CO_2 savings through remanufacturing of spare parts using the example of combustion engines

Remanufacturing as a building block of sustainability strategies
in OEM aftersales

Abstract

This article deals with the analysis of possible savings of emissions and energy through the reprocessing of used parts and the utilization of these as spare parts in the automotive industry. The focus is on the contribution that can be made to achieving ecological sustainability goals.

Using the example of a widely used 4-cylinder replacement engine, this article explains step by step how the emission and energy balances for new production and remanufacturing can be drawn up and compared. It can be shown that in this reference scenario, 62% of emissions and 63% of energy can be saved compared to new production.

Even if only electricity from sustainable energy sources is used for production, the remanufactured engine releases 66% fewer emissions than the conventionally manufactured new engine when comparing the two types of production. Furthermore, fewer resources in the form of (metal) raw materials are required, as hardly any primary materials are needed to build remanufactured components.

Remanufacturing, the process of reconditioning of components that have already been used in operational condition, is therefore a resource-, energy- and emission-saving approach to offering spare parts in the automotive sector, in addition to other advantages such as cost-effectiveness and availability. Last but not least, the combination of these aspects can also make a corresponding contribution to customer loyalty.

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1 Introduction

The topic of sustainability is currently omnipresent in the automotive industry. Hardly any discussion on future alignments and objectives can avoid the diverse topics of sustainability. The focus is not only on zero-emission vehicles and government-imposed CO_2-fleet targets. The focus is also on the entire life cycle, from the procurement of raw materials and production of the vehicle through to the return of used parts to the cycle, which is discussed in both the professional circles and the popular press under the terms "Circular Economy" and "Closed Loops".

Since the financial year 2017, large companies (listed companies with more than 500 employees) have been obligated to create and publish a sustainability report. Since then, sustainability has evolved from being merely a "fashionable term" to becoming an integral part of the corporate strategy. In addition, many companies recognize that sustainability is not just a "reporting obligation", but an important purchasing argument for consumers and therefore essential in order to remain competitive in the future. With the statement "Consistently anchoring sustainability in the core business", Markus Schäfer, member of the Daimler Board of Management and Co-Chairman of the Group Sustainability Board, outlines the path for the future sustainability strategy. In an interview, he describes how resource consumption and emissions caused directly by the company, for example through production, have already been successfully reduced. The sustainability view must not be limited to the company's own boundaries, but the entire supply chain from raw parts to recycling must be included in order to "change lanes" (cf. title of the Daimler 2020 sustainability report).[1]

The fleet targets set for car manufacturers (target: CO_2 emissions of max. 95 g/km, European target for 2021[2]) relate exclusively to the vehicle's use phase. Nevertheless, the manufacturing processes, including supply chains, should be given at least as much importance, as they already generate **15-20% of all emissions over** the entire **life cycle**.[3] Furthermore, these fleet targets only have a small impact on the overall picture of emissions in road traffic: according to the Federal Motor Transport Authority, around 3.6 million new cars were registered in Germany in 2019.[4] This compares to a total of 47.7 million vehicles.[5] The leverage of the vehicles already registered on the CO_2 balance of road traffic is therefore not insignificant, as illustrated in *Figure 1*. OEMs must therefore not only focus on their new vehicle fleet, but must also start with the **current vehicle population** and find ways to increase the sustainability of the vehicle population.

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[1] *Daimler - "SpurWechsel. Daimler Nachhaltigkeitsbericht 2020".*

[2] *VDA- Verband der deutschen Automobilindustrie e.V.- "CO_2 -Regulierung bei Pkw und leichten Nutzfahrzeugen".*

[3] *VCÖ – Verkehrsclub Österreich - "Wie viele Ressourcen werden bei der Pkw-Produktion verbraucht?".*

[4] *KBA- Kraftfahrtbundesamt – "Jahresbilanz- Neuzulassungen: Zahlen des Jahres 2019 im Überblick".*

[5] *KBA- Kraftfahrtbundesamt –"Pressemitteilung Nr. 6/2020- Der Fahrzeugbestand am 01.Januar 2020".*

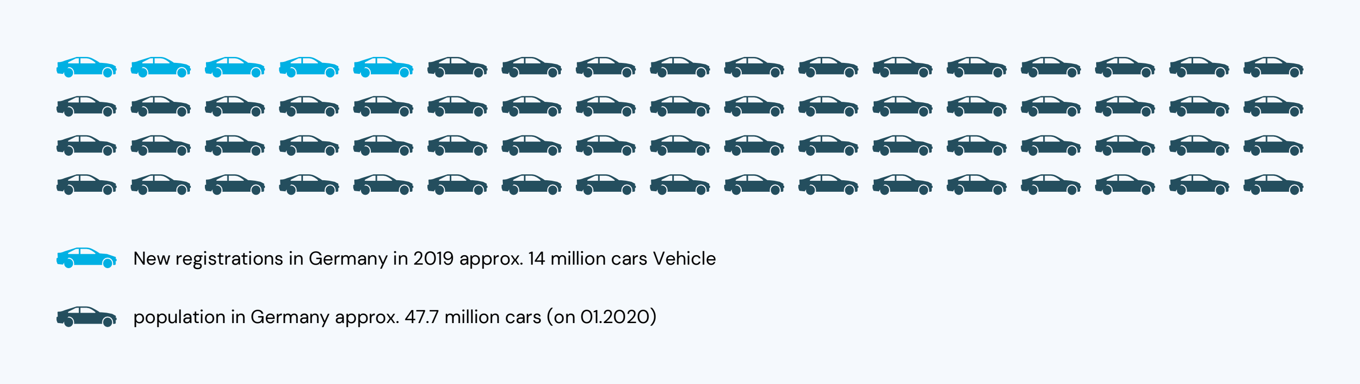

Figure 1: Comparison of new registrations per year with the total vehicle population according to Federal Motor Transport Authority

One possible approach is a low-emission and resource-saving spare parts supply through the consistent implementation of the "circular economy" concept. In this context, **remanufacturing** in the form of professional reconditioning of used parts and systematic supply to the market is a key factor.

In the past, manufacturers of automobiles and components have increasingly relied on reuse strategies for their products, such as the remanufacturing of gearboxes, clutches, brake calipers, steering systems and brake discs. This involves retrieving used parts from the market and reconditioning them.
The motivations were generally to ensure supply reliability and to reduce manufacturing costs in small series production. However, with the ever more restrictive CO_2 targets, remanufacturing is moving further into the foreground as part of sustainability strategies and is already an integral part of aftersales (spare parts business) as a business model for well-known OEMs. OEMs are now involved in the remanufacturing of more complex spare parts, such as the combustion engine.
This article therefore looks at the carbon footprint of a remanufactured replacement engine compared to a newly manufactured replacement engine.

The article also deals with a classification of remanufacturing, its positive effects and an argumentation on its impact on the carbon footprint. Using an example, it demonstrates the amount of energy and emissions that can be saved through remanufacturing, with the results analyzed and visually presented. Finally, an outlook on remanufacturing in automotive aftersales is given.

2 The "Remanufacturing" business and process model and the carbon footprint

Remanufacturing is the industrial refurbishment process of used parts. The used part is remanufactured via defined process steps so that it is then functionally comparable with a new part.[6]

In contrast to a repair, the used parts are completely dismantled and each component is checked for reusability, followed by assembly and testing of the entire component according to comparable requirements for a new part. Cores are recovered by not disposing of or recycling products at the end of their usage phase, but instead feeding them into the remanufacturing process (see *Figure 2*).

Remanufacturing is therefore strongly based on the so-called principle of the **Circular Economy**, as the material cycle is closed. In addition, energy and resources that have already been put into the used part can be reused and do not have to be obtained anew. This results in additional resource and energy saving potential. Compared to new production, remanufacturing saves significant process steps in the extraction of raw materials. The remanufacturing process (see *Figure 3*) begins with the collection and logistics of used parts, which are then recycled and reused.
If they are suitable for reprocessing, they are dismantled, cleaned and restored. Finally, they are assembled into a functioning end product and undergo end-of-line testing.

Figure 3: The remanufacturing process (own illustration)

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[6] *cf. Dr.-Ing. Ulrike Lange -Ressorceneffizienz durch Remanufacturing- Industrielle Aufarbeitung von Altteilen 2017, p. 11.*

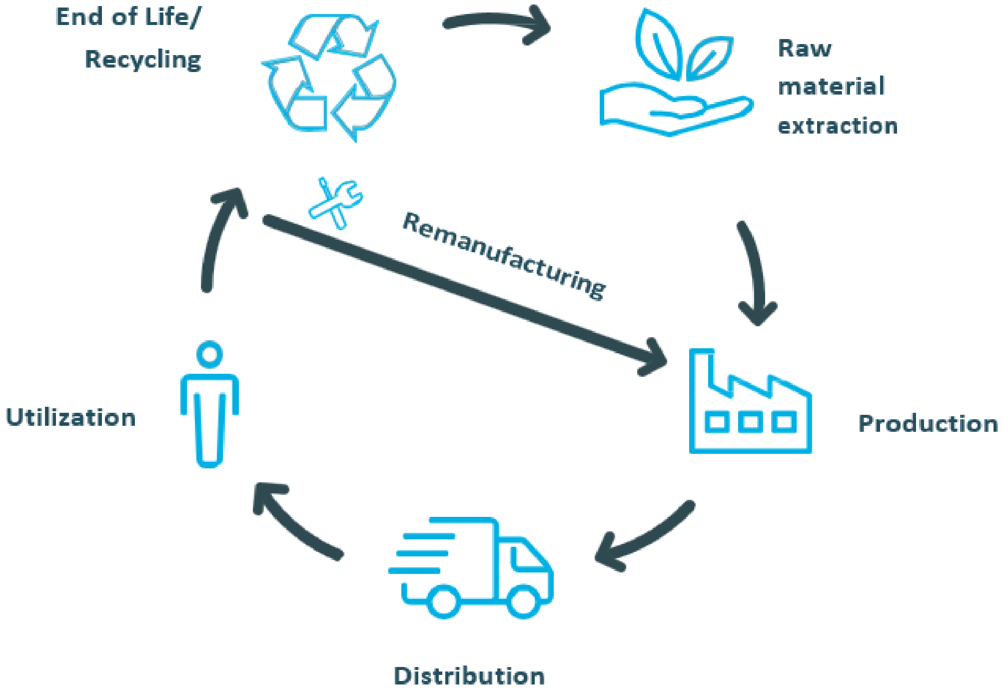

Figure 2: Remanufacturing as a component of the circular economy (own illustration)

2.1 Positive effects of remanufacturing

Remanufacturing not only pursues ecological goals, such as saving resources, energy and CO_2 . The focus is also on economic efficiency and customer benefits.

Remanufacturing results in significant **savings in manufacturing costs**, as key production steps from the original and remodeling areas are eliminated. In aftersales, **sales** can also be **increased,** as the customer can be offered a more favorable offer in line with the vehicle's current value compared to a new spare part. This increases the chance that the customer will purchase the spare part from the OEM and not from an independent third-party supplier who may offer a lower price but delivers undefined quality and cannot provide an OEM warranty on the spare parts.

At the same time, **customer loyalty** is increased by offering new parts quality. Due to the aforementioned advantages over an independent spare parts provider, new customers for older vehicles can be acquired.

In addition, remanufacturing can also make an important contribution to fulfilling company promises or the legally stipulated **supply of spare parts** after the end of series production by using returned used parts instead of expensive or partially impossible new part production.

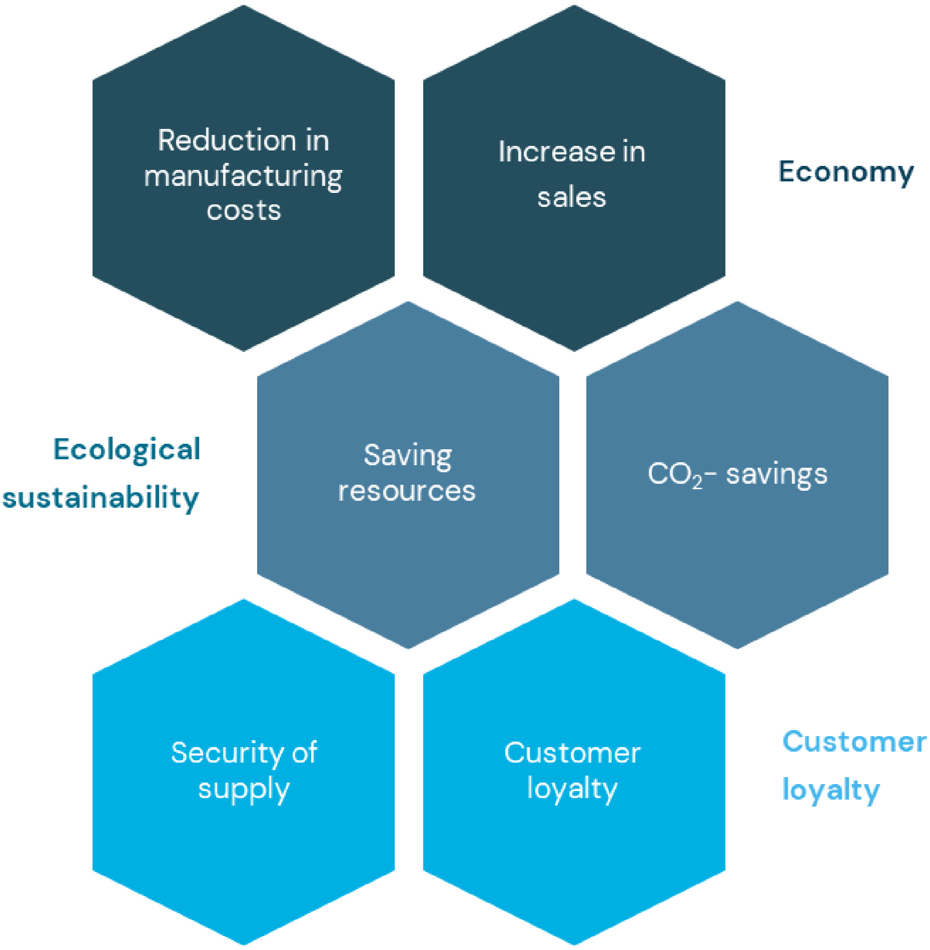

Figure 4: The advantages of remanufacturing (own illustration)

2.2 Determination of the carbon footprint

First of all, the concept of the carbon footprint needs to be clarified. In general, the term "footprint" describes all traces that humans leave behind in the utilization of raw materials and in the use of raw materials themselves. The documentation of these (negative) effects is referred to as **footprinting.**

The entire life cycle of the system to be analyzed must be taken into account (from the cradle to the grave), including the life cycles of the raw materials (so-called **life cycle assessment**, see *Figure 5*). There are different types of footprints that can be calculated, e.g. in terms of land use, water consumption and energy consumption.

A key aspect of this is the carbon footprint, which describes all CO_2 emissions associated with a specific action, product, etc.[7] It has become established practice to account for all other greenhouse gases that contribute to global warming in addition to CO_2 . The climate-damaging effect of other gases such as methane, nitrous oxide and various hydrocarbons is normalized to the effect of CO_2 , i.e. by a multiple of the effect of 1 kg of CO_2 . The total **global warming potential GWP** is therefore given as a **CO_2** equivalent (CO_2e). The global warming potentials of the individual gases are specified by the Intergovernmental Panel on Climate Change (IPCC).[8]

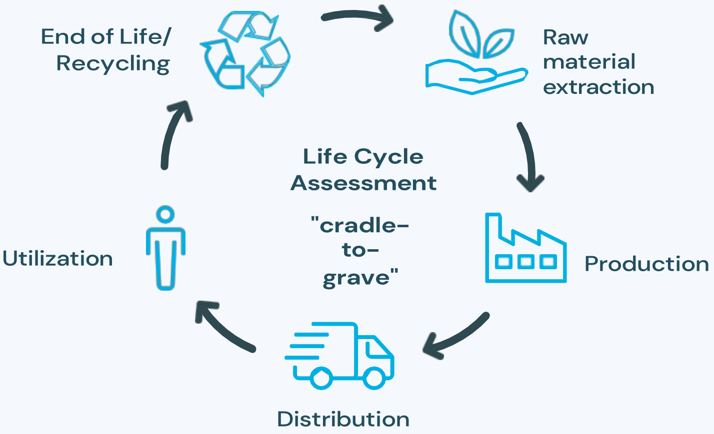

Figure 5: Investigation framework of a life cycle analysis (own illustration)

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[7] *cf. Stibbe, Global Life-Cycle Controlling, p. 6 ff.*

[8] *cf. Heidi Hottenrot, Bettina Joa, Prof. Dr. Mario Schmidt, Pforzheim University, Institute for Industrial Ecology.*

The carbon footprint can be specified for products or even entire companies, depending on which system limit is set. The **product carbon footprint (PCF)** accounts for all direct and indirect GHG emissions (expressed as CO_2 equivalent) that occur throughout the entire product life cycle of a product (or service) (see *Figure 5*). This life cycle approach is referred to as **"cradle-to-grave".** It is also possible to determine a partial PCF, i.e. only a section of the life cycle is considered. In contrast to the PCF, the **corporate carbon footprint (CCF) covers** all direct and indirect emissions that occur within the system boundaries of a company.[9]

There are numerous regulations that deal with the calculation / measurement of environmental impacts and greenhouse gas emissions for products and companies. Depending on the application, the appropriate set of rules should be used. Table 1 shows a classification of norms and standards established in the automotive industry, indicating the environmental factors considered and the system boundary.[10] Product climate assessments are best suited to the present application.

	Object of consideration		**System boundery**	
	Climate-damaging effect of greenhouse gases	**All environmental impacts**	**Entire company**	**Product/ Service**
Environmental management systems	×	×	×	
Corporate carbon footprints (CCF - Corporate Carbon Footprint)	×		×	
Product carbon footprints (PCF - Product Carbon Footprint)	×			×
Environmental footprint of products	×	×		×

Table 1: Classification of standards for CO_2 emissions from products and companies

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[9] *cf. Heidi Hottenrot, Bettina Joa, Prof. Dr. Mario Schmidt, Pforzheim University, Institute for Industrial Ecology - Carbon Footprints für Produkte - 2013, p. 9 f.*

[10] *cf. Eva Maria Streppel, Prof. Dr.-Ing. Henning Hinderer - CO_2 als Wettbewerbsfaktor in der automobilen Wertschöpfungskette- 2016, p. 16.*

3 Determination of the carbon footprint using the example of a remanufactured 4-cylinder car engine

As shown in Chapter 2, the carbon footprint for an engine is best determined on the basis of a product life cycle assessment. There are a number of norms and standards that lead to a systematic approach to determining product carbon footprints.

A comprehensive overview of all environmental impacts (e.g. use of resources), including the climate impact of greenhouse gases over the course of a product's life cycle, is provided by the preparation of a **life cycle assessment** in accordance with **DIN EN ISO 14040/14044.** Such a comprehensive life cycle assessment forms the basis for the other standards, which are limited to the climate impact of greenhouse gases (carbon footprint).

The **PAS 2050** "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" published by the British Standards Institute BSI in 2008 describes an initial approach to describing a product **carbon footprint.** The PAS 2050 specification is merely a guideline and does not (yet) represent an internationally accepted standard for determining the product carbon footprint.[11] The "Product Life Cycle Accounting and Reporting Standard" of the Greenhouse Gas (GHG) Protocol Initiative (**GHG product standard**) was published in 2011.

This product standard represents an international, generally applicable framework for balancing the greenhouse gas emissions of products (or services) across all phases of the product life cycle. The internationally valid standard **DIN EN ISO 14067** "Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification" was published in 2013.

Figure 6: Procedure for determining the PCF in accordance with DIN EN ISO 14067 (own illustration)

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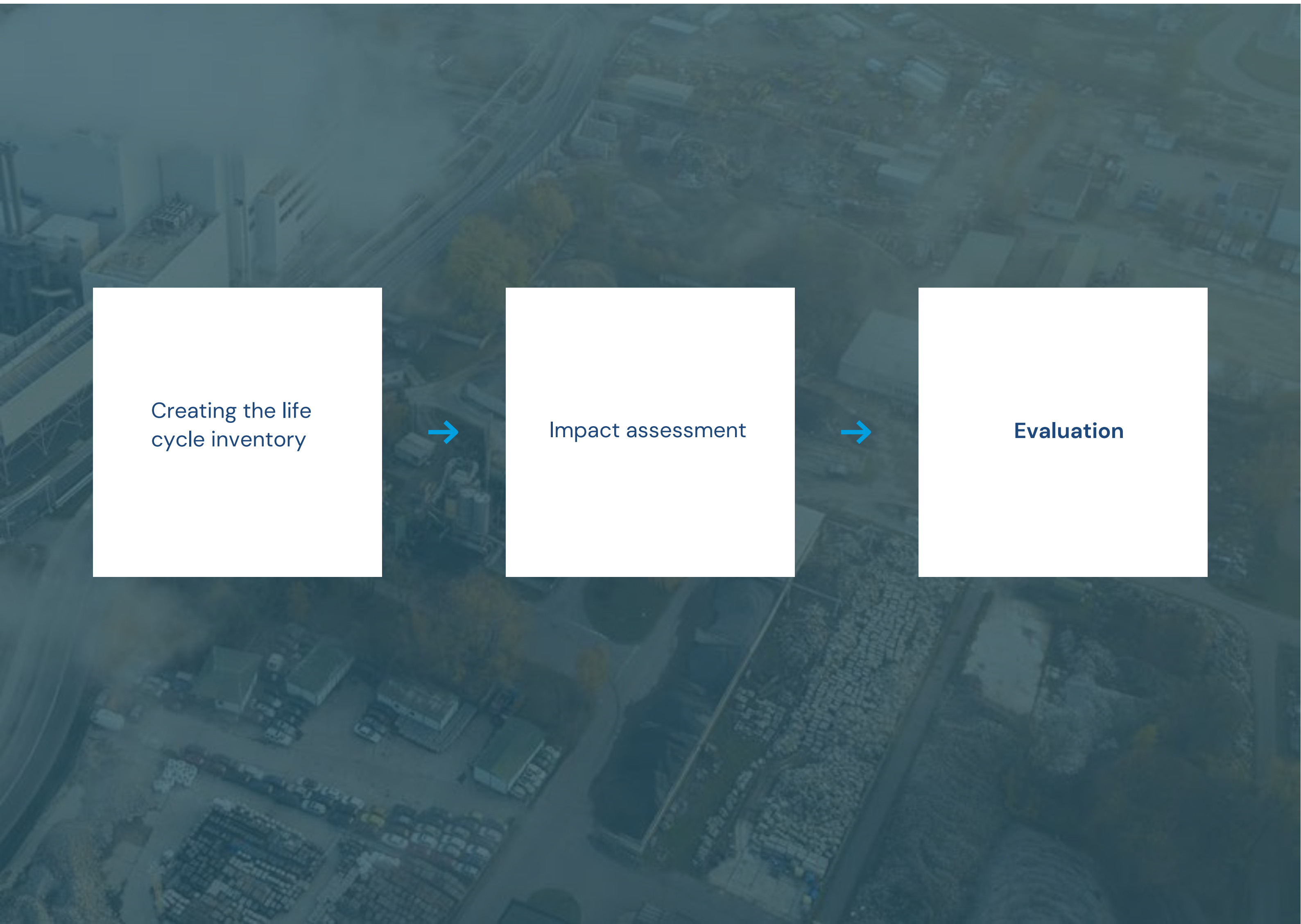
[11] *cf. Heidi Hottenrot, Bettina Joa, Prof. Dr. Mario Schmidt, Pforzheim University, Institute for Industrial Ecology – Carbon Footprints für Produkte – 2013, p. 13.*

The aim of this standard is to quantify all greenhouse gas emissions emitted across all stages of a product's life cycle.[12] As a generally applicable standard, this standard is suitable as a framework for determining the product carbon footprint for remanufactured products.

A corresponding PCF study comprises the four phases of the life cycle assessment, "i.e. the definition of the objective and the scope of the study […], the life cycle inventory […], the impact assessment […], and the evaluation […]".[13] Following this procedure, the energy and greenhouse gas balances of a remanufactured engine and a new engine are drawn up below.

[12] *cf. DIN German Institute for Standardization, Carbon Footprint von Produkten (February 2019), p. 11.*

[13] *DIN German Institute for Standardization, Carbon Footprint von Produkten (February 2019), p. 38.*



Creating the life cycle inventory → Impact assessment → **Evaluation**

3.1 Definition of the objective and the scope of the investigation

The aim of the analysis is to demonstrate and quantify the greenhouse gas and energy savings of remanufactured engines compared to newly manufactured engines. For this purpose, new engines and remanufactured engines are analyzed and the data obtained in each case is compared. A 4-cylinder passenger car engine serves as an example.

The core components of the engine (**cylinder crankcase, cylinder head, crankshaft, camshaft, connecting rod and oil pan**) account for **74% of the total weight** of the engine and can basically all be remanufactured.

The majority of the remaining components must be replaced with new parts and cannot be repaired or reused at an adequate cost. These are essentially wear parts that are also replaced at regular intervals or in the event of failure during operation. Data from the aforementioned core components is evaluated, both for new production and remanufacturing. This data serves as the basis for calculating the energy and carbon footprint. The evaluation is limited to the first part of the product life cycle (**raw material extraction, manufacturing processes in the supply chain and production at the OEM**), as there is no difference between the use and disposal phases for remanufactured and new engine components (see *Fig. 7*).

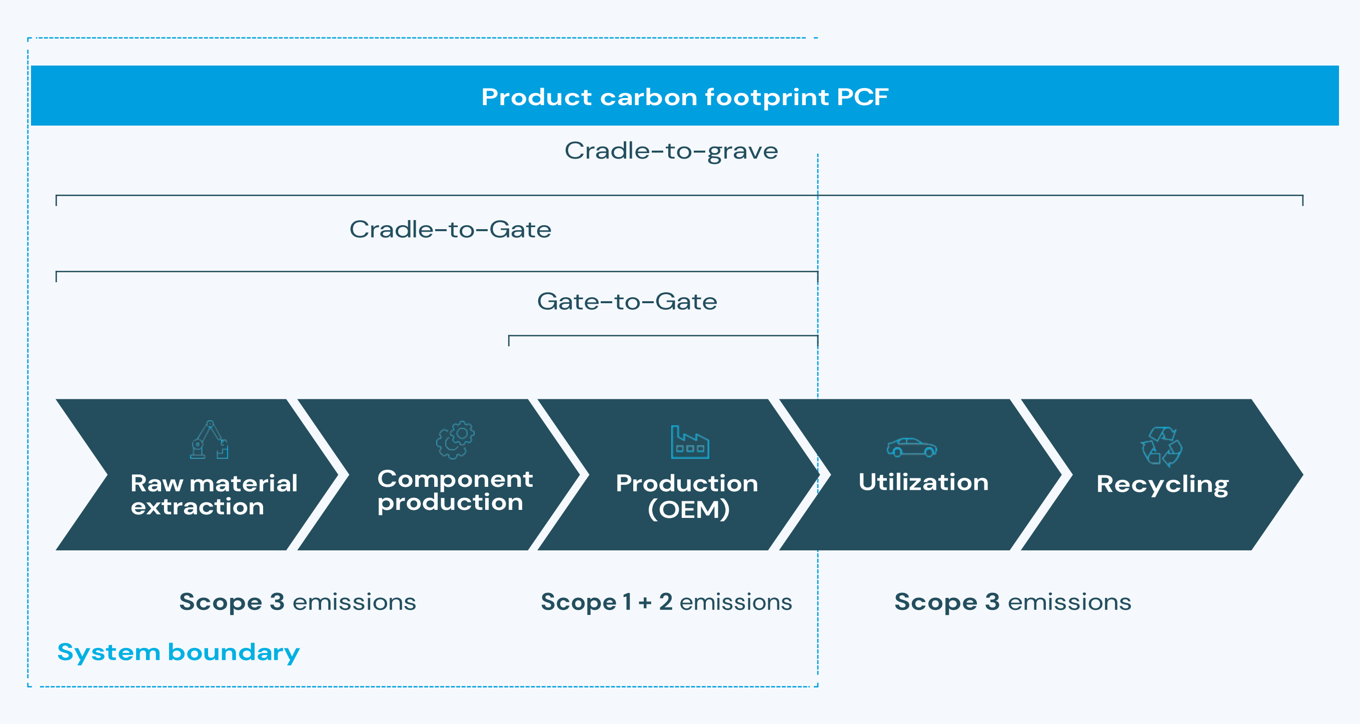


Figure 7: System boundaries for calculating the PCF of remanufactured or new components (own illustration)

The analysis is therefore referred to as a **"partial PCF" or "cradle-to-gate"** assessment. The emissions can be divided into three categories according to the GHG product standard:[14] **Scope 1** describes all direct emissions caused by the combustion of fossil fuels or biomass in the company's own plants and vehicles, i.e. in the OEM's production.

Scope 2 are all indirect emissions caused by activities within the company itself, for example emissions caused by the provision of electricity or heat. **Scope 3** includes all emissions that arise outside the company's own boundaries, i.e. emissions that occur in upstream processes (e.g. raw material extraction, transportation) and downstream activities (e.g. distribution, use, recycling).[15]

Each remanufactured or newly manufactured engine (core) component is based on the process sequence shown in *Fig. 8*. The representation of this sequence as a so-called value stream serves as a starting point and basis for the localization of the emissions generated and the total energy consumption at process level.

The "Assembly and EOL test" steps relate to the entire engine and do not differ with regard to the new part and reconditioning variant. - For this reason, these processes are not analyzed separately for the two engine variants. The first part of the value stream is decisive for the balancing of the core components.

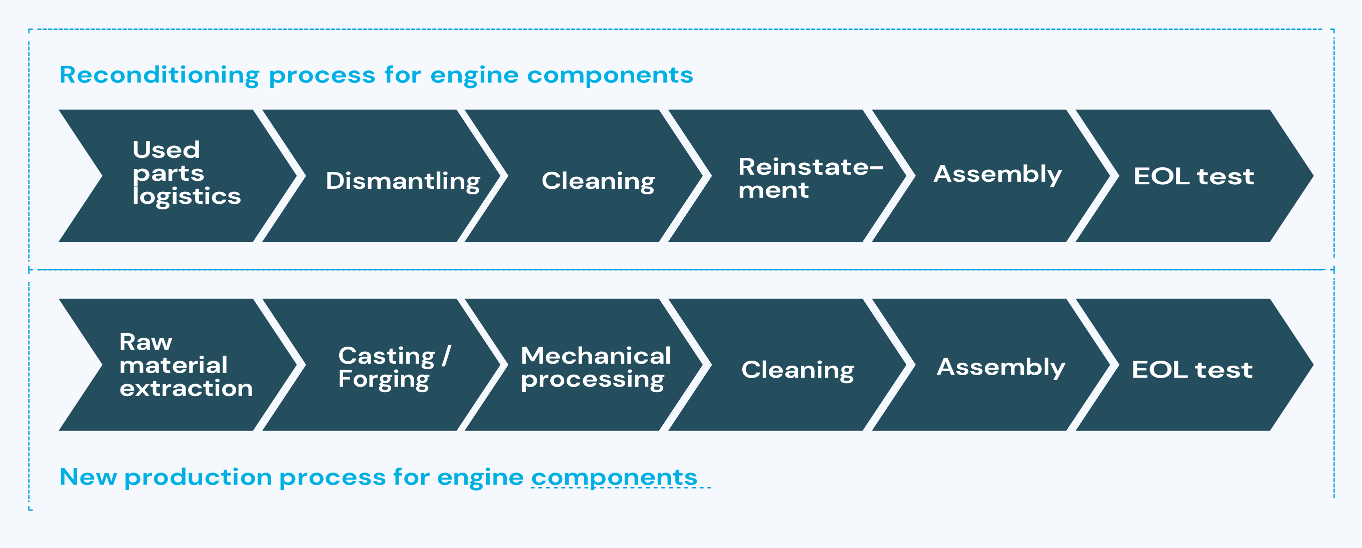


Figure 8: Comparison of the value streams for newly manufactured and remanufactured engine components (own illustration)

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[14] *cf. Greenhouse gas protocol, Product Life Cycle Accounting and Reporting Standard, p. 5-6.*

[15] *cf. Eva Maria Streppel, Prof. Dr.-Ing. Henning Hinderer - CO_2 als Wettbewerbsfaktor in der automobilen Wertschöpfungskette - 2016, p. 17.*

3.2 Preparation of the life cycle inventory

The data required for the emissions and energy balance must be collected for all of the process steps listed in *Figure 8*. This data collection is referred to as life cycle inventory.

The following data must be obtained for each of the six components mentioned:

- Type of raw material (aluminum / steel / etc.)
- Manufacturing processes (casting / forging / etc.)
- Weight of the unmachined part (for cast components) or weight of the shell (for forged components)
- Net processing times for mechanical processing, cleaning and other processing steps
- Machine performance mechanical processing / cleaning / other processing

The first three pieces of information mentioned above can only be determined for newly manufactured components, while the machine performances and processing times are important for remanufactured and new components. Furthermore, the data relevant for core logistics must be collected. The **balances for logistics are** drawn up in accordance with **DIN EN 16258** (method for calculating and declaring energy consumption and greenhouse gas emissions for transportation services).

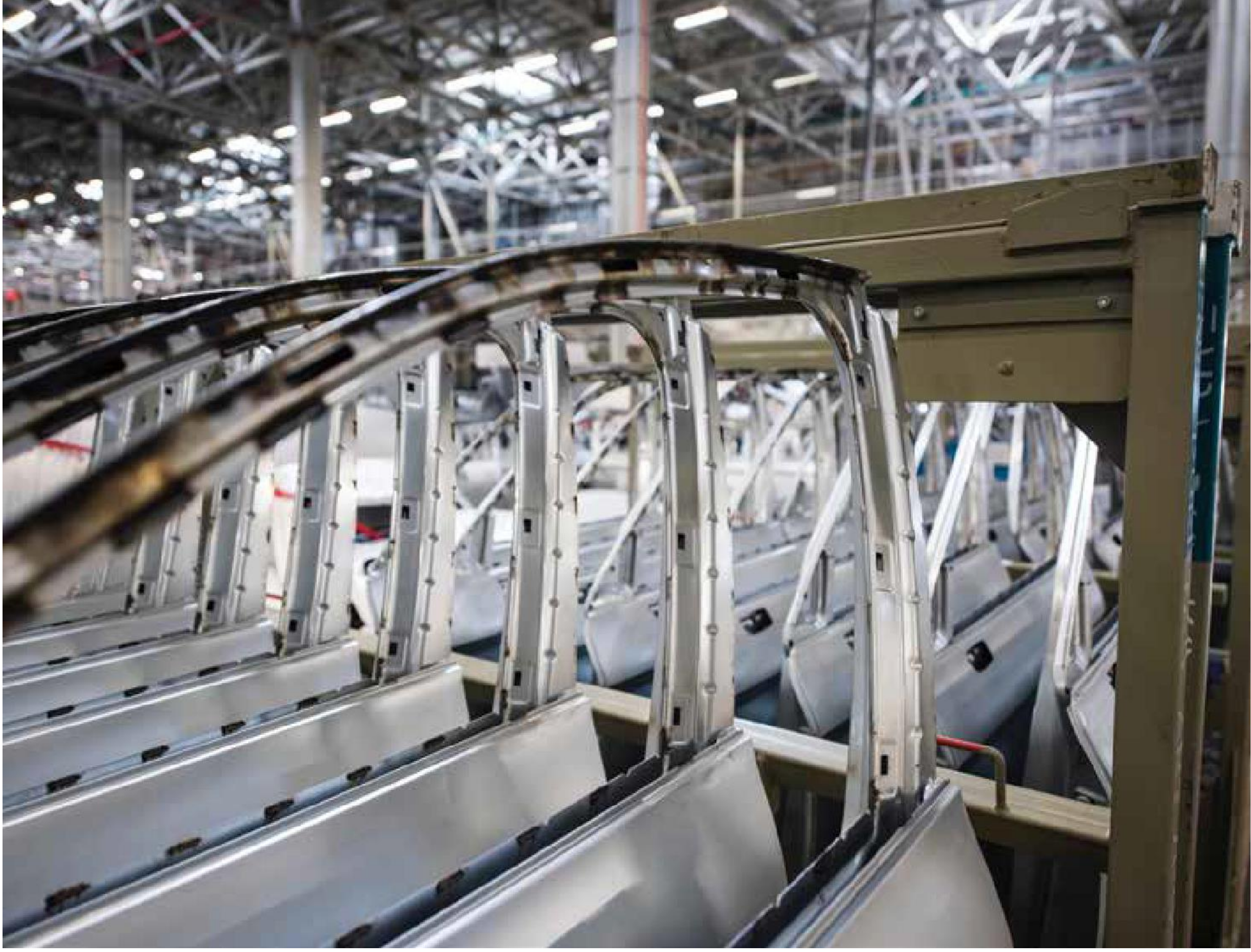
The following data is required:

- Number of used parts returned within a certain period, broken down by country of origin
- Means of transport used, their fuel type and average consumption and how many used parts the means of transport can load

The transport emissions can be derived from this data. The disassembly time is required to be able to draw conclusions about the energy consumption during the disassembly of an used part. For this purpose, it is assumed that a pneumatic screwdriver is used for approximately 50% of the disassembly.

In order to be able to create the balance sheets from this information, further generally valid input is required:

- Energy and emission factors for raw materials
- Energy and emission factors for the individual energy sources (electricity, fossil fuels, etc.)
- Energy consumption for the forging process, broken down by energy source
- Energy consumption for the casting process, broken down by energy source
- Compressed air consumption of the disassembly tools used and electricity consumption per m^3 of compressed air
- Used core quota, i.e. how many used engines are needed to produce a remanufactured engine



Energy and emission factors can be taken from various environmental databases (e.g. the ProBas of the Federal Environment Agency[16]) or, for fossil fuels, from the regulations according to DIN EN 16258. The energy consumption during casting or forging can be used to determine an energy and emission factor for these processes per kilogram of material processed using the emission factors of the energy sources.

To determine the energy consumption and greenhouse gas emissions for assembly and the EOL test (in this example by cold test, i.e. the motor is driven by an electric motor, not by fuel), information is also required on the electricity and compressed air consumption in the assembly plant in a reference period and how many motors were assembled within this period.

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[16] *ProBAS - " Prozessorientierte Basisdaten für Umweltmanagementsysteme".*

3.3 Impact assessment

In the next step, the total energy consumption and greenhouse gas emissions can be calculated from the life cycle inventory.

Adding up all core components (cylinder crankcase, cylinder head, crankshaft, 4x connecting rods, 2x camshaft and oil pan), the remanufactured components produce greenhouse gas emissions of 101 kg (see Table 2), whereas new production produces 508 kg (see Table 3).

	Used parts logistics	Dismantling	Cleaning	Reinstatement	Total
Total energy consumption [in MJ]	894	63	325	136	1.418
Total GHG emissions [in kg CO_2 e]	69	4	20	8	101

Table 2: Energy and greenhouse gas balance for remanufacturing, totaled across all core components

	Raw material extraction	Casting/ Forging	Mechanical processing	Cleaning	Total
Total energy consumption [in MJ]	5.692	1.088	971	126	7.877
Total GHG emissions [in kg CO_2 e]	378	66	56	7	508

Table 3: Energy and greenhouse gas balance for new production, totaled across all core components

In order to obtain the balances for the entire engine, the process steps of assembly and EOL testing, which result from the energy and compressed air consumption of the assembly plant, must also be taken into account.

Furthermore, the balances of the exchange components must be estimated. Due to their weight share (in this example, around a quarter of the total engine), 26% of GHGs are emitted for the overall balance. Table 4 shows a comparison of the overall result for the two engine variants.

	Reman motor		New engine	
	Energy [in MJ]	**GHG** [in kg CO_2 e]	**Energy** [in MJ]	**GHG** [in kg CO_2 e]
Total production of core components	1.418	101	7.877	508
Exchange components	2.048	132	2.048	132
Assembly and EOL testing	277	16	277	16
Total	3.743	250	10.202	656

Table 4: Sum of the energy and greenhouse gas balances over the entire engine

3.4 Evaluation

The main advantage of remanufacturing is obviously that resources are saved, especially in the form of raw materials, as the used parts are used as the starting point for a new product.

Table 3 shows that the **extraction of raw materials in particular** has a significant influence on greenhouse gas balances. Energy-intensive **primary and forming processes can** also be **saved through remanufacturing**, and the processing times for mechanical processing are significantly reduced. However, this is offset by a large proportion of emissions caused by the **collection of used materials from all over the world.**

Nevertheless, there is a positive balance to be drawn for remanufacturing. For a 4-cylinder engine of a passenger car, around **400 kg of emissions** can be **saved**, i.e. over 60% less greenhouse gases are produced compared to new production, see *Figure 9*.

In their sustainability reports, they state that in the near future or already today, they will work exclusively with electricity from renewable energy sources in their in-house **production**, which means that no CO_2 emissions are generated.

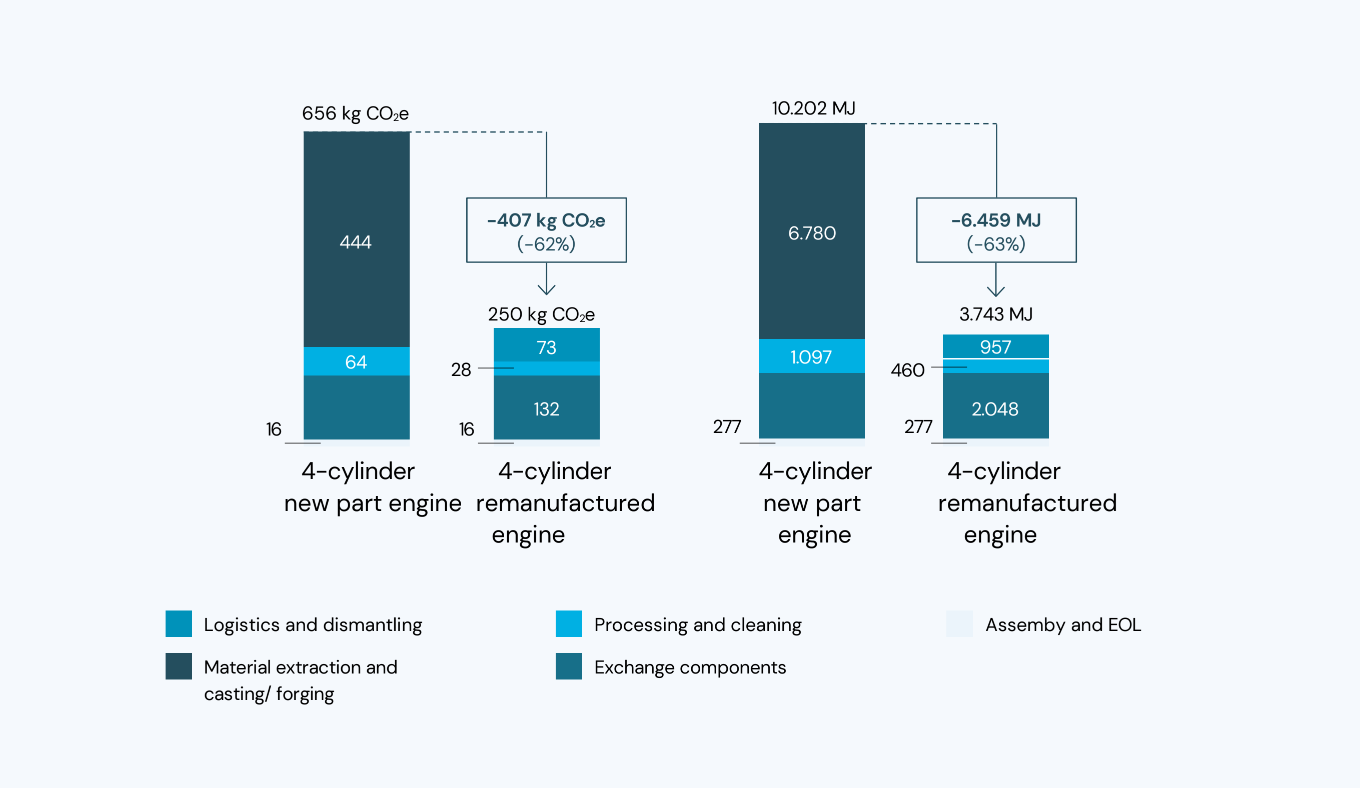

Figure 9: Comparison of greenhouse gas and energy balances for new engines and reman engines (own illustration)

Furthermore, the aim is to oblige the **supply chain** to produce a large proportion of its electricity **using green electricity, i.e. electricity based exclusively on renewable energy.** This would mean that the actual emissions would be significantly lower than those shown in the example based on currently available data. Against the background of these assumptions, the results for the example of the 4-cylinder engine was recalculated. For all remanufacturing processes as well as for new production for component manufacture (excluding raw material extraction), it was assumed that the **emission factor for electricity from renewable energy sources is to be set to zero, as currently communicated as an objective by many OEMs.**

The result is as shown in *Figure 10*. This means that despite the use of green electricity, there is still a significant reduction in emissions and energy consumption due to the energy-intensive extraction of raw materials and heat consumption during casting and forging.

However, remanufacturing also continues to generate emissions due to the complex logistics processes caused by fuel combustion.

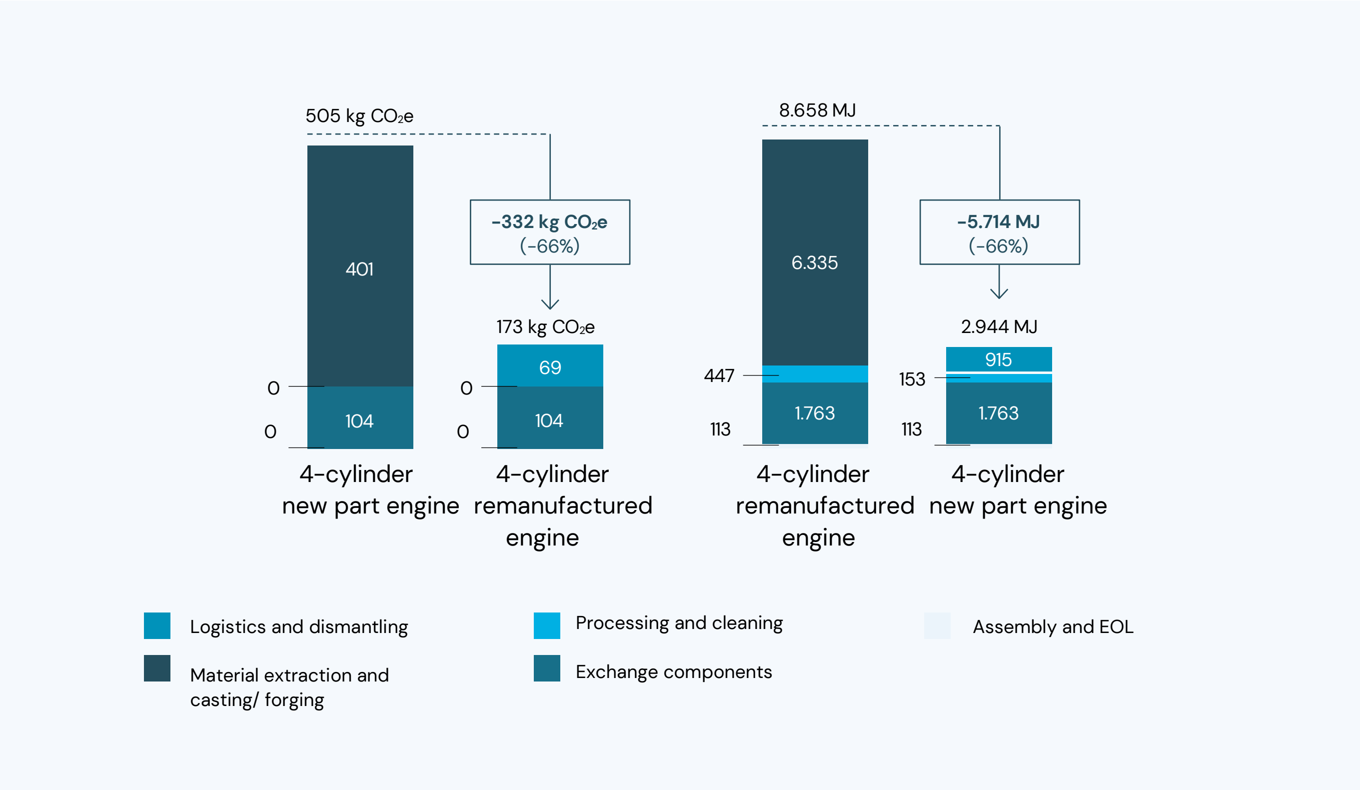

Figure 10: Comparison of greenhouse gas and energy balances for new engines and reman engines using green electricity in production and in the supply chain (own illustration)

To make the result more tangible, the energy saved (6,459 MJ) and the emissions saved (407 kg CO_2e) can be compared with equivalent examples. For example, it is interesting to see how long the same amount of CO_2 can be utilized by natural resources. On average, a tree converts around ten kilograms of CO_2 per year.[17]

In other words, **a remanufactured engine saves as much CO_2 as 41 trees** convert through photosynthesis **within a year.** If the energy saved is converted into kWh, it can be compared, for example, with the **number of kilometers saved by an electric vehicle powered by electricity**.

If we consider a vehicle with an electricity consumption of 15 kW per 100 km (comparable to a VW e-Golf), the energy saved could be used to drive around **4,900 km.**

The assumption is that the current German electricity mix is used, which requires around 2.46 MJ of energy to provide 1 MJ.[18] If only **renewable electricity is** used, almost **12,000 km** could be covered, as no energy has to be used for renewable energies in the upstream chain (for example in the form of coal).

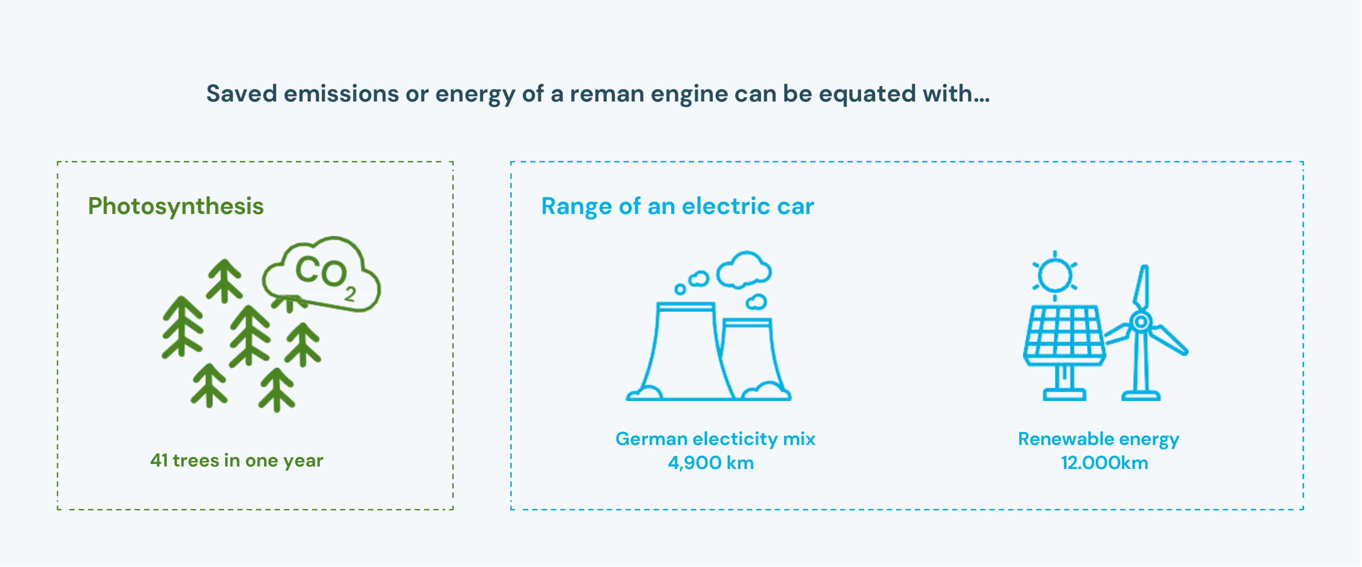

Figure 11: Comparison of savings when remanufacturing an engine with examples

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[17] *Plant for the Planet - "Bäume sind genial".*

[18] *ProBas - "Prozessdetails El-KW-Park-DE-2015 (German electricity mix)".*

3.5 Accounting for the resource savings

In the following, we will shed light on the actual amount of resources saved in the form of metal raw materials in a remanufactured engine.

If only the engine core components (cylinder crankcase, cylinder head, crankshaft, camshafts, oil pan and connecting rods) are considered, the raw parts consist of approximately 42 kg of cast aluminum alloy and 21.6 kg of steel. If, in addition, material losses in the industry are taken into account (approx. 10% due to casting processes, shell weight for forged components), 46.6 kg of aluminum alloy and just over 72 kg of steel are required to manufacture the parts.

It can – rightly – be argued that even in a new engine, not only primary materials are used in production, but that the raw materials also **consist** to a certain extent of **recycled secondary material** (this fact was also taken into account when calculating the emission and energy balances for raw material production). Secondary material imply that various parts of the raw materials are produced through recycling processes from scrap.

According to OEMs, around **50% secondary aluminum** and **25% secondary steel** are already used in vehicle production today.[19] In terms of on the raw part weight of the engine core components, remanufacturing can therefore save 21 kg of primary aluminum and 5.4 kg of primary steel per engine. Taking into account the material losses in the primary forming processes, this results in savings of 23.3 kg of primary aluminum and 18 kg of primary steel.

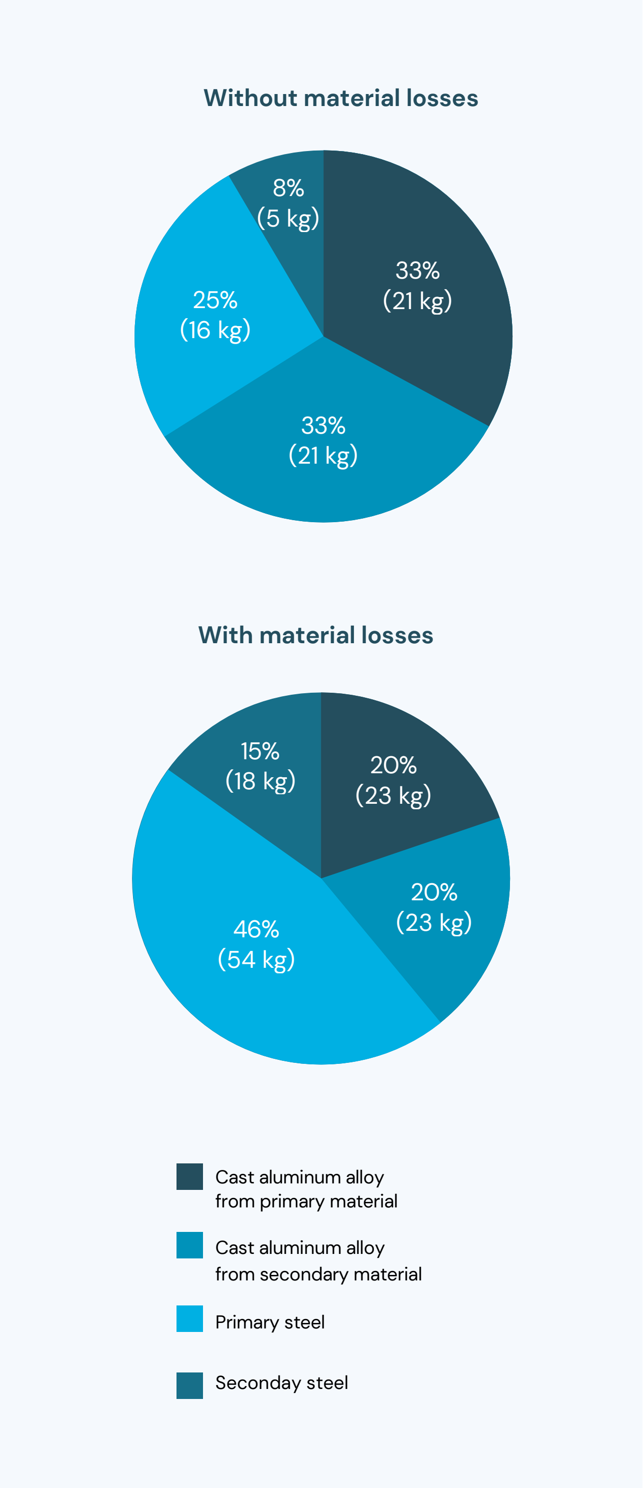

Figure 12: Material composition of the core components of a 4-cylinder engine (right: without material losses, left: with material losses)

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[19] *BMW AG - "Nachhaltigkeit bei BMW: Mit einer konsequenten Nachhaltigkeitsstrategie setzt die BMW Group neue Maßstäbe in der Automobilbranche.".*

4 Summary and Outlook

As systematically derived in this article, there is considerable potential for saving resources, energy and emissions through the remanufacturing of spare parts. Even with a possible increase in the use of green electricity (from CO_2 neutral electricity generation) for production, significant savings can still be expected, especially in the area of resources.

In addition to the **environmental benefits** of remanufacturing, there are generally additional **economic potentials**, such as reductions in manufacturing costs and winning back customers with older vehicles, which lead to positive contribution margin effects for OEMs.

In addition to internal combustion engines, there are other mechanical components in the automotive industry that have a high potential for remanufacturing and are already partially remanufactured by OEMs or OES, such as gearboxes, generators, and steering systems. In addition to mechanical components, electrical components can also be remanufactured. The current shortage of raw materials (e.g. chips) and increased prices may prove to be an additional catalyst for remanufacturing in the future.

In the long term, there is also great potential in the area of **e-mobility**. More and more registrations in this segment (estimated at 4.5% purely electric vehicles and 15.8% hybrid vehicles in relation to the total number of cars in Germany in 2025[20]) also mean a steadily increasing demand for spare parts. These volumes will inevitably be part of the respective sustainable spare parts strategies to be developed. The extraction of lithium alone, the essential raw material for the battery cells of an electric vehicle, produces around 18 kg of CO_2e per kilogram of raw material.[21] In order to make e-mobility sustainable in the long term, the spare parts business and the reuse of components are also of enormous importance in order to mitigate the negative effects of such energy- and emission-intensive manufacturing processes. The remanufacturing of spare parts, as is already the case with combustion engines, is currently the subject of various studies. It will be crucial to transfer existing remanufacturing concepts to components such as the electric motor and to develop innovative and creative solutions for components not previously used in the automotive industry, such as the high-voltage battery.

The authors of this article are convinced that creative solutions based on technical expertise and the strategic objectives of the companies implementing them will be the driving force behind many innovations in the field of parts processing in the future. This will make a valuable contribution to reducing the emission of climate-damaging substances, despite future high demands for individual mobility solutions.

It is particularly important not to follow short-term trends or emotional currents in this area, but to take a long-term and holistic approach. There are sufficient fact-based arguments for using remanufacturing for significantly more volumes than are currently implemented.

[20] *cf. Niklas Hostnik - ZDK-Studie Elektromobilität 2025 - 2018, p. 36.*

[21] *ProBas - "Prozessdetails: Lithium".*

5 About roeren GmbH

roeren GmbH is an internationally active management consultancy with focus on production solutions from Landshut. It was founded in 2011 by Sven Roeren, Professor of Production Management at Landshut University of Applied Sciences and is currently an established partner for manufacturing companies with 85 employees.

In addition to strategy consulting and solving acute production problems, the company's business activities focus on thematic focus areas such as the circular economy, foundry management and interface management in supply chains.

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As a member of the management team, he is responsible for customer projects in the field of remanufacturing, among other things. In addition to supporting industrialization topics, he is also involved in the development of new business models.

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BSI	British Standards Institution
CCF	Corporate Carbon Footprint
CO_2	Carbon dioxide
CO_2 -e	Carbon dioxide equivalent
DIN EN ISO	German Institute for Standardization; European Standard International Organization for Standardization
e.g.	for example
EOL	End- of- Line
etc.	et cetera
e.V.	Registered association
GHG	Greenhouse Gas
i.e.	that is
IPCC	Intergovernmental Panel on Climate Change (IPCC)
KBA	Federal Motor Transport Authority
KFZ	Motor vehicle
kg	kilogram
km	kilometers
kW	kilowatt
kWh	kilowatt hour
MJ	megajoule
OEM	Original Equipment Manufacturer
PAS 2050	Public Available Specification 2050
PCF	Product Carbon Footprint
PKW	Passenger car
ProBas	Process-oriented basic data for environmental management instruments

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