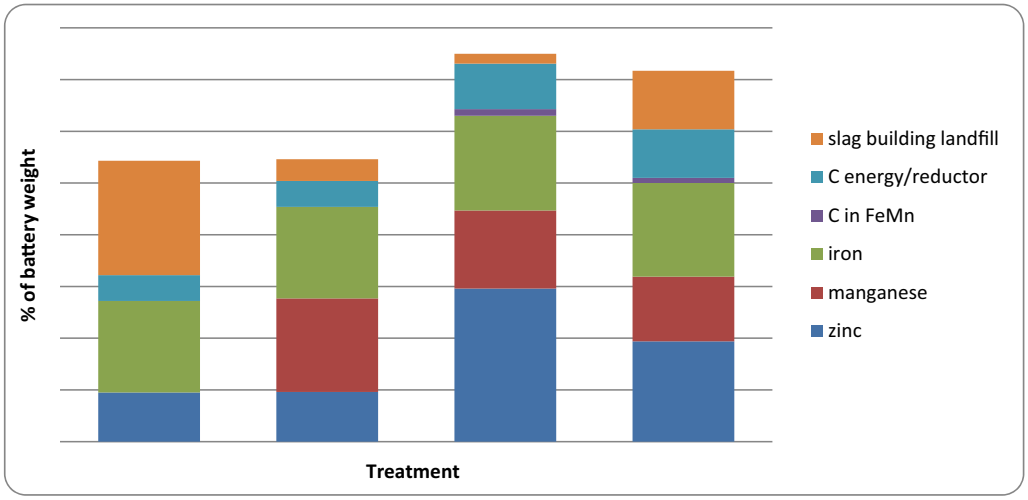


Fig. 2. Recycled/recovered material distribution for different technologies to treat an average zinc carbon waste battery.

recycling processes that determined the net environmental impacts.

The results corresponding to animal fats are shown in Figure 1.

Recycling (scenarios 3 and 4) as well as the fuel production that substitutes alternative biodiesels (scenario 5a) imply the avoidance of agricultural crops (rape seed, soybean and palm oil) as a source of vegetable oil. The saving of the related NO*x*, SO_2 and NH_3 emissions accounts for important benefits in the impact categories of acidification/eutrophication and respiratory inorganics. The benefits in the land use impact category are obvious. Avoided transports related to palm or soy oil are not environmentally insignificant, while all other transport related effects are. Furthermore, avoided crops have important benefits regarding the land use impacts. The effects of these agricultural crops on biodiversity were not considered in this study. Still, recycling always results in net environmental benefits, except in the case of avoided alternative

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biodiesel production from rapeseed, since the rapeseed crop was assumed to uptake cadmium from the soil, so that its substitution results in a burden. In case of oil palms and soy, the use of fertilizers results in a net-input of cadmium to the soil. Furthermore, rapeseed production is associated with a relevant emission of metals to the agricultural soil, making its avoidance key in the impact category of ecotoxicity.

In the scenarios that aim at the recovery of energy from fats and edible oils (scenarios 1, 2 and 5b), the net impacts of the recovery depend on the quantity and type of conventional fuels that are substituted. In comparison with material recycling, a shift can be seen towards higher benefits in climate change and fossil depletion. Net burdens are only observed for (1) the substitution of fossil diesel by biodiesel from animal fats and edible oils, due to methane emissions during biodiesel production; this is reflected in the respiratory organics category; (2) substituted production of steam from natural gas, due to the higher combustion emissions (NO*x*) generated by animal fats and edible oils; (3) electricity production with limited recovery of residual heat; (4) the production of biodiesel to substitute fossil diesel yields net impacts for mineral depletion, due to important biodiesel production process impacts related to the indirect use of metals and metal alloys.

In conclusion, it can be stated that material recycling out of animal fats and edible oils yields more benefits in land use, ecotoxicity, acidification/eutrophication and respiratory inorganics (and biodiversity), when and because material sources from cropping can be substituted. Energy recovering alternatives are preferable when benefits are aimed in the categories of climate change and fossil depletion.

For the remaining environmental impact categories, no clear best option (recycling/energy recovery) can be put forward.

3.2 Treatment of alkaline and zinc carbon waste batteries [7, 8]

Waste consumer batteries can be recycled using different routes based on hydrometallurgical and pyrometallurgical processes. For this case study, four different treatments for the recycling of Belgian waste batteries with an average composition were compared: two options with hydrometallurgical treatment (A and B), and two pyrometallurgical treatment options (C and D). Hydrometallurgical treatment A focuses on zinc and iron recycling. When allowing manganese recycling, as in B, the energy demand of the hydrometallurgical process increases considerably. Both pyrometallurgical options recycle zinc, iron and manganese.

Recycled non-metallic battery components include carbon and slag. The carbon can be used for energetic valorization (incineration of plastics), as reducing agent or will be recycled as a component of the ferromanganese. Slag can be applied as building material on landfills. The average distribution of the different recycled components can be observed in Figure 2.

An LCA was performed to compare the environmental performance of each treatment, and publicly available Life Cycle Inventory (LCI) data from the Eco-Invent database[3] were used. LCI-data on the average production of electricity in Europe were used.

The different treatment alternatives again result in a variety of secondary products. Similarly as in the case of animal fats and recycled edible oils, system expansion is performed to make possible the comparison of the treatment options, whatever the resulting outputs of a specific option might be. Data on the avoided primary processes were updated and adapted based on recent information from companies and expert-judgment.

The end-products of the treatment processes have very specific applications. Most LCI-data from the Eco-Invent database describe average processes, for example the average production of ferromanganese. As a consequence, it is not possible to distinguish between the avoided ferromanganese in different scenarios, though in reality the ferromanganese produced by one treatment option is used in foundries, while the ferromanganese produced by another option is used for the production of stainless steel.

[3] The study was performed in 2006.

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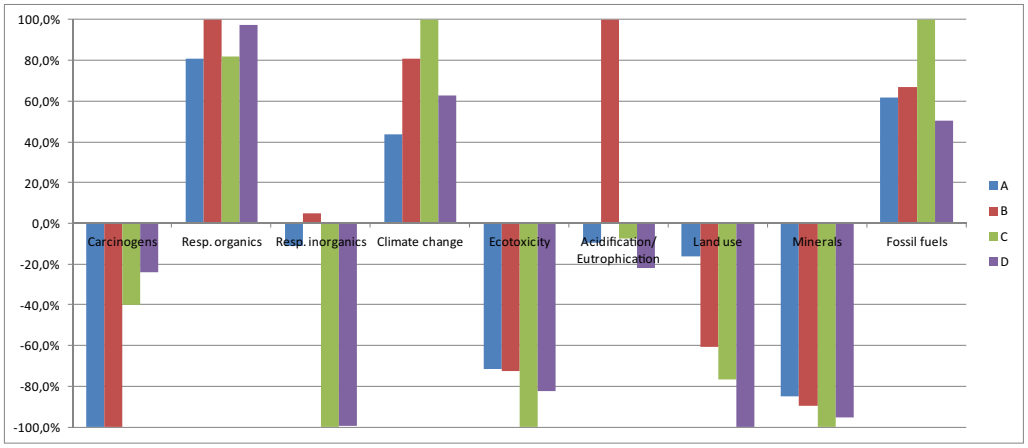


Fig. 3. Relative impacts for different waste battery treatment options.

Analyzed midpoint impact categories correspond to damage to human health, caused by emissions of carcinogens (carcinogens), respiratory effects caused by the emission of organic (resp. organics) and inorganic components (resp. inorganics) and greenhouse gases (climate change); damage to ecosystem quality, caused by toxic stress (ecotoxicity), acidification and eutrophication, and land use; damage to mineral and fossil resources, caused by the use of minerals (minerals) and fossil fuels (fossil fuels). The results are shown in Figure 3.

It was concluded that battery recycling holds environmental benefits as well as important burdens. All treatments show net burdens in the categories of respiratory organics, climate change, and fossil fuel depletion. The analyzed processes present different energy needs and efficiencies, that are reflected in specific requirements of electricity and fossil fuels, resulting in different direct and indirect emissions and fuel consumption characteristics that account for burdens in the climate change and fossil fuel depletion impact categories. Treatment B uses a high input of primary sulphuric acid for the production of zinc sulphate, resulting in net burden in the eutrophication/acidification category. Transport of the batteries to the treatment installations has significant impacts. The efficiency of the process corresponding to option C, with a high energy consumption attributed to the mercury distillation unit, increases with mercury content.

Large credits in the ecotoxicity category result from the avoided production of metallic zinc. The production of zinc concentrate and the roasting of zinc concentrate results in zinc and lead emissions to the air, causing the large avoided impact. The avoided production of pig iron in treatments A and B, due to the recycling of the steel cases, results in important environmental credits, yet important emissions of carcinogenic substances arise during the sintering process of iron ore.

On basis of the LCA results, none of the evaluated treatment options has a global environmental benefit over the others. Each option has specific advantages and disadvantages. Based on metal recycling only, treatment A has a low recycling rate (<40%) because manganese is not recycled as a metal. Nevertheless, increased efforts for manganese recycling go at the expense of energy usage, as is demonstrated by treatment B, which provides an alternative for the option A focusing on manganese recycling. Unfortunately, because manganese is less scarce than zinc, this shift does not improve the environmental performance for the impact category "damage to mineral resources". In this case study, higher recycling rates do not necessarily lead to lower environmental impacts.

3.3 Treatment of waste oils [9]

This case study evaluated three treatment options for waste oils that were covered by

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the Flemish Environmental Policy Agreement on Used Oil (MBO Afgewerkte Olie). This Agreement contained a list of oils, that included most automotive waste oils and excluded most other waste oil types, such as nutritional oils, PCBs, PCTs, solvents, residual tank cleaning oil, etcetera.

The three treatment options for waste oil that were evaluated were:

1. Use of waste oil as auxiliary fuel to provide process heat in a rotary kiln (RK) designed for treating liquid and solid hazardous waste streams with organic content, equipped with a flue gas treatment system.
2. Recycling of waste oil by thermal cracking into light distillate fuel oil. The process steps are (at least) filtration, dewatering, thermal cracking, distillation and stabilization.
3. Recycling of waste oil into base oil by through five different re-refining techniques. Lubricating oil is obtained by adding additives to the base oil that results from the re-refining process.

In view of the experience that was gained in the previous comparative waste treatment analysis, the traditional LCA-oriented approach was widened and deepened by integrating the JRC Guidelines supporting environmentally sound decisions in waste management. The conclusions from five earlier comparative waste oil treatment studies, as well as the validity of the assumptions they contained, were checked with the actual Flemish study, and used to validate and to put in perspective the conclusions. LCI data for five different re-refining techniques were taken over from one of these studies [10].

Furthermore, the waste oil market covered by the Flemish Environmental Agreement was studied into detail, as regeneration processes are constrained both by feedstock and product prices which are dictated by oil product prices generally [11], and the economic return of waste oil derived products will vary with the price of the substituted primary product and the quality of the corresponding waste oil derived product. It was concluded that the quality of treatment outputs, even in the same product category, that are obtained by the available waste oil treatments also varies considerably, as output characteristics depend on the input quality, client requirements, process characteristics and technical or regulatory constraints. All these parameters show location dependent variations.

For the characterization of the environmental impacts the ReCiPe LCIA-method was used. Background data were obtained from the Ecoinvent 2.2 database.

The environmental evaluation of the treatment techniques under study showed that the variation in environmental impacts related to the different re-refining techniques can be larger than the variation between these techniques and the rotary kiln and/or cracking. Because of this variation it was considered inappropriate to define one average re-refining technique as a representative for all re-refining techniques. Furthermore, the re-refining technique with the best environmental performance focused on the maximisation of (internal) re-use of energetic fractions rather than optimising the production of base oil.

Overall, the environmental profiles that are shown in Figure 4 demonstrate that for none of the impact categories all re-refining options have significantly lower environmental impact scores than treatment in RK or cracking. Moreover, in every impact category there are one or more re-refining options with environmental impacts that exceed the RK score, and there can always be identified a re-refining option with an environmental impact score comparable or worse than for thermal cracking, making it impossible to establish a clear general prioritisation between rotary kiln, cracking and re-refining, based on the environmental impacts of each technique.

4 Critical appraisal of the case study methods and results

4.1 Case study results

Alternative treatment options, focused on recycling or energy recovery, were compared for three different specific Flemish waste streams, to facilitate the establishment of a priority order of techniques that eventually might differ from the standard waste hierarchy. For none of the studied waste streams,

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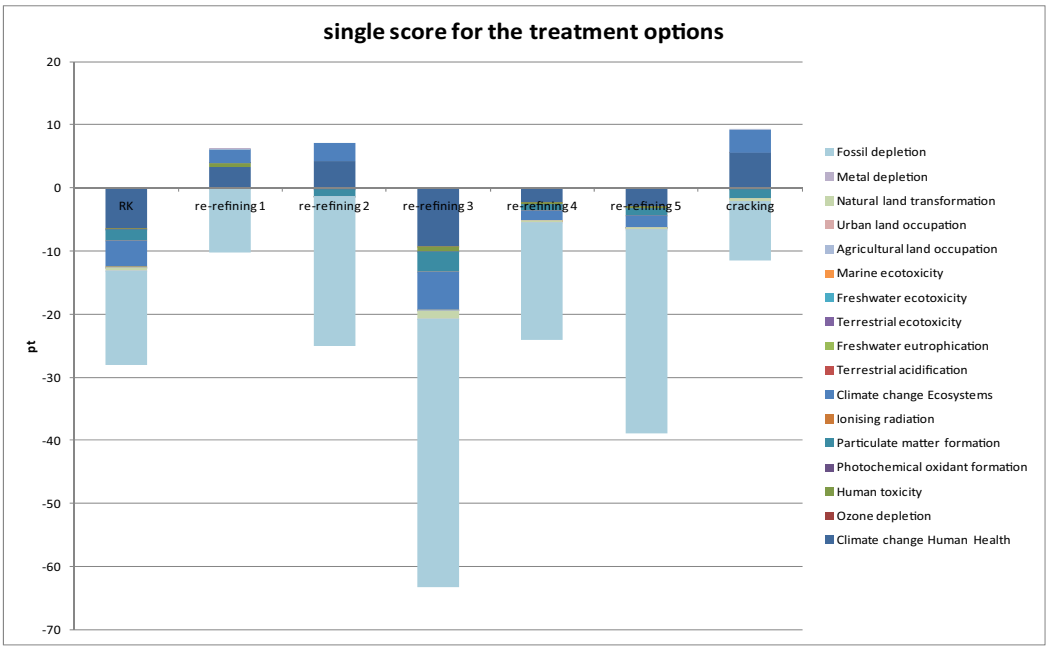


Fig. 4. Comparison of single scores for different waste oil treatment options.

such order could unambiguously be established, nor could one option be considered as environmentally the best.

The study of treatment options for animal fats and recycled used edible fats and oils showed that specific characteristics of the studied substances played no significant role regarding the net environmental effects of a technique. The quantified effects are largely dominated by benefits that reside in the primary products that are substituted by the treatment output. The choice of the substituted product as well as its origin (crop versus fossil fuel) determine the extent of the net benefits as well as the specific impact categories where the benefit is mostly realized. A prioritizing of e.g. biodiesel production can only be justified if it can be unambiguously determined to what degree fossil diesel and alternative biodiesels of well-known origins are substituted. The knowledge of that origin includes the identification of the specific primary crop and its geographical location, applied farming practices, climate conditions, transport distances, related land uses, etcetera.

In the battery recycling case on the contrary, the recycling process parameters, like energy use, and the specific characteristics of the processed batteries are highly relevant for the net environmental outcome, and result in net burdens for several impact categories. It was shown that higher metal recycling rates do not automatically improve the environmental performance for the damage to mineral resources impact category, despite the fact that countering mineral depletion is the main driver for recycling batteries. Specifically, higher manganese recycling rates imply an additional energy consumption from which the effect is not compensated by recycling a relatively abundant mineral.

The different waste oil treatment options show a mixed picture. The presence of heavy metals, sulphur and chlorine in the waste oil (which can be considered parameters with a potential environmental impact) does not or merely influence the environmental profiles of the treatment techniques. As a result, varying concentrations of pollutants in waste oil neither will. When the environmental impacts are combined to a single score, all treatment techniques had a net avoided impact, because the impacts of the treatment technique itself are more than compensated by the avoided impacts of the useful outputs. The assessment shows that the environmental profiles of the considered treatment techniques are dominated by the

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impacts related to climate change and fossil depletion. This could be expected as on the one hand the treatment techniques are quite energy consuming and on the other hand the produced useful outputs are in all cases petroleum derivatives The re-refining treatment technique with the best environmental performance (based on the single score), focuses on the maximisation of (internal) reuse of energetic fractions rather than optimising the base oil production. At the other hand, the market analysis concluded that a wide variety of secondary or primary base oil qualities is produced, making the decisive question on the substituted products extremely complex for re-refining.

4.2 Case studies methodology

Tolinski [13] refers to the fact that a balance needs to be found between over-interpretation of LCAs or making them too specific, raising questions about their underlying data or assumptions; and at the other hand of making LCAs too comprehensive or standardized, limiting their particular usefulness.

In the case studies, that considered stakeholder engagement, it was possible to gather very specific and locally validated data on the waste characteristics, but (1) these turned out not to be relevant for determining the net environmental impacts (e.g. fats and oils); or (2) no direct link with the output qualities could be established, and thus neither with the potentially substituted products (e.g. the re-refining of waste oils); or (3) these specific characteristics largely determined the net impacts, thus impeding the comparison of techniques based on an average input (e.g. waste battery metal content).

At the other hand, only limited or very general information was available on several substituted primary products of which the specific characteristics, to a large extent were determinant for the overall net environmental effects of a technique (e.g. bio-based oleochemicals, biodiesel, base oil, ferromanganese, steam production). Such limitation can only be countered by making additional assumptions.

Finally, detailed recycling or recovery process parameters could be obtained for individual plants. Unfortunately, it results impractical to separate the effects of the application of a certain "average" technique, from the influence of location or plant-specific parameters, such as the type and characteristics of available energy sources, the possibility to use residual energy, the flexibility regarding the waste acceptance criteria, etcetera.

The case studies demonstrated that such a combination of very specific data on some parameters together with very general data on others, does not facilitate the drawing of unambiguous conclusions regarding the overall best technique to recycle or recover a specific waste stream.

Even in the case that a comparative LCA would deliver an environmentally best technique, complex interactions of market drivers and limitations will play a significant role in the results that can be obtained by policies that pretend to impact the order of preference of waste destinations.

On the other hand, the LCA-methodology is designed to calculate global environmental effects. The realization of the benefits of a technique might take place to a smaller or larger extent abroad, or in the worst case even entail local nuisances and burdens that are difficult or impossible to be recognized through the application of an LCA. National or regional policy makers definitely might be sensitive to such arguments.

5 Conclusions towards the methodological framework

The European Waste Framework Directive (2008/98/EC) promotes the application of Cycle Thinking (LCT) to assess the overall impacts of alternative waste management options. As a consequence, policy makers call for objective assessment methods to be applied. Several arguments plead in favor of Life Cycle Assessment (LCA) as a tool to assess the global environmental impacts of a waste management option or treatment technique, especially its holistic approach and the fact that detailed standardized procedures and extensive data records are publicly available.

LCA is indeed recognized as an analytical tool that can provide information for decision support. Nevertheless, it is important

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to note that the obtained results do not replace the decision making process nor the decision itself.

Three case studies that each analyzed different treatment alternatives for a specific waste stream, were conducted with the objective to give orientation to the Flemish authorities regarding the environmental effects of a number of recycling and recovery techniques. For each case an attributional, comparative LCA was performed. In none of the cases an overall best option could be unambiguously identified.

The evaluation showed that location-specific characteristics of inputs, outputs, processes and installations have a decisive impact on the outcome of the performed LCAs.

From the case studies, some proposals regarding the methodological approach for applying Life Cycle Thinking to assess recycling or recovery techniques can be formulated:

- The goal and scope of the assessment should be defined in close consultation with the commissioner (authority, sector organisation, company,. . .), as it is extremely important to consent on the question that needs to be answered. The question itself will give a first indication regarding the appropriateness of using general, average data for building the inventory or whether instead installation or location-specific information is preferable.
- A review of relevant existing studies, data and experiences will allow to examine and compare the different possible assumptions, conditions, system boundaries, viewpoints and scopes that could be used to give an answer to the question that was agreed on.
- The representativeness of the data must be carefully checked: comparing treatment options for which only general or average data are available, with techniques for which local or plant-specific figures will be used, can bring about a considerable bias in the results and conclusions.
- A screening LCA can be performed to identify environmental hot spots, as to assess whether the net environmental effects will be determined mainly by process parameters, or by input characteristics, or by the substituted or avoided products. If limited data availability or time constraints enforce a mixed use of specific and average figures linked to different techniques, the eventual consequences of such approach for comparing alternative waste management options should be estimated and communicated.
- The JRC guidelines (2010) for supporting environmentally sound decisions in waste management [12] include a practical decision tree concerning the performance of a full detailed LCA.

Life Cycle Thinking implies that environmental information is complemented with social, economic and legal aspects, by means of tools such as social LCA, CBA or LCC. Tolinski [13] compares LCA with a hammer that is needed to renovate a house, accepting that its use is efficient only alongside many other tools that are needed to do the job, as well as some creative thinking on how to use the tools. Indeed, a wide range of methods is available to complement, broaden en deepen LCA. Nevertheless, there is no generally accepted way of integrating different LCA concepts, models and methods. To maintain an overview on different methods it is useful to distinguish procedural and analytical methods. The focus in procedural frameworks is on procedures to guide the process to reach and implement environmental decisions, whereas analytical methods provide technical information for a better-informed decision-making by modelling the system in a quantitative or qualitative way [14].

The conclusions of the case study appraisal are in line with the findings of Curran [15], who gave an overview of American studies into the sustainability of a number of alternatives for various applications, including in most cases a biobased alternative. The examples chosen showed that a biobased alternative was not necessarily the most sustainable option, and made the author conclude that LCA is a good tool to support decision making between a variety of alternatives for, in this case, a preferential buying policy, but that the decision is not made by the LCA itself. There is a growing consensus on the idea that, to serve decision

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making, the numerous environmental indicators require clear guidance for their appropriate use and full transparency in the report of results and assumptions made [16].

Making a decision on waste management policies using a life cycle thinking approach will mostly, if not always, imply value choices. Furthermore, the pillars of sustainability cannot be considered as separate entities. Economical and societal values will drive, reinforce, weaken or reverse the intended environmental outcome and results of decided waste policies. Even if decisions are sustained on purely environmental grounds, sustained by transparent assumptions and reliable data with a limited uncertainty, the decision maker will be forced to valuate or weigh the different impact categories. Are, in his appreciation, burdens related to e.g. land use and biodiversity subordinate to climate change and fossil depletion?

Additionally, it should be noted that LCA environmental indicators do not cover all relevant environmental criteria that could be taken into account. e.g. within a perspective of closing material cycles, policies might aim to promote higher recycling rates, even when this holds no or negative environmental effects as calculated with LCA.

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