




# Electrification in the automotive industry: effects in remanufacturing

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## Abstract

The automotive market is changing. For many years, cars with internal-combustion engines were dominant. Recently, more cars with alternative drive trains have become available, and their market share has increased, a trend that has had an effect on the remanufacturing industry for automotive parts. This paper aims to describe and evaluate the challenges and opportunities in the coming years for the remanufacturing industry as a result of the increasing number and share of electric vehicles. Both theory and empirical data have been used to meet this aim. From theory, the two different drive train concepts of the internal combustion engine and the battery electric vehicle are described, along with the major differences from a remanufacturing standpoint. These differences and effects are described, evaluated, and fully or partly confirmed by industry experts. The results show that future market actors are unset today, less space-consuming machinery parks will be needed, major investments into knowledge and equipment (especially for testing) will be required, and the necessity to handle different kinds of end-of-use/life solutions, especially the recovery for the electric vehicle battery packs, will be a challenge. As future development is still uncertain, the authors recommend that market actors investigate the challenges and opportunities highlighted in this paper and watch future developments carefully.

**Keywords** Remanufacturing · Automotive · Electric vehicles (EV) · BEV · ICE · Mechatronics · Design for Remanufacturing

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## Introduction

The automotive industry, one of the key industries in Europe, is undergoing substantial changes in drive train technology. For decades, cars with internal combustion engines (ICE) were the technical “state of the art.” However, in 2017, for the first time, more than 1000,000 new electric vehicles (EVs) were registered. More than 60% of these EVs were registered in China [3]. Different studies forecast that in ten years, 20% of all newly sold cars will be EVs and in twenty years, around 25% [6, 27].

Political leaders, as well as those in industry, see the future in this technology. The German Chancellor, Angela Merkel, sees EVs as an appropriate solution to reach emission targets [30]. The targets defined by the European Union (EU) for 2015 and 2021 represent reductions of air pollution emissions of 18% and 40%, respectively, compared with those of 2007 [12]. Given these trends, already in June 2017, the automotive specialist, Professor Ferdinand Dudenhöfer, announced in a radio interview: “The combustion engine is dead!”

This transformation process has direct influences in today’s supply chains for automotive parts and their design and production processes. Car manufacturers are investing large sums of money into research and development (R&D) as well as into new production facilities to be prepared for these future trends, and many of these efforts are financed by large national development support programs [17]. Besides changes in the tasks, there will be changes in the market actors. The drive train of an electrical vehicle (EV) consists of different parts compared to an internal combustion engine (ICE) vehicle (see Fig. 3 and [38]). Often, these different parts are or will be sourced from different types of car part suppliers [2, 6]. These organizational changes have to be planned, implemented, and thoroughly proven/tested for quality assurance of the new types of car parts for EVs. Besides these direct effects, there will be a transformation with an inevitable delay: a need for spare parts for these new products from the first day they appear on the road. This need will increase rapidly due to the rising quantity and age of the EVs on the road.

## Aim

The aim of this paper is to describe and evaluate the challenges and opportunities in the coming years for the remanufacturing industry as a result of the increased number and share of electric vehicles on the market.

## Research methodology

Both theory and new empirical data have been collected and analysed to meet the aim of this paper. The overall research method consisted of five steps (as illustrated in Fig. 1), which has included several data collection methods.

**First**, knowledge from theory was gathered. Here, relevant literature in connection with remanufacturing and EVs was reviewed. The literature was found by searching the databases of *Emerald*, the *Journal of Remanufacturing*, the *electronic database of Linköping University*, and *accessible sources on the web*. The main search words for the literature search were *remanufacturing*, *remanufacturing challenges*, *closed-loop-supply chain*, *electric vehicles*, *battery electric vehicles*, and *hybrid vehicles*. Both combined search words and single search words have been used.

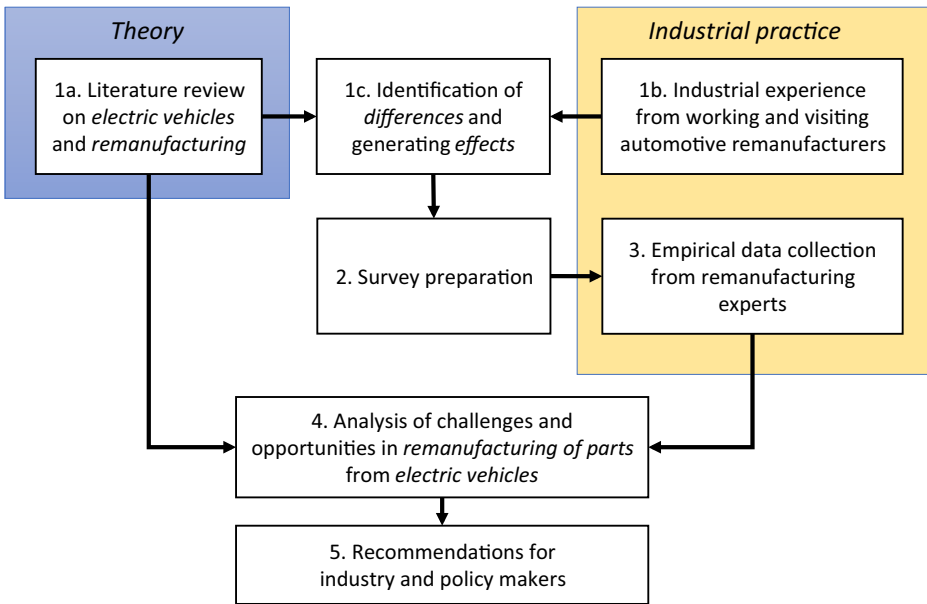


Fig. 1 Research method of this paper

The main types of today’s electric vehicles (Table 2) were investigated, along with their technical design differences. The main drive train components of EVs and ICEs were highlighted, and potential parts for remanufacturing were described (Fig. 2). From theory, the remanufacturing processes of these parts were also described and compared (Table 3). Based on the seven differences identified from theory, eleven effects on the remanufacturing industry were generated (Table 4).

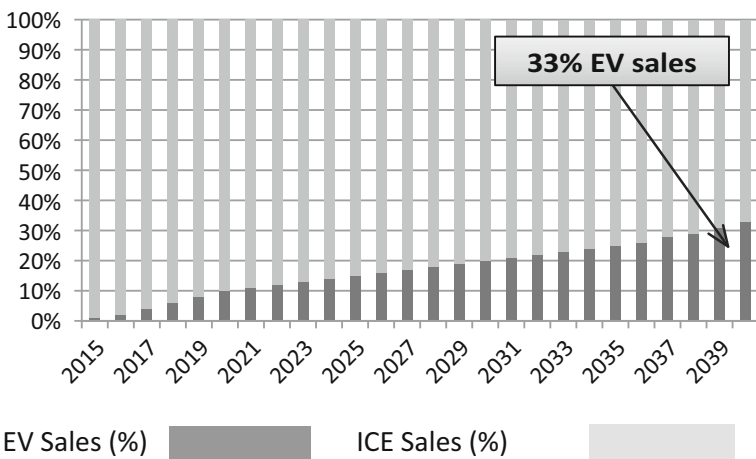


Fig. 2 Forecast of annual sales of electric vehicles (based on Bloomberg [3])





**Table 1** Information about the remanufacturing industry experts who answered the questionnaire (see [Appendix](#)) for this paper's research

Function	Company type
Director	Consultancy in Remanufacturing
Project Manager Core-Management	Consultancy in Remanufacturing
Engineering	Consultancy in Remanufacturing
Consultant	Consultancy in Remanufacturing
Consultant	Consultancy in Remanufacturing
Co-Owner and Commercial Director	Independent Remanufacturer
Managing Director	Independent Remanufacturer
CEO	Independent Remanufacturer
CEO	Independent Remanufacturer
Project leader – Electronics	Independent Remanufacturer
CEO	Independent Remanufacturer
CEO	Independent Remanufacturer
Production Manager	Independent Remanufacturer
Head of Business Development	OE Tier-1
Technical Business Specialist	OE Tier-1
Aftersales Buyer	OEM / Vehicle Manufacturer
Technical Manager	OEM / Vehicle Manufacturer
Product Supervisor	OEM / Vehicle Manufacturer
Researcher & Senior Project Manager	Research / State-Owned Research Institute
Researcher	Research / University

As a **second** step, a standardized questionnaire (see [Appendix](#)) was prepared based on the eleven effects described in Table 4. This questionnaire was sent out to industry experts to verify seven statements based on the eleven effects and gain additional data about how the automotive remanufacturing business is changing with the trend of electrification of cars. The industry experts were sourced from the authors' industrial and academic network of automotive remanufacturing companies. Table 1 shows what kind of function the experts have and in what kind of company they work.

**Third**, the empirical data and findings were gathered (Table 5) and analysed. The analysis was made according to the outcome of confirmation of the initial statement, an adaption of the

**Table 2** Main types of today's electric vehicles (based on Mahmoudi et al. [20])

Type	Description of technical concept	
Battery electric vehicle (BEV) (All-electric vehicle (AEV))	BEVs take all needed power for propulsion from the battery pack. This battery pack is recharged by plugging it into an electric power source.	
Hybrid electric vehicle (HEV)	HEVs are powered from an electrical motor (mostly used for low-speed driving, e.g., in urban areas) and a combustion engine (for high-speed driving, e.g., on the motorway). The battery pack is charged by the combustion engine.	
Plug-in hybrid electric vehicle (PHEV)	PHEVs are based on the HEV concept, but can also be plugged into an electric power source to recharge the battery pack.	 

initial statement, or the need for additional research. The individual actions are described in Table 4 below.

**Fourth**, the findings from theory and industrial practice were aggregated and clustered into challenges (threats) and opportunities (possibilities) for the automotive remanufacturing industry when following the trends of electrification of cars.

As a **fifth** and final step, recommendations for actions for the industry and for its policy makers were made.

## Literature review

For economic and ecological reasons, the need for automotive spare parts will be partly covered by remanufactured parts. The market conditions for EV new part production are changing as a result of the above-mentioned reasons. Therefore, the market conditions for EV remanufacturing parts are also changing.

The remanufacturing of drive train components for ICEs has already been analysed in several academic publications, for example, by Steinhilper [32], Subramonium et al. [34], and Sundin and Dunbäck [35]. In particular, the remanufacturing of combustion engines and transmissions was already the focus of multiple research studies. In addition to their electrical components, hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) consist of combustion engines and transmissions. This paper, to focus on the new research area, looks exclusively at battery electric vehicles (BEVs) to sharpen the results linked to this new technology and the challenges and opportunities which it offers.

In other research, Schneider et al. [28] described the remanufacturing of battery packs, while Groenewald and Barai [16] described the most relevant process steps of EV part remanufacturing, and Erich and Witteveen [19] compared the quantity of moving parts in BEVs in comparison to ICEs.

## History of electric vehicles

EVs have existed since the beginning of the invention of car production in the very early twentieth century [18]. Nevertheless, cars with ICEs have always been the standard, and EVs the exotic exceptions. The reasons for the lack of interest in early EVs were [37]:

- the decreasing price of ICEs through the implementation of mass production by Ford;
- better roads extending the potential radius of usage, which was still very limited for EVs at that time; and
- technical improvements of ICEs, such as electric starters.

However, the advance of new technologies has significantly changed the future prospects for EVs for several reasons, including the environmental impacts of ICEs and the fear of peak oil [8]. Several car manufacturers are putting much effort into making new EVs:

- **General Motors** plans to go for an all-electric vehicle by 2023 [15]
- **Ford** will have seven electrified and custom plug-in hybrids in the future [14]
- **Mazda, Denso, and Toyota** are jointly developing technologies for electric vehicles [24]

- **Daimler** plans to electrify its entire portfolio by 2022 [5]
- **Renault, Nissan, and Mitsubishi** are developing pure electric cars and plan to release 12 EVs by 2022 [9]
- **Jaguar Land Rover** plans to electrify its entire line-up by 2020 [25]
- **Volvo Cars** plans to electrify its entire vehicle line-up by 2019 and have five EVs by 2020 [39] and plans to develop its own electric motors and control systems for its future EVs [23]
- The **Volkswagen group** (including brands like Audi and Porsche) plans to offer an electric and hybrid version of 300 vehicles by 2030 [10]

In addition, Bloomberg [3] has also looked into the increasing trends of electric vehicles, as illustrated in Fig. 2.

## Main types of electric vehicles

An EV consists of one or multiple electric motors for propulsion. In recent years, many car manufacturers invested significant research and development efforts to transform traditional vehicle concepts with ICEs into concepts with alternative drive train systems.

In this evolving transformational process, car manufacturers are exploring several different technical approaches. The three main approaches are the BEV, HEV, and PHEV, as further described in Table 2 [7, 20, 22, 36].

Other available types, for example, the extended-range electric vehicle (EREV or REEV), fuel cell electric vehicle (FCEV), and solar electric vehicle (SEV), currently have a small market portion and are not expected to grow rapidly.

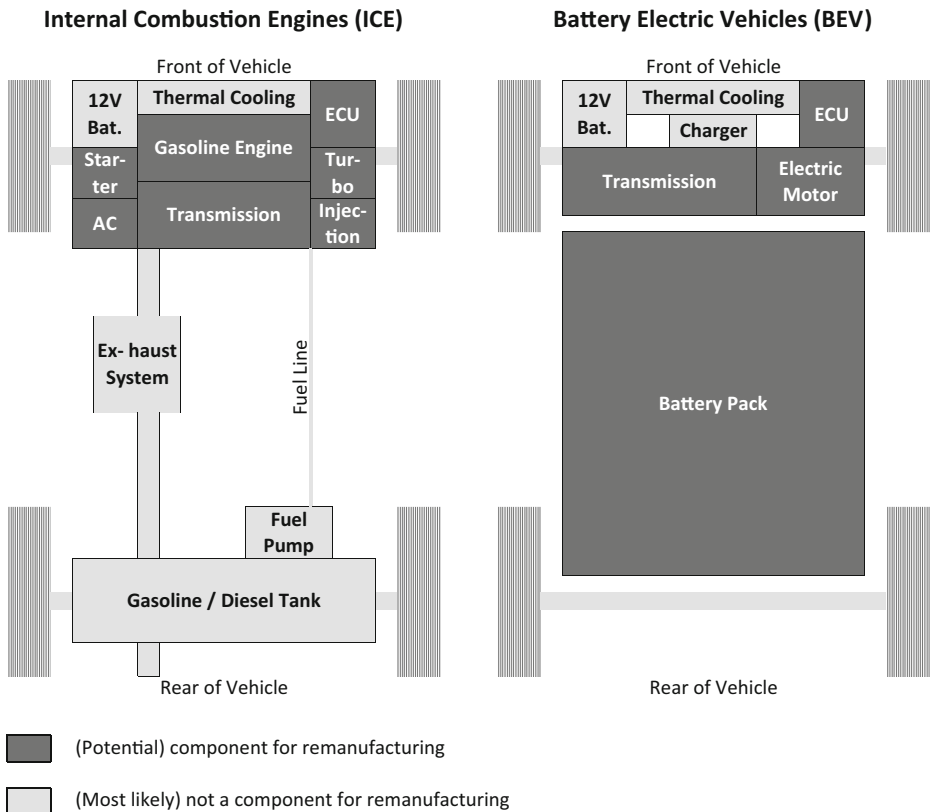
## Drive train differences of ICEs and BEVs

The drive train concepts and components of BEVs are significantly different from those cars having ICEs (see Fig. 3). The cars with ICEs generate force with a central engine, most often in the engine compartment in the front of the car and direct this force via the transmission and a clutch to two or all four wheels of the vehicle. Complex peripheral components are responsible for engine control, the starting process, energy management, heating and cooling, fuel storage and supply, and exhaust management. The BEVs have one central motor or separate motor per wheel and a battery pack. The periphery is less complex.

As demonstrated in the figure above, BEVs and ICEs consist of common or similar components, for example, transmissions, electronic control units (ECUs), air conditioning (AC) units, and thermal cooling systems. The remanufacturing of these common parts has already been researched and analysed by, for example, Steinhilper et al. [33]. This paper, therefore, focuses on the main, differing components: the electric motor and the battery pack.

In addition, Erich and Witteveen [19], has highlighted the significantly lower quantity of moving parts in BEVs in comparison to ICEs. It is estimated that a car with an ICE consists of about 1400 parts. A third of the total value of the automotive supply chain is generated in industries related to the drive train. In comparison, a BEV consists of 200 parts (i.e., 86% reduction) [19].

## Drive train components



**Fig. 3** Simplified illustration of the main drive train components of cars with internal combustion engines (ICE) (left) and battery electric vehicles (BEV) (right). Parts that have the potential for remanufacturing are highlighted (based on the U.S. Department of Energy [38])

### Recovery alternatives to BEV components

Automotive remanufacturing is of growing importance within the automobile industry. Currently, every car manufacturer has programs with remanufactured components, and the market volume of these components is growing. Popular motives for this trend are economic, legislative, and environmental issues, as highlighted by, for example, Seitz [29] and Wei et al. [40]. In the following sections, the recovery alternatives for the main components of a BEV (battery pack and electric motor) are described.

#### Battery packs

Battery packs are designed for an average lifetime of about 150,000 km [11]. Today, 90% of all lithium-ion batteries are installed in BEVs. The increasing demand for the needed raw materials (e.g., Cobalt) is leading to an increasing price for raw materials [27]. Even though the above-mentioned price increase for raw materials had a negative effect on the production costs,

the costs per kWh have decreased significantly. From 1000 \$/kWh in 2010, the price went down to about 200 \$/kWh in 2017 thanks to improved production technologies and enlarged production capacities [1].

The recovery of battery packs from BEVs can be divided into three alternatives [31]:

#### a) **Remanufacturing of Battery packs**

The battery pack is collected, transported to a specialised company, and remanufactured in a standardized process. A battery pack is most often organized in battery modules; for example, 12 battery modules with 8 battery cells would make a battery pack of 96 battery cells in total. Every cell is checked in a defined inspection process, and damaged cells are replaced. All process steps, especially the phases of the assessment process for cells, are described in detail by Schneider et al. [28]:

- Step 1: Battery disassembly; sorting into PCB, housing, and cells.
- Step 2: Visual inspection of cells: OK/NOK parts.
- Step 3: Voltage verification of approved cells.
- Step 4: Grouping/configuration to new battery modules.
- Step 5: Re-assembly.
- Step 6: Charge retention test.

In studies of the costs and benefits of the remanufacturing of battery packs, after all relevant process steps (including transportation) were taken into account, the business case was found to be positive [28].

#### b) **Repurposing of Battery packs**

The battery pack is collected and then transported to a company that prepares the pack for an off-highway application, for example, for a stationary solution. The cells are inspected and renewed if they are damaged to adapt the battery pack to its new application. Afterwards, the cells are rearranged and provided with a different control system. This procedure has been described in detail by, for example, Casals et al. [4], with the following steps:

- Step 1: Dismantle the battery into modules.
- Step 2: Pack them up again in another configuration.
- Step 3: Group the modules by similar characteristics.

The profitability of this procedure is very much dependent on the former application as well as on the future purpose. Therefore, general statements are difficult, and more research is needed in this area.

#### c) **Recycling of Battery packs**

A common way to take care of batteries, in general, is to recycle them. A detailed recycling process of BEV battery packs is described by Mancha [21] and Groenewald [16], with the following steps:



- Step 1: Battery packs are collected.  
 Step 2: Battery packs are transported to a specialized recycling company.  
 Step 3: Packs are disassembled into their sub-components.  
 Step 4: Metals, chemicals, and by-products are separated.  
 Step 5: The separated materials are reused, sold, or properly disposed of separately, by following all relevant health, safety, and environmental regulations.

Even if the recycling of battery packs is very cost intensive, there are strong reasons to recycle, for example, environmental protection, resource efficiency, closed-loop supply chain policies, or legal regulations such as those found in the EU and China [2, 13, 26].

### Electric motor

Some other drive train components can be reused through a remanufacturing process. The remanufacturing process of an electrical motor differs from that of a combustion engine. Sundin and Dunbäck [35] highlighted the major process steps of ICE part remanufacturing. In contrast, Groenewald and Barai [16] described the most relevant process steps of EV part remanufacturing. These two schematic process flows are presented in Table 3, where the main differences are highlighted.

This comparative demonstration shows several **similarities**: several visual inspection steps, disassembly of the parts, cleaning the parts, replacing defect and worn-out parts, final reassembly, and testing procedure.

At the same time, there are major **differences** between the two procedures, for example, the number of functional tests and the amount of measuring and machining.

### Effects on the remanufacturing processes based on drive train differences of BEVs and ICEs

The following table summarizes the differences in the design and processes of BEVs and ICEs described previously. Moreover, it highlights the effects resulting from these described differences.

**Table 3** Simplified process flows of the remanufacturing procedure of mechanical parts from internal combustion engines (left column, based on Sundin and Dunbäck [35]) and parts from an electric motor (right column, based on Groenewald and Barai [16])

Remanufacturing process of internal combustion engines (ICE)	Remanufacturing process of electric motors from BEVs
Initial visual inspection	Initial visual inspection
Disassembly	Initial functional testing
Cleaning	Disassembly
Second visual inspection	Cleaning
Measuring	Second visual inspection
Machining	Second functional testing
Insert new (replacement parts)	Insert new (replacement parts)
Reassembly	Reassembly
Final testing	Final testing

In order to validate these effects, the authors of this paper performed a survey. A standardized questionnaire was sent out to industry experts. The effects, which were highlighted in seven statements (Table 5), were evaluated by the industry experts. In total, we received twenty validly completed questionnaires. The answers of the experts are shown in Table 5.

The feedback received from the 20 industry experts has been respected in the research of this paper as follows:

1. **Confirmation of statements:** The experts clearly confirmed S1, S2, and S6.
2. **Adaption of effects:** This concerns feedback that provided new or additional input. This feedback has been directly respected in this paper (see S3 and S5). For example, there was clear feedback on our statement that large, cost-intensive machinery parks are no longer needed for remanufactured parts for EVs. A large group of experts replied that the machinery park would be different from the park used today. Nevertheless, it would lead to major investments in this new technology.
3. **Additional research:** This concerns feedback that highlighted the need for additional research (see S4 and S7). For example, there was controversial feedback on the statement that handling hazardous waste is not so important when remanufacturing EV parts. There was agreement on the fact that there will be less hazardous waste like oil, fat, coal, and grease. On the other hand, many experts highlighted that EVs contain hazardous waste, especially due to the battery pack. For this, waste recovery concepts have to be investigated more closely, as highlighted in the subchapter “Battery packs” on Pages 7 and 8.

## Challenges and opportunities in the remanufacturing of automotive parts for electric vehicles

The emerging market of EV parts offers challenges and opportunities for companies that are already operating in the remanufacturing of mechanical parts, as well as for companies that are not yet currently operating in remanufacturing. In the group of “challenges”, issues are gathered which demand great effort from the market actors and consist of potential risks. In the group of “opportunities”, issues are gathered that are offering new possibilities, options, and chances for improvement of the market actors. These challenges and opportunities have been highlighted and summarized in the eleven effects (Table 4) and the seven statements (Table 5). Based on these sources and the experts’ feedback to the survey, the authors of this paper found the following three challenges and six opportunities for the automotive part remanufacturing industry:

### Challenges

1. Because BEV technology is young, ***remanufacturing processes for EV parts are not defined nor proven like they are for mechanical remanufacturing***. Investments in the knowledge and testing equipment are necessary (E1 and E2 in Table 4). A remanufacturing expert stated, critically, “*I consider the main parts of EVs, batteries, are not very suitable for remanufacturing. They are more suitable for material recycling or cascading usage for other purposes*”.
2. ***The chemical formulation and shape of battery packs are not standardized today***, which makes it more difficult to implement standardisation in remanufacturing processes [27].

**Table 4** Effects based on the main differences between the remanufacturing procedure of drive train parts from BEVs and ICEs

Differences (D1-D7)	Effects (E1-E11)
<p>Process-related</p> <p>D1: <b>Functional tests</b> are of great importance for electrical parts. In this process step, the decision is made if a component can be reused or has to be replaced (OK/NOK-part).</p> <p>D2: <b>Measuring procedures</b> are of integral importance in the remanufacturing of mechanical parts (e.g., diameter of cylinders, diameter of connecting rod bores, roughness of surfaces). It provides the decision of if a part is still within specification or has to be replaced.</p> <p>D3: When electrical parts are identified as defective (NOK part), they are most often replaced with new parts. In contrast, mechanical parts are often <b>machined</b> to make them usable again.</p> <p>D4: Even if both procedures consist of <b>cleaning process</b> steps, the quality is different: Mechanical components are most often contaminated with oil, grease, coal, and other operating residues.</p>	<p>E1: <b>Availability of special test equipment</b>, including the relevant software. The staff has to be trained and highly skilled.</p> <p>E2: <b>Measuring equipment / technical specification</b> has to be available, and permissible limits have to be known.</p> <p>E3: <b>Less spacious machinery parks</b>, due to the fact that parts are often not machined and NOK parts, are replaced. More compact factory layouts are possible.</p> <p>E4: <b>Recovery rate</b> of components becomes lower since fewer parts are machined.</p> <p>E5: Less demanding <b>cleaning processes</b>. Improved work environment and less use of cleaning agents.</p> <p>E6: Different <b>hazardous waste</b> is generated. For the new hazardous waste, recycling concepts have to be set up (especially for the battery pack).</p>
<p>Design-related</p> <p>D5: The big and heavy <b>battery packs</b> of BEVs contain hazardous materials.</p> <p>D6: Electrical motors are <b>smaller and less complex</b> than ICEs. Highly automated production sites for electrical motors and for battery packs are technically possible.</p> <p>D7: <b>Fewer parts</b> - the number of parts has decreased by 86%.</p>	<p>E7: <b>Work environment</b> has to be carefully designed and monitored.</p> <p>E8: <b>Additional hazardous waste</b>; not all materials can be recycled.</p> <p>E9: <b>Less staff</b> but potentially more expensive staff, as higher qualified (see also E1 above).</p> <p>E10: <b>Fewer and possibly different suppliers</b>.</p> <p>E11: <b>Decreased complexity</b> and a smaller range of potential parts for remanufacturing.</p>

**Table 5** Evaluation of statements made by industry experts ( $N = 20$ ). The entire questionnaire sheet is shown in the [Appendix](#)

Statement	strongly agree	agree	uncertain	disagree	strongly disagree
S1. The market for remanufactured parts for EV (electric vehicles) will grow fast in the next twenty years.	11	3	5	0	1
S2. Market actors for remanufactured parts for EV are not set yet.	5	9	5	1	0
S3. Large, cost-intensive machinery parks are no longer needed for remanufactured parts for EV.	2	5	7	6	0
S4. Handling hazardous waste is not so important when remanufacturing EV parts.	0	1	4	9	6
S5. Labour costs will be lower when remanufacturing EV parts.	1	4	4	9	2
S6. Knowledge and testing equipment will be a challenge for EV part remanufacturing.	11	9	0	0	0
S7. The recovery rate (= material saved due to the mechanical remanufacturing process) is lower for EV parts.	2	5	6	6	1

3. As fewer EV parts are machined in the remanufacturing process, ***the recovery rate of material will change***. With respect to the weight or quantity of recovered parts, the recovery rate of EV part remanufacturing will decrease. For this effect, there is disagreement among the experts. With respect to the value of recovered parts, the recovery rate of EV part remanufacturing will increase (due to the high value of the battery pack). These two effects will have an effect on the environmental performance (E5 in Table 4) of EV part remanufacturing. However, moving from the use of fossil fuel might overcome this negative effect on the environment.

## Opportunities

1. ***The market for EVs has had a steady growth*** [3] (S1 in Table 5), and this offers potential growing fields of business activities. Nevertheless, the growth is forecasted as being slow in the beginning. An expert in the evaluation of the remanufacturing market noted, “*Market size will, for a start, not be attractive*”.
2. ***The market actors are not yet finally set*** (S2 in Table 5), which offers the possibility for market entry to companies not operating in the remanufacturing industry today. This effect is valid for EV part remanufacturing (e.g., batteries, electric motors) but not for other remanufacturing parts (e.g., steering, braking systems), which already have an existing infrastructure for remanufacturing.
3. In major markets, ***the responsibility to recycle battery packs is already in the authority of the manufacturer***. This is the case today in the EU [16] and China [37] and will affect the increasing capacity of battery recycling and a positive effect on the availability and the price of remanufactured batteries.
4. ***The machinery for EV part remanufacturing is space-saving***. The huge machines for mechanical work are often not needed for EV part remanufacturing. This can influence decision-making for easier market entry into EV part remanufacturing and offers new layout and allocation options (E3 in Table 4). At the same time, cost-intensive investments into new machinery are needed, which is very often related to testing procedures. In that sense, a remanufacturing expert stated, “*Most likely, current tooling cannot be used; completely new tooling has to be developed and bought*”.
5. ***The handling of hazardous waste is changing***. In the ICE part remanufacturing process, mainly operating fluids (oil, fuel) and residues from the combustion processes are present. Not having to deal with these hazardous materials with EVs could have a positive effect on the economic and environmental performance as well as on the work environment (E7 in Table 4). Nevertheless, EV part remanufacturing will have to deal with the handling of battery packs, which involves many uncertainties and could potentially lead to new problems. A remanufacturing expert wrote, “*Environmental issues for disposed of EV parts could be more serious because more hazardous materials are contained in EV parts. Proper treatments for used EV parts, including reman, are especially needed*”.
6. ***The work process and the requirements for personnel are changing***. There will be less work in the field of cleaning and mechanical machining, but there will be more work in the field of testing and assembly. This could have an effect on geopolitical decisions with respect to the allocation of production sites, which could change. So-called “best-cost countries” with lower wages (e.g., Eastern Europe or Mexico) could seem less attractive (E10 in Table 4).

## Recommendations for industry and policy makers

Based on the analysis of the challenges and opportunities in the remanufacturing of automotive parts for electric vehicles, the authors give the following recommendations to decision-makers in the remanufacturing industry and to its policy makers:

- As demonstrated, the conditions in the market for automotive remanufacturing are changing, and future development is uncertain [2, 6, 38]. The trends must be carefully and continuously monitored and evaluated to offer a solid decision-making basis. This goes especially for the remanufacturing of new parts on the automotive aftermarket, for example, battery packs and electric motors [16, 19, 28].
- The changes affect all major strategic and operative fields for the automotive part remanufacturing industry (see previous chapter on challenges and opportunities), which offer potential opportunities as well as potential challenges.
  - Industry decision makers should carefully evaluate opportunities (see Opportunity #1, 2, 4, 5, 6) resulting from these changes and create adaptable measurements to react to the challenges (see Challenge #1, 3).
  - Policy makers should carefully evaluate if their current framework of laws, guidelines, and incentives reflect these actual changes. Their activities should be sufficiently adapted to the challenges (see Challenge #2) and opportunities (see Opportunity #3, 5).

## Contribution, limitations and future research

This paper contributes to previous work and research by comparing the existing literature on the remanufacturing of ICE and BEV parts. From this comparison, the main differences are highlighted and evaluated. As a major contribution, challenges, and opportunities in the coming years for the remanufacturing industry are provided.

The focus of this paper was on remanufacturing companies and their production processes. The supplying companies were only analysed if they were in direct contact with the remanufacturing companies (Tier-1, not Tier-2). The customer perspective focused on the company level (the individual aftermarket (IAM) and the original equipment manufacturer (OEM)), but less on the end customer level.

The paper's findings point out that there is a need for more research regarding collaboration between new actors in the automotive aftermarket. It could then also include the study of how the electricity trend goes hand in hand with the servitization trend and how the automotive aftermarket – and especially the remanufacturing of parts – is affected by new business models (including servitization) within the automotive industry.

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## Appendix

### Challenging changes in the remanufacturing of automotive parts for electric vehicles (EV)

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Name:  Company:

I would like to stay anonymous. (→ your name will not be mentioned in our publication.)

You were chosen as an industry expert in the field of remanufacturing of automotive parts. Thank you for supporting this non-profit university study. Please complete the following questionnaire with specific regard to the by placing a  in the appropriate box. Your additional comments are welcome and are highly appreciated.

	Statement	strongly agree	agree	uncertain	disagree	strongly disagree	Your comment
1.	The market for remanufactured parts for EV (electric vehicles) will grow fast in the next twenty years.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
2.	Market actors for remanufactured parts for EV are not set yet.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3.	Large, cost-intensive machinery parks are no longer needed for remanufactured parts for EV.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4.	Handling hazardous waste is not so important when remanufacturing EV parts.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
5.	Labour costs will be lower when remanufacturing EV parts.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
6.	Knowledge and testing equipment will be a challenge for EV part remanufacturing.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
7.	The recovery rate (= material saved due to mechanical remanufacturing process) is lower for EV parts.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

For these four aspects your opinion and comment is highly appreciated:

Which major changes would you see in future, when comparing the remanufacturing of parts for electrical cars (EV) to the remanufacturing of parts for cars with combustion engines...	
...in respect of <b>techniques</b> :	
...in respect of <b>investments</b> :	
...in respect of <b>market sizes</b> :	
...in respect of <b>environment</b> :	

Thank you for your support.

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