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SUMMARY

Updated LCA for regeneration of waste oil to base oil

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IMPRESSUM

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Summary

The European Waste Framework Directive (2008/98/EC), amended by the Directive (EU) 2018/851, gives explicit instructions for the management of waste oils. Above all, it should be conducted in accordance with the priority order of the waste hierarchy. Moreover, preference should be given to options that deliver the best overall environmental outcome. Life cycle assessment (LCA) is the commonly used instrument to identify such options. There is a large number of LCAs dealing with waste oil treatment. Two of these LCA studies was performed by ifeu on behalf of the GEIR (Fehrenbach (2005), Abdalla & Fehrenbach (2018)). This latest iteration of an LCA to evaluate different treatment options considers the current state of technologies available on the market as well as key developments in the industry and (background-) data. This study therefore represents an update to the previous studies conducted by the same author(s).

The **goal** of this study is to provide an updated and forward-looking view on the environmental aspects of the treatment of waste oil. The conclusions of the earlier study refer to the situation of the last decades and comprise a smaller number of participating companies. Information regarding the regeneration processes draws upon the conditions practiced at six leading companies operating across Europe.

This study has been **reviewed** by a panel of experts in accordance with ISO 14040 section 7.3. The review process was started after the finalization of a draft report of the assessment. All amendments have been taken into consideration during the final editing of the study.

This study and its predecessors share the same **scope** in principle. However, apart from implementation of the most current process data, the scope was expanded from four to six companies, as outlined above. Moreover, process data averages of two years[1] was chosen as input. In addition, the background datasets, especially in regard to crude natural gas and crude oil production and, consequently, all datasets of derived products have been updated in order to account for the latest scientific findings. The study at hand, too, considers the most relevant alternative treatment option, and, in accordance with the study in 2018, treatment to fuel oil was chosen as the most relevant alternative.

The waste oil qualities for regeneration are based on separately collected used engine and waste oil and other industrial oils suitable for regeneration to base oil. Qualities which don’t meet the specification for regeneration (e.g. oils contaminated with very high chlorine or PCB, or so-called MARPOL oils) are not within the scope of this assessment.

The **reference unit** of this study is 1,100,000 Mg waste oil per year. This comprises the entire quantity of regenerated waste oil within the European Union. The waste oil qualities for regeneration are based on separately collected used engine oils and other industrial waste oils suitable for regeneration to base oil.

The six regeneration techniques represent the range of advanced refining technologies including hydro-treatment and solvent extraction in Europe. The produced base oils are low on sulfur- and unsaturated content and contain very low aromatics content. They fulfill specifications of high-graded base oils, leading to a key question: Which quality of virgin base oil

[1] The reference years were chosen in particular to exclude any possible effects of the corona pandemic and to represent an adequate process flow as far as possible.

is substituted on a market level and has thus to be considered within this LCA? We assume a range from a minimum to a presumed achievable optimum, describing the minimum as base oil corresponding to group I base oil ("standard"), with no synthetic compounds, and an optimum described by a mix of 70 % group I base oil and 30 % group IV base oil ("advanced"), where group IV base oil constitutes a fully synthetic base oil. This hypothetical blend corresponds to a **v**iscosity **i**ndex (VI) of 115, matching widely the qualities of regenerated base oil under study.

Results from comparing regeneration (scaled to 1) with the substituted production processes of the two primary base oil categories described above are shown in Fig. 1: Regeneration of waste oil to base oil causes less environmental impact than processing base oil from virgin crude oil across the board. Regeneration therefore clearly leads to a decrease in environmental burdens when compared to the primary production of base oils of corresponding qualities. The percentage figures show the relative impact reduction achieved for a regenerated base oil compared to its' respective primary base oil for both categories.

Does this still apply when comparing the regeneration to the alternative reference system, the processing to fuel oil? The answer is clearly yes. As fig. 2 shows, the treatment to fuel is disadvantageous throughout all impact categories when compared with regeneration. The percentage figures show the relative impact reduction achieved for a regenerated base oil in each quality category compared to its' alternative fate, treatment to fuel oil.

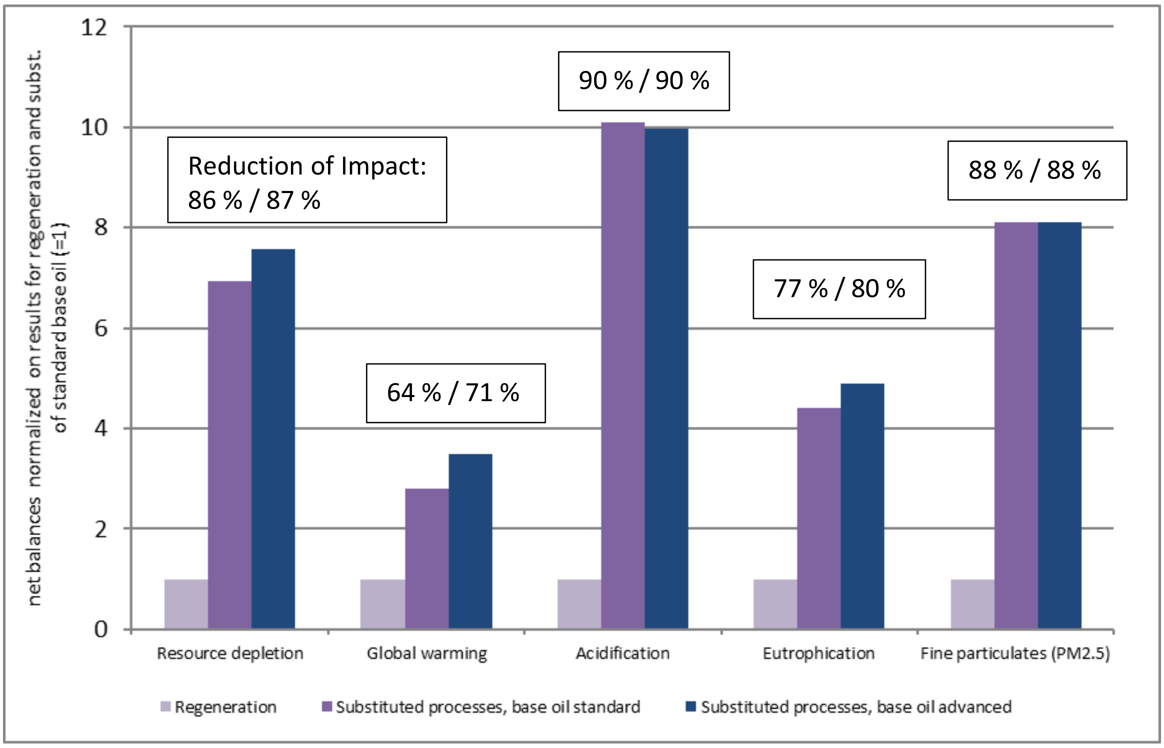

Figure 1: Total view on the impact assessment results; all figures related to the particular result of "regeneration", main bars: average result (arithmetic mean) of the six techniques; Reduction of impacts refer to savings in each impact category for regeneration of both base oil qualities against their primary product equivalents (e.g. for GWP, regeneration of a standard base oil results in 64 % reduced impacts while regeneration of an advanced base oil reduces impacts by 71 %, compared to their respective primary products)

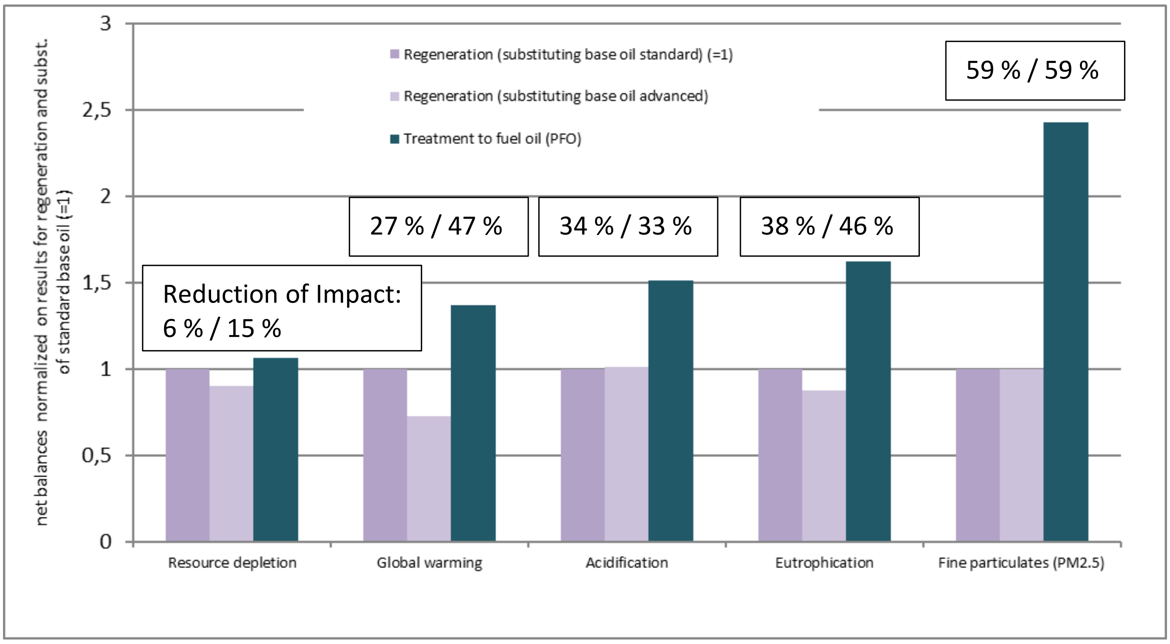

Figure 2: Synopsis on the comparable impact assessment results – regeneration (average) vs. treatment to fuel; values <1 describe better performance than regeneration and substitution of standard base oil and vice versa. Reduction of impact refer to savings in each impact category for regeneration of both base oil qualities against treatment to fuel oil (e.g. in terms of GWP, regeneration of standard base oil achieves 27 % reduced impacts compared to treatment to fuel oil, while regeneration of an advanced base oil reduces impacts by 47 %)

In summary, a clear advantage in favour of regeneration of waste oil to base oil can be observed when compared to the most common alternative use in Europe, treatment to fuel oil.

Moreover, a sensitivity analysis was carried out. Fehrenbach (2005) analyzed that the following items contain assumptions of more or less relevant influence on the results:

- Allocation method
- Fuel substitution
- Distribution distances

Aspect 1 and 3 do not need any further examination. Their influence has been sufficiently evaluated within Fehrenbach (2005).

In addition, Abdalla & Fehrenbach (2018) highlighted the following points of attention:

- What kind of fuel is substituted?
- How strongly does the selection of regeneration technique affect the result – in other words: how robust is the average result?[1]
- Is there a bias concerning data quality of primarily collected data from regeneration and possibly outdated information about the refence system?

[1] Note that the scope of Abdalla & Fehrenbach (2018) comprised four companies, which covered around two-thirds of the European regeneration market.

- How strongly does the base oil quality supposed to be achieved by the regeneration techniques affect the result?

All the factors above have been thoroughly investigated within the previous studies. To this day, no additional factors regarding sensitivities have arisen. Moreover, the changes within this study compared to Abdalla & Fehrenbach (2018) in terms of their potential to influence sensitivity of results have been negligible with the exception of the scope of the investigated plants.

Since the study at hand involves a larger number of investigated plants, the potential for variance is subsequently greater. In addition, applied technologies differ quite significantly, as was the case in Abdalla & Fehrenbach (2018), too. This leads to significant ranges across all investigated impact categories. However, for each impact category under study, the avoided impact through substitution was invariably greater, even when comparing the least advantageous option in each category with the most advantageous pendant within each category (e.g. the max. $GWP_{regeneration}$ vs. the min $GWP_{substitution}$). On average, the worst-case for the regeneration system showed 4 times lower impacts than the best-case substitution system of standard base oil.

These effects are even more pronounced when comparing an advanced base oil as a substitute. With the exception of the impact category Acidification Potential, all impact categories showed better results for substitution of advanced base oil by the regeneration system. On average, environmental burdens were 4.25 times lower for the worst-case regeneration, compared to the best-case substituted system.

It can be summarized that the average result thus gives a solid picture of the overall performance of the assessed regeneration techniques, taking into account that some perform better than others and vice versa.

In terms of fuel substitution, the authors are not aware of substantial changes of the practice of admixing low-sulphur fuel oil for the purpose of upgrading heavier and more sulphur-rich fuel oils. To this end, the same trends as described in Abdalla & Fehrenbach (2018) still remain: substituting heavy fuel oil with accompanying lower efforts / expenditures would shift the scale even more in favour of regeneration.

In terms of temporal bias concerning the different applied data, the same trends as described in Abdalla & Fehrenbach (2018) could be observed. In this assessment, the burdens associated with treatment to fuel oil still were lower than the burdens of regeneration, given the general significant differences of both processes as well as their purpose. For instance, even assuming significant technological breakthroughs in terms of energy efficiency (factor 50 % less energy consumption), the GWP net-balance would still be in favour of the average regeneration system of a standard base oil. Here, too, results would even be more favourable, when assuming an advanced base oil regeneration system.

As outlined above, the base oil quality aimed at, influences results significantly. This has not changed compared to Abdalla & Fehrenbach (2018). Therefore, the observations made in Abdalla & Fehrenbach (2018) remain valid: if the environmental burdens associated with the production of an advanced base oil exceed those of a category I base oil, the conclusions of this study remain unchanged. However, an adjustment to Abdalla & Fehrenbach (2018) has to be made in terms of the impact category Acidification Potential, as in this case, production of a category II+ base oil carries slightly lower environmental burdens.

In total, considering the number of analyzed sensitive aspects, the authors deem the result and subsequent conclusions robust in the light of the goal and scope as defined in this study.

Comparing these **results** with the results of the studies carried out in 2005 and 2018, respectively, we discovered the following aspects:

- First of all, the environmental advantages of the regeneration of waste oil to base oil hold true throughout all applied impact categories;
- This is also the case when base oil group I quality is substituted
- Substitution of higher base oil groups (e.g. group II+) leads to even better results in favor of regeneration for all applied impact categories, except acidification, where group I base oil achieves the overall best results.

Moreover, even in view of the changes in the background data regarding the production of crude natural gas and crude oil[1], we discovered that regeneration is still favourable compared to the reference system, treatment to fuel oil. Moreover, there are a number of further points of attention, in particular those referring to the update of data:

- The update of data by the regeneration companies as well as the expanded scope lead to improved results with regard to some aspects, but not to others: This study, in line with Abdalla & Fehrenbach (2018) considers data from real practice. The expanded scope leads to even more robust results when compared to previous iterations of this study.

- The update of background data influences results, especially when comparing primary base oil and regenerated base oil. Here, the gap widens and, subsequently, the net-benefit in favour of regeneration, following increased impacts of the production of natural gas and crude oil. However, in contrast, but for the same reasoning, the overall benefits in favour of regeneration are somewhat smaller, when compared with the other treatment option of waste oil, treatment to fuel oil, as compared to Abdalla & Fehrenbach (2018).

In summary, we found that the regeneration of waste oil for the recovery of base oils is still considerably advantageous, especially in terms of resource preservation and relief from other environmental burdens.

This study underlines the results of 2005 and 2018 and enhances the previous conclusions, stating that an advanced regeneration technology shall be the favored way to keep waste oil as long as possible as high-graded material within the circular economy. In brief: this LCA supports the higher ranking of regeneration versus energy recovery according to the waste hierarchy required by EU policies.

[1] Both aspects negatively affect the regeneration to base oil results, as here, a substantial amount of natural gas is consumed, whereas the net-benefit of substituting light fuel oil with waste oil treated to fuel oil also increases, the worse the primary production of light fuel oil is.