No. U 6471
June 2021

LCA of SKF RecondOil Double Separation Technology process

Commissioned by SKF RecondOil AB

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Report number: U 6471

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Summary

The SKF RecondOil Double Separation Technology (DST) process enables a longer expected life span of industrial oils by reconditioning and purification of different types of oils. With the aim of mapping and comparing the climate impact of the SKF RecondOil process to a conventional industrial oil cycle, IVL Swedish Environmental Research Institute has carried out lifecycle-based calculations commissioned by SKF RecondOil AB. Two set-ups of the SKF RecondOil DST process have been included in the LCA: the DST Integrated and the DST Stand-alone. The two DST case studies are based on existing facilities in Airasca, Italy (DST Integrated) and in Schweinfurt, Germany (DST Stand-alone).

The results show that the climate footprints of both SKF RecondOil DST processes are lower than the footprint of a conventional oil life cycle. By regenerating oil, less oil needs to be produced and thereby less oil needs to be incinerated. The climate impact of a conventional oil cycle is 3830 kg CO_2-eq. per m^3 oil, compared to 154 kg CO_2-eq. (DST Stand-alone) and 20 kg CO_2-eq. (DST Integrated).

The main contributor to the DST Stand-alone process is flushing oil, both production and incineration of said oil. The main contributor to the DST Integrated process is the top-up oil, both production and incineration.

The results also show that the SKF RecondOil DST processes use less fossil resources during the life cycle compared to a conventional oil cycle. By regenerating oil, less fossil resources need to be depleted and thereafter discarded.

The results are linked to some uncertainties which are tested in sensitivity analyses. By alternating different electricity mixes (an average EU mix and electricity from coal-fired power plants) it is possible to conclude that the choice of purchased electricity to SKF facilities has an impact on the total climate footprint. If electricity from fossil sources were to be used instead of electricity from hydropower, the climate footprint will increase by 40 to 50 percent per m^3 regenerated oil.

By including the energy recovery perspective, where heat and electricity from incineration of oil were to replace alternative energy sources, the resulting climate impact would decrease for all three scenarios. This does not affect the overall comparison: the conventional oil cycle still has the highest climate footprint out of all three cases.

1 Introduction

IVL Swedish Environmental Research Institute have been commissioned by SKF to perform an LCA of the SKF RecondOil DST process. The DST process enables regeneration and reuse of lubricants by removing contaminants and thereby increasing the lifespan of the oil.

Today, the most common practice is to discard the used oil and to replace it with new industrial oil. In Sweden, incineration with energy recovery is the most common way of discarding the oil, but in Europe the most common waste treatment method for used oil is to either incinerate the oil, or to re-refine the waste oil to produce new base oils for production of lubricants. When lubricants are re-refined only around 50 percent of the lubricant is recycled, and the rest is used as energy.

By implementing the DST process, lubricants can be regenerated, emissions from incineration and production of new lubricants can be avoided. To map and to quantify the environmental impact of the process and to compare it to the common practice, an LCA has been performed and the results are presented in this report.

1.1 What is LCA?

Life cycle assessments (LCA) investigate the environmental impacts related to a product or a system during its whole life cycle. This includes evaluating energy and resource consumption as well as emissions, from all life cycle stages including material production, manufacturing, use and maintenance, and end-of-life. A schematic overview of the life cycle assessment framework is shown in Figure 1. LCA is a widely used and accepted method for studies of environmental impact of various products and systems.

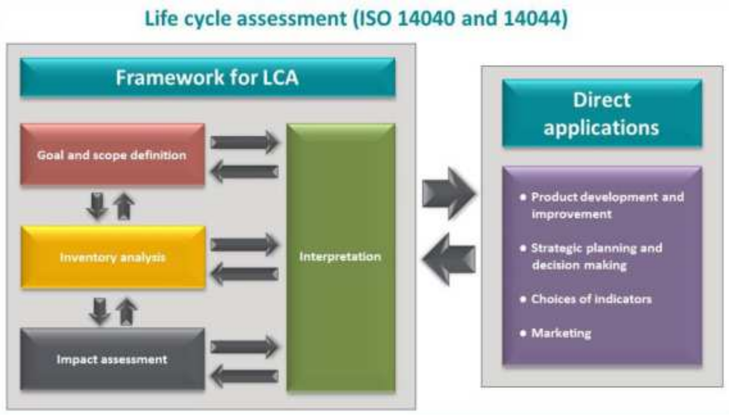

Figure 1. Illustration of the LCA system.

2 Goal and scope

In this chapter, the goal and scope of the study are defined. The systems included in the study are described in section 2.2 Scope, as well as the functional unit, the system boundaries, the limitations of the study and the environmental impact categories assessed.

2.1 Goal

The goals of this LCA study are:

- To calculate the environmental impact of reconditioned oil using the DST process,
- To highlight the environmental hot spots of the DST process and,
- To compare the environmental impact of the DST process to a conventional lubricating oil cycle, where the used oil is discarded rather than recirculated.

2.2 Scope

2.2.1 Studied systems

In this study, two types of SKF RecondOil's regeneration systems are analysed: the integrated system and the stand-alone system. Common for both types is that they employ the patented process technology Double Separation Technology (DST). Based on principles derived from biochemistry, this chemical/mechanical separation process can remove contaminants from industrial oil, preventing it from ageing.

In an integrated DST system, the oil undergoes a so called "continuous regeneration". This entails a DST unit being integrated into the customer's application, where it continuously regenerates the oil.

In the stand-alone DST system, the approach is instead a "batch regeneration", which happens either at defined intervals or based on the condition of the customer's oil. A used batch of oil is brought from the customer's system to a DST stand-alone unit, where it is regenerated. The oil is then brought back to the customer's application for re-use. The stand-alone system can treat several different types of oil. However, in between different oil types, the tanks in the stand-alone system need to be flushed with flushing oil.

The two DST systems are compared to a conventional lubricating oil cycle where the used oil is replaced with new industrial oil. The same oil is later discarded and incinerated.

2.2.2 Functional unit

The function of lubricating oil is to reduce friction between surfaces in contact. Ultimately, the function of the oil is also to reduce heat generated from moving surfaces. Industrial oil can also be used for transmitting forces, transporting particles, and transferring heat.

The main purpose of this LCA is to analyse regeneration with the DST methods and compare with conventional lubricating oil cycles, not to compare the efficiency or impact of oil in use in its final application. The functional unit has therefore been defined as ***1 m³ of industrial oil*** to be used by a customer. The raw material of the oil can either be from virgin resources (petroleum) or from regenerated oil.

2.2.3 System boundaries

Two setups of the SKF RecondOil process are included in this LCA: an integrated solution where a part of the lubricating oil is continuously reconditioned and fed back into the system where it is used, and a stand-alone solution where the oil is extracted from the application and transported to a separate oil reconditioning facility. For the latter, the regenerated oil is assumed to be shipped back to the same application and process.

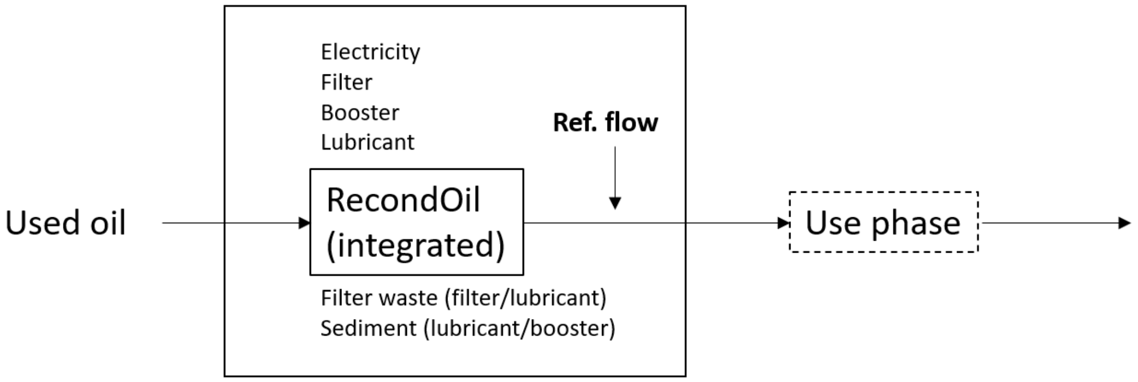

Figure 2. System boundaries of the DST integrated system. The used oil enters the system boundaries without any burden from previous life cycles. The use phase is excluded.

The system boundaries of the DST Stand-alone system are presented in the figure below. Unlike the Integrated solution, transports of the lubricant to and from the SKF facility are included as well as a cleaning equipment (flushing oil), used for cleaning of the reactor between batches of different oil types.

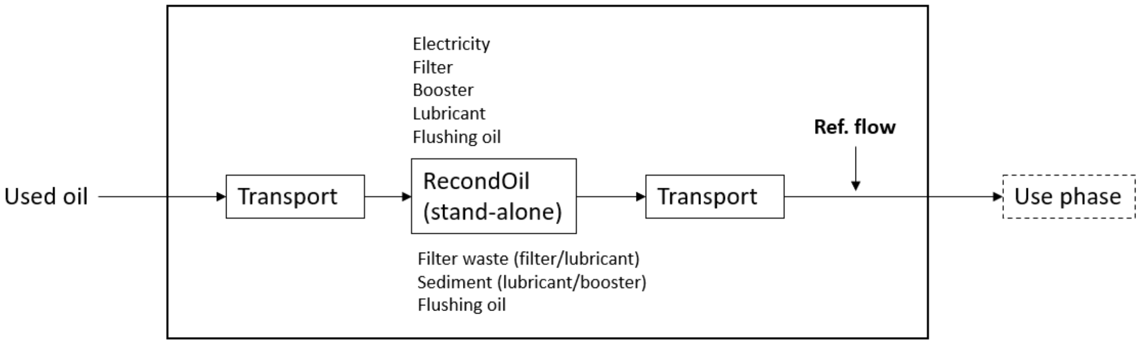

Figure 3. System boundaries of the DST stand-alone system. The used oil enters the system boundaries without any burden from previous life cycles. The use phase is excluded.

The life cycle of the conventional lubricating oil includes production of base oil from crude oil at petroleum refineries, which are transformed into lubricants at blending plants. Depending on the application, a wide range of additives can be added to different extents at the blending plant. For example, antioxidants, friction modifiers, anti-wear and extreme pressure agents, corrosion inhibitors, viscosity modifiers etc. In this LCA it is assumed that the addition of additives is low, and the production of additives have therefore been excluded from the scope.

Blending plants are usually not located in connection to a refinery but can be for special applications. In this analysis, it is assumed that the blending plant is not located in vicinity to the refinery and that the base oil needs to be transported to the blending plant. From the blending plant, the lubricant is transported to a customer. The use phase and the collection of the used oil is excluded from the system boundaries of this LCA. It is assumed that the used oil is transported to a nearby waste incineration plant and the oil is destructed.

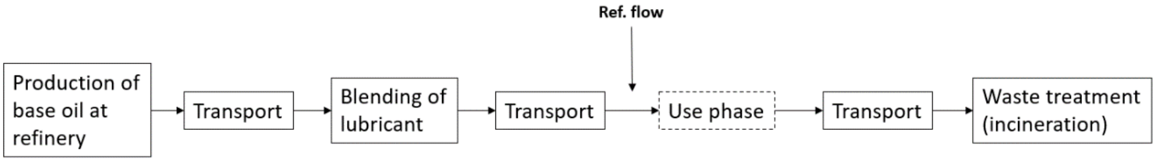

Figure 4. System boundaries of the conventional lubricant cycle. The lubricant is produced from fossil resources. The use phase is excluded.

2.2.3.1 Geographical boundaries

The DST Integrated system is based on an existing plant in Airasca, Italy. The Stand-alone system is based on a plant in Schweinfurt, Germany. The corresponding conventional oil cycle, where oil is used one time and then discarded, is based on a European common praxis and is thus comparable to both DST systems.

2.2.4 Limitations

Excluded from the scope of the study are infrastructure, buildings, and process equipment (production of and disposal) due to it having a minor impact on the total results (<1.5 percent or less). Data on process equipment materials, weights, life span and treatment capacity were provided by the project team at SKF. The heat demand of the buildings and the environmental impact related to the personnel such as transportation, are excluded as well.

The environmental impact from packaging materials is excluded.

The use phase of the lubricant is excluded in this study. Lubricating oil can be used in several different applications and depending on the application, the rate of oxidation, losses, and the overall span of the life cycle of the oil varies. Since the aim of this study is not to compare different applications of lubricating oil, the impact from the use phase is not covered in this LCA. Although the function of the oil can remain the same regardless if virgin or regenerated oil is used – the cleaner the oil, the better performance – over time less oil resources are needed when oil is regenerated.

By implementing the SKF RecondOil Double Separation technology, companies can experience an increase in productivity due to a better average oil quality, compared to a conventional oil cycle where the smallest contaminants often remain in the lubricant causing different challenges. Observed effects of regenerated oil are:

- Reduced wear on machines,
- Longer lifetime of equipment,
- Reduced oil and energy consumption,
- Improved production efficiency,
- Improved product quality.

The above effects are not included in this analysis since the use phase of the oil is outside the scope of this study. The effects are however important to include when considering other aspects, such as increased revenues and decreased maintenance costs. It is possible to assume that these effects can have a greater environmental benefit than that of the regeneration of oil.

2.2.5 Environmental impact categories and indicators

One impact category is assessed in this study: climate change, and one indicator as well: fossil resource depletion. The latter is expressed in total use of fossil energy resources. The impact assessment method CML 2001 has been used to calculate the environmental impacts (updated August 2016). The result of the LCA is given in kg CO_2 equivalents and in MJ. Since only two impact categories have been used, this study may be considered as a limited LCA study and not as a full LCA study.

2.2.6 LCA modelling

All systems were modelled using the LCA software GaBi version 10.5 and database content version 2021.1. Specific datasets used in the study are presented in Appendix A.

3 Data collection

In this chapter the inventory analysis, transports and data on lubricant properties are presented for each studied system (DST Integrated system, DST Stand-alone system and the conventional lubricant cycle).

3.1 DST Integrated system

The lubricant processed in the Airasca facility is a low viscosity honing oil and the properties are presented in the table below. The lubricant contains approximately 5% rapeseed methyl ester (RME). No other additives have been modelled for this lubricant.

Table 1. Lubricant properties in the DST Integrated scenario.

Lubricant properties	Amount	Unit
Density	820	kg/m^3
Energy content	42.7	MJ/kg

The base oil is assumed to be transported 100 km to a locally situated blending plant where lubricants are produced. In reality, the distance probably is further than 100 km, however this assumption does not influence the results. The energy needed for heating and cooling of the lubricant at the blending plant is approximately 250 kWh electricity. The transport and electricity consumption are included in the model of lubricant production, and the electricity is modelled as an average EU electricity mix.

The inventory analysis for the DST Integrated process in Airasca, Italy, is presented in the table below. Data have been provided by the project team from SKF.

Table 2. Inventory analysis for the DST Integrated scenario.

Raw materials	Amount	Unit	Comment
Lubricant (low viscosity honing oil)	1.0	m^3	
Top-up lubricant	3.1	kg	
Energy	**Amount**	**Unit**	**Comment**
Electricity	10	kWh	100% hydropower.
Auxiliary materials	**Amount**	**Unit**	**Comment**
Booster	2.0	kg	

Filter aid	2.5	kg	
Filter material	0.11	kg	
Product	**Amount**	**Unit**	**Comment**
Lubricant	1.0	m^3	
Waste	**Amount**	**Unit**	**Comment**
Oil	3.1	kg	Incineration
Booster	2.0	kg	Incineration
Filter aid	2.5	kg	Incineration
Filter material	0.11	kg	Incineration

All relevant transportation distances and types for the Integrated system in Airasca are presented in the table below. All waste fractions are transported to a waste treatment facility (incinerator) 35 km away.

Table 3. List of transports modelled in the DST Integrated scenario.

Material	Transportation distance	Supplier site	Type of transport
Top-up oil	130 km	Alessandria, IT	Truck
Booster	2960 km	Sundsvall, SE (via Belgium)	Truck
Filter aid	1514 km	Germany (via Belgium)	Truck
Filter material	1229 km	Germany (via Belgium)	Truck
Waste	35 km	-	Truck

3.2 DST Stand-alone system

The lubricant processed in the Schweinfurt facility is a zinc free hydraulic oil and the properties are presented in the table below. The lubricant is assumed to contain 100% base oil with very low amounts of additives and the additives are thus excluded from this analysis.

Table 4. Lubricant properties in the DST Stand-alone scenario.

Lubricant properties	Amount	Unit
Density	870	kg/m^3
Energy content	42	MJ/kg

The base oil is assumed to be transported 100 km to a locally situated blending plant where lubricants are produced. In reality, the distance probably is further than 100 km, however this assumption does not influence the results. The energy needed for heating and cooling of the lubricant at the blending plant is approximately 250 kWh electricity. The transport and electricity consumption are included in the model of lubricant production, and the electricity is modelled as an average EU electricity mix.

The inventory analysis for the DST Stand-alone process in Schweinfurt, DE, is presented in the table below. Data have been provided by the project team from SKF.

Table 5. Inventory analysis for the DST Stand-alone scenario.

Raw materials	Amount	Unit	Comment
Lubricant (zinc free hydraulic oil)	1.0	m^3	
Top-up lubricant	6.25	kg	
Energy	**Amount**	**Unit**	**Comment**
Electricity	62.5	kWh	100% hydropower.
Auxiliary materials	**Amount**	**Unit**	**Comment**
Booster	2.0	kg	
Filter aid	2.5	kg	
Filter material	0.11	kg	
Flushing oil	20.75	kg	
Product	**Amount**	**Unit**	**Comment**
Lubricant	1.0	m^3	
Waste	**Amount**	**Unit**	**Comment**
Oil	6.25	kg	Incineration

Booster	2.0	kg	Incineration
Filter aid	2.5	kg	Incineration
Filter material	0.11	kg	Incineration
Flushing oil	20.75	kg	Incineration

All relevant transportation distances and types for the Stand-alone system in Schweinfurt are presented in the table below. The filter waste is processed in a nearby incinerator and the transportation distance have thus been omitted. The other waste fractions are treated by an external recycling company. A part of the flushing oil can be recycled, but since the end use is unknown it is assumed that all oil fractions and booster are incinerated.

Table 6. List of transports modelled in the DST Stand-alone scenario

Material	Transportation distance	Supplier site	Type of transport
Regenerated oil	250 km (x2)	Average distance for oil input to the Stand-alone process	Truck
Top-up oil	240 km	Mannheim, DE	Truck
Flushing oil	548 km	Antwerp, BE	Truck
Booster	2401 km	Sundsvall, SE (via Belgium)	Truck
Filter aid	955 km	Germany (via Belgium)	Truck
Filter material	670 km	Germany (via Belgium)	Truck
Waste filter aid and material	0 km	-	Truck
Waste lubricant, flushing oil and booster	115 km	-	Truck

3.3 Conventional scenario

The lubricant processed in the conventional scenario reflects an average composition of a lubricant and common properties are presented in the table below. Since the amounts of additives in lubricants vary depending on the application, it is assumed that the lubricant contains 100% base oil and no additives.

Table 7. Lubricant properties in the conventional scenario.

Lubricant properties	Amount	Unit
Density	860 (820-900)	kg/m^3
Energy content	42	MJ/kg

The base oil is assumed to be transported 100 km to a locally situated blending plant where lubricants are produced. In reality, the distance probably is further than 100 km, however this assumption does not influence the results. The energy needed for heating and cooling of the lubricant at the blending plant is approximately 250 kWh electricity. The transport and electricity consumption are included in the model of lubricant production, and the electricity is modelled as an average EU electricity mix. More information on which datasets have been used in the LCA can be found in Appendix A.

All relevant transportation distances and types for the conventional system in the LCA are presented in the table below. Since no specific plant or place of use is considered, the transport distances have been estimated.

Table 8. List of transports modelled in the conventional scenario.

Material	Transportation distance	Supplier site	Type of transport
Base oil	100 km	Assumed distance between refinery and blending plant.	Truck
Lubricant	100 km	Assumed distance between blending plant and facility where the lubricant is in use.	Truck
Waste lubricant	100 km	-	Truck

4 LCA results

In this chapter the results of the LCA are presented. Two environmental impact categories are presented: climate change and fossil resource depletion. Sensitivity analyses are presented in chapter 4.3. The results are presented in table format in Appendix B.

4.1 Climate change

The results of the climate impact potential for all studied systems are presented in Figure 5 below. It is clear from the results below that both DST systems have a lower climate footprint than the conventional scenario. For the conventional lubrication oil cycle, it is the waste treatment, i.e. incineration, of the oil which causes the largest emissions of carbon dioxide and thereby affecting the climate negatively. The production of lubricant also affects the climate change impact. Both of these life cycle stages have minimal impact for the DST systems since the lubrication oil is reused and the emissions originating from production and waste treatment can therefore be avoided.

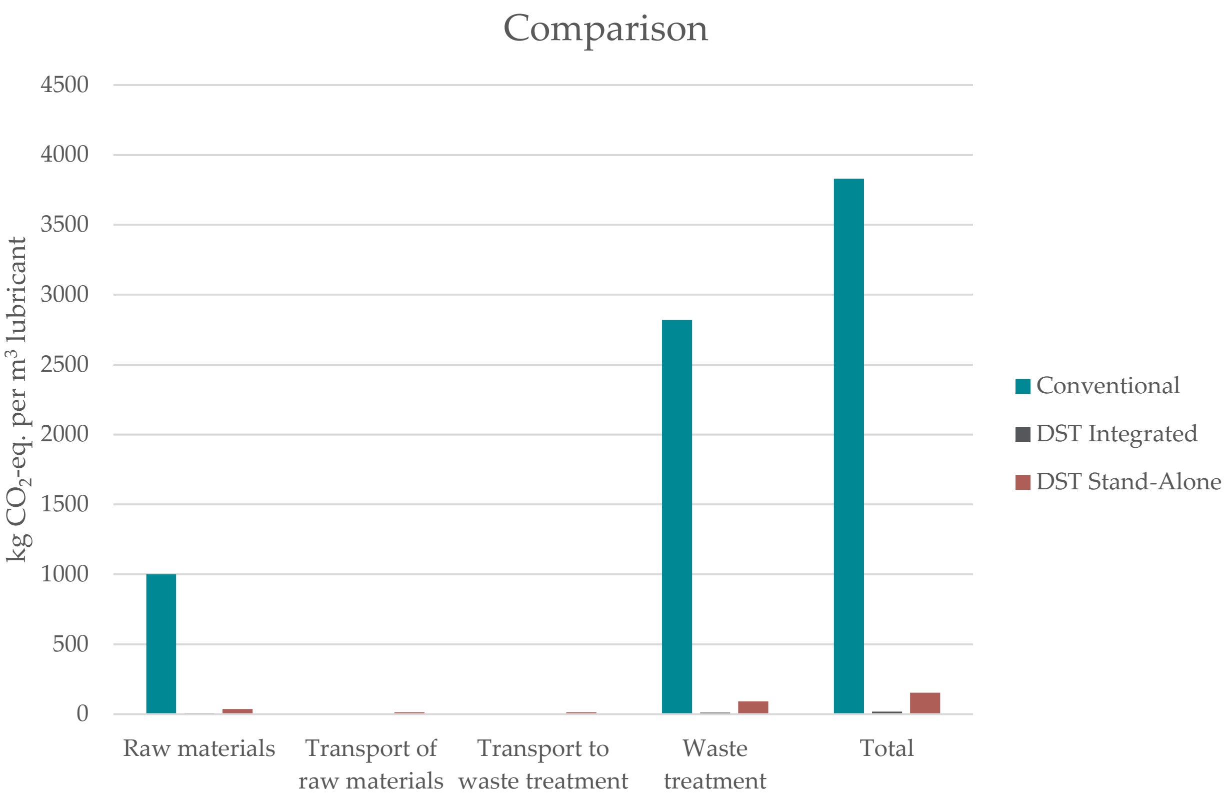

Figure 5. Climate change impact potential of the three studied systems.

Looking into the DST Integrated system more in detail (see Figure 6 below), it is possible to see that the overall climate footprint is low (around 20 kg CO_2-eq. per m^3 of oil) compared to the conventional cycle (which is close to 3800 kg CO_2-eq. per m^3 of oil). Incineration of the waste fractions (lubricant, booster, and filter) have the highest climate footprint, while transports have a low impact. Production of lubricant (top-up) refers to the lubricant, which needs to be added to make up for the loss of oil that occurs during the reconditioning. The main part of the lubricant which is reconditioned is assumed in this analysis to be burden-free from its previous life cycle since it is regenerated.

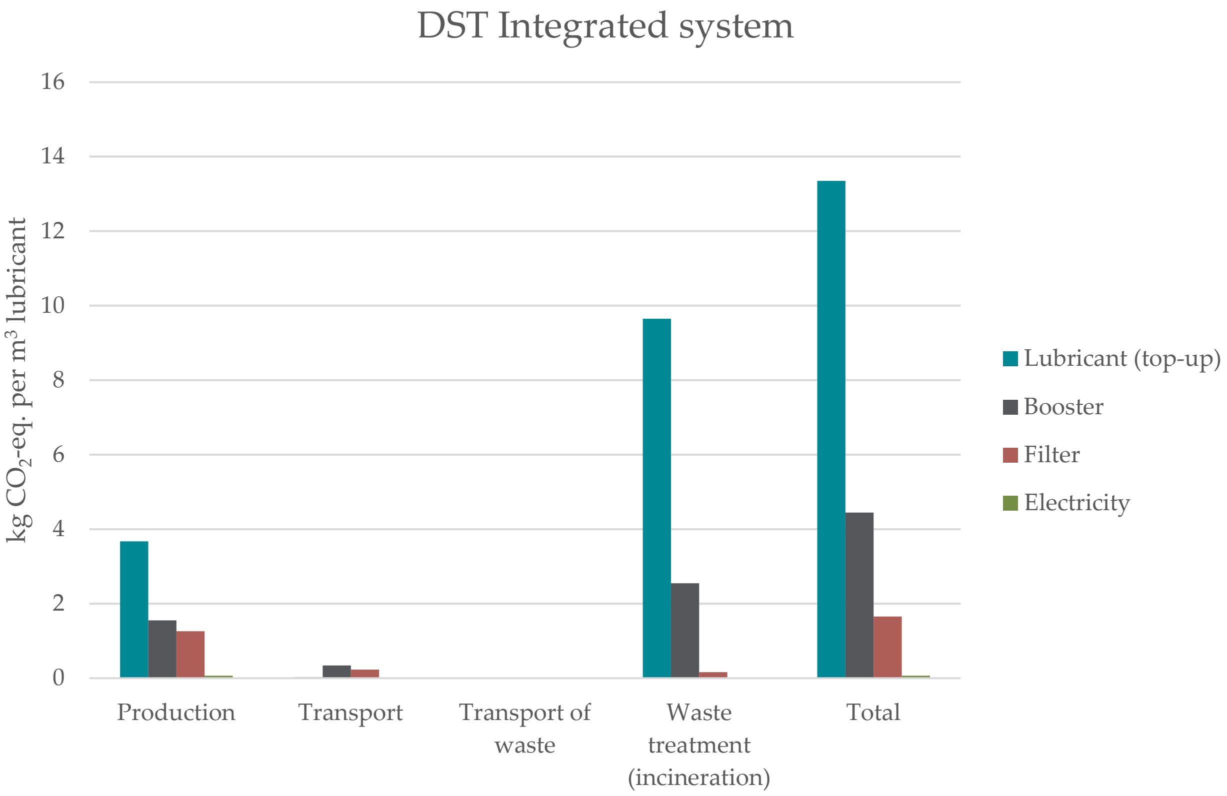

Figure 6. Climate footprint of the DST Integrated system in Airasca, Italy.

The Stand-alone system has a higher climate footprint than the Integrated system (in total 154 kg CO_2-eq. per m^3 oil compared to 20 kg CO_2-eq. per m^3 oil). The main differences between the two are the additional transport of oil to the facility, the use of flushing oil for cleaning the reactor between different types of oil and the additional electricity need for heating the reactor. The main contributor is the production and waste treatment of flushing oil.

Although the electricity consumption is six times higher than for the Integrated solution, the related climate impact is low since the purchased electricity is 100 percent hydropower.

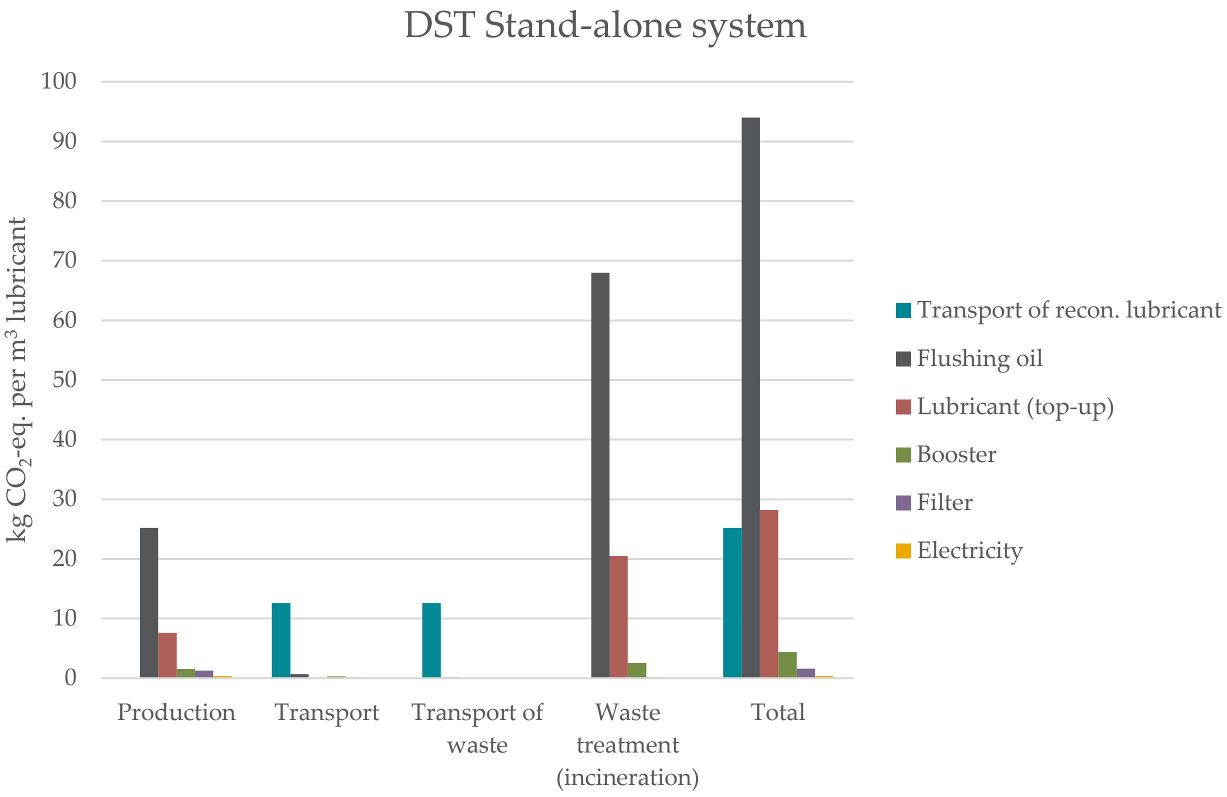

Figure 7. Climate change impact of the DST Stand-alone in Schweinfurt, Germany.

4.2 Fossil resource depletion potential

The purpose of reconditioning of lubrication oil is to avoid the production of new lubrication oil based on petroleum, which can be both cost efficient and have a lower environmental footprint. Apart from the potentially lower environmental impact, avoided production of lubrication oil can most of all save up on fossil petroleum, which is a non-renewable resource.

When comparing the fossil resource depletion potential (see Figure 8 below), it is evident that reconditioning of lubrication oil saves up on the non-renewable resource. The figure displays the total use of non-renewable primary energy through the entire life cycle of 1 m^3 of lubricant.

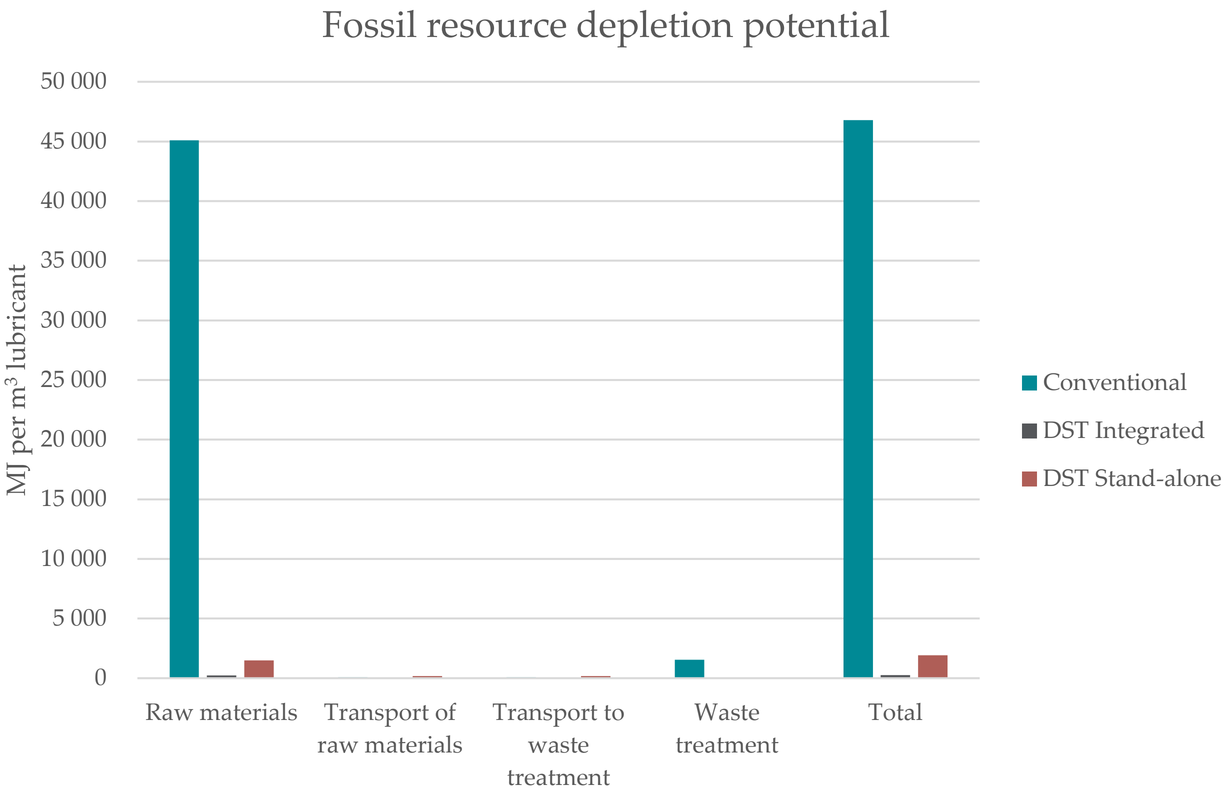

Figure 8. Fossil resource depletion potential of the three studied systems.

4.3 Sensitivity analysis

4.3.1 Alternative electricity mixes

In the first sensitivity analysis, different electricity mixes are modelled to test the influence on the total results for the DST processes, and the results can be viewed in Figure 9 below. In the baseline, electricity from hydropower is modelled since SKF purchases electricity from renewable sources, in this case hydropower, to their facilities. To understand what effect this modelling choice has on the overall results, two other sources for electricity have been tested: an average European grid mix and electricity sourced entirely from hard coal to represent electricity produced on the margin.

Electricity produced on the margin should in this case be interpreted as the source of electricity which is connected to the grid when all other sources are producing at maximum capacity. This usually means the most expensive electricity source, such as coal, oil or in some cases natural gas.

If an average European grid mix were to be modelled, the climate footprint of the processes would increase by 15 to 17 percent, but if a carbon-intense grid mix were to be used, the climate change potential would increase by 40 to 50 percent.

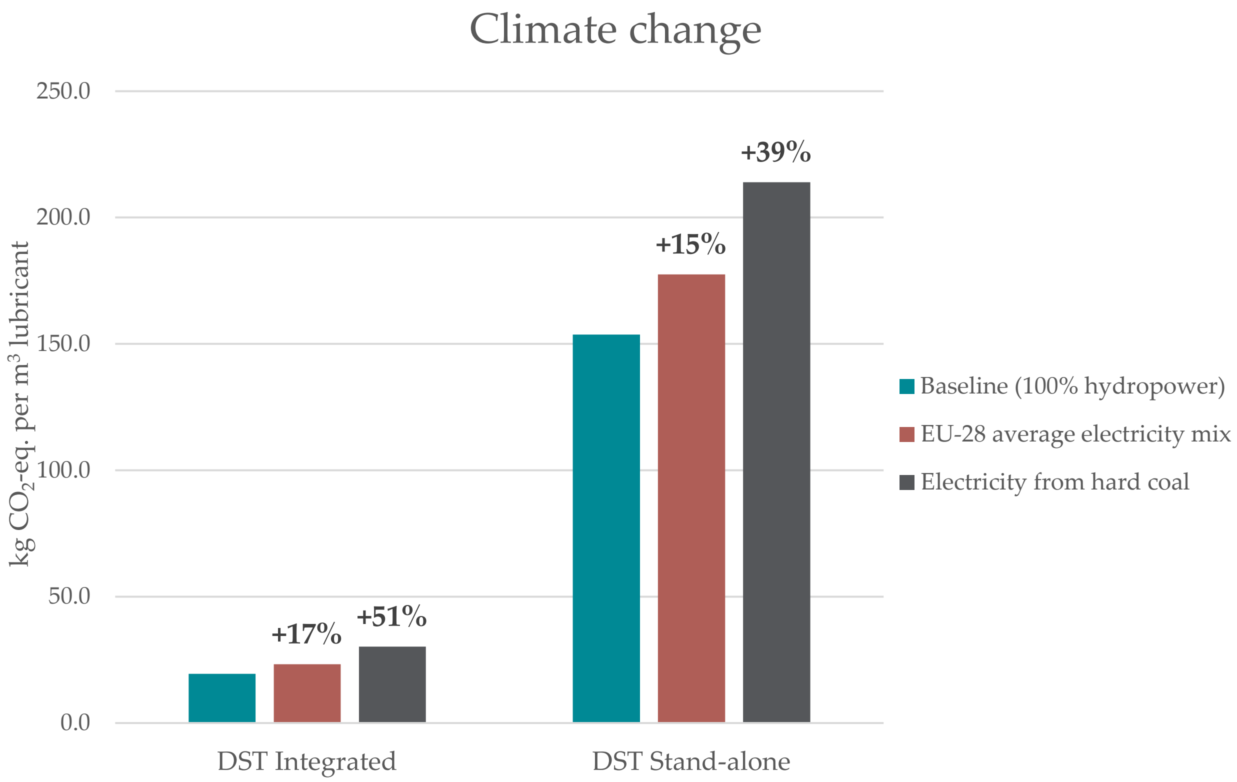

Figure 9. Result from sensitivity analysis where different electricity mixes have been tested for the DST systems.

4.3.2 Avoided impacts from energy recovery

In the baseline model, the emissions occurring from incineration of lubricants during the end-of-life phase are the biggest contributor to climate change in this LCA. As presented in the results above, regeneration of the oil decreases the amount of oil which needs to be discarded by increasing the lifespan of the oil. In most incineration plants, however, energy is recovered, either as heat, electricity, or a combination of both.

Since the lubrication oil is considered to be a waste after its use it is possible to assume that the waste oil can replace another more expensive fuel used for energy recovery. In this sensitivity analysis, it is assumed that the waste lubricant from all three scenarios (conventional and DST treated) can replace energy recovered from incineration of heavy fuel oil (HFO). HFO was chosen since it is the most similar to lubrication oil in energy content, and it is reasonable to assume that waste oil will be incinerated in oil incineration plants thus replacing fuel oil. The conversion efficiency from fuel to heat of the incineration plant is set to 85 percent.

The result is presented in the figure below. Although the total climate change impact for the conventional scenario is lower when considering the energy recovery potential, it still has the highest climate impact compared to the two DST systems. The main impact of the conventional scenario originates from the production of lubricant from crude oil to finished lubricant.

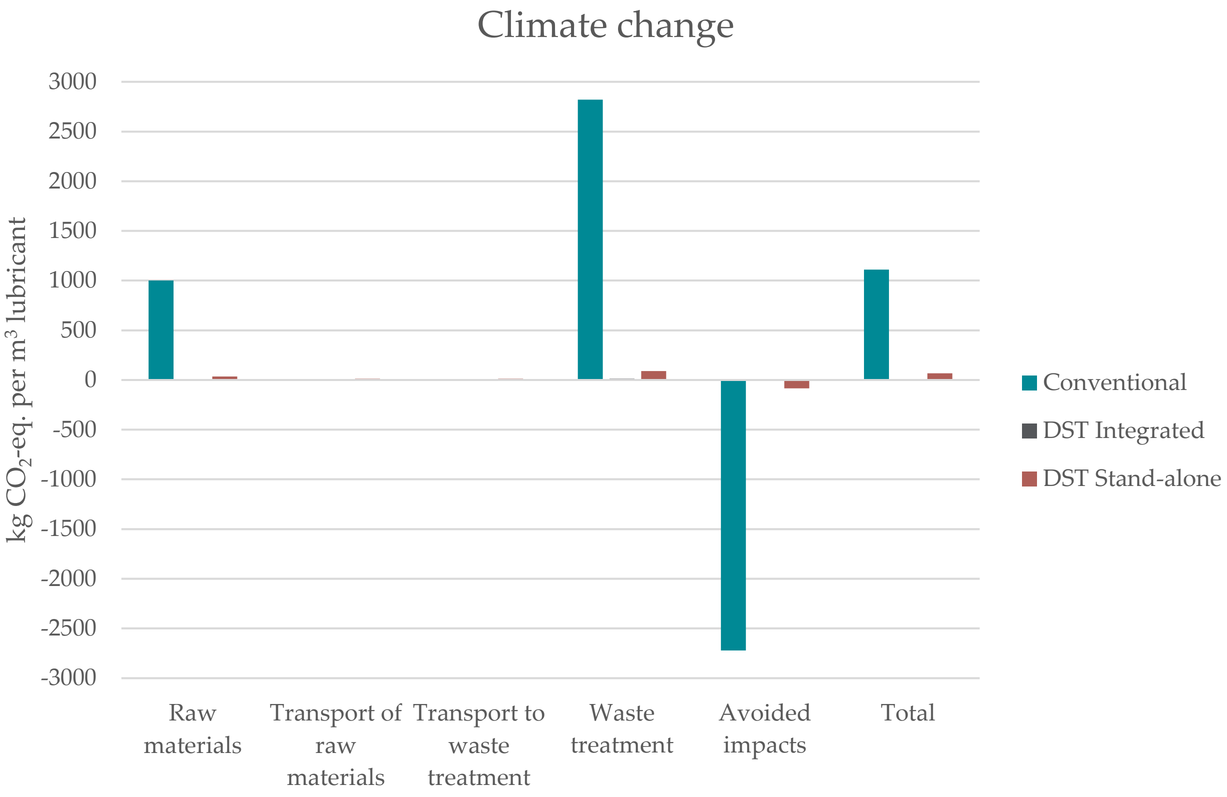

Figure 10. Result from sensitivity analysis where the avoided impacts from energy recovery have been included. The incinerated waste lubrication oil is assumed to replace heavy fuel oil.

5 Interpretation and recommendations

5.1 Identification of hotspots

Common to both the DST systems and the conventional lubricant life cycle, it is the incineration of waste oil, which has the potentially highest climate change impact. To reduce the environmental impact, it is therefore important to aim for oil recovery and reuse when possible. By implementing oil recovery, the impact from producing new lubrication oil will be reduced since less oil needs to be used in the process. As presented in this report, the environmental impact from regenerated oil is significantly lower than for new oil.

In the Stand-alone DST facility in Schweinfurt, it is the production and incineration of flushing oil which contributes the most to climate change. The consumption of flushing oil is based on a worst-case scenario since it is not needed between every batch of reconditioned lubrication oil. To reduce the environmental impact, it is, as mentioned before, necessary to reduce the need of flushing oil (if possible) or to reuse the oil.

Another important aspect of the Stand-alone DST concept is the need for transporting the oil between the customer and the SKF facility. The LCA results shows that the impact from transport of industrial oil has a relatively high impact. To reduce the impact from transports, the transportation distance should be kept to a minimum by opening more facilities or to offer transports based on renewable fuels.

Although the results show that electricity use has a relatively low impact on the climate footprint for both DST systems, it is important to consider that this is the case since renewable power is used. In cases where other power sources than renewable electricity is used, the impact can potentially increase by 40 to 50 percent, which the sensitivity analysis show.

5.2 Comparing the environmental impact of DST systems to conventional oil cycle

The DST processes have a lower climate impact and a lower fossil resource use than a conventional lubricant life cycle, according to the findings in this LCA. The main difference is the avoidance of oil production due to the regeneration. Since less oil needs to be produced, less waste oil needs to be incinerated. This life cycle stage is also where most greenhouse gases arise.

In this LCA, it is assumed that the oil input to the DST processes enters the system boundaries without any burden from previous life cycles since the oil is regenerated from used oil, i.e. the impact from earlier life cycles is cut off. An alternative method to cut-off is to split, or to allocate, the initial environmental impact of the oil production evenly onto all oil regeneration cycles.

For example, if the oil were to be reconditioned 10 times at an SKF site before the oil needed to be replaced all together and if we did not use cut-off between each regeneration cycle, the total climate impact of the DST processes would increase with 380 kg CO_2-eq. per m^3 of oil. Since the climate impact of a conventional oil cycle corresponds to 3800 kg CO_2-eq. per m^3 of oil, a tenth of this impact would be allocated to each oil regeneration cycle if we assume that the oil can be regenerated 10 times before it needs to be replaced completely. This would result in a total climate impact of 400 (20+380) kg CO_2-eq. for the DST Integrated and 534 (154+380) kg CO_2-eq. for the DST Stand-alone.

As stated in the example above, it is clear that the choice of allocation method does not affect the comparison between the DST processes and a conventional oil cycle – the conventional oil cycle still has a higher climate footprint independent of which allocation method is used.

By including the potential positive impact from energy recovery, an alternative perspective of the environmental impacts is presented. Even though the lubricant which is incinerated after its use can replace energy produced from heavy fuel oil, the total climate impact is still higher than for the DST processes. The main reason for this is that the climate impact from production of lubricants is higher than the impact from production of heavy fuel oil. Also, the efficiency of the energy recovery process has an impact: only 85 percent of the energy content in the oil is recovered.

6 Conclusions

The main conclusions from this LCA are:

- The DST Integrated and Stand-alone processes have lower climate footprints than a conventional life cycle of industrial oil.
- By reconditioning lubrication oil savings in a fossil non-renewable resource (oil) can be achieved.
- The highest impact for all studied systems originates from incineration of waste oil. It is therefore important to focus on potential savings here.
- Transport of lubrication oil to and from the DST Stand-alone facility will have a significant impact on the climate footprint depending on the transportation distance.
- If the avoided burden from energy recovery is included, the climate impact for all scenarios decrease but the conventional scenario still has a higher climate impact than the DST processes.
- By using renewable electricity at SKF RecondOil sites the climate impact of the process can potentially be lowered by 40 to 50 percent compared to using electricity from coal-fired plants.

Appendix A: List of GaBi datasets

Table 9. List of datasets used in the LCA study of DST processes.

Raw material	GaBi dataset name	Reference year	Data source
Base oil	EU-28: Lubricants at refinery Sphera	2017	Sphera
Filter aid and material	RoW: cellulose fibre production, inclusive blowing in ecoinvent 3.6	2019	Ecoinvent
Booster	EU-28: Ethylene glycol Sphera	2020	Sphera
Booster	EU-28: Tap water from groundwater Sphera	2020	Sphera
Top-up lubricant (DST Integrated)	EU-28: Biodiesel based on rape seed methyl ester (RME) Sphera	2020	Sphera
Electricity			
Conventional oil cycle	EU-28: Electricity grid mix 1kV-60kV Sphera	2017	Sphera
SKF site in Airasca, IT	IT: Electricity from hydro power Sphera	2017	Sphera
Top-up oil DST Integrated	IT: Electricity grid mix 1kV-60kV Sphera	2017	Sphera
Sensitivity analysis (DST Integrated)	IT: Electricity from hard coal Sphera	2017	Sphera
SKF site in Schweinfurt, DE	DE: Electricity from hydro power Sphera	2017	Sphera
Top-up oil DST Stand-alone	DE: Electricity grid mix 1kV-60kV Sphera	2017	Sphera
Sensitivity analysis (DST Stand-alone)	DE: Electricity from hard coal Sphera	2017	Sphera
Transport			
Truck	GLO: Truck, 28-32 t tot weight, MPL 22 t, Euro 6	2020	Sphera
Fuel	EU-28: Diesel mix at refinery Sphera	2017	Sphera
Waste treatment			
Industrial oil/system expansion (avoided energy production)	EU-28: Thermal energy from heavy fuel oil (HFO) Sphera	2017	Sphera
Industrial oil/system expansion (avoided energy production)	EU-28: Heavy fuel oil at refinery (1.0wt.% S) Sphera	2017	Sphera
Filter aid and material	IT: Paper and board (water 22%) in waste incineration plant Sphera <p-agg>	2020	Sphera

Appendix B: LCA results

Table 10. Presentation of results from Figure 5 in main report.

Comparison (Figure 5)	Conventional	DST Integrated	DST Stand-Alone	Unit
Raw materials	1000	6.55	36.0	kg CO2-eq.
Transport of raw materials	4.98	0.59	13.8	kg CO2-eq.
Transport to waste treatment	4.98	0.016	12.8	kg CO2-eq.
Waste treatment	2820	12.4	91.2	kg CO2-eq.
Total	3830	20	154	kg CO2-eq.

Table 11. Presentation of results from Figure 6 in main report.

Integrated (Figure 6)	Lubricant (top-up)	Booster	Filter	Electricity	Unit
Production	3.67	1.55	1.26	0.068	kg CO2-eq.
Transport	0.023	0.34	0.23	0	kg CO2-eq.
Transport of waste	0.0063	0.0041	0.0053	0	kg CO2-eq.
Waste treatment (incineration)	9.65	2.55	0.17	0	kg CO2-eq.
Total	13.3	4.45	1.66	0.068	kg CO2-eq.

Table 12. Presentation of results from Figure 7 in main report.

Stand-alone (Figure 7)	Transport of recon. lubricant	Flushing oil	Lubricant (top-up)	Booster	Filter	Electricity	Unit
Production	0	25.2	7.58	1.55	1.26	0.37	kg CO2-eq.
Transport	12.6	0.66	0.087	0.28	0.143	0	kg CO2-eq.
Transport of waste	12.6	0.14	0.042	0.013	0	0	kg CO2-eq.
Waste treatment (incineration)	0	68.0	20.5	2.55	0.17	0	kg CO2-eq.
Total	25.2	94.0	28.2	4.39	1.57	0.37	kg CO2-eq.

Table 13. Presentation of results from Figure 9 in main report.

Sensitivity analysis: electricity (Figure 9)	Baseline (100% hydropower)	EU-28 average electricity mix	Electricity from hard coal	Unit
DST Integrated	19.5	23.3	30.2	kg CO2-eq.
DST Stand-alone	154	178	214	kg CO2-eq.

Table 14. Presentation of results from Figure 10 in main report.

Sensitivity analysis: energy recovery (Figure 10)	Conventional	DST Integrated	DST Stand-alone	Unit

Raw materials	1000	6.55	36.0	kg CO2-eq.
Transport of raw materials	4.98	0.59	13.8	kg CO2-eq.
Transport to waste treatment	4.98	0.016	12.8	kg CO2-eq.
Waste treatment	2820	12.4	91.2	kg CO2-eq.
Avoided impacts	-2720	-9.30	-85.3	kg CO2-eq.
Total	1110	10.2	68.4	kg CO2-eq.

Table 15. Presentation of results from Figure 8 in main report.

Fossil resource depletion potential (Figure 8)	Conventional	DST Integrated	DST Stand-alone	Unit
Raw materials	45100	239	1503	MJ
Transport of raw materials	67.2	8.0	186	MJ
Transport to waste treatment	67.2	0.21	173	MJ
Waste treatment	1540	6.5	49.5	MJ
Total	46774	254	1911	MJ

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