TRACE CERTAINTY

TRAnsitioning to a Circular Economy via CERTificAtion in INdusTrY

Testing metrics for measuring the circularity while metrics are being standardized

PROJECT FINAL REPORT

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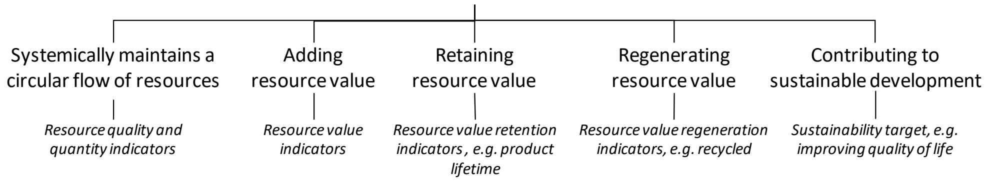
Executive Summary

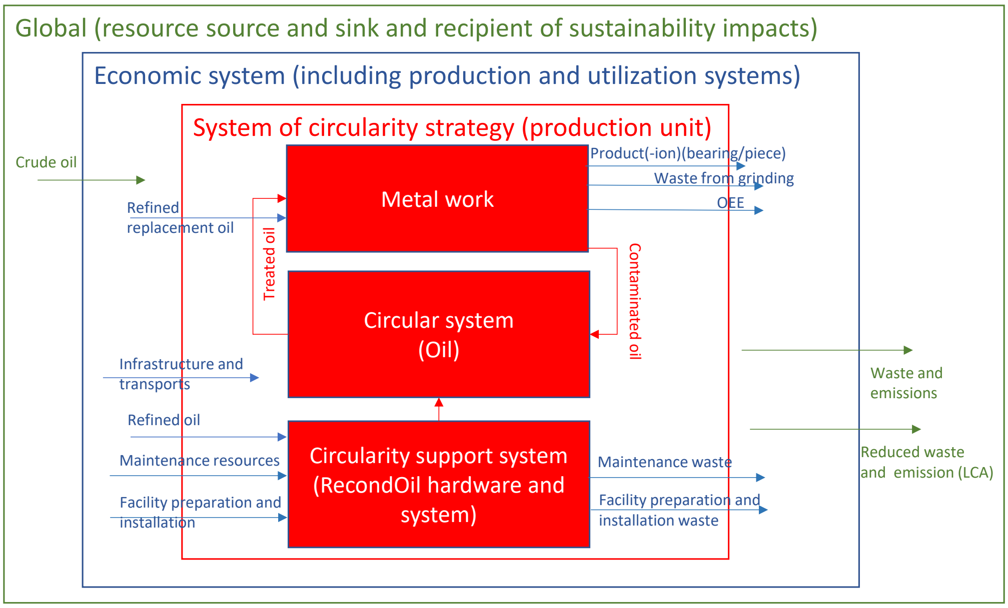
This report describes the results and the learnings of a project that had the **aim to develop a protocol for measuring circularity for products**. The project was centered around an assessment of the real-world example of a lubrication cleaning and recirculation system by SKF RecondOil. The process of assessment required that the team match circularity in principle (*how circularity can be measured in theory*) with circularity in practice (*how circularity can be measured in a real system*). In the process, the team identified different ways to measure circularity based on drafted circularity principles (from ongoing ISO work on circularity). In the end, these alternatives were to be practically verifiable and certifiable. Learnings are to be fed into ongoing work on developing international standards (ISO) for assessing circularity.

In the progress of the work, a **framework for understanding and measuring circularity for the system at hand was developed** including: a *heuristic* (diagram) describing a system of interest and a *list* of chosen circular economy principles see Figure 3. It is thought that the heuristic and list of principles could be used to guide an entity in the process of first, creating their system model, and then, making sense of and applying principles.



Structure of indicators used to measure circularity, also based on (from ISO 59004/WD2, Clause 6)

The circularity qualifications and quantifications are based on the system model (below):



General system model with RecondOil parameters included (based on ISO 59004/WD2, Clause 6)

The following five categories of indicators are identified:

1. Systemically maintains a circular flow of resources
2. Adding resource value
3. Retaining resource value
4. Regenerating resource value
5. Contributing to sustainable development is the circular indicator

1 Introduction/Overview

The TRACE CERTAINTY project (VINNOVA 2020-04410) focused on finding alternatives to measure circularity for products, which should be practically verifiable and certifiable, and in line with the best knowledge the ISO and European standards in the area are likely to achieve.

The overall objective was to test the practical value of a palette of circularity metrics (indicator system) for the innovative product of study of SKF RecondOil. This product closes one major loop on the use of industrial lubrication oil. Based on principles derived from biochemistry, the company's patented Double Separation Technology (DST) can remove contaminants from industrial oil, preventing it from declining in value despite age and use. Such a case study provides a useful illustration and understanding of what different meanings circularity metrics might express.

The specific goal of the project was to define and test circularity metrics (indicator system) that could reasonably be considered certifiable. For this purpose, the project established a product category wider than the studied product, for which such a certificate is valid. Criteria for certifiability are based generally on the standard ISO/IEC 17029:2019 – *General principles and requirements for validation and verification bodies*, and specifically on general data quality requirements for the statements made by the specific indicator system. Neither the specific indicator system nor the data quality requirements were known at the beginning of the project.

The project ran in parallel with the development of the upcoming ISO standardization within the standardization committee *ISO/TC 323 Circular economy*, in particular *ISO 59004 Circular Economy – Terminology, Principles and Framework for Implementation* and *ISO 59020 – Circular economy – Measurement and assessment of circularity*. The result of the project can also provide experiences and input into that standardization work, as well as testing parts of the framework for that standard while in the making.

2 Definition of Key Terms Linked to Circular Economy

In parallel with the above-mentioned standardization of *ISO 59020 Circular Economy – Measuring and assessing circular economy*, there is a current draft work for a standard that will define circular economy, *ISO 59004: WD2 Circular Economy – Terminology, Principles and Framework for Implementation*.

To invite the reader into what is being standardized, we will here list a number of terms subject to definition in the upcoming ISO 59004, and which will be used to different degree of significance in this document.

In the current version of the draft (2021-10-22, not official version), circular economy is defined as an:

> *"economic system that uses a systemic approach to maintain a circular flow of resources*[1]*, by regenerating, retaining or adding to their value, while contributing to sustainable development".*

An **economic system** is the *"system by which a society organizes and allocates resources within a geographic region or country"*. The system can vary depending upon the geographic region or governmental jurisdiction and it can include the regulation of resources (including land, capital, and labor) and the production, use and disposal of these resources.

Resource is defined as an *"asset from which a solution is created or implemented"*[2]. Asset in this definition refers to *"natural resources, virgin resources* and *recovered resources",* and a resource can be either a *renewable* or *non-renewable*. Depending on the context, reference to 'resource' includes *"raw material"*, *"feedstock"*, *"material"* or *"component"*.

A **product** is a *"physical-based object designed or utilized with a purpose"*, and it can be, e.g., goods of any type, hardware (e.g., engine mechanical part, spare parts, consumables, etc.) or processed materials (e.g., lubricant).

A **circular flow of resources** is defined as a *"systematic cycling of the provision and use of resources within technical or biological cycles"*.

Value is defined as *"gain(s) from satisfying needs and expectations, in relation to the use of resources"*. The gain can relate to the specific function and performance of a product and the value is relative to, and determined by the perception of, the interested party(ies). Furthermore, value is dynamic over time and be financial or non-financial e.g., social value. Examples of values are e.g., revenues, savings, productivity, sustainability, satisfaction, empowerment, engagement, experience, and trust.

Sustainable development is a "*development that meets the environmental, social and economic needs of the present without compromising the ability of future generations to meet their own needs*".

Circularity measurement and assessment is a "*process to determine the circularity performance*."

Circularity indicator is an "*indicator of the extent to which the principles related to the circular economy are effectively implemented and progress is achieved to reach the relevant objectives*". Indicator can be a quantitative, qualitative, or descriptive measure. A coherent set of indicators are referred to as an indicator system.

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[1] Resources can be considered concerning both stocks and flows.

[2] Resource includes the energy content or energy potential of materials.

3 Circular Economy Principles

The above-mentioned standard draft (ISO 59004) also contains a proposal for circular economy principles, based on the understanding of the interactions between the environmental, societal, and economic systems, and their inter-relationships, see Figure 1. The economic system is understood as embedded into the societal system, and both are relying on and embedded into the environmental system.

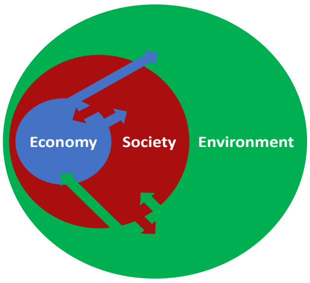

Figure 1*. Illustration of the interactions between the environmental, societal, and economic systems. Note that the length of the arrows has no meaning.*

In line with the definition of a "circular economy" the economic system should be designed based on a system thinking approach and on the following interlinked set of principles. Each principle focuses on a specific dimension of the system that in combination makes a more sustainable economic system.

The circular economy principles are according to the ISO 59004 (draft text as of 2021-10-22):

- **Value Creation** – Organizations regenerate, retain, or add value by providing effective solutions that use resources in an efficient way and contribute to meet the needs of society.
- **Value Sharing** – Organizations and stakeholders collaborate along the value chain or value network in an inclusive way, by sharing the value created with the provision of a solution.
- **Resource Availability** – Organizations manage and regenerate stocks and flows of resources in a sustainable way to contribute to their availability over time and continue to regenerate, retain, or add value, while securing the quality and resilience of ecosystems.
- **Resource Traceability** – Organizations manage, and track stocks and flows of resources in a transparent and accountable way so that they continue to regenerate, retain, or add value, while maintaining the circular flow of resources.

In line with this draft text of ISO 59004, we applied the circular economy principles on RecondOil system. We have gone through all of them and could see that, e.g., the RecondOil system *creates value* since it provides the solution to use oil in an efficient way, as well as maintains *resource availability* since we use less crude oil applying the RecondOil system. We can *trace oil as resource* in a transparent and accountable way, which, in turn, helps us *regenerate* oil and maintain the circular flow of resources. This aspect fulfills the principle of *resource traceability*.

4 System Conceptualization

To measure and assess the circularity of the RecondOil system, we need to establish a system model that sufficiently well represents the basic resource flows of the technology as well as distinguishes resources to and from nature, resources within the economic system, and resources circulated in and by the RecondOil system. Figure 2 shows the results of establishing such a system model, which contains the following levels:

- **The Global level of the system** model represents use of the natural resources and emissions.
- **The System of circularity strategy** is the core of this measurement and assessment, and it consists of *Circularity support system* needed to realize any circularity, the *Circular system*, which demonstrates what is being circulated, and the *Application system*, which represents where the circulated resource is put to use.
- **The Economic system** level represents the economic activities outside of the *System of circularity strategy*. These economic activities include production and utilization systems that extract, refine, transport and operate businesses needed to provide resources and materials to the *System of circularity strategy*, as well as receive products, goods, and functions, and manage rejected resources from the *System of circularity strategy*.

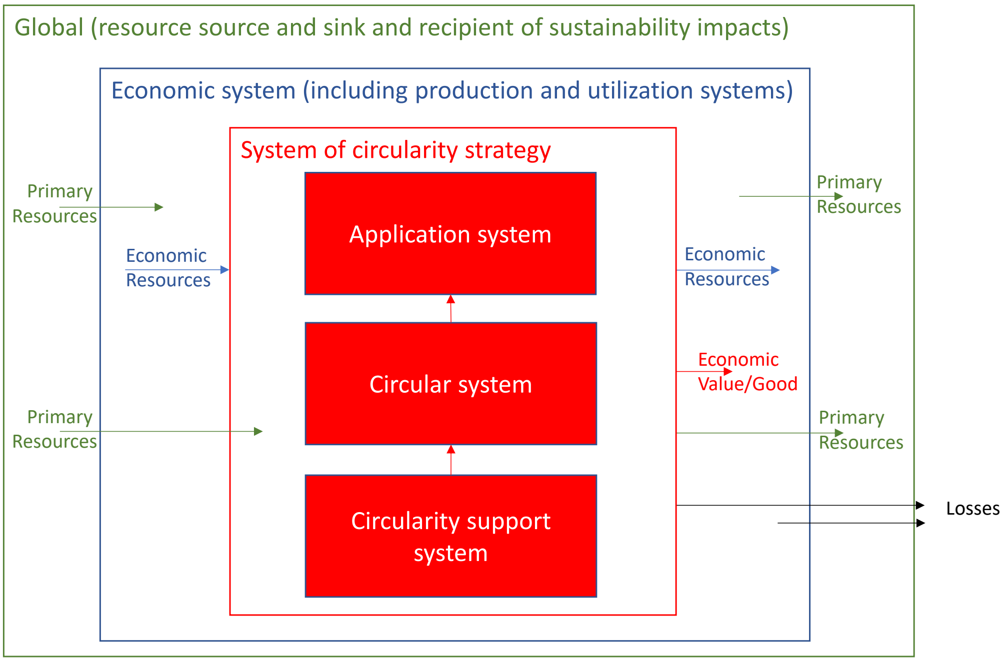

Figure 2. *System conceptualization: Description of system and subsystems*

The arrows in Figure 2 represent the flows that are indicators for measuring the circularity of the system.

When measuring and assessing the circularity by using the system model in Figure 2, we expect to be able to simultaneously quantify the technical circularity performance of the *System of circularity strategy*, how well the *System of circularity strategy* is synchronized with circularity potentials in the *Economic system*, as well as how well the circularity strategy in fact saves resources and contribute to sustainable development in the *Global system*. More technically, the arrows representing losses by increase in entropy, which in practice means diffusion of concentrated resources, loss of heat through friction and other statistical and thermodynamic losses.

5 Literature Review of Oil Lubrication Systems Case Studies

The aim of the literature study is to explore the current research regarding oil lubrication systems as understood through the lens of the circular economy. The analyzed literature is divided according to three categories of circular economy (CE) measurement: 1) global, 2) economic system, and 3) system of circularity strategy (see Table 1). Such analysis intends to contribute to the proposed CE measurements by framing the value and context.

Table 1. *Matching of studies to the categories of CE measurement (columns named according to Figure 2).*

Reference	**Global**	**Economic system**	**System of circularity strategy**
Sivanandhini et al., (2021)		MILP mathematical model	
Pinheiro et al., (2018)	Greenness criteria	Cost criteria	Performance of extraction
Pinheiro et al., (2018b)			Solvent extraction system
Botas et al., (2017)	LCA: Global warming potential, cumulative energy demand (IC), acidification, human toxicity and ecotoxicity (IC)		
Dudak et al., (2021)	LCA: GHG emissions' impact on ecosystems, human health, and resource consumption		
Sánchez-Alvarracín et al., (2021)			Re-refining technology

Sivanandhini et al. (2021) provide and test the Multi Integer Linear Programming (MILP) mathematical model for a lubricant oil closed-loop supply chain focusing on CE approach. The model extends the application of earlier models in lubricant oil supply chains with a re-refining approach and additional parameters such as setup cost and supply constraints for spent oil. Furthermore, run modes are also considered in the model. The proposed model determines the number of raw materials and intermediate products to be procured and transported, as well as the number of raw materials, intermediate and final products for inventory. This study contributes to knowledge of the *Economic system* level of CE measurement since the proposed mathematical model suggests economic feasibility and profitability of re-refine spent oil, given the assumption that end products from regular crude oil and base oil are of the same quality.

Pinheiro et al. (2018) develop a new methodology of solvent selection for the regeneration of waste lubricant oil (WLO), by adding the so-called Greenness Criteria. Solvent selection methodology includes two phases: the first phase comprises a sequential screening based on process constraints aiming at identifying possible extraction-flocculation candidates. In a second phase, solvents are evaluated regarding three major aspects of the process: greenness, performance of extraction, and cost. The assessment of Greenness criteria (1) is based on the

GlaxoSmithKline (GSK) solvent selection guide. Each of the categories and their areas of assessment were analyzed for each solvent and scored ranging from 1 to 10. The overall Greenness score can be formulated through the following geometric mean (1), where Wm – waste; Em – environment, HHm – human health, PSm – process safety:

$$GSK\ greenness\ score = \sqrt[4]{Wm \times Em \times HHm \times PSm} \quad (1)$$

Cost score (2) includes acquisition costs and costs related to solvent recovery:

$$cost\ score = \sqrt{SA \times Re} \quad (2)$$

For Performance of extraction, the same methodology used by GSK for assignment of scores and comparison of indicators was applied. Thus, to the lowest and highest of the percent of sludge removal (PSR) values, a score of 1 and 10 was assigned, respectively. Then, the scores of each solvent are calculated by interpolation. PSR is calculated through the geometric mean (3), where $W_{\text{dry-sludge}}$ is sludge without any oil, $W_{\text{waste-oil}}$ is waste lubricant oil

$$PSR\ (\%) = \frac{W_{dry-sludge}}{W_{waste-oil}} \times 100 \quad (3)$$

The Greenness criteria relates to the Global level of CE measurement since it evaluates categories such as incineration, recycling, biotreatment, emissions of volatile organic compound (waste metric), aquatic and air impact (environment metric), health hazard and exposure potential (human health metric), and flammability & explosion and reactivity & stability (process safety metric). The Cost score considers economic parameters and thus comprises Economic system level. The Performance of extraction belongs to the System of circularity strategy as it aims to analyze the efficiency of extraction to segregate out impurities of waste lubricant oil and obtain a good-quality base oil.

In another study, Pinheiro et al. (2018b) specifically analyze the removal of contaminants from WLO by solvent extraction to recover the base oil. The authors sample three WLO with different properties and examine their effects on the efficiency extraction using response surface methodology. The profiler, the desirability approach, and including acceptable process trade-offs helped to determine the best conditions of extraction. The solvent extraction system contributes to the System of circularity strategy of CE measurement.

Several studies treat LCA as a measurement indicator for circular economy. For instance, Botas et al. (2017) evaluate environmental and energy performance of recycling of used lubricating oil using LCA and highlighting the following impact categories:

1. Global warming potential is calculated in CO_2-eq emissions corresponding to the treatment stages required to produce 1t of upgraded engine oil (kg-eq CO_2/tonne base oil).
2. Cumulative energy demand determines and compares the energy intensity of processes (MJ-eq/tonne base oil).
3. Acidification, which is an environmental impact closely related to the use of fossil fuels, is used for the evaluation of processes that consume high quantity of energy coming from non-renewable sources (MoI N or S eq/tonne base oil).

4. Human toxicity is based on both the inherent toxicity of a compound and its potential dose and reflects the potential harm of a unit of chemical released into the environment (CTUh/tonne base oil). Ecotoxicity relates to the potential for biological, chemical, or physical causes that affect ecosystems. (CTUeco/tonne base oil).

All these categories can be referred to the *Global level* of CE measurement.

Similarly, Dudak et al. (2021) provide a life cycle assessment showing the impact of GHG emissions on human health, ecosystems, and resource consumption based on the calculated quantities of untreated oils in Serbia and examining different waste lubricant oil management scenarios of waste oil treatment. Sánchez-Alvarracín et al. (2021) characterize the used lubricant oils in Cuenca in Ecuador, compare them with the properties of used oils from other countries, and suggest the best re-refining option. As a result, the choice of treatment technology was based on several aspects such as the water content, recovery rates and quality of the regenerated product, as well as available market, operating costs, transportation, energy, and the quality of oil to be obtained.

Summing up, the literature analysis provided insights into how oil lubrication systems are assessed in terms of environmental impacts and the broader concept of sustainability. These insights are intended to be used to develop circularity indicators representing features of SKF RecondOil.

6 Circularity Measurement Process

To verify whether a technology, product, material, process[3] or system corresponds with the properties of a circular economy we need to ask whether the system meets the definition of a circular economy. To verify this, we can ask whether we can find at least one measurable indicator for each of these questions (compare with definition of circular economy in clause 2):

- Do we see systematic maintenance of a circular flow of resources?
- Do we see adding resource values?
- Do we see regenerating resource values?
- Do we see retaining resource values?
- Do we see contribution to sustainable development?

If we can find such indicators, it may also be possible to measure to which degree the technology, product, material, process, or system can be considered as a *circular system*. Figure 3 shows a structure of indicators to be used to measure circularity.

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[3] Set of interrelated or interacting activities that transforms inputs into outputs [SOURCE: ISO 14044: 2006, 3.11].

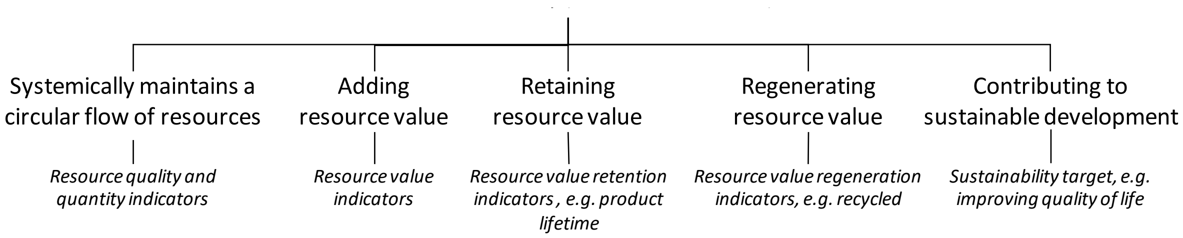

Figure 3*. Structure of indicators to be used to measure circularity, also based on (ref to 59004/WD2).*

6.1 Confirming and Measuring Circularity of RecondOil System

In the following sections, we will qualify whether the RecondOil system corresponds to the current ISO draft definition of circular economy, and if so, how to calculate to which degree it corresponds.

6.2 Systemically Maintains a Circular Flow of Resources

Figure 4 presents a general system model with RecondOil parameters included.

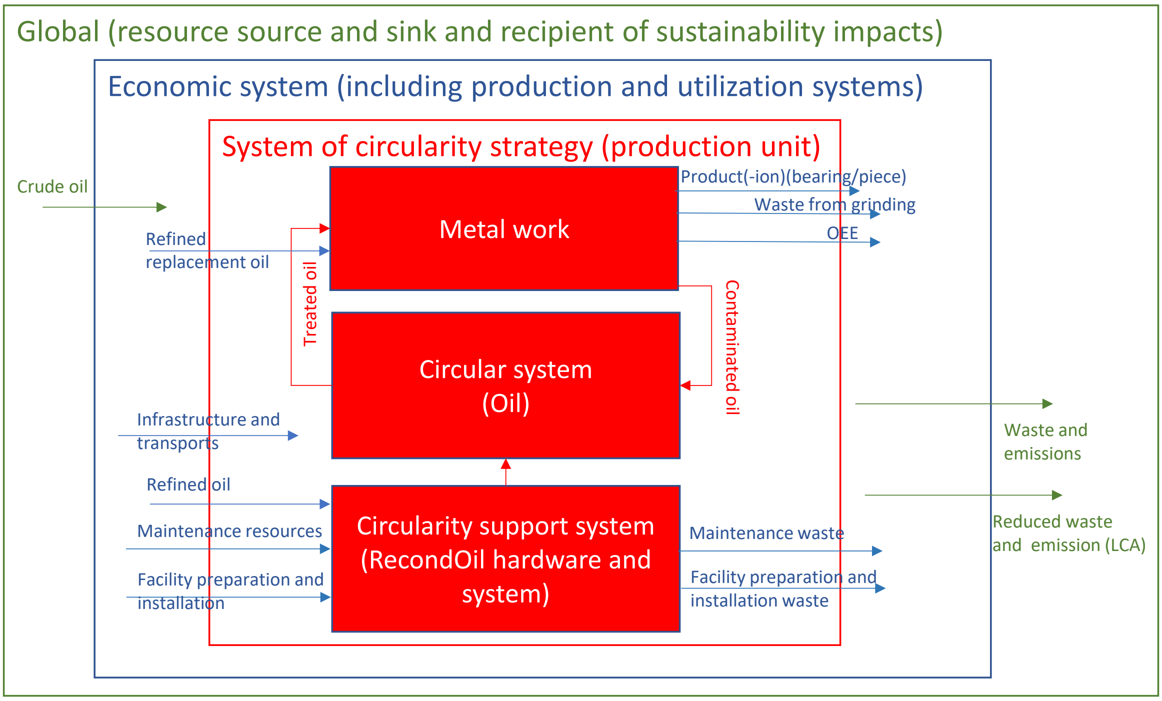

Figure 4. *General system model with RecondOil parameters included*

The arrows in Figure 4 represent the flows that are indicators[4] for measuring the circularity of the system. There are three system levels in the scheme. The *System of circularity strategy* contains the *Circularity support system* (the RecondOil system), *Circular system* (oil), and Metal work (where the RecondOil system is used to reuse oil). The *Global system* demonstrates how the *System of circularity strategy* uses the global resources, in our case – crude oil, and what returns back (e.g., waste and emissions). The *Economic system* includes production and

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[4] Not all these indicators are measured at the current RecondOil system but are represented here for discussion.

utilization systems. In our case, refined oil is taken from *Economic system* to the production unit and then we see what we return to *Economic system*, i.e., any economic resources (e.g., product), but also maintenance waste or waste from honing.

Choice of Indicators. From Figure 4, we identify the following circular economy indicators:

- From Global to Economic system
    - Crude oil
- From Economic system to Circularity system
    - Refined oil
    - Maintenance resources
    - Facility preparation and installation
- Within Circularity system
    - Contaminated oil
    - Treated oil
- From Circularity system to Economic system
    - Product
    - Waste from grinding
    - Contaminated oil
    - Maintenance waste
- Facility preparation and installation waste from *Circularity system* to *Global*
    - Waste and emissions

Quantification of Indicator Value. The above-mentioned circular economy indicators are quantified in Table 2.

Table 2. *Quantification of Indicator Value*

Item	Definition
From Global to Economic system	
Crude oil	A factor quantifying how much crude oil is needed for producing Refined oil
Reduced amount of Crude oil	Representation of how much less crude oil is used when using less Refined oil in the RecondOil system
From Economic system to Circularity system	
Refined oil	Full replacement of oil in RecondOil system
Production	Number of produced pieces per full replacement of oil in RecondOil system
Linearly used oil	With the same Production, the amount of linear oil used
Refined oil per piece	Formula = Refined oil / Production
Linearly used oil per piece	Formula = Linearly used oil / Production
Resource efficiency factors for RecondOil system	Formula = Refined oil per piece / Linearly used oil per piece
Maintenance resources	Amount of resources used for one fully replaced RecondOil system
Facility preparation and installation	Full resource investment (expressed in monetary terms)
Fixed resource costs per produced unit	Formula = Facility preparation and installation / Production (expressed in non-monetary terms)
Within Circularity system	
Contaminated oil	Amount of contaminated oil returned into RecondOil treatment
Treated oil	Amount of treated oil by RecondOil system returned into production
From Circularity to Economic system	
Product	Quantification of product, i.e., piece
Waste from grinding	Amount of oil and amount of metal scrap
OEE	See Section 6.3

Facility preparation and installation waste	Amount of resource waste
Maintenance waste	Amount of waste produced during one full replacement of oil in RecondOil system
From Circularity to Global	
Waste and emissions	Amount of waste and emissions produced during Production
Reduced waste & emissions	Reduced amount of waste and emissions produced during Production (LCA)

Case Study of SKF RecondOil. The input for the Cassino (SKF site in Italy) Integrated Large installation in cubic meters of oil per year:

Table 3. *Quantification of Indicator Value for the RecondOil system.*

Item	Definition
From Global to Economic system	
Crude oil	70 m³/year
Reduced amount of Crude oil	0 m³/year
From Economic system to Circularity system	
Refined oil	70 m³/year
Production	150 million pieces/year
Linearly used oil	70 m³/year
Refined oil per piece	0,000000467 m³ per piece
Linearly used oil per piece	0,000000467 m³ per piece
Resource efficiency factors for RecondOil system	1
Maintenance resources	1 FTE (full time equivalent), same as before
Facility preparation and installation	8 MSEK
Fixed resource costs per produced unit	8 MSEK/150 million pieces = 0,053 SEK
Within Circularity system	
Contaminated oil	70 m³/year
Treated oil	
From Circularity to Economic system	
Product	150 million pieces/year
Waste from honing	same as before
OEE	OEE: 1% improvement
Facility preparation and installation waste	n/a
Maintenance waste	Reduced honing stone consumption: 10% less Reduced oil sludge amount: 24 m³/year Reduced filter consumption: 20% less
From Circularity to Global	
Waste and emissions	n/a
Reduced waste & emissions	n/a

Discussion and conclusion. The data provided by SKF shows that the indicators suggested by the current working draft of the standard can indeed be represented by data provided from the industry. The fact that the data was not of high quality or empirically based make it difficult to measure the actual values of the represented indicators, but it may be considered a practical proof of concept with regards to the representability of indicators to describe systemically maintenance of circular flows of resources.

6.3 Adding Resource Value

Choice of Indicators. In Figure 4, *Adding resource value* is represented by the change in Overall Equipment Effectiveness (OEE). OEE represents the valued parameters with regards to the productivity of a production equipment. The OEE that SKF uses consists of three components:

- Availability component represents the percentage of Scheduled Hours that the equipment is available to operate.
- Performance component shows the actual equipment performance in relation to the design and/or reference output during the available time.
- Quality component indicates the good units produced as a percentage of the total units produced.

How each of the three components are quantified is presented in the following subsection.

Quantification of Indicator Value. OEE is calculated from measured values as the product of the three separate components as follows:

$$OEE = Availability \times Performance \times Quality \tag{4}$$

in which:

$$Availability\ Rate = \frac{Available\ Hrs}{Scheduled\ Hrs} = \frac{Scheduled\ Hrs - Availability\ Losses}{Scheduled\ Hrs} \tag{5}$$

$$Performance\ Rate = \frac{Performance\ Hrs}{Available\ Hrs} = \frac{Total\ Nr\ Pcs \times Std\ PCT}{Available\ Hrs} \tag{6}$$

$$Quality\ Rate = \frac{Effective\ Hrs}{Performance\ Hrs} = \frac{Good\ Nr\ Pcs}{Total\ Nr\ Pcs} \tag{7}$$

The different ways to measure the values are provided in case studies below.

Case Study of SKF RecondOil. OEE: 1% improvement[5]

Discussion and Conclusion. The use of OEE as a representation for value for circularity system was suggested during the research project. It was discussed and eventually chosen as a measure for the value indicator, which turned out to be meaningful for how to communicate the technical benefits of the RecondOil system beyond its actual resource savings. The 1% OEE improvement probably is not statistically significant, but when monitored more systematically real figures is expected to reveal the relationship between RecondOil and OEE.

6.4 Retaining Resource Value

Choice of Indicators. *Retaining resources value* indicator determines the total circularity of all resource value over the chosen timeframe. It involves indicators that quantify contribution to retaining resource value.

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[5] SKF provided a general value for the combined improvement of OEE, which are based on current indications rather than formally performed measurements.

Quantification of Indicator Value[6]. We define it as follows:

$$RecondOil\ retainment\ factor\ per\ piece\ = \frac{Treated\ oil\ per\ piece}{Linearly\ used\ oil\ per\ piece} \times 100\% \qquad (8)$$

Case study of SKF RecondOil.

$$RecondOil\ retainment\ factor\ per\ piece\ = \frac{2000}{40} \times 100\% = 5000\% \qquad (9)$$

Discussion and Conclusion. *Retaining resource value* is key in circular economy since it directly leads to less resources needed to provide a function. Being able to show how the oil retained 50 times longer by RecondOil system therefore demonstrates the practical value of this indicator. The data for this indicator also seemed to be of sufficiently high quality.

Additionally, this indicator may be of lesser significance to a standalone system, considering the increased logistics and/or infrastructure needed.

6.5 Regenerating Resource Value

Choice of Indicators. To capture to which degree the RecondOil regenerates resource value, we tried to develop an indicator 'Oil regeneration factor'.

Quantification of Indicator Value[7]. It is quantified as follows:

$$Oil\ regeneration\ factor\ = \frac{Treated\ oil\ per\ piece}{Refined\ replacement\ oil\ per\ piece} \qquad (10)$$

Case Study of SKF RecondOil. We received data from SKF, for the standalone equipment. For each 2 000 liters of treated oil, there is a loss of about 40-45 liters discarded with the oil in the waste, sludge and filter.

$$Oil\ regeneration\ factor\ = \frac{2000\ litres}{40\ litres} = 50 \qquad (11)$$

As seen in equation 11, the oil regeneration factor for the RecondOil system is 50, which amountsto 50 avoided oil changes. It shows how many times the oil can be reconditioned at SKF system before the oil needs to be replaced all together.

Discussion and Conclusion

Retaining and regenerating resources value are quite similar, and they are interconnected since the 5000% of retained lifetime equals 50 times longer lifetime for the oil. In the standardization discussions disclosed interconnectedness between regeneration and retaining tend to lead the discussion towards removing one of these two indicator types. However, there are situations where retainment may lead to either stocks of resources or regeneration of resources. Which of these two cases are actually the case, it will be revealed by the results.

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[6] The formula is considered being in analogy with the formula of % circular water inflow in the report "Circular Transitions Indicator V2.0 Metrics for business, by business" published by World Business Council for Sustainable Development.

[7] The formula is considered being in analogy with the formula of onsite water circulation (reuse & recycle) in the report "Circular Transitions Indicator V2.0 Metrics for business, by business" published by World Business Council for Sustainable Development.

6.6 Contributing to Sustainable Development

Choice of Indicators for sustainable development includes:

- protecting social aspects e.g., occupational health and safety
- protecting environmental aspects
- protecting renewable and non-renewable resources.

Here we use the ones from SKF LCA report from 2021[8].

Quantification of Indicator Value. Methods to measure such indicators include variants of LCA and other systems analysis that address sustainability targets (e.g., improving quality of life).

Case study of SKF RecondOil. The LCA was used for measuring this indicator, in which one impact category is assessed such as *climate change*, and one indicator such as *fossil resource depletion*.

Climate change. The LCA results show that the climate footprints of both SKF RecondOil DST processes are lower than the footprint of a conventional oil life cycle (see Figure 5). The climate impact of a conventional oil cycle is 3 800 kg CO_2-eq. per m^3 oil, compared to 20 kg CO_2-eq. of DST Integrated system and to 154 kg CO_2-eq. of DST Stand-alone system.

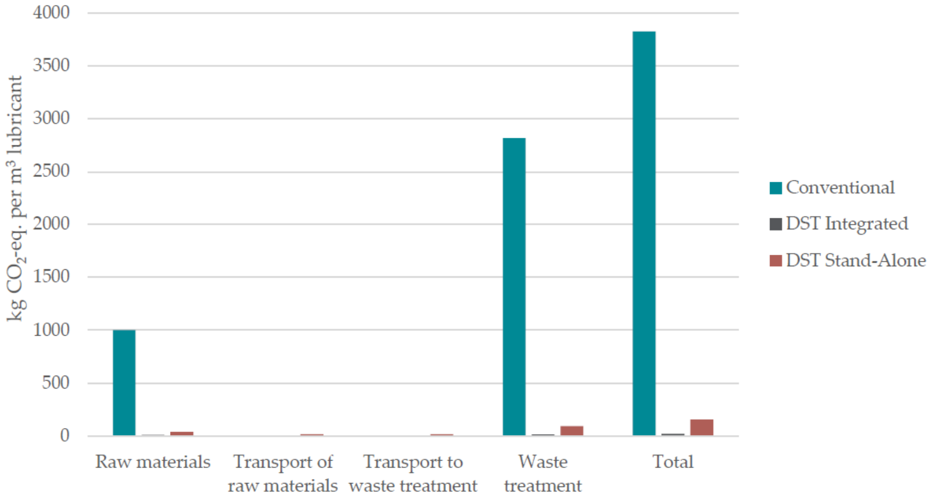

Figure 5*. Climate change impact potential of the three studied systems (source: LCA report).*

Fossil resource depletion. Apart from the potentially lower environmental impact, avoided production of lubrication oil can substantially save non-renewable fossil petroleum (see Figure 6). The results 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.

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[8] The LCA report is not publicly available but is part of SKF's internal investigation of the performance of the RecondOil system.

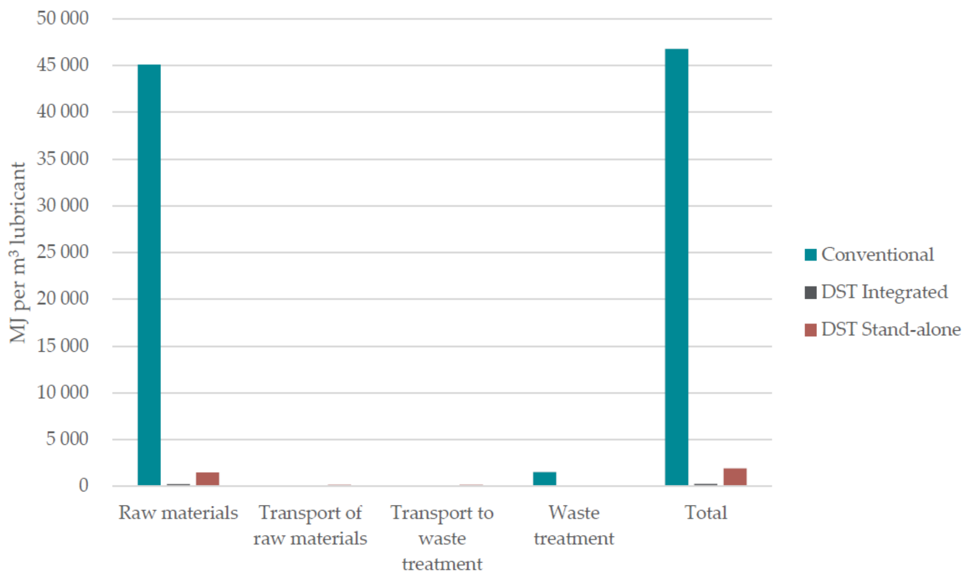

Figure 6. *Fossil resource depletion potential of the three studied systems (source: LCA report)*[9].

By using LCA as a system analytical tool for benchmarking with Sustainable Development Goals, the SKF RecondOil DST processes contribute to several SDGs, of which the more suitable are:

- *SDG 7. Affordable and clean energy* since it reduces the use of non-renewable energy resources, due to material resource efficiency.
- *SDG 9. Industry innovation and infrastructure.*
- *SDG 12. Responsible consumption and production*, since resources are saved.
- *SDG 13. Climate action* since it reduces GHGs emissions due to regeneration of oil.

Discussion and Conclusion. The circularity measurements provided by systematically maintaining resource flow, retaining, regenerating, adding resource value specifically address circular economy objectives. To reach a circular economy that meets the goals from which it was derived, solutions also need to contribute to sustainable development. However, sustainability assessment tools are not particularly developed for circular economy since there are many existing tools and standards to choose from. Here we used LCA according to ISO 14044 to provide information to the sustainability indicator.

In addition to providing sustainability information, the LCA also provided circularity related information about resource savings. 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 the following[10-11]:

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[9] The figure displays the total use of non-renewable primary energy through the entire life cycle of 1 m^3 of lubricant.

[10] The above effects are not included in this analysis since the use phase of the oil is outside the scope of this study.

[11] No numeric indicators.

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

6.7 Draft certification scheme

The full clause 6 from ISO 59004/WD2 exemplifies how the certification scheme for measuring circularity may work. By building the verification scheme on the definition of circular economy and establishing representative indicators for all aspects of the definition, a full circularity measurement has been scoped. In this clause, it has been shown that all data required by such an approach is practically available for the organization. However, specific quality requirements for data have not been set and full verification could hence not be achieved. Regardless, the case still provides a proof of concept for applying the suggested principles.

7 Discussion and Conclusion

In the Vinnova funded TRACE CERTAINTY project, **a framework for understanding and measuring circularity for the system** at hand was developed including: a *heuristic* (diagram) describing a system of interest and a *list* of chosen circular economy principles. It is thought that the heuristic and list of principles could be used to guide an entity in the process of first, creating their system model, and then, making sense of and applying principles.

The case at hand concerned a specific technology, RecondOil system, that enables quality improving circularity. This means that we had to acknowledge the circularity support system (RecondOil system) and separate it from circular system (oil). This separation also identified a few key resource flows that describe the circularity of the system. The report shows the rational for the chosen methodology since it is related to ongoing ISO/TC323 Circular economy standardization. Based on the literature review of oil lubrication systems case studies, the report provides benchmarking with alternative ways to measure oil recycling. However, there doesn’t appear to be an established manner of measurement for assessing whether the system is circular or not and to which degree. We therefore conclude that this project is unique in that sense. This **project yielded direct input into standardization work related to circular economy** but also **showed some of the challenges and rewards of attempting to apply circularity to industrial systems**. The process of assessment required that the team match circularity in principle (*how circularity can be measured in theory*) with circularity in practice (*how circularity can be measured in a real system*). In practice, this required a significant amount of communication and co-learning. On one hand, the research team presented principles of circular economy and circularity to representatives of SKF RecondOil and helped them make sense of the principles for their context. On the other hand, representatives at SKF RecondOil needed to explain their solution(s), including how they work, the inflows and outflows and how they impact things around them. Together, researchers and company representatives arrived at a set of practically measurable metrics that fit circular economy principles.

In addition, a few key learnings were revealed. First, due to that RecondOil technology is under development, the current knowledge and data are not fully available. This was an advantage for the methodology development since much of the methodological testing also became a test for how circularity indicators made sense also for the technological development. In addition, the lack of good quality data has less significance in comparison to how relevant the indicators proved to be both to the understanding of the technology and for the feasibility of the chosen circularity indicators.

Second, since the standards are under development, there are still conceptual uncertainties on how to realize indicators within the categories ‘retain’ and ‘regenerate’, which have provided some arguments and discussions in ISO standardization about these categories. Our work thereby relates meaningfully to the work done in parallel in ISO. The open questions that we identified about the meaning of, for example, the ’added value’ indicator and the seemingly redundant indicators ’regenerate’ and ’retain’ gave practical substance to standardization discussion. We also identified that it is necessary to take further detailed development actions with regards to meaningful data in relation to the meaning of the indicators. To develop a full certification scheme for the circularity measurements, it will be necessary to dig deeper into the aspect of data quality. This has not been done here whereas focus was on testing the application of circularity principles in practice.

In this project, we utilized the draft definition of circular economy from the ongoing ISO work with standardization of circular economy terminology (ISO 59004). We found that definition and key principles therein provided a useful point of departure for measuring circularity. We further conclude that the measurements made this way may guide technology development and provide statements of circularity performance of a technology. There are **two major ways forward from this study**. One way is to continue and go deeper into the RecondOil system, to get better data and more precise choice of indicators. This is important to complete certification scheme and will be a necessary step for any such certification scheme. Another way is to broaden the study into investigating how well the approach tested here also suits similar or different circularity strategies. If tested in similar systems, we may learn more about comparability and where to draw system boundaries scopes. If tested in different circularity strategies, we may learn more about the generalities of applying the ISO standards during development to prepare for applying them as well as continue to provide feedback to the standardization process. In order to provide feedback, the continuing projects need to be started soon since the standardization process is gradually stabilizing with regards to consensus setting.

If we allow ourselves to speculate, what would we expect from trying to apply learnings from this project on e.g., material product take-back system, sharing economy, or retaining lifetime of products? We can expect that the *circularity support system* will probably often be completely forgotten or omitted. We also expect that in a sharing economy there will be more emphasis on the shared value, and it will be more detailed than what we have seen in OEE measurement. Regarding regeneration, a take-back system of products may regenerate resource value by reuse of full products, components of the product or material of products. Reuse of full products will not need reproduction. Reuse of components may either be done in reproduction or after-market service. Reuse of material is a fully different material handling of the sorting, recycling, and reproduction. Regeneration in general takeback systems hence significantly differs from the regeneration in the RecondOil system. Therefore, we can expect deviations to how to apply the methodology for different regeneration systems. In addition, in the RecondOil system, the retaining of the oil is made entirely by the *circularity support system*, but in a discrete physical product a larger emphasis will likely be given to both product design and maintenance of the product. These are only some specific speculations, but we may expect many such particular differences when applying the indicators in new cases.

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