ReziProK
Resource-efficient Circular Economy –
Innovative Product Cycles

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Resource-efficient Circular Economy – Innovative Product Cycles (ReziProK)

Final Publication

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Preface

MinR Dr. Wolf Junker, Federal Ministry of Education and Research, Head of Department 726 Resources, Circular Economy; Geosciences
(Source: W. Junker)

To preserve a world worth living in for future generations, we must fundamentally change our current way of life: The highest priority must be to protect our climate - in conjunction with a decoupling of economic growth from resource consumption to the largest possible extent.

To achieve this, we need, above all, a fundamental transformation of our current, often linear economic system (production, usage, disposal) towards a resource-efficient Circular Economy. The promotion of the Circular Economy is therefore a priority of Germany's Federal Government. We can only achieve a sustainable value creation if we extend the life span of products and materials and reuse and recycle them instead of disposing them. In this way, we can keep the value of products and their materials in the economic cycle for as long as possible. Circular Economy can make a special contribution to making Germany as a business location more independent of raw material imports and thus more resilient.

With the funding measure “Resource-efficient Circular Economy – Innovative Product Cycles (ReziProK)”, the Federal Ministry of Education and Research (BMBF) provides, within the framework of its “Research for Sustainability (FONA)” strategy, the necessary scientific foundations. The researchers of the “ReziProK” projects focused on common R&D themes such as the reuse of used products, the repair- and recycling-friendly product design as well as the refurbishment or replacement of modules in devices. Central starting points for R&D are innovative business models for the Circular Economy in conjunction with eco-efficient product design and digital technologies.

The final publication provides an insight into the results of the 25 “ReziProK” projects, which were achieved during three years of research. It demonstrates their potential for solving socially relevant problems, such as reducing the amount of electronic waste or lowering the environmental impact of textiles. Barriers to implementation and the need for further research were also identified and recommendations for political action are discussed. Only if all involved parties can be convinced of both the economic and the long-term ecological benefits of the Circular Economy, the necessary implementation will succeed.

The results of the funding measure will make a valuable contribution on the way to a resource-efficient Circular Economy.

Your Federal Ministry of Education and Research

“ReziProK” – Results from 25 research projects for a resource-efficient Circular Economy

Friege, H.; Wolfmeyer, P. (N[3] Nachhaltigkeitsberatung Dr. Friege & Partner); Schielke, C. and Wendler, K. (DECHEMA e.V.)

Sustainable resource management is more than recycling – it involves numerous and very different stages of the value chain, from repair-friendly product design and the repair and reuse of used products to the recycling and recovery of raw materials. The Federal Ministry of Education and Research (BMBF) is funding the funding measure “Resource Efficient Circular Economy - Innovative Product Cycles (“ReziProK“)” with around 30 million euros as part of its FONA strategy (Research for Sustainability). “ReziProK” is part of the BMBF's research concept “Resource-efficient Circular Economy” and aims to develop innovative business models for the Circular Economy in conjunction with eco-efficient product design and digital technologies. Within the 25 projects of the funding measure “ReziProK”, numerous new insights for a more sustainable use of resources were gained. In the research projects, experts from business, science and industry developed sustainable solutions for innovative product cycles over a period of three years. The networking and transfer project “RessWInn” provided technical support to the research teams of the “ReziProK” projects and supported the transfer of the results into economic practice.

The projects focused on very different, mostly durable products such as components, building materials, electrical and electronic devices, pumps, industrial tools, electric vehicles, and spare parts, but also packaging materials and textiles. The findings from the “ReziProK” funding measure demonstrate that design concepts based on the durability, repairability and recyclability of materials are crucial prerequisites for any product development. Another essential aspect is the guaranteed retrievability of the products. To ensure this, most projects examined business models in which the producers remain in contact with the users via the services they offer or can access the products again after the use phase. “Digital twins” of components, “learning” labelling on textiles or the automatic recognition of returned products with the support of artificial intelligence are new tools that have been successfully applied in the “ReziProK” projects.

The results of the “ReziProK” projects show that there are many ways to reduce the high consumption of raw materials - statistically, 16.1 metric tons of raw materials were consumed per capita in Germany in 2017 (Federal Environment Agency, 2018). With such a resource-efficient Circular Economy, it will be possible to keep products, modules, and components within the economy for much longer than before. In view of the rising prices worldwide, especially for metals, these are also economically urgent measures. At the same time, it can significantly reduce energy consumption and associated greenhouse gas emissions over the “product life cycle”.

The task now is to transfer the research results into economic practice as quickly as possible. To support corresponding products and business models in competition with the classic, linear model of “production, usage, disposal”, flanking measures are needed, e.g., in product labelling, and specifications for product design. The acceptance of products made from secondary raw materials by consumers and their commitment to returning used products to manufacturers are indispensable elements of a resource-efficient Circular Economy.

The “ReziProK” research projects

With the funding measure “Resource-efficient Circular Economy - innovative product cycles (ReziProK)”, the Federal Ministry of Education and Research supports the research and development of innovations for a resource-efficient Circular Economy. Together with experts from industry and science, 25 research teams developed new business models, design concepts and digital technologies to close product cycles while addressing a broad range of topics and sectors (see Table 1). The main topics were divided into 4 clusters and included the promotion of the use of recycled materials, the extension and intensification of product use, the expansion of remanufacturing and the development of blockchain technologies as well as the improvement of the recyclability of electric vehicles. The research projects and results are presented below.

Table 1: Overview of the research focus of the “ReziProK” projects

Project data – overview		All-Polymer	ConCirMy	DIBICHAIN	Di-Link	DiTex	OPTIRODIG	REPOST	UpZent
Innovation potential of the project	Business model	++	+	++	+++	++		+++	+++
	Material / Products	+++		++	++	+++	+++	+++	+++
	Technical processes	+		++	++		+	+++	
	IT		++	+++	+++	++	+++		
	Distributed Ledger Technology/Blockchain			+++					
	Sensor technology				+++	++	++		
	Lightweight construction	++						+	
	Module construction	++							
	Logistics	++			+			+++	
	Mobility	++							
	Circulation/resource saving	+++	+++		+++	+++	+++	+++	+++
Sustainability	Sustainability assessment	+++	+++	+++	++	+++	++	+++	+++
	Direct relation to sustainable development goals	+++			++	+++		+++	+++
	Usage or development of sustainability indicators	++	+++	+++		+++			+++
	Life Cycle Assessment (LCA)	++	+++	+++		+++		+++	+++
Laws, regulations, standards	Do European, German legal regulations and/or international standards affect the work carried out in the project?	++	++		+			+++	+++
	Are there plans to develop standardization (e.g., DIN-Norm, DIN SPEC) in the project?		++	++	+				
Transferability	Transferability of the developed technology/business model/design to other sectors or products?	++	++						+++
European reference	Transferability of the project results to European issues?	+++			+++		+++	++	+++

Project data – overview		AddRE-Mo	EIBA	ReLIFE	REPARE	C.O.T.	CircularBy Design	EffizientNutzen	LongLife	MoDeSt	PERMA	praxPACK	RESMAP	RessProKA	Wear2Share	KOSEL	LEVmodular	LifeCycling²
Innovation potential of the project	Business model	+++	++	+++	++	++	++	+++	+++	+++	+++	+++	+	+++	+++	+++	+++	+++
	Material / Products	+++		+++	+++	+	+++	++		+++	++	+	+++	+++	++	+++	+++	++
	Technical processes	+++	+++	+++	+++	++	+	++	+	+	++		++	+++		++	+++	++
	IT	++	+++	+	++			++	+++	++	++	+	+++	++	+		++	++
	Distributed Ledger Technology/Blockchain							+										
	Sensor technology		+++	++	+				+++				+	+		++	+++	+
	Lightweight construction															+++	+++	
	Module construction			+			+++			+++	+++		+	++		+++	+++	
	Logistics	+	++		++	+					++	+++	++	++	+	+	+++	++
	Mobility	+++	++													+++	++	+++
	Circulation/resource saving	+++	+++	+++	+++	+++	+++	+++	+++	+++	++	+++	+++	+++	+++	+++	++	+++
Sustainability	Sustainability assessment	+++	++	++	+++	+++	++	++	+++	+++	+++	++		++	+++	+++	+++	+++
	Direct relation to sustainable development goals	++	+++			+++	+++	++	+	+	+++		+	+++	+		++	+++
	Usage or development of sustainability indicators	+			++	+++	++				+++			++		+++	++	
	Life Cycle Assessment (LCA)	++	++	++	+++	+++	++	+	++	+++	++	++	+++		+++	+++	+++	+
Laws, regulations, standards	Do European, German legal regulations and/or international standards affect the work carried out in the project?						++	+++		++		++	++	++			++	++
	Are there plans to develop standardization (e.g., DIN-Norm, DIN SPEC) in the project?						+++	++			+++	+						
Transferability	Transferability of the developed technology/business model/design to other sectors or products?	+++	+++	+++		+	+++	++	+++				+++	+++	++	++		+++
European reference	Transferability of the project results to European issues?	+++	+++	+			+++	+++	+++		++	++		++	+	+++	+++	+++

LEGEND

Level of relevance:

- +++ High
- ++ Medium
- \+ Low

Blank fields: no indication by projects

Cluster affiliation:

- Optimized use of recyclates
- Extended product use
- Remanufacturing
- Recyclable electric vehicles

Source: kyrychukvitaliy - stock.adobe.com

Cluster 1: Optimized use of recyclates

Berg, H. (Wuppertal Institut für Klima, Umwelt, Energie)

Recycling remains one of the central strategies of sustainable resource management. Accordingly, nationally, and internationally established regulations, technologies and markets exist for most material fractions. Nevertheless, the situation for many materials is still dynamic and fluid. New regulations and incentives at EU level, triggered by the Green Deal and the associated strategies, above all the Circular Economy Action Plan but also the sector strategies, have given new impetus to the expansion of recycling in recent years. There are still major challenges to enable high-quality recycling or even upcycling, to avoid downcycling or material losses, to establish markets for recyclates or to develop (mechanical) recycling in the first place. The need for research remains therefore also high. According to the challenges mentioned, it ranges from the materials to be recycled, over process improvements, the establishment of markets and the development of business models, to the generation of digital ecosystems.

The necessities and opportunities for research were also evident in Cluster Group 1 “Optimized use of recyclates” of the “ReziProK” project network. Eight projects were launched here, covering the full breadth of the outlined research agenda. In terms of materials, the spectrum ranged from metals over minerals (old pore concrete) and textiles to various plastics – there was a slight focus here. To ensure that the results produced make a positive contribution to sustainable development, sustainability assessment was also prominently featured in the projects. Since transparency, information transfer and process control are central challenges of recycling strategies, digitalization plays a special role here. Digital technologies to support and optimize recycling and the associated material cycles were therefore investigated and further developed in five of the eight projects. The range of approaches considered was wide. They ranged from sensors for production monitoring and control, over product passports, tracking technologies and blockchain to the use of optimization algorithms for market and supply control.

At the end of “ReziProK”, all cluster projects can point to successes. These may not always correspond exactly to the objectives and measures defined in advance – in keeping with the idea and the imponderables of research projects – but this is often where the special opportunity for progress lies. Even at the end of the “ReziProK” program, the situation for recycling remains dynamic. For many materials – primary and secondary – have been characterized by supply fluctuations the likes of which we have not been seen for a long time. Currently, there are no signs of an easing of this situation. However, this is creating a clear push for more recycling efforts. After all, in foreseeably tight supply situations, making materials available again makes an important contribution to a safer and more environmentally friendly economy. The cluster group projects, and their results are therefore more significant than ever!

Fig. 2: Resource conservation through re-use. (Source: pixabay)

Digital solutions for the Circular Economy of plastics

Plastics, recycling, digitalization, recyclates, product passport, business models, measurement technology

Berg, H. and Bendix, P. (Wuppertal Institut für Klima, Umwelt, Energie)

"DiLinK" – Digital solutions for industrial plastics cycles

Project participants:
Wuppertal Institut für Klima, Umwelt, Energie; SKZ – Das Kunststoff-Zentrum; FIR e.V. an der RWTH Aachen; Infosim; HOFFMANN + VOSS Technische Kunststoffe; MKV GmbH Kunststoffgranulate

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Project duration:
01.06.2019- 31.05.2022

Project website:
www.di-link.de

Funding code:
033R235

Context and problems

The rising waste volumes as a result of our increased material consumption is increasingly being perceived as a problem by large sections of society. A Circular Economy in which material resources are recycled instead of being disposed of is desired by the public, politicians, and companies. There is currently a particular focus on the area of plastic waste and plastic recycling. This is reflected in the intensive discussion of the topic by political committees at all levels, but also reflected in the great public interest in plastic waste, which leads to broad reporting in national newspapers. However, for the plastics industry in particular, the principle of a closed-loop economy is proving challenging to implement. Technologically, a significant improvement of the status quo of plastics recycling is possible. However, there are many other hurdles that stand in the way of a comprehensive establishment of the Circular Economy.

Project goals and procedure

In the "DiLinK" project, digital solutions were created and tested that allow plastics to be recycled in larger quantities and in better quality. Through the developed app, information regarding the quality of the recyclate is passed on digitally along the value chain. This creates confidence in the material recyclate and improves recycling, and new, high-quality fields of application for the recyclates.

Research results and measures of transfer and transmission

"DiLinK" App
Data on plastics is passed on from the manufacturer to the processing companies. This is usually done via the data sheets supplied. The "DiLink" App goes one step further here and creates a virtual replica of the plastics, which contains the required data and makes it available to the relevant companies. Sensors determine the quality of the recyclates and provide evidence of the consistently high quality over the entire production period. The app enables communication of relevant quality parameters like these between the recycler and the plastics processing plant. Data on the quality and quantity of plastic residues and the recyclates produced from them, as well as the possibility of passing on this data digitally along the value chain, can enable plastics processing and commercial companies as well as recyclers to keep such plastics in the cycle as high-quality recyclables. Complementary to this, expert knowledge on recyclate preparation and processing can be displayed.

Digital measurement technology

Online spectroscopy is used to monitor process quality. This measures the light absorption of the molten plastic in the extruder. With suitable data evaluation, changes in the plastic, e.g., due to thermal degradation, can then be detected or tracked. This information can be used to detect inhomogeneities in the starting material or to adjust process parameters such as temperature and torque. The technology has been tested for its applicability to the special requirements of recompounding.

Business models

The increasing use of plastic recyclates is changing the exchange of materials and information between the various players in the value-added network of the plastics cycle. In order to integrate the "DiLink" application and to optimize the information flow between the actors, the role models of the different actors will be further developed and a new value stream system based on the "Business Ecosystem Design"-method will be developed. Based on the "DiLink" App, innovative and sustainable business models for the central roles are identified, with a focus on the value proposition, the revenue mechanics and the value creation logic. Thus, new cooperative business models and novel roles in the overall system could be identified.

Contribution to resource efficiency and sustainability

Even though recycling is only the third best option after waste prevention and reusing or repairing products, it will have to play an important role in bringing CO_2 emissions to net zero in near future. A recycled plastic has a significantly smaller footprint during its production than virgin plastics. This footprint will also decrease significantly if the share of green electricity in process energy continues to increase in the future. By enabling more plastics to be recycled at a higher quality, the "DiLink" project thus contributes to sustainability.

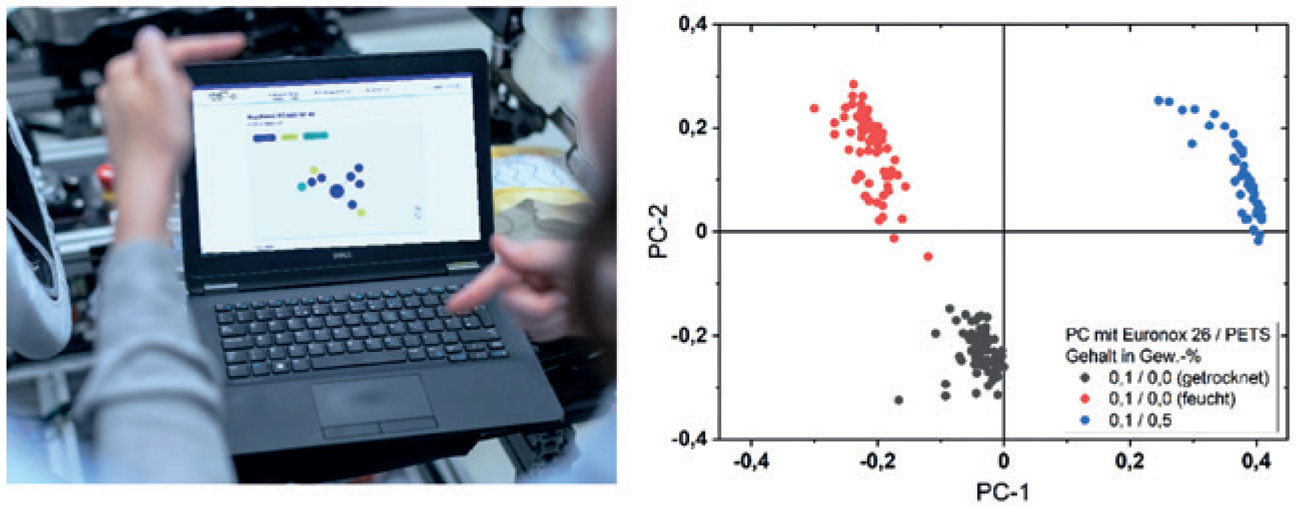

Fig. 3: "DiLinK" App in application – left (Source: Infosim)**. Example of a principal component analysis based on polycarbonate with different contents of stabilizers – right** (Source: SKZ)

Towards a circular textile economy

Business models, textile service, workwear, textile recycling, resource conservation, bed linen, recycling

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Context and problems

More and more textiles are being produced around the world – with serious consequences for the environment. Managing the end-of-life phase for textiles and reducing environmental impacts in the textile chain are core elements of the European Commission's Strategy Textiles. One potential solution for the textile industry could be functioning recycling processes and circular infrastructure. "DiTex" tested the feasibility of a Circular Economy for the textile industry in the business customer segment. The trade volume for workwear and personal protective equipment in Germany amounted to € 2.9 billion in 2019. Textile rentals accounted for about one third of all workwear. Of the 42 million employees in Germany, 34 million needed protective or occupational clothing in 2020. Enormous volumes of identical textiles with known composition circulate through textile services in established logistical processes. "DiTex" aimed to test how these structures can be used for the textile cycle, to develop these structures further and assess the environmental potential of approaches to a Circular Economy.

Project goals and procedure

"DiTex" selected five key approaches

- high level of recycled content
- use of durable components to extend life cycle
- a "smart label" as a digital tracking solution
- testing of circular business models and chemical fibre-to-fibre recycling at end-of-life,

with the goal of narrowing, slowing down and closing material cycles, thereby reducing the impact on the environment and resources. Supplementary approaches included eco-efficiency, certification, and the development of new business relationships with recyclers. These goals were pursued in a work programme consisting of conceptual, empirical, and evaluative components, which ultimately led to a comprehensive analysis. The core element was a field trial: a *polo shirt for emergency medical services* (100 % recycled polyester – rPES), a *police business shirt* (62 % certifiably organic cotton / 38 % recycled polyester – rPES) and a *bed linen set* (50 % lyocell, regenerated cellulose / 50 % recycled polyester polyester – rPES) were used and evaluated by users between summer 2021 and spring 2022. The textiles were provided by a textile service, picked up and laundered. Textile and use data were tracked digitally. Extensive tests were conducted during and after the field trial:

"DiTex" – Digital Technologies as Enabler of a resource-efficient Circular Economy

Project participants:
Institut für ökologische Wirtschaftsforschung (IÖW); ifeu – Institut für Energie- und Umweltforschung Heidelberg; Hohenstein Institut für Textilinnovation; Hochschule Reutlingen; MEWA Textil-Service; circular.fashion; Dibella; Wilhelm Weishäupl

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Project duration:
01.08.2019 – 31.12.2022

Project website:
https://www.ditex-kreislaufwirtschaft.de

Funding code:
033R228

- Spectrophotometric measurements tracked the physical properties (including morphology, colour) and the chemical composition over the course of use.

- The "DiTex" textiles were subject to different textile tests including mechanical properties, care properties for laundering, physiology) to determine whether they met the Hohenstein quality standards.

- In (screening) life cycle assessments, the environmental impacts and resource efficiency of the standard textiles were compared with the "DiTex" textiles, and sensitivity analyses were compiled.

- The experiences of the users of "DiTex" textiles, the textile service providers (laundries) and the test user institutions were evaluated in interviews and through surveys.

Research results and measures of transfer and transmission

- The fibre composition and surface structure of the "DiTex" textiles largely meet the quality requirements for textile rental. The three designs made of recycled materials were found to be of a quality equivalent to standard textiles made of primary materials. To maximize lifespan, it is important that garment assembly be designed for durability.

- Results of the (screening) life cycle assessments of the "DiTex" textiles showed:
  - Carbon footprint: the footprint of the "DiTex" textiles is only slightly smaller than for standard textiles, with lower emissions the more times the textiles are worn or used.
  - The same applies to fossil fuel savings.
  - Land footprint: in this case, the footprint is moderately to significantly smaller.
  - Water footprint: depending on the "DiTex" textile, the footprint ranges from slightly smaller (police shirt) to significantly smaller (bed linen, polo shirt).
  - Other environmental impacts: the quantity of primary materials needed is moderately to significantly reduced through the use of "DiTex" textiles.

- Digital strategies can ensure the tracking of material, care and use data of textiles along the life cycle, but there is a lack of standardization and interfaces between stakeholders. Environmental impacts of digital infrastructure and electronic components must be considered.

Contribution to resource efficiency and sustainability

The following conclusions can be drawn from "DiTex" for commercially used textiles:

- The aim is to reduce the flow of resources. Changes in habits related to buying and using textiles, or using textiles for longer periods of time have considerable potential in keeping with the principle of avoidance.

- More sustainable use of resources is encouraged through material substitution (cotton › organic cotton › lyocell › PES › recycled polyester – rPES).

- Replacing primary fibres with recycled fibres of the same fibre type brings minor environmental benefits.

- The B2B textile service contributes to a circular textile industry by including easily recyclable textiles in its product portfolio and giving them to recycling companies instead of throwing them away.

- Recycling is one element of sustainable resource use, but it is not the solution to the environmental impacts of the textile industry. When textiles can no longer be used, they should be recycled when they can be recycled efficiently and without high chemical and energy input. This applies to scrap textiles from garment assembly and mono-materials whenever possible.

- Optimizations at various stages of the value chain can yield further environmental benefits, e.g., by optimizing laundering. Training and education as well as technological retrofitting, if necessary, are required here.

Fig. 4: Workwear used in textile service (Source: MEWA 2022)

Fig. 5: "DiTex" police shirt in use (Source: ZPD NI 2022)

Optimizing secondary raw material productivity through digitization and networking

Digitalization, networking, secondary raw materials, energy consumption, machine learning, linear optimization (simplex)

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Context and problems

In the foundry and steel industry, around 45 % of raw material requirements are already covered by secondary raw materials. This share should and can be increased.

Project goals and procedure

In the "OptiRoDig" project, a digital network system between the recycling industry and smelters should be developed. This system should provide comprehensive analysis data on available secondary raw materials - metal scrap. This database should enable smelters to procure suitable raw materials, optimize their smelting processes and thus use higher proportions of secondary raw materials in a targeted manner.

Procedure:

- Analysis of various scrap according to chemical and physical attributes
- Development of the simplex algorithm to determine the cost-optimized composition of various scrap types
- Optimization with machine learning (ML) to increase the use of secondary raw materials and reduce energy consumption
- Combination of the Simplex algorithm and the machine learning to determine an overall efficiency.

Research results and measures of transfer and transmission

In the cloud-capable optimization tool created for the project, the composition of the melt in terms of minimized costs can be calculated using a simplex algorithm. The boundary conditions (e.g., proportion of chips) can be set flexibly. Data protection is ensured by a log-in. Users can add and change their own data; however, data of other users cannot be viewed. All materials from the "Steel material key" can be selected as target materials and own materials can also be added.

"OptiRoDig" – Optimizing secondary raw material productivity through digitization and networking

Project participants:
RHM Rohstoff-Handelsgesellschaft GmbH;
Friedr. Lohmann GmbH; Universität Duisburg-Essen;
Hochschule Kempten

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Funding code:
033R247

The melting process in the furnace of a foundry was modeled with machine learning (ML) to analyze the process-related influencing variables. The ML models are integrated into the cloud application so that an overall optimization can be made about metallurgical interactions in the melt and total costs.

Factors influencing energy consumption during melting in the medium-frequency induction furnace:

- Direct factors such as geometry, bulk density, chemical analysis, impurities, etc. of the available scrap Melting behavior.
- Indirect factors such as process delays resulting in longer furnace start-up time.
- Melting is a non-linear process (e.g., heat loss by radiation when the furnace lid is open increases with T^4).

- This is one of the reasons why data-based modeling with methods such as linear regression is difficult or impossible → Motivation for Machine Learning

Contribution to resource efficiency and sustainability

By modeling the melting process and considering the respective gated raw materials, a process model was developed that provides information on the variables influencing energy consumption during melting. Furthermore, such models reveal "weak points" in the process. With the help of linear optimization (simplex) and the process model created (based on ML), it is possible to compile optimized grades about not only the raw material costs but also the expected energy consumption. In addition to the pure raw material costs, the energy and primary raw material consumption predicted by the models is therefore also considered.

Optimizing the melting process (increasing the proportion of secondary raw materials) enables savings in energy, primary raw materials, and CO_2 emissions. There is a strong fluctuation in the required melting energy during the melting process. This is probably due to the process and the raw materials used and their variation in terms of chemical analysis. The optimization potential is estimated to be enormous.

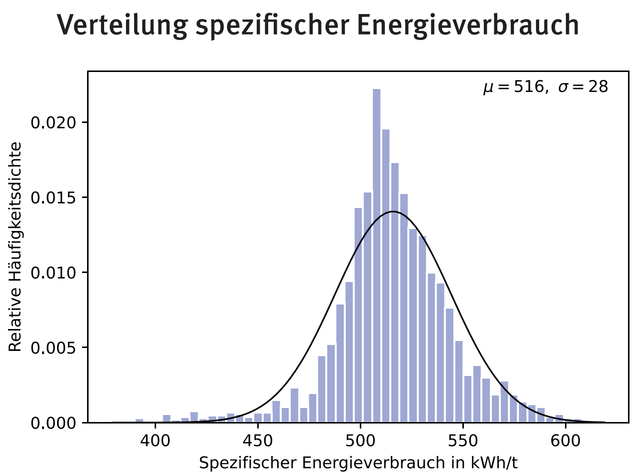

Fig. 6: Distribution of specific energy consumption of 1.2379 steel melts (Source: HKE)

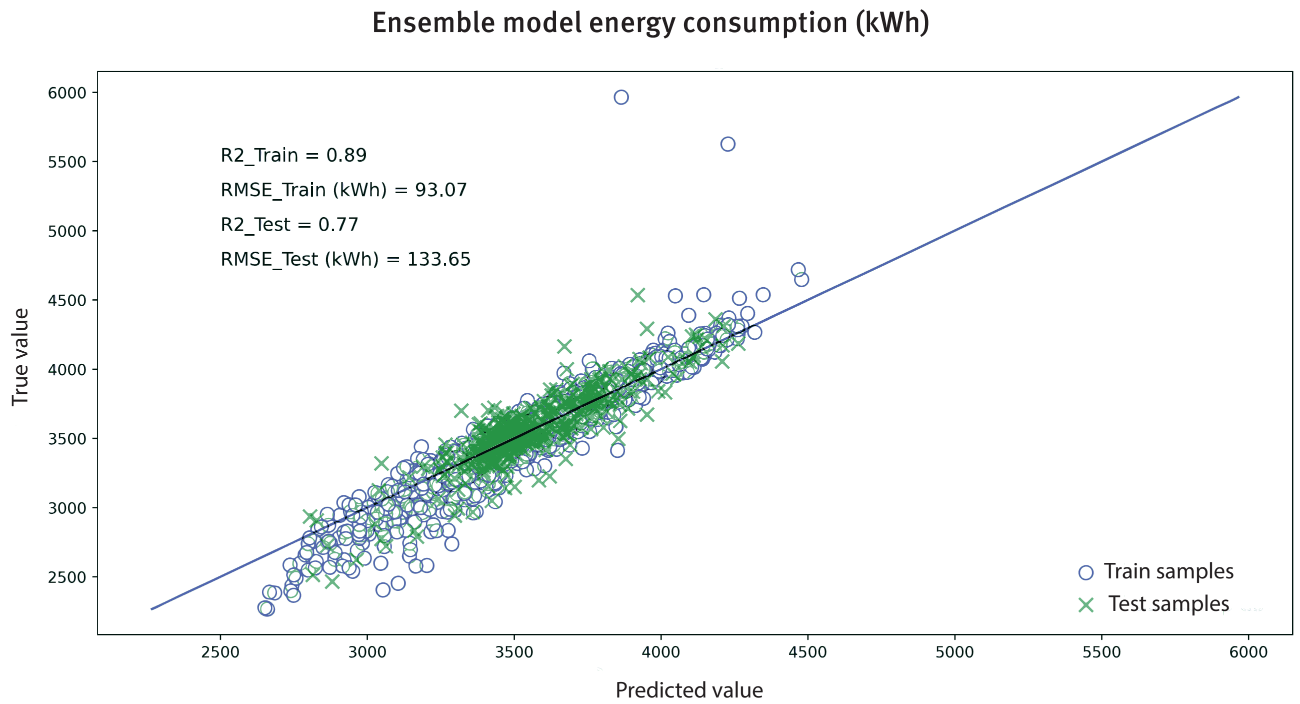

Fig. 7: Ensemble model regarding energy consumption of these melts (Source: HKE)

Development of a cross-stage and cross-circuit networked configurator for Circular Economy

Circular Economy, configurator, tyres, LCA

Krahtova, P. (CAS Software AG)

Context and problems

In Germany, around half a million tonnes of end-of-life (EoL) tyres accumulate annually and only a small proportion is used as recycled material to produce new tyres. Within the framework of "ConCirMy", it is being investigated whether and how tyres can be optimised with regard to the goals of a Circular Economy without compromising on quality. A tool is being developed to provide information on environmental compatibility to various stakeholders in the supply chain which can be considered in purchasing decisions. Although technologies for the recycling of used tyres are available, their use is still rather limited. Vehicle manufacturers are also interested in increasing this proportion – a motivation based, for example, on the EoL-Vehicles Directive, according to which 85 % of end-of-life vehicles by weight must be re-used or recycled and 95 % must be recovered. These requirements are also important about the development of new vehicles and their components, the pressure is increasing with the transformation to electromobility because some components are difficult to recycle.

"ConCirMy" – Configurator for the Circular Economy

Project participants:
CAS Software AG; Deutsches Institut für Normung e. V. (DIN); Technische Universität Berlin, Fachgebiet Innovationsökonomie; DECHEMA Gesellschaft für Chemische, Technik und Biotechnologie e. V.

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Project duration:
01.07.2019 – 31.12.2022

Project website:
www.concirmy.org

Funding code:
033R236

Project goals and procedure

The aim of the "ConCirMy" project was to develop a product configurator which informs users about the environmental impacts and other sustainability aspects of the product (raw materials used, possibilities of recycling or reuse) in the life cycle of the tyre and enables them to consider this information in their purchasing decisions.

These can be accessed by different user groups situated at different levels in the supply chain – consumers, designers, recyclers – and considered in decisionmaking alongside other important factors such as functionality and cost. Ultimately, the aim is to support the production and purchase of more sustainable products, the development of more environmentally friendly designs and the move towards recycling and reuse. The configurator acts as a unifying core system that makes specific information available to different actors in the supply chain. Technically, both the integrated environmental assessment of products and components in a product configurator for the end customer and the comparative implementation of different calculation approaches are new.

Socio-economic analyses are conducted to learn about consumer preferences and demand potentials for bio- and Circular Economy-based automotive components, including related sustainability aspects. Recommendations are derived for the various supplier groups of the targeted Circular Economy system. For the successful implementation of the circular system, business models are developed. Furthermore, the need for standards to support the development of the supply chain towards a Circular Economy is examined.

Research results and measures of transfer and transmission

FFor the analysis of the value chain, the process chain of tyre production from raw material to recycling technologies has been investigated and recycling possibilities and recovery routes of recyclates from tyres have been identified. The initial research has shown that tyres are a highly complex product and that an established product classification at raw material level is not freely available. An important result of the project is also the development of a generic tyre model an exemplary life cycle inventory, which serves as a basis

for product configuration. The integrated sustainability assessment with life cycle assessment data from the Ecoinvent database has been integrated into a prototype and shall be now tested and demonstrated. Furthermore, a cloud-based prototype was developed to support multidimensional sustainable monitoring of a product (tires). Furthermore, the concept for sustainability assessment was expanded with an interface to a life cycle assessment database (Ecoinvent) and an interface for retrieving data from ERP systems. Further research has showed that the use phase of a tire has the biggest impact on the environmental assessment of its whole life cycle. In order to be able to integrate information from the use phase, several variants of sensor data collection were examined and implemented as a prototype in the form of an app. In parallel to the technical developments, socio-economic analyses as well as single- and multi-stage surveys on acceptance factors were carried out, e.g., among private individuals, professionals of the tyre value creation system, vehicle fleet managers as well as leasing companies. They resulted in a variety of implications for "ConCirMy"'s software solution. In addition, framework conditions and implementation barriers of circular public tyre procurement were identified and recommendations for action were formulated.

Contribution to resource efficiency and sustainability

In main project objective to increase the sensibilisation regarding Circular Economy using the example of tires. The aim is to show the possibility of making a more sustainable purchasing decision by choosing tires with a higher recycling rate, rethreaded tires, or tires with a lower environmental impact. Through this newly created awareness, the project contributes to resource efficiency and more sustainable action. An exchange with stakeholders such as fleet managers, leasing consultants or public procurement showed that they are already aware of the topic of recycling. The project increases awareness in the quantity demanded and thus contributes to sustainable demand for tyres. The higher purchasing power of the parties mentioned enables a multiplier effect due to the greater purchasing power. At the same time, the standardization and certification of data exchange using a DIN SPEC is intended to advance the digitization of the Circular Economy. This development would facilitate the introduction of environmentally friendly technology in the production of tires and contribute to new market opportunities. Another option for CAS AG is to integrate sustainability information into the product selection in the configurator, to promote sustainable purchasing decisions.

Fig.8: Recycling of end-of-life tyres (Source: pxhere)

Fig. 9: Used tyres at the recycling centre (© Ramona Simon)

More transparency in the supply chain with blockchain

Circular Economy, sustainability, Blockchain, supply chain, transparency on demand, LCA

Kötter, A. (Altran Deutschland S.A.S. & Co KG/Capgemini Engineering)

Context and problems

Today's product development and manufacturing is linear in terms of its raw materials and material flows. Products are developed, used and often disposed of at the end of their lifetime. In the process, valuable materials and raw materials are lost and are thus no longer available for subsequent products and life cycles. This applies both to commodity products and to complex products such as e.g., an aircraft. It is even the case that disposal companies are commissioned to take care of the disposal of complex products. Often, however, valuable materials or products are not extracted from the complex product on a sufficient scale to be fed into further life cycles. This is due to factors such as missing material information or missing dismantling information. Furthermore, it is not possible today to determine a reliable ecological footprint for a complex product, as the product is built up via the supply chain, and the supply chain itself (e.g., transport) should be considered when determining e.g., the CO_2 footprint of the product. Both problems require a higher transparency in the supply chain, on the one hand to get additional information for a higher recycling quote at the end of life, and on the other hand to create a reliable life cycle assessment over the entire supply chain of production, which is necessary to identify the neuralgic points with a highly negative but also positive environmental impact. This way is it possible to identify critical points in the supply chain with regards to environmental impacts and optimize them in accordance with the requirements of a Circular Economy.

Project goals and procedure

To find a suitable solution for digital tracking and sharing of information about the supply chain, the topic of blockchain first had to be examined more closely. For this purpose, the blockchain technologies established at the beginning of the project were compared with each other. The criteria applied were capabilities for information security and data protection of product data, community and support, but also aspects such as interoperability, dissemination and, last but not least, the environmental aspect and, in particular, the energy consumption of operation.

"DIBICHAIN"

Project participants:
Airbus; Blockchain Research Lab; Chainstep; iPoint Systems

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Project duration:
01.07.2019 – 30.06.2022

Project website:
https://dibichain.com

Funding code:
033R241

In addition, the following 4 challenges were examined in more detail throughout the project.

1. (Re)tracking of selected materials, their refinement and processing from the extraction of raw materials to their return into material cycles.
2. Ensuring compliance with social and ecological standards throughout the entire product life cycle (cycle)
3. Blockchain as a "single source of truth
4. Clear identification and traceability of products over the entire product life cycle.

A cabin partition from the partner Airbus, whose production, life cycle and end-of-life can be used as an example for many complex products, served as a model for the project. After focus group surveys and use case workshops were conducted, the requirements were clustered and classified in a development roadmap. In addition, categorisation and prioritisation of requirements were carried out. The results were then used to successively work through conception, design and software development in an iterative, agile approach to develop a demonstrator.

Research results and measures of transfer and transmission

The requirements for the demonstrator collected from the focus groups revealed a conflicting interest between the need for transparency and the unconditional desire of the supply chain participants to retain control over the shared product data. Especially in recipes or special manufacturing procedures, the protection of trade secrets is a top priority. To meet these and other requirements, it was necessary to reduce the product-related data on the blockchain itself to the most necessary. At the same time, it must not be possible to easily identify the participants within a specific supply chain.

The solution is a decentralised infrastructure that allows product information to be exchanged on demand. The blockchain acts as an anonymous, integrated "broker" that can anonymously forward and deliver requests for a product/batch/material. The recipient can decide for himself whether he wants to answer the request or not. The answers can consist of any data, which can then be further processed in the sender's IT landscape. In our example, this is a data set of a life cycle analysis (LCA) of a supplier, which can then be integrated into the overall LCA of the final product to obtain LCA information directly from the supply chain. This makes it possible to reliably evaluate the product from "cradle to X". It is also conceivable that exchanged product data can be traded, which could create new revenue streams and business models.

The design of the demonstrator is intentionally kept in such a way that any IT applications from the organisations of the supply chain participants can be docked to deliver, read in or process product-related information. (Example: LCA applications, Manufacturing Execution System - MES, or SAP applications).

Contribution to resource efficiency and sustainability

First and foremost, the demonstrator creates an opportunity to bring transparency into the supply chain and to make the environmental impacts along this chain visible. This means that an Original Equipment Manufacturer – OEM can, for example, identify the negative drivers of the life cycle assessment of its complex product much more precisely and thus take much more targeted measures to eliminate them. In addition, the solution creates an opportunity to improve the recycling rate, as disposal companies can specifically request material or dismantling information. With this information, it becomes much easier to dismantle complex products for improving the recycling of individual product components and then feed them into the material cycles. In addition, valuable materials can be identified in a more targeted manner and, if necessary, better extracted. This promotes Circular Economy and avoids waste. In addition, the limited resources are conserved.

Fig. 10: Product centricity to preserve data protection (Source: "DIBICHAIN" Project).

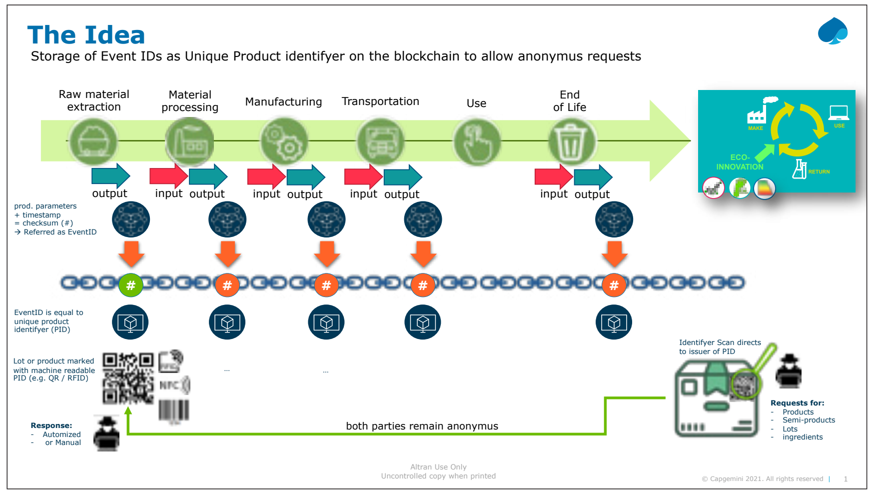

Fig. 11: Product-ID as "anchor of information" (Source: "DIBICHAIN" Project).

Fully recyclable fiber composite plastics for the Circular Economy

Circular Economy, recycling, fiber-reinforced plastics, plastic fibers sustainable business models, plastics processing, climate neutrality

Görzen, J. (A+ Composites GmbH)

Context and problems

IIn the global sustainability debate, there are increasing calls for the complete avoidance of plastics, especially because of the pollution of the world's oceans by plastic waste. In the EU, around 26 million tons of plastic waste are generated annually, of which less than 30 % is collected for recycling. The regulatory environment – especially due to the EU Plastics Strategy published in January 2018 - is challenging for companies operating in the plastics industry. For example, the plastics industry is to be completely transformed into a Circular Economy.[1] In addition, CO_2 emissions are to be minimized to achieve climate neutrality. There is a correspondingly great need to increase the resource efficiency of plastics and to help secondary plastics to be used more. However, it is often not easy to substitute primary plastics with secondary plastics. Recycled plastics are generally less efficient than the original materials. An obvious solution is to upgrade secondary plastics with thermoplastic fiber composites. However, these composite materials are often not recyclable, which stops the cycle of recyclability.

"All-Polymer" – Fibre reinforcement for increase resource efficiency high quality, fully recyclable plastic products

Project participants:
Technische Universität Kaiserslautern; Universität Koblenz-Landau; Infinex Holding GmbH; Hahn Kunststoffe GmbH; A+ Composites GmbH

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Project duration:
01.09.2019 – 30.11.2022

Project website:
https://allpolymer.de

Funding code:
033R237

Project goals and procedure

This is where the "All-Polymer" project starts. The aim of the project was to develop fully recyclable fiber-reinforced plastic products so that primary plastics can be replaced by secondary plastics and recyclates can be used for new applications. To achieve these goals, prototypes were made from the three major sectors of the plastics industry - packaging, construction and automotive – which were upgraded with suitable fiber-reinforced plastic tapes from the company A+ Composites GmbH. The advantage of these so-called UD tapes is that they minimize costs by minimizing material usage and offer a great deal of flexibility in the choice of application. The development of the prototypes was followed up by material and sustainability studies carried out by the universities of Koblenz-Landau and Kaiserslautern, so that a holistic view was taken in the project. The participating companies were evaluated using the Ellen Macarthur Foundation's "Circulytics" tool to determine their status in the area of circular business management. Based on the strengths and weaknesses identified, management implications were developed to help the companies make the transformation to fully circular and sustainable operations. A volume-reducible container from Infinex Holding GmbH was chosen as a test product from the packaging industry. When unloaded, the container can be folded in such a way that it takes up a fifth of the original space. With "All-Polymer", the material from which this container is made is meant to become circular. A life cycle analysis showed that a plastic container that is used in multiple cycles is ecologically advantageous compared to disposable containers made of cardboard after just 18 cycles. It is assumed that a container manages more than twice as many cycles on average.

The plank from Hahn Kunststoffe GmbH, which is already made entirely of plastics from the yellow bag, was selected as a prototype from the construction industry for the "All-Polymer" project. The planks are mounted on substructures. Due to the improved strength provided by the UD tapes, it is possible to increase the support spacing, thus opening new fields of application and saving on joists during installation. As an associated partner, Roechling Automotive GmbH provided the prototype from the automotive industry. The basic idea behind the underbody structure under investigation was to use glass fiber-reinforced tapes to compensate for the drop in performance of the components with recycled material and to reduce the previous proportion of glass long fibers by using UD tapes.

Research results and measures of transfer and transmission

Significant improvements in the technical parameters of the prototypes made of secondary plastics were achieved in the project. The main objective of the project, to add value to secondary plastics, was thus achieved. The process and material developments have also shown that the prototypes can be transferred to series production, which are not only transferable to the applications and industries considered in the project, but also to many other plastic applications. With tape laying and hot pressing, it is possible to apply or insert UD tapes in a series production process, and this means that they can be used immediately without major conversions in many applications that use this technology. The life cycle analysis showed that the main factor driving CO_2 emissions is the energy used for production. By completely converting the electricity used to renewable electricity, CO_2 emissions can be reduced by 93 %. This means that reusable plastic systems outperform conventional disposable solutions after just a few cycles.

Contribution to resource efficiency and sustainability

The fact that fully recyclable applications were developed as part of the project means that manufacturing companies can save very large quantities of primary plastics. The transferability to numerous other applications shows that the research project opens a new product spectrum for the use of secondary plastics that is characterized by resource efficiency and sustainability. The advantages of reusable systems demonstrated in the project provide companies with a strong incentive to examine their own structures and manufacturing processes in terms of sustainability and to strive for a complete conversion to renewable energies.

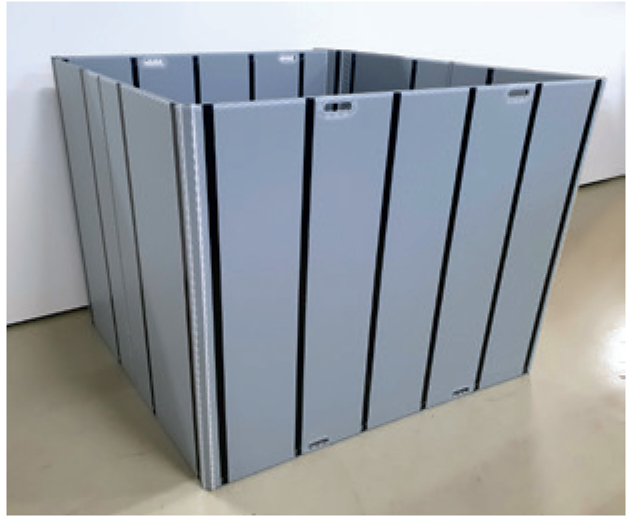

Fig. 12: Volume-reducible container
(Source: Infinex Holding GmbH).

Fig. 13: Section of a fiber-reinforced substructure
(Source: A+ Composites GmbH).

1 https://www.europarl.europa.eu/news/de/headlines/priorities/kreislaufwirtschaft/20180830STO11347/eu-strategie-fur-weniger-plastikmull-in-europa (14.06.2022)

High-quality Circular Economy of autoclaved aerated concrete (AAC)

Autoclaved aerated concrete, AAC, raw material substitution, recycling, low-carbon binders, circular management, LCA

Kreft, O. (Xella Technologie- und Forschungsgesellschaft mbH)

Context and problems

Autoclaved aerated concrete (AAC, for example Ytong®) has been a well-known and proven building material for almost one hundred years. In principle, AAC is fully recyclable: During production, broken or residual AAC is either further refined into granulate (oil binder, thermal insulation fills, roof greening substrates or animal bedding), or milled and returned into the ongoing production of AAC. By contrast, post-demolition AAC (pd-AAC) usually contains foreign matter, which makes high-quality recycling difficult.

Project goals and procedure

The aim of the project was to develop the basis for a resource-efficient, high-quality, and economical recycling system for AAC. Thus, in the central sub-project of "REPOST" the existing material cycle for AAC should be opened for AAC-waste material. Building material prototypes (AAC, calcium-silicate-units (CSU) and lightweight concrete blocks) for masonry constructions were developed from pd-AAC of various grades, each of which was to contain the maximum possible quantities of pd-AAC while complying with normative required material properties. Where pd-AAC cannot be directly recycled, thermal conversion into dicalcium silicate, a main component of cement clinker, is being investigated. The aim is to minimize the amount of AAC that must be landfilled and to partially replace the primary raw materials cement or quick lime in AAC production with a recycled product that caused lower energy consumption and, hence, lower CO_2 emissions in its production. Furthermore, it was investigated whether and how the transformation of a conventional, linear economy of AAC towards a circular and sustainable economy can succeed. The aim is thus to evaluate options for action based on a techno-economic and ecological analysis as well as to optimize site capacity and logistics planning.

Research results and measures of transfer and transmission

During the project, several deliveries of pre-sorted pd-AAC have been delivered by Otto Dörner Entsorgung GmbH to the Xella granulate plant in Rotenburg/Wümme. For this purpose, pd-AAC from demolition measures in Hamburg was sorted by trained Dörner personnel. The preliminary visual inspections for critical foreign matter did not reveal negative findings and the material was fed into the crushing plant. The resulting pd-AAC powder was free of pollutants in accordance with LAGA M20, TR Boden, so that from a chemical point of view there were no restrictions on its use. After optimizing the process parameters and formulations, a total of over 100 kg of belite clinker was synthesized from four different grades of pd-AAC at the Karlsruhe Institute of Technology, Institute for Technical Chemistry (KIT-ITC) and made available to the project partner Xella. Data on material and energy balances were sent to the Institute of Industrial Production (KIT-IIP) for techno-economic analysis. On a pilot scale, up to 50 % of the Portland cement (OPC) otherwise used in AAC manufacture could be replaced by RC cement clinker (belite) from pd-AAC (Fig. 15 shows material from a first upscaling in the large-scale pilot plant of Xella Technologie und Forschungsgesellschaft mbH with 25 % RC cement clinker). Recipes for AAC were developed that contain up to 40 wt.% of pd-AAC. Today, formulations are available with 20 wt.% (quality class PP2, see Fig. 14), 30 wt.% (PP4) and 40 wt.% pd-AAC-powder (AAC-slabs for use as a non-load-bearing interior walls). In 2021, these three product groups accounted for around 95 % of Xella's total AAC-production in Germany. Test productions based on these new formulations are currently being carried out in Xella plants. The aim is to obtain recipe approvals and to start the production. The development of CSU with pd-AAC-powder and a lightweight concrete block using granulated pd-AAC as a lightweight aggregate was completed on pilot scale. By means of modelling, the KIT-IIP determined the quantities of pd-AAC that will be generated in Germany by 2050 (resolution on district level). In the coming years and decades, a significant increase in pd-AAC-volumes is to be expected, which could possibly rise from 1.2 million m³ in 2020 to more than 4 million m³ in 2050 (see Fig. 14). Transfer opportunities exist in the expansion of AAC recycling to whole Europe. Significant volumes of pd-AAC can be expected especially in the UK and Poland. On the other hand, the methods developed can be used to establish/optimize recycling networks for other building materials.

"REPOST" – Recycling Cluster Porenbeton

Project participants:
Xella Technologie- und Forschungsgesellschaft mbH; Otto Dörner Entsorgung GmbH; Karlsruhe Institut für Technologie (Institut für Technische Chemie, Institut für Industriebetriebslehre und industrielle Produktion)

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Project duration:
01.06.2019 – 31.12.2022

Project website:
https://innovativeproduktkreislaeufe.de/Projekte/REPOST

Funding code:
033R249

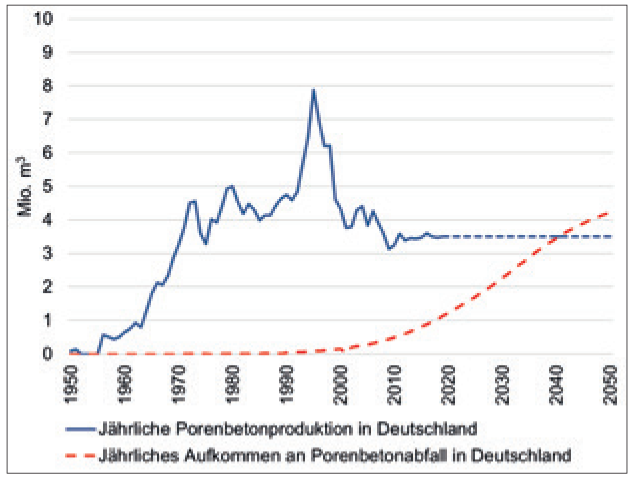

Fig. 14: AAC-production and expected volumes of pd-AAC in Germany 1950 – 2050 (Source: Steins et al. (2021): Assessment of post-demolition autoclaved aerated concrete (AAC) volumes in Germany, Resources, Conservation & Recycling, DOI: 10.1016/j.resconrec.2021.105504)

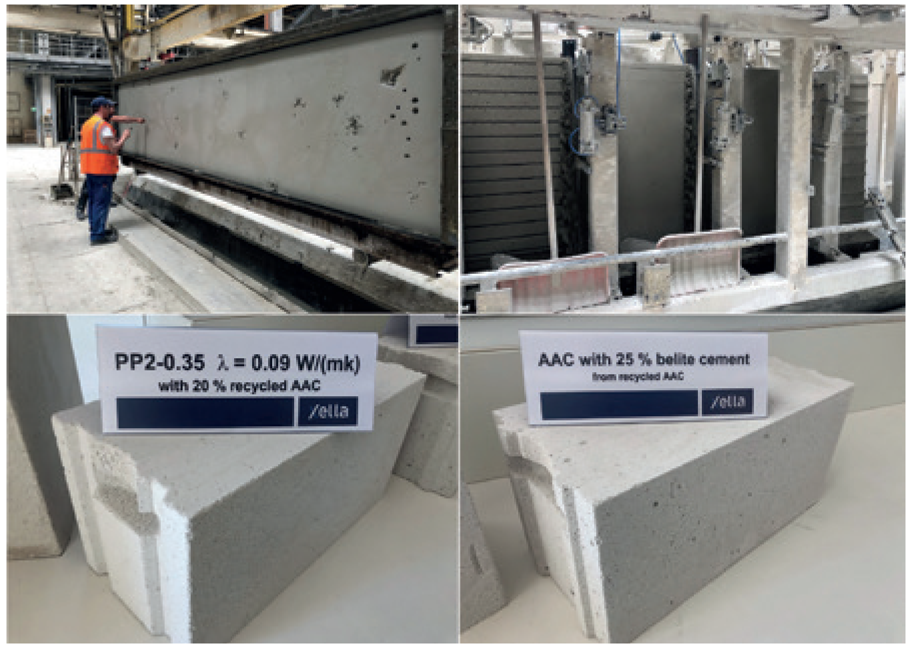

Fig. 15: top: Production of AAC-prototypes in the large-scale pilot plant of Xella Technologie- und Forschungsgesellschaft mbH; bottom left: AAC block Ytong PP2-0.35 with 20 % pd-AAC; bottom right: AAC block with rc-cement clinker (belite) from pd-AAC (Source: Xella Technologie- und Forschungsgesellschaft mbH)

Contribution to resource efficiency and sustainability

A life cycle assessment of different recycling options for pd-AAC revealed that recycling is associated with large CO_2 savings as well as significant savings in other environmental impacts. The best recycling alternative in terms of GHG-emissions is the addition of pd-AAC into the production of new AAC (closed-loop recycling). With this strategy, savings of almost 0.5 kg CO_2 per kg of pd-AAC can be achieved. For a complete recipe change within Xella Deutschland GmbH, approximately 60 kt of pd-AAC would be required per year. This would lead to GHG-savings of up to 30 kt CO_2eq per year.

Upcycling Center

Circular Economy, resource efficiency, cascading use of residues, upcycling, product development, circular design, social inclusion

Heck, P. (Hochschule Trier/IfaS - Institut für angewandtes Stoffstrommanagement)

Context and problems

Project aim was to convert the upcycling center approach into a transferrable business model, as well as, to test and transfer it to other locations. "UPZENT" combines resource efficiency, Circular Economy and social commitment through professional product development and focuses on building a closed material cycle. The main components of the "UPZENT" products are commercial residues from regional partner companies. The residues were checked and selected for their sustainable and reusable properties, as this is a prerequisite for the cascading use of the residues in the sense of Circular Economy. The following residues fractions were used: wood, cardboard, textiles, and plastics. The combination of high-quality design and regional residues creates something new: socially integrative and resource-saving design products, which were manufactured by long-term job seekers and migrants.

"UPZENT" – Upcycling Center

Project participants:
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Project duration:
01.09.2019 – 31.08.2022

Project website:
www.upzent.de

Funding code:
033R239

Project goals, procedure and results

The project pursued an interdisciplinary and transdisciplinary research approach with a high degree of practical relevance. The skills of "UPZENT" ranged from material flow management to financing and Circular Economy, project management, engineering sciences, networking to product design. Furthermore, the manufacturing industry and the waste disposal industry are involved.

During the project, the network partners have continuously developed the circular product design, the manufacturing process and the product quality and safety. Several working meetings for the further development of the product catalogue, numerous product conferences, the standardization of the "UPZENT" procedures and coordination for product marketing were carried out. "UPZENT" connects diverse living environments and strengthens social cohesion by allowing people of different educational and social backgrounds, age groups to work together. Jobs were created for those who have a hard time in the current job market.

"UPZENT" products were manufactured at the social workshops AQA gGmbH in Neunkirchen (Saarland) and FAUK e. V. in Herzogenrath (Aachen Region), who experience market access, qualification, and appreciation through the cooperation with "UPZENT". The leaders of the workshop and employees of AQA gGmbH cooperated with scientifically active people and designers as part of the project to produce the upcycling products sustainably. With increasing awareness and success of "UPZENT", cooperation with other social workshops is planned.

In cooperation with the partners, around 90 residues from local companies were organized and processed into upcycling prototypes and products that are already being marketed. "UPZENT" currently has around 15 market-ready products, around 10 prototypes are in development and a further five products have undergone a redesign process. Since the start of the project, more than 2,500 products have been made from commercial residues by the social partner workshops. Nearly 30 partnerships were settled with local companies in the regional vicinity of the "UPZENT" locations in Neunkirchen and Herzogenrath. The goals of the cooperation are the cascade use of residual materials and raising awareness among the partner companies for recycling-oriented recycling of the residual materials produced in their company and for greater resource efficiency. At the same time, "UPZENT" raises awareness of sustainable consumption. The residues that could be acquired through the cooperation were inventoried in the form of a residue library and stored for further cooperation and product design purposes.

Resource-efficient business model

For the development of the business model, suitable forms of organization and cooperation were examined, which enable the existing approach to be expanded. The upcycling center that has already been set up in Neunkirchen with its corporate partners acts as a best-practice model. As part of the development of a business and organizational model, the status of development in the field of circular business models was researched, a methodology for the development of the Circular Economy model was defined and the organizational models of existing upcycling companies were analyzed. During workshops, the "UPZENT" business model was developed based on the Business Model Canvas, considering social, economic and ecological aspects. This developed model enabled innovative approaches that had not previously been considered. Based on the previous results, the processes of "UPZENT" were analyzed and the most important project-related processes (material flow and residue analysis, product design and design, order processing and production) were defined. The aim of defining the process chain was to standardize the work processes and to clarify the respective responsibilities.

Contribution to resource efficiency and sustainability

Three categories were defined during the sustainability assessment:

1) A qualitative analysis based on selected UN– Sustainable Development Goals (SDGs) to identify the effects of "UPZENT" on sustainability, circularity, and the Circular Economy.

2) a qualitative and quantitative summary of the social, economic, and ecological performance indicators of the "UPZENT" activities in the project period was developed.

3) "UPZENT" selected products were examined in detail; with the aim of finding out to what extent greenhouse gases can be saved per product compared to conventional recycling of the used residues, which usually takes place in the form of thermal recycling.

Several high-profile activities were carried out. During the project period, an estimated 450.000 people were reached through newspaper articles: 110.000 people through film contributions and around 1.000 people through lectures, networking meetings and awareness-raising measures.

Measures of transfer and transmission

During the project, the phases, and processes of "UPZENT" were analyzed in detail. These were documented and standardized in such a way that the project approach can be adopted by other social workshops and joint work with all the involved stakeholders can be facilitated. The standardization of the processes ensures and simplifies the transferability of the concept even after the financing phase.

The operation of "UPZENT" will continue in close cooperation with the project partners; the experience and know-how acquired over the past few years are of crucial importance.

Fig. 16: "UPZENT"- material cycle, "UPZENT"-products
(Source: "UPZENT", 2022)

Cluster 2: Extended product use

Eichert, C. (RITTEC Trade + Consulting GmbH & Co. KG)

A resource-efficient Circular Economy is not limited to the recovery of raw materials, but explicitly aims at the longest possible use of products. Reuse plays a central role in the waste hierarchy, which is the basis of all legal regulations. While the waste hierarchy sees avoidance ("reduce") as a starting point, this is directly followed by "reuse". Only when avoidance and reuse are no longer possible does recycling follow, in which the materials and raw materials are recovered from the products to be used in new products.

In the funding programme "ReziProK", a variety of approaches were being researched and developed that focus on the reuse and life extension of products. This ranged from the extension of the use of electrical and electronic product through repair and second-hand equipment trade, rental models for clothing or models for the further use of furniture and equipment to the further use of specific metalworking tools and cutting equipment. The foundations for further use, repair or even value-added recycling are laid in the design. Individual projects have investigated the influence of design on, for example, repair or component replacement to improve the performance characteristics of the products. How can the functionalities of a mobile phone be increased through a modular design or how does a reduction in the variety of materials in large electrical appliances contribute to an increase in product quality in recycling? The question of the sense and possible uses of reusable packaging in online retailing was also investigated, because its shipping packaging today represents an incalculably large amount of waste.

Even though the contents of the individual ten projects of the "Product Use" cluster could hardly be more different, the have one thing in common: the development of business models. These were just as diverse as the projects themselves. During the exchange across the project boundaries, it became clear that there is no "THE" business model for extending product use. For example, in one project it is the data that is collected during the use phase of a pump to give the fitter direct possible repair instructions, so that not the entire pump but only individual parts have to be replaced, or also the standardized creation of repair instructions, which help to optimize repair expenses and thus become more efficient. Other identified business models focus on ownership, so that the manufacturer already thinks about the later dismantling and reuse of the products and materials when the product is created. Such models have been developed not only for mobile products, but also for office equipment or entire office landscapes.

In addition to many promising approaches that will find their way into realization after the development phase within the framework of the projects, it also had to be recognized that in addition to good technical solutions and viable business models, in the and the customer must be convinced that the continued use of products cannot, should not be a "second-class solution", but a meaningful addition to the constantly new. The market studies carried out in the projects of the "Product Use" cluster have revealed deficits here, the elimination of which often requires a much greater effort than the realization of technical changes. The social mindset must be changed. This is and remains a task for all those involved in the value chain. To realise this, the projects lacked broad impact. Other actors, such as brand manufacturers, are called upon to take up the results from the projects of the funding programme ReziProK and to integrate them into the redesign of their business models and their customer communication in terms of resource efficiency.

Fig. 17: Extended product use conserves resources (Source: pixabay).

More than Scrap – Rethinking Resources!

Steel, cutlery, remanufacturing, Repurposing

Kästner, T. (TKM GmbH)

Context and problems

The global and national consumption of resources is continuously increasing and associated with environmental impacts. The Circular Economy approach offers opportunities to reduce both effectively. In the steel sector, one established possibility is recycling, i.e., closing material loops. Other possibilities that start before remelting are remanufacturing and repurposing. In this way, the materials can be used longer in the economic cycle. In the "CoT" project, the cooperating research institutions and companies are exemplarily closing material cycles in the local metal-processing industry. The project aims to reduce resource and energy consumption and make the new production processes economically viable. There are many challenges in the development. For example, new processes are needed to reuse high-quality tool steel, either to use it in the original manufacturing process or to integrate it into production chains across companies. The main progress here lies in avoiding remelting as part of the dominant recycling process in the steel industry. Although this is desirable and in the spirit of a Circular Economy, it is associated with losses of alloying metals and high energy and resource consumption.

Project goals and procedure

The project's major aim was the exemplary implementation of the Circular Economy strategies of remanufacturing and repurposing. It included redesigning the production processes of three manufacturers in the metalworking industry. Another goal was to extend the life of high-quality steel and avoid losses. The extension of materials also included the quantification of material properties. In addition to a strong product focus, the project also included the investigation of regional transferability. A central concern was to use the influence of digital support, actor networks, and cooperations for regional transferability. The project was permanently accompanied by the goal of quantifying ecological and economic effects against the background of resource efficiency. Fundamental to the development of a functioning production process was selecting suitable hand tools as target products, which are suitable for removal from the industrial knife as a starting product. After surveying the status quo and investigating product-specific material properties and functionalities, the existing production processes were developed and adapted. This also included the development of a returning process and its integration into the administrative processes of the companies as well as the business model. The process of survey and development was fundamental for ecological and economic evaluation. The transferability of the application was fundamental for scaling up the effects onto the company level, followed by an analysis of the leading industrial sectors in the region. The participatory transfer formats served to disseminate the innovative project approach and identify barriers that require recommendations for action.

"CoT" – Circle of Tools

Project participants:
TKM GmbH; Kirschen-Werkzeuge Wilh. Schmitt & Comp. GmbH & Co.; P.F. Freund & CIE. GmbH; Wuppertal Institut für Klima, Umwelt, Energie gGmbH; Bergische Universität Wuppertal; PlanConsult GmbH

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Project duration:
01.07.2019 – 31.12.2022

Funding code:
033R230

Research results and measures of transfer and transmission

The research project demonstrated the feasibility of the Circular Economy in the cutlery industry. This manufacturing process avoids the energy-intensive remelting in recycling and uses the high-quality material properties in a second product life cycle. This leads to an increase in the functionality of the hand tools through improved wear resistance. The service life is increased by up to five times. This made it possible to halve energy and resource requirements and greenhouse gas emissions. The same applies to the costs. This means that the postulated ecological and economic advantages of the Circular Economy can be realized in the cutlery industry. In this context, resource- and energy-intensive processes such as grinding, and the additional process of returning must be optimized. Otherwise, there is a possibility that the ecological and economic savings will be overcompensated. The communication of the project results shows a great interest in the metal processing industry to rework scrap and use it to produce new goods. Here, material flows at a low processing stage are particularly suitable. However, the transferability must be examined individually. The selection of target products is decisive for feasibility. Factors such as geometry, suitable manufacturing processes, redesign of the target product, the ability for disassembly, and, above all, the compatibility of material properties are decisive. Economic efficiency must also be considered early in the process. The most suitable products allow the increased sustainability to be priced in and thus compensate for possible additional economic expenses.

Contribution to resource efficiency and sustainability

The exemplary integration of the value chains of three companies in the cutlery industry showed the potential ecological and economic added value of the Circular Economy. The multiple uses of steel also increased resource efficiency. Due to the material properties of the high-quality steel of the initial product, the service life of the target products can be significantly increased, which also leads to a slowing of the material flows. The actual realization of the savings in repurposing depends on the service life and the reduced production in the long term. However, the project also showed the interest and potential of a regionally concentrated industry - in this case, the cutting and metalworking industry in the Bergisches Städtedreieck. The supposed waste streams of one company can be a valuable resource input of another company.

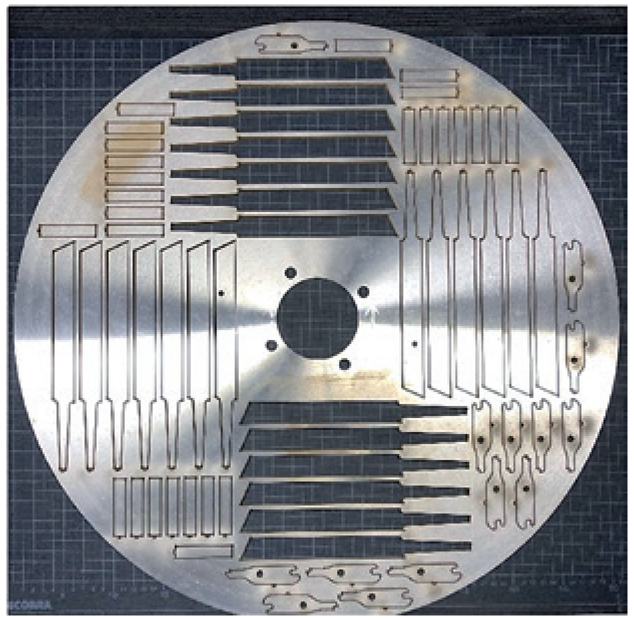

Fig. 18: Reworking of cutlery
(Source: Bergische Universität Wuppertal)

Fig. 19: Removed and ground Repurpose products
(Source: Bergische Universität Wuppertal)

Platform for efficient resource utilization in the furniture and interior design industry

Circular Economy, furniture, platform, business models, product service systems

Wulf, F. (Hochschule für nachhaltige Entwicklung Eberswalde) and Balder, J. (Technische Universität Berlin)

Context and problems

Office furniture manufacturers as well as exhibition, trade fair and scenery builders must increasingly respond to more flexible needs such as coworking offices. These new working environments were already identified in 2015[2] by the German Furniture Industry Association as the "New Work" megatrend. At the same time, a change in environmen-tal awareness among customers and increased environmental regulations are leading to the consideration of also offering furniture in a closed-loop system. Recent material shortages and price increases[3] are also causing the furniture and furnishings industries to rethink their value chains.

The research project "PERMA" picks up on these trends and aims to establish suitable business models to extend the product life cycle, especially in the areas of furniture, trade fair, event, exhibition and scenery construction. These follow the so-called R-strategies[4] (Fig.1) and enable the reduction of the consumption of primary resources as well as an increased recycling of materials.

In order to implement these business models, a platform will be established that enables the marketing of products and services as well as the exchange of resource-efficient design and production solutions for furniture construction.

Project goals and procedure

In order to achieve the project goals, circular business models (BM) were first developed in the sense of the "Product-as-a-Service" (PaaS) approach5, which can significantly extend the product life of furniture and equipment. In this approach, product ownership remains with the manufacturer, and the product is provided to customers in return for a usage fee. A planner mediates between the manufacturer and the customer and also coordinates logistics and ser-vice companies for all necessary repair and refurbish measures during the product life cycle. Planners thus have a central role, as they remain the central contact throughout the furniture's service life.

"PERMA" – Platform for efficient resource utilization in the furniture and interior design industry

Project participants:
System 180 GmbH; Kubix GmbH; StoneOne AG; Technische Universität Berlin; Hochschule für nachhaltige Entwicklung Eberswalde

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Project duration:
01.08.2019 – 31.07.2022

Project website:
www.planet.furniture

Funding code:
033R227

By providing information on the design, the necessary repair, refurbishment and reuse measures can be minimized in terms of time and cost already during the development of new furniture and interiors. Furthermore, a label is being designed in PERMA, which presents the hierarchically ordered product states separately in the categories "appear-ance" and "functionality". The development of a reusability label allows the identification and classification of the durability and reusability of a piece of furniture, as well as the service offered by the manufacturer.

In order to be able to realize the new business models, provide design information and assess product conditions, a digital platform was developed on which these activities are bundled and which connects all actors with each other.

2 Megatrends, imm cologne; Verband der Deutschen Möbelindustrie e.V., Bad Honnef, 2015

3 Verband der deutschen Möbelindustrie (2021). Materialengpässe in der Möbelindustrie verschärfen sich weiter. URL [https://www.moebelindustrie.de/presse/3431/materialengpaesse-in-der-moebelindustrie--verschaerfen-sich-weiter.html] Zugriff am 16.05.2022

4 Kirchherr J, Reike D, Hekkert M (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resour Conserv Recycl. 127: 221-232

5 Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. Journal of cleaner production, 97, 76-91.

Research results and measures of transfer and transmission

Cycle-oriented business models were defined and business and value creation processes required in the future were identified. Subsequently, the associated workflows and support processes were first formulated as user stories and then described in BPMN 2.0 with the help of the tool Signavio.

Core functionalities were defined for the platform and required data interfaces were derived and transferred into a rough concept. With the help of the resulting process landscape, the design draft for the user interface of the plat-form could be implemented. From this, a functional prototype was developed, which is continuously enhanced. At the design level, resource-efficient design rules, a concept for the condition assessment of the products offered on the platform, and a reusability label were created. Furthermore, first steps were taken to build up a partner network.In the future, by opening up the innovation process, it should be possible for participants of the platform to jointly create further innovations for the furniture and furnishings industry within the framework of a value creation net-work.

To this end, the business models found must be expanded and the business processes required for this must be defined. The platform must also include functionalities such as a WIKI for the collaborative collection and documenta-tion of experience and knowledge, a knowledge base library, and the possibility of open innovation.

Contribution to resource efficiency and sustainability

The research work has provided fundamental insights into the adaptation of circular business models for the furniture and furnishings industry. The design rules developed enable the construction of furniture that is easy to assemble, disassemble and reassemble. In terms of resource efficiency,

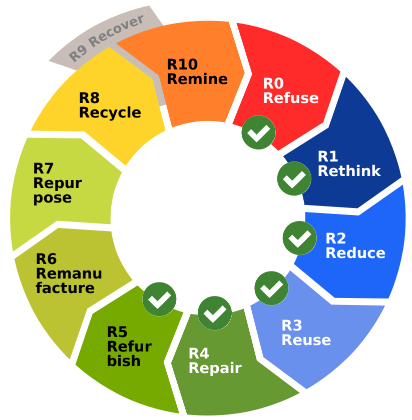

Fig. 20: R-strategies for reducing consumption of natural resources and closing material cycles with identification of those covered by the research project "PERMA" (Source: in Anlehnung an Kirchherr et al. (2017) und. Potting et al. (2017)).

energy and thus CO_2 can be saved in production, logis-tics and storage.By applying resource-efficient design rules, the design of the furniture can already take into account that it will meet the customer's needs in the long term and can be used over several periods of use. The application of the modularity principle allows the exchange of functional elements and components and thus creates the necessary flexibility to adapt furniture to the needs of different working environments over its lifetime.

The awarding of the reusability label creates competition between manufacturers to design furniture more resource-efficiently and to optimize it for the service offering in the sense of the PaaS approach. This approach also makes it possible to extend the service life of furniture and open up new markets. For example, implementing rental models makes it easier for customers to access higher-quality furniture from regional production, reducing the import of discount furniture mostly from low-wage countries and made of non-indigenous materials. Manufacturing and repair also take place regionally.

The establishment of a digital platform makes the practice of circular business models possible in the first place. Since the circular economy has been rather uncommon in the furniture manufacturing sector up to now, the estab-lishment of the platform is expected to strengthen the circular economy.

At the same time, the platform serves to form a network (Fig. 2) of research and educational institutions as well as standardization institutes, which contribute their expertise to the modular design of furniture by collaborating on the recommendations for action for the ongoing optimization of the design rules. Via the platform, findings on design rules and on circular processes are published in the form of publications or blog and social media contributions, so that other manufacturers are inspired to participate in circular economy processes. This enables a transfer not only to the participating companies, but also beyond the boundaries of the PERMA community.

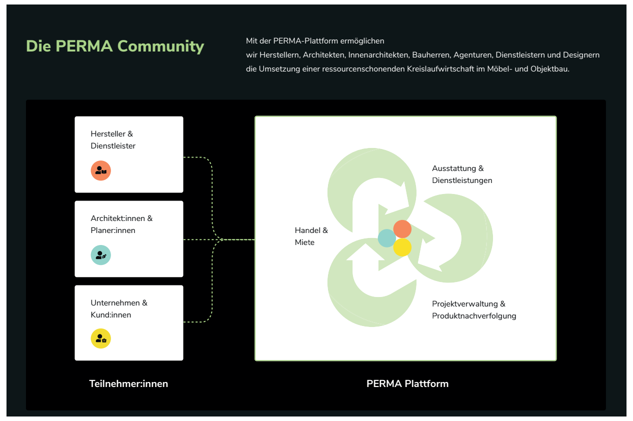

Fig. 21: "PERMA"- community website (Source: „PERMA").

Closing of cycles for building products from interior construction by means of suitable business models

Business models, interior construction, product cycle, recycling, 2nd use, amount of raw materials used, CO_2 emissions, business game

Flamme, S. (FH Münster)

Context and problems

With a transaction volume of around 136 billion euros and around 1.2 million employees in 252,000 companies, the finishing trade is the most important sector in the German construction industry. The building products used in this sector have significantly shorter turnaround times compared to carcass construction, usually less than ten years. This can be explained by a change of users or changed needs of the users, e.g., due to design aspects, technical modernization or changed space utilization concepts. While the building cover and the construction remain largely untouched, the interior finishing trades are particularly affected, so that products are often disposed before they have reached the end of their technical life. To increase the intensity of use or the resource efficiency of the materials used, a solution could be found not only in technical modifications (e.g., to improve the recyclability of building products), but also in leasing the products from the manufacturers. In this case, the manufacturers remain responsible for their products throughout their entire life cycle. Basically, two goals should be pursued within this project: 1. Extending the service life of a product, e.g., through modular conversion in existing buildings or remarketing as a second use component. 2. Securing raw materials by efficient recycling processes for the products that are not reusable.

Project goals and procedure

The aim of the "RessProKA" project was to close cycles for building products used in interior construction. In this context, manufacturers assume responsibility for their building products over the entire life cycle using suitable business models. Precondition for a functioning, resource efficient business model is the interplay of the technical cycle (product design, production, installation, use, maintenance, removal, recycling options) in a supporting legal and commercial framework. For this reason, "RessProKA" dealt with the optimization of the technical cycle under consideration of selected ecological aspects and the development of commercial and legally verified business models for recyclable products. Responsible for the return after use and the remanufacturing is the manufacturer. "RessProKA" followed a systemic approach, which conceptually and instrumentally should enable a transfer of the developed models to other building products.

"RessProKA" – Closing resource-efficient product cycles in the finishing trade through new business models

Project participants:
FH Münster, Institut für Infrastruktur · Wasser·Ressourcen·Umwelt (IWARU); Betriebswirtschaftliches Institut für Abfall- und Umweltstudien (BIFAS); Lindner Group KG, Arnstorf

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Project duration:
01.07.2019 – 30.06.2022

Project website:
www.fh-muenster.de/forschung/forschungsprofil/projekt.php?anzeige=projekt&pr_id=1020

Funding code:
033R250

Research results and measures of transfer and transmission

Within the scope of the project, three selected products of the Lindner group representing the floor, ceiling and wall were considered as examples. Being the pilot product, the NORTEC raised floor was considered first and the procedure was then transferred to the steel ceiling sail and qualitatively to a system wall. First, the products were evaluated from a technical point of view. To enable recycling and at best reuse of the products, an easy removing and, if possible, standardization of the components must be ensured. Both the raised floor and the ceiling sail already offer a high potential in this regard. With the system wall, standardization, e.g., by adherence to grid dimensions, is required. The business models developed include so-called "Circular Economy modules" such as the agreement of an obligation to return, a right to return and the offer of 2nd use products, services within the contract period and the selection of financing models. These modules were subjected to an initial simulated practical test by means of business games in which customers of the Lindner group as well as production engineers and service providers from the real estate industry took part. Among the issues discussed were the role of CO_2 assessment, the potential cost impact, and the desire for services. As a result, there was a great interest in the developed business models and the willingness to use 2nd use products. Above all, great importance was attached to the consideration of the CO_2 balance. This was carried out within the ecological evaluation together with the calculation of the amount of raw materials saved. By implementing the business models developed, up to 42 % of the CO_2 equivalent emissions and up to 48 % of the raw materials could be saved for the raised floor. The corresponding economic effects were examined during a dynamic scenario analysis. The analysis of the raised floor showed that, in terms of costs, the circular model is already superior to the status quo. For the 2nd use products, cost reductions between 10 % and 25 % can be achieved. In the scenarios considered, it was showing that this range will increase significantly as energy and CO_2 prices rise. To implement the developed business models in practice, a legal assessment is also required. This focused on the framework conditions under civil law and tax law, with the result that the business models can already be implemented under the current jurisdiction of the civil law. In terms of tax law, however, further clarification is necessary. The transferability of the business models to other building products and other building sectors has already been discussed with associated partners such as Schüco, e.g., for the windows, exterior doors or facade segments, and the resource Stiftung e. V. as an independent initiative from business, society, science, and politics, and will be pursued further.

Contribution to resource efficiency and sustainability

The process- and practice-oriented development of business models based on the example of Lindner products enables recycling friendly deconstruction and reuse or recycling of the elements of interior construction. This allows significant savings in raw materials and CO_2 equivalent emissions. In the flooring sector, initial approaches are already being implemented by offering refurbished gypsum fiberboards as 2nd use products. In addition, pilot projects have already been initiated. Within the intensive consideration of the individual process steps, a transferability to other building products and other building sectors is given.

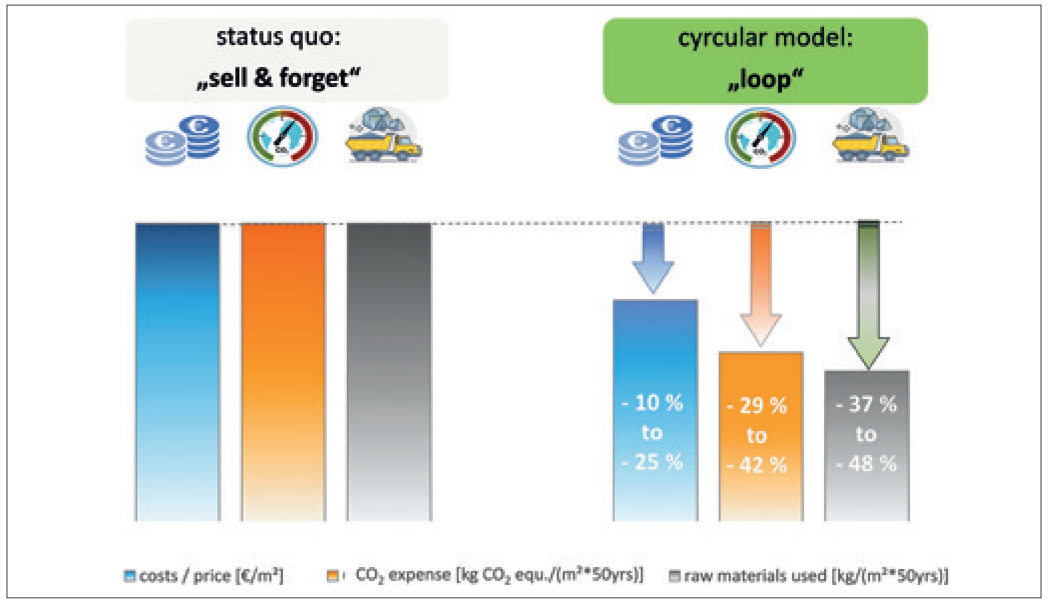

Fig. 22: Economic and ecological effects (Source: "RessProKA")

Can fashion rental make the industry more sustainable?

Access over ownership, Circular Economy, clothing and textiles, business models, fashion rental, sustainable fashion, product service systems, collaborative fashion consumption

Bodenheimer, M. (Fraunhofer-Institut für System- und Innovationsforschung)

Context and problems

The European Union estimates that between two and ten percent of the negative environmental impact of consumption in the member states is associated with the fashion industry.[6] This burden results, among other things, from the fact that so many items are sold, but only used rarely. The potential for resource savings in this sector is considerable, since on average one in three garments is never worn or worn less than four times a year.[7] To address these problems, the use of individual garments needs to be intensified, thus reducing the need for new production. Possible solutions are either that people wear their clothes longer and more often and at the same time buy fewer of them, i.e., slow fashion, or that items are worn by several users in succession. This principle is used in fashion rental models, where customers rent clothing for a certain period before the same items are then rented out to the next user. This can significantly intensify the use of individual items of clothing.

“Wear2Share” – Innovative circular business models in the textile industry

Project participants:
Fraunhofer-Institut für System- und Innovationsforschung ISI; Thekla Wilkening/Cool Circles UG; bubble.kid berlin kidswear; Ehemals Relenda GmbH

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Project duration:
01.07.2019 – 30.06.2022

Project website:
https://t1p.de/prejn

Funding code:
033R248

Project goals and procedure

The aim of the project “Wear2Share” was to investigate the ecological and economic sustainability of fashion rental models and to identify optimization potential from an ecological, business and consumer psychology perspective. The core of the project was a close cooperation with the management of the former Relenda GmbH, who had years of experience in renting out sustainable women’s wear and children’s fashion and provided researchers with in-depth insights into their business model. This made it possible to prepare a realistic economic analysis of the concept, identifying both the biggest hurdles and opportunities for the future. This information was supplemented by an analysis of the market potential, which was based on customer and two representative target group surveys. Furthermore, two stakeholder workshops were held with representatives from the textile industry and its periphery, and interviews were conducted with experts. To assess the environmental sustainability of the business model, a simplified life cycle assessment according to DIN EN ISO 14040 (2021) was carried out, which considered the impact categories greenhouse gas potential (GWP100), cumulative energy demand (CED) and water use.

Research results and measures of transfer and transmission

To start with, the good news is that fashion rental has a more favorable environmental balance compared to online shopping, as the water and energy saved to produce new garments outweighs the energy required for higher transport loads due to repeated shipping. The savings potential for the modeled case of women’s outerwear with real-world usage data is about 31 % for greenhouse gas emissions and cumulative energy use, and 37 % for water consumption (Fig. 23). Savings are possible as of the second rental cycle. However, the sensitivity analyses also show that savings can be lost due to incorrect user behavior, such as long car journeys during return shipping, many washing cycles and the use of tumble dryers.

6 www.europarl.europa.eu/RegData/etudes/BRIE/2019/633143/EPRS_BRI(2019)633143_EN.pdf
7 www.greenpeace.de/si-tes/www.greenpeace.de/files/publications/20151123_greenpeace_detox_ergebnisbe-richt_fast_fashion.pdf

The target group surveys showed that 32 % of the women and 53 % of the parents surveyed can imagine renting clothes; women can also picture using a subscription model, which is common in the industry. In the case of subscription models, the price is the decisive criterion for the respondents, more important than the number of items, frequency of change, sustainability or brands that can be obtained via the subscription flat rate. Motivations for renting include not having to buy clothing that is only used once (77 %), avoiding bad purchases (61 %) and the opportunity to try out new styles (60 %). Many of the respondents are also motivated by environmental considerations (53 %). One factor that is often underestimated is a hurdle: trust. Sharing economy business models based on collaborative consumption are based on trust. Sensitive issues for potential customers of fashion rental models are the question of liability for damages (70 %), the fear of paying more money in the end than if the product was bought directly (53 %) and doubts about the quality of the rented products (55 %). The desire to own clothes instead of renting them also still plays a significant role (66 %). Also hindering is the lack of awareness of alternative consumption models: only 39 % of respondents know about the possibility to rent clothing, and two-thirds of respondents have never heard of the concept. The last point is a major challenge for the business model, where customer acquisition and retention proved to be very expensive. In combination with the high price pressure on the market caused by the oversupply of cheap fast fashion, the business model quickly reaches its limits when applied to everyday clothing.

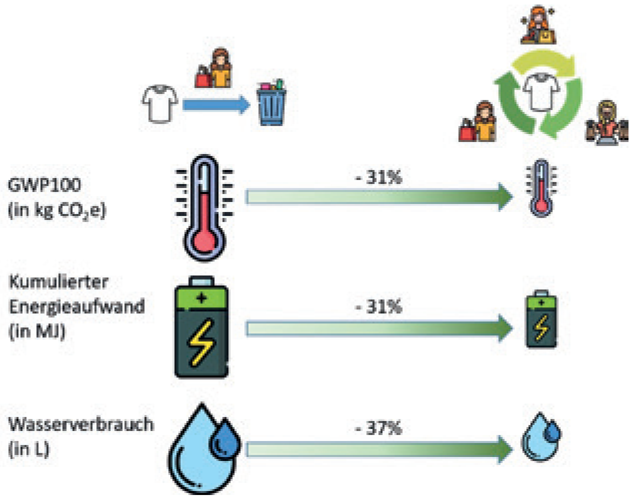

Fig. 23: Comparison of the project results of the life cycle assessment of a linear purchase model (left) and a closed-loop model (right) for women’s outerwear (Source: Fraunhofer ISI, Flaticon).

Contribution to resource efficiency and sustainability

The exchange with practitioners was at the heart of the project. In addition to detailed discussions with the management of Relenda GmbH, workshops and interviews were also held in which the project results were discussed and further developed with a total of 27 representatives from manufacturing, logistics, retail, rental, and aftercare. Based on these exchanges, several recommendations can be derived to better develop the clearly existing resource efficiency potential of fashion rental models in the future. For future providers of rental fashion, it is recommended to start with a range of high-priced and durable garments for special occasions and to plan for high marketing investments to increase awareness of the offer. Once this model is successfully established, subscriptions for everyday fashion should be introduced, which can significantly increase the sustainability potential further. To support this development, the general conditions on the market must also change. For example, extended producer responsibility would create incentives for manufacturers to make their clothing more durable. This would allow individual items to be rented out more frequently, which would be welcome from both an environmental and a business perspective. A reduction in value-added tax for sustainable business models could counteract the competitive pressure from cheap but less sustainable fast fashion. Insurance solutions adapted to the business model are needed to reduce customer concerns about liability for damages and thus remove a major hurdle to participation.

Data-based business models for the cascade use and extended product use of electrical and electronic devices

Electronic products, Circular Economy, cascade use, extension of use, repair, remarketing, sustainable business models

Eichert, C. (RITTEC Trade + Consulting GmbH & Co. KG)

Context and problems

Electrical and electronic products have become indispensable in modern societies. Due to higher incomes, shorter product life cycles and global industrialisation, more and more electrical and electronic products are introduced into the market.1 The multi-material composition, the different connection techniques and the products optimised for manufacturing/assembly are complex. The linear principle of the industrial economy, which is based on the make, use, and dispose pattern, has reached its limits. The amount of e-waste is increasing worldwide by around 2 million tonnes per year. In 2030, 74.7 million tonnes of electronic waste are expected.[8] The resulting considerable environmental impacts and the increasing loss of resources must be counteracted by a closed loop, circular system.

Project goals and procedure

Against this background, the project "EffizientNutzen" aimed to significantly increase the service life and especially the useful life of electrical and electronic products. Besides the analysis of current market structures or the development of sustainable business models (see Fig. 24), two central fields of action were pursued in the project:

- Repair of electrical and electronic products" (see research results I), as well as
- "Remarketing of used electrical and electronic products" (see research results II).

"EffizientNutzen" – Data-based business models for the cascade use and extended product use of electrical and electronic devices

Project participants:
RITTEC Trade + Consulting GmbH & Co. KG; Robert Bosch GmbH; Circular Economy Research GmbH; TEQPORT Services GmbH; TU Braunschweig; TU Clausthal

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Project duration:
01.07.2019 – 31.12.2022

Project website:
www.effizientnutzen.de

Funding code:
033R240

Research results and measures of transfer and transmission

I) Repair of electrical and electronic products
Within the framework of the first field of action "Repair of electrical and electronic products", a cost-free and manufacturer-independent repair study with accompanying participant surveys was carried out over a period of 18 months. The findings were recorded in many repair manuals and publications (Rudolf et al. 2022). At the end of the repair study, it was shown that 58 % of the 524 repaired electrical and electronic products could be repaired within an average of 5.5 hours and thus an extension of use could be achieved. For an economic repair, the new price of a product must be at least 90 € on average. Most customers are willing to repair electrical and electronic products if the repair costs are 20 – 40 % of the new purchase price. Surveys conducted and analysed within the project revealed that repair has an image problem (Hieronymi et al. 2020). One of the reasons for this is the lack of trust in the quality and durability of used equipment, which is usually difficult for potential buyers to assess. Based on the results of the repair study, a repair portal prototype was developed with the aim of reducing the repair time and thus the costs for repairs through easy access to repair instructions for (professional) repairers (see recommendations for action in Rudolf et al. 2022). The underlying business model is now being further investigated to make it accessible to other actors.

8 Forti, V.; Baldé, C.; Kuehr, R.; Bel, G. The Global E-Waste Monitor 2020. Quantities, Flows, and the Circular Economy Potential; International Solid Waste Association; ISBN 978-92-808-9114-0.

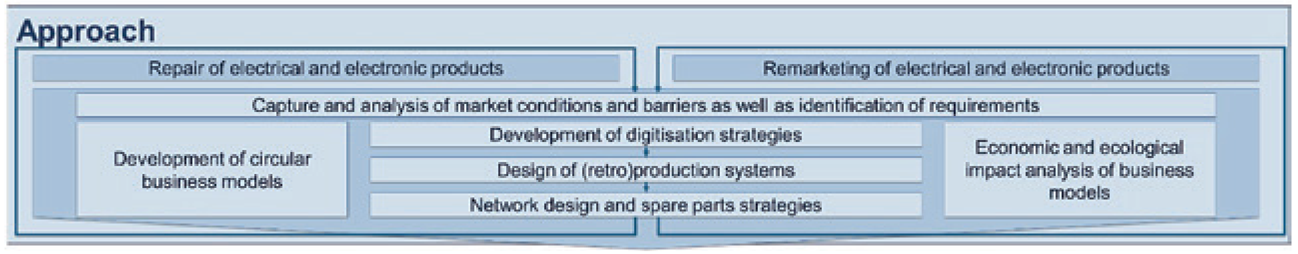


Fig. 24: Procedure and work packages in the Project "EffizientNutzen" (Source: "EffizientNutzen")

II) Remarketing of used electrical and electronic products
Within the framework of the second field of action "remarketing of used electrical and electronic products", it was possible to develop an innovative method for the design of sustainable business models (see Fig. 26, Niemeyer et al. 2022). In the project, central barriers and recommendations for action for the remarketing of second-hand equipment were developed. Currently, the establishment of an initiative entitled "Initiative Gebraucht" (working title) is being examined, which can propagate the topic of "second-hand equipment" and contribute to an increased use of second-hand equipment by means of measures (e.g. the development of quality criteria that are easy to apply, legal protection of expectations of second-hand equipment, guidelines for reuse).

Contribution to resource efficiency and sustainability

The research results and the business models developed contribute to reducing barriers to second-hand appliances, closing resource cycles and transparently show customers the positive environmental effects of sustainable consumption. At best, this will lead to a rethinking of the purchase of second-hand appliances and the use of repair services. It has been shown that it is economically possible to achieve an extension of use through repair or remarketing and thus save primary resources for the production of new electrical and electronic products.

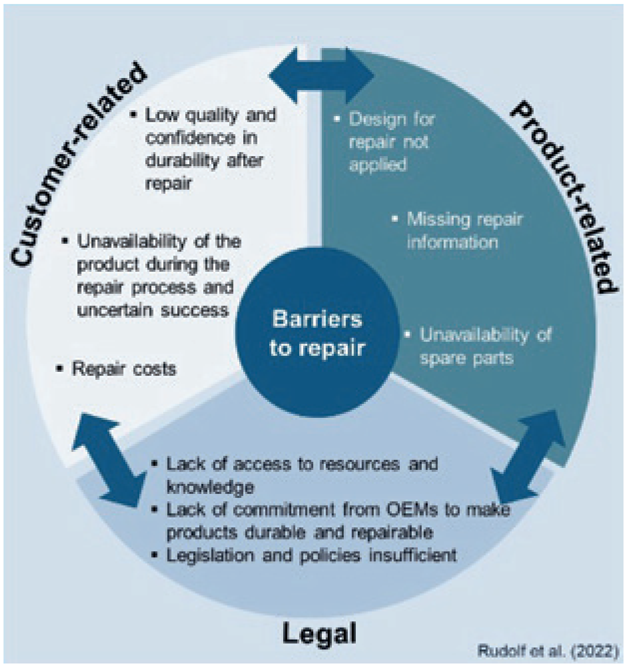
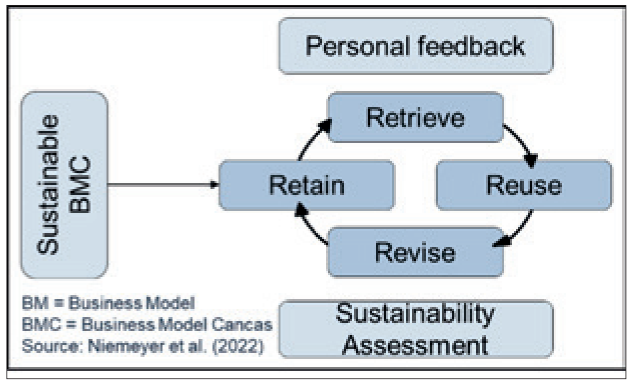


Fig. 25: Repair barriers (Source: Rudolf et al. 2022).



AFig. 26: Methodology for BM-development
(Source: Niemeyer et al. 2022).

Prognosis of the remaining useful life of technical systems

Machine components, component lifetime, predictive maintenance, resource efficiency, condition diagnosis, remaining useful life prognosis

Tietjen, T.; Westphal, I.; Egbert, L.; Steindfeld, M. and Zitnikov, A. (Universität Bremen/BIK/BIBA)

Context and problems

The technically possible service life of components is often not exhausted. One reason for this is that maintenance cycles are often too short dimensioned, which can, among other things, dictate replacement. Safety factors play a significant role in machine design, which is usually calculated to avoid failure under predictable conditions. However, risks related to unplanned operational failures are very difficult to plan for, as are the associated consequential damages. Therefore, components are disposed of earlier than necessary, which represents an avoidable consumption of resources. This situation can be countered with a modified, resource-efficient maintenance strategy. This requires a methodology for determining the condition and predicting the remaining useful life of critical components. To ensure that this option of using components for a longer amount of time is applied, supporting business models are required that benefit both the machine/component manufacturer and the machine user.

Project goals and procedure

With the help of external sensors, the condition of a technical system can already be recorded directly or indirectly. The aim here is to check compliance with design parameters of critical components. The implementation requires a detailed examination of the components to be monitored and their potential damage patterns and associated damage mechanisms, which are recorded using physical measured variables. Based on the identified measured variables, a suitable sensor system is selected. It can be integrated directly into the machine or attached in the form of a mobile inspection station (MIS), which also saves costs. The MIS developed as part of the project has a modular design and it´s integrated sensors can be customized according to the appearing damage mechanisms. The MIS also makes a small contribution to resource conservation, since not every machine has to be equipped with sensors. In addition to the sensor technology, a software solution is required in which current data from machine operation is merged with historical data classified according to the component conditions. This means that data from known cases of damage are assigned to the currently recorded data from operation. Starting from this data basis, a rule-based approach is necessary

"LongLife" – New business models for the continued use of technical systems based on a simple, decentralized status determination and forecast of residual service life

Project participants:
Universität Bremen/BIK; Aimpulse Intelligent Systems GmbH; CoSynth GmbH & Co. KG; encoway GmbH; DESMA Schuhmaschinen GmbH

Coordinator:
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Project duration:
01.07.2019 – 31.12.2022

Project website:
www.longlife.uni-bremen.de

Funding code:
033R246

to classify the current condition of the component. If the collected data cannot be assigned to a state, the data basis must be reclassified, or these data must first be assigned to a similar state. Classification here is an iterative process through which the condition diagnosis becomes steadily more precise as new damage cases arise.

Research results and measures of transfer and transmission

As one result of the considerations on Business Models (BMs) that support the "LongLife" approach of extending the service life of technical components some characteristics of potential application scenarios were identified that are relevant for the design of suitable BMs. On the one hand, it became apparent that it is frequently necessary to involve a network of partners to generate the desired added value. The performance relationships in such a network go beyond a mere transactional exchange and can be characterized more as cooperative or collaborative. Thus, the chosen approach is to configure BMs according to the requirements of the involved partners based on the defined reference building blocks. The savings of material that are result of an extended service life are in many cases not sufficient to finance the development of the prognosis model. Therefore, the BMs have to consider further value propositions, e.g., transparency regarding a reliable remaining service life of the component and the added value that the gathered data related to conditions of components could provide for their further development.
The mathematical approach for quantifying component wear is based on a target/actual comparison of relevant measured variables and forms the basis for the remaining useful life prognosis. First, the failure-critical components were identified for the machines in the application cases under consideration. These machines already have integrated sensor technology, which was supplemented by the developed MIS. The MIS is designed in such a way that it can be integrated as easily as possible into the data technology of the machine users, and the data obtained is incorporated into the mathematical model developed for condition determination and remaining useful life prognosis. The procedure developed in the project can also be applied to different technical systems.
The same applies to the developed procedure for analyzing the use case and the approach for business model configuration based on described reference modules. This can be transferred to other use cases of the Circular Economy aiming at extended useful life of components. The prototyped business model configurator was used for concept verification but can also provide inspiration for other use cases.

Contribution to resource efficiency and sustainability

The condition-based maintenance approach extends the useful life of components in technical systems, thus eliminating unplanned downtime. Premature replacement of components is avoided, thus saving resources. Furthermore, service calls by maintenance technicians are reduced, the plannability of maintenance work is increased and thus the costs for the machine user are reduced, which at the same time contributes to a more environmentally friendly use of resources. In addition, there is the possibility of process adaptation to be able to continue using components that are already worn out under lower stress. The use of the MIS also eliminates the need to install additional sensors on the individual technical systems. The value proposition of the business models for this Circular Economy approach is not primarily based on material and energy savings. Rather, this is a positive side effect of the focus on the added value of reliability. A quantified statement regarding resource efficiency can be made with an increasing number of successful use cases.

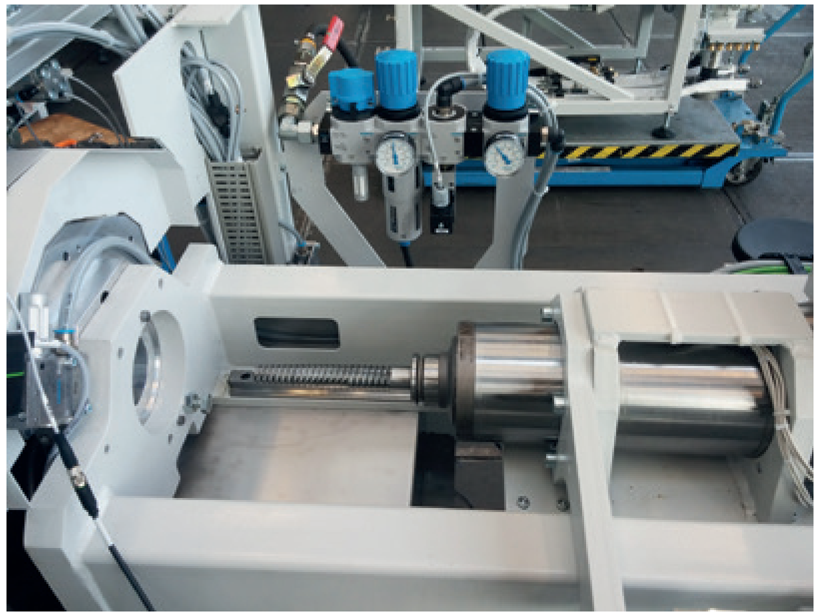

Fig. 27: A drive spindle of a shoe machine as good as new which becomes clogged during operation and thus initiates changed operating parameters (Source: "LongLife").

Fig. 28: A retaining strap showing signs of wear after approx. 280,000 load cycles
(Source: "LongLife").

Resource efficiency through smart pumps: Enabling high-quality circulation on a component basis

Heating pumps, Technical building equipment, resource efficiency, Circulation, Re-use, Climate protection, Digitalization, Remote processes

Fetting, T. (WILO SE)

"ResmaP" – Resource efficiency through smart pumps

Project participants:
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Project duration:
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Funding code:
033R233

Context and problems

State-of-the-art, "smart" heating pumps rely on several electronics components that allow – in addition to efficiently controlling the pump's operation – for remote maintenance operations and condition monitoring. These pumps collect data throughout their product lifecycle enabling a better understanding of the condition of individual parts at their end of life. However, more electronics components in the pumps also increase their environmental footprint. In the research project "ResmaP", the partners aim to identify ways to increase the overall resource efficiency of pumps throughout their entire lifecycle based on the possibilities emerging from the pumps' additional functionalities. Heating pumps are part of the technical building equipment and are as such underlying the same global trends surrounding the construction and operation of buildings: Demands for more living comfort and efficiency of buildings lead to increased linkages between technical devices and thus, specifically regarding the production of electronics components, higher resource consumption. Additionally, more usage-related data is collected throughout the product lifetime and can be exploited. The consortium thus assume that heating pumps can be seen as a representative product for other parts of the technical building equipment and – if circumstances allow – findings from the project can be transferred.

Project goals and procedure

To achieve the project's goals, the consortium has identified four key research questions: (1) How can "smart" contribute to increasing circulation and material efficiency of heating pumps? (2) How must supporting processes and organizational structures be designed? (3) How big is the potential for resource savings and efficiency gains? (4) Which results from the project can be transferred?

The consortium worked on these research projects across four work packages. Starting with an as-is analysis (WP 1), the state of the art for technological and organizational framework conditions was processed and transferred into a design for the ecological assessment and pilot operation. This work package also encompassed a review of the current legal framework and relevant business model innovations. Based on this, during the pilot operation (WP 2) a comprehensive amount of data was collected to enable an assessment of the condition of the pumps' parts and components based on the operational parameter and environmental conditions. Additionally, occurring error patterns have been analyzed to identify starting points for remote maintenance and repair operations as not every error occurring requires physical presence of a technician to be fixed. Data from the test operation was then used in the work package optimization (WP 3). Data was processed and assessed to support the environmental analysis as well as technical and operational implementation. During the project's networking activities (WP 4) specialized tradespeople were addressed in addition to the scientific community. Due to the products' long lifetimes that regularly surpass legal warranty requirements, specialized tradespeople are an important link between customers and manufacturers. They were thus introduced to the project's topics as part of a stakeholder engagement process and survey regarding their attitude towards them.

Research results and measures of transfer and transmission

Although remote maintenance of pumps is currently not state of the art and market penetration of smart pumps is only increasing slowly due to the products' long lifespan, the consortium could identify several scenarios in which a remote repair of failures is potentially possible, directly saving driving and working hours for technicians as well as transport emissions. As an increased share of smart pumps is expected for the future, these potentials will grow accordingly. These findings can generally be transferred to other parts of the technical building equipment. Depending on the technical condition of collected, defective pumps, a variety of options for the circulation (i.e., recycling, refurbishing, reuse) of a significant share of their parts and components is possible. More than 80 % of collected electronic control modules can be reused in total or partly while preserving a high level of value creation. This component accounts for roughly 45 % of the total emissions related to the pump's production. A reuse is thus reasonable from a resource efficiency and climate protection perspective. Through the stakeholder engagement process, the project consortium could identify a high awareness for the topics digitalization, resource efficiency and reuse/circularity. As a high percentage of newly produced pumps is used to replace older pumps and only a fraction of the production goes into new buildings, this high awareness within the community of specialized tradespeople is of high relevance for the long-term success of the topics addressed by the project.

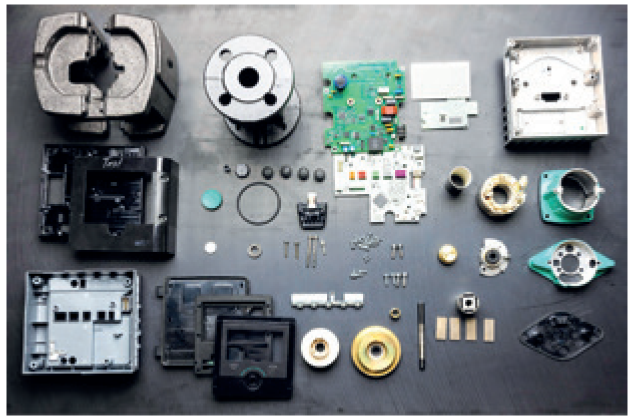

Fig. 29: A disassembled heating pump (Source: WILO SE).

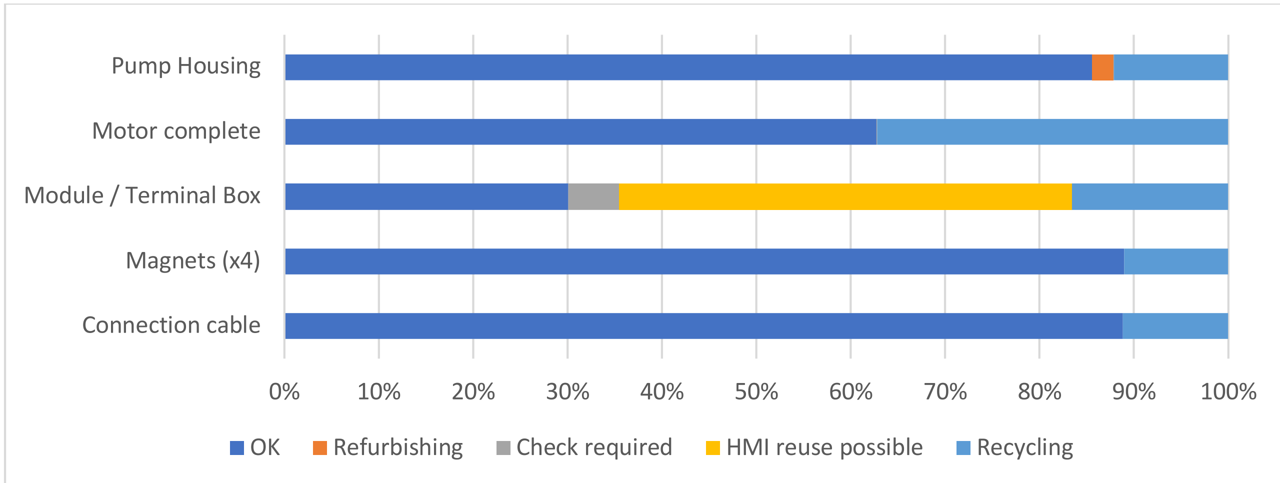

Fig. 30: Circulation options on component level (Source: "ResmaP").

Contribution to resource efficiency and sustainability

Within the project, the consortium could demonstrate that a targeted, high-quality circulation of components, especially in electronics parts, is possible and the initial surplus emissions due to the production of the electronics parts can be at least partially compensated by applying these principles to increase longevity and reusability. The feasibility was demonstrated exemplary in a company with a high manufacturing depth and from the consortium's understanding the underlying findings can be transferred to other complex, technical products in the field of technical building equipment and investment goods. However, some fields of action could be identified that are relevant to be addressed to enable a transfer of the research findings into a company's day-to-day business operation. The main concern are legal uncertainties regarding the reuse of reclaimed components as new parts or like-new parts (assuming they pass the same technical examinations as new parts).

Sustainable product design of consumer goods using the case study refrigerator/freezer

Energy and resource efficiency, recyclate use rate, WEEE, product design, remanufacturing, recyclability

Raatz, S. (Helmholtz-Institut Freiberg/Helmholtz-Zentrum Dresden-Rossendorf)

Context and problems

To ensure a stable supply of raw materials to the German economy in the future, rethinking the use of primary and secondary raw materials is urgently needed. According to Eurostat, the recyclate use rate has barely changed since 2015 (the start of collection) until today, rising from 11.6 to 12.2 percent. One of the reasons for this is that the recyclability at the end of life (EoL) has hardly been considered in the manufacturing of products (product design). This is where the "Circular by Design" project comes in, to show, using a specific household product, which material efficiency potentials are available about the recovery of the raw materials contained, both in terms of the constructive product design and the choice of materials.

Project goals and procedure

The central objective and innovation of the "Circular by Design" project was to evaluate the standardization and design process of a prototype refrigerator/freezer, which should be optimized not only for energy efficiency but also for resource efficiency. One of the most frequently used and already well characterized consumer goods, the refrigerator/freezer, served as an example. A current refrigerator model from the manufacturer Liebherr represented the starting point. The aim was to run through various design scenarios during the project period within a Living Lab design process and to design different variants whose modular structure and intelligent material composition allow almost complete recycling and the reuse of individual components, thus opening new market/business models (repair, cash-back, leasing, etc.). With the cooperation of the project partners Becker Elektrorecycling (BEC) and Entsorgungsdienste Kreis Mittelsachsen (EKM), and based on the current reference product, which is particularly geared towards energy efficiency, the quantification of actual losses will be used to show where raw materials are lost, how these losses can be reduced through a suitable product design and how raw materials can be kept in the cycle for as long as possible.

"Circular by Design (CbD)" – Sustainable product design of consumer goods using the case study refrigerator/freezer

Project participants:
Helmholtz-Zentrum Dresden-Rossendorf e.V.; Wuppertal-Institut für Klima, Umwelt, Energie gGmbH; Folkwang Universität der Künste; BEC Becker Elektrorecycling Chemnitz GmbH; EKM Entsorgungsdienste Kreis Mittelsachsen GmbH

Coordinator:
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Tel.: 0351 260-4747

Project duration:
01.07.2019 – 31.12.2022

Project website:
https://innovative-produktkreislaeufe.de

Funding code:
033R244

Research results and measures of transfer and transmission

With the help of the publication on the cultural history of refrigeration produced in the project, one can follow the constantly increasing complexity of the product "refrigerator/freezer" along a timeline. For example, initially there were no electronic components at all built into the interior, but now there are up to six printed circuit boards that support the display or the ice crusher in their function. This development, in combination with the difficult-to-detach connection types (gluing instead of plugging), makes it increasingly difficult to dismantle the product at the end of the use phase and thus to recover pure material streams. In order to be able to assess the product design of current and older refrigerators/freezers comparatively with regard to their repair and recycling friendliness and to derive design options from this, a

simulation tool is needed, at the end of which, among other things, there is a recycling index. A first model was created. This includes both the physical initial treatment for refrigeration devices (crushing and pre-sorting) and the further treatment steps of the metallic material flows (metallurgical treatment) and can map a process simulation if required. For further qualification of the simulation tool, detailed product and material information must be entered to provide information on recyclability, quantified by indicators for material recovery, environmental impact, and resource consumption. Since such data are currently not available, individual devices were manually disassembled in the laboratory and 100 units were processed in a realistic large-scale test at STENA. The evaluation of the large-scale test is currently underway. The related micro-level evaluation approach includes a digital model for refrigerator recycling, which is intended to estimate recyclability in the form of material-specific recovery rates (according to DIN EN 45555).

Proposals for improving Resource efficiency and sustainability

1. The technical components are concentrated in one technical unit and not distributed and foamed into the whole device, as up to now. Due to the compact design, the coolant can be easily extracted, and the electronic components can be easily removed.
2. The service life of the refrigerator/freezer is extended by a modular design, as it is easier to repair individual parts. Defective parts can simply be replaced or sent for repair by post.
3. Defective parts can simply be replaced or sent for repair by post to the producer.

Wherever possible, high-alloy stainless steels and non-recyclable plastics are not used, plug-in connections are used for easy disassembly, and information and services can be quickly accessed via product-specific identifiers on individual components.

Due to the proposed modular, disassembly-friendly design, which is flexibly adapted to the size of the household, the material-efficient design concept contributes significantly to the recycling of the materials used in consumer goods. It is assumed that there is an enormous savings potential that can be achieved by reducing the use of materials, substituting non-sustainable materials such as PU foam or coolants and improving the recycling of materials by sorting. By avoiding downcycling, the quality of the recyclate and thus the recyclate use rate increases to the same extent.

Fig. 31: Comparison of the content of electrical components in refrigerators/freezers: year of manufacture approx. 2000 (left), year of manufacture 2019 (right) (Source: Own images HZDR, M. Heibeck, 2021).

Fig. 32: Fridge with technical unit between refrigerator and freezer (Source: Own illustration Wuppertal Institute, C. Tochtrop, C. Richter, 2022).

Potentials through modularity

ICT, modularity, smartphones, user perspectives, use-time extension

Proske, M. (Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration)

Context and problems

According to Bitkom, more than 20 million smartphones were sold in Germany in 2021. 60 % of users have purchased their device within the last 12 months and the average useful life of smartphones is increasing slightly, but is still only 2.5-3 years, with technical defects not accounting for most replacement reasons. At the same time, device manufacturing requires many valuable raw materials, some of which are critical, and is associated with a greenhouse gas potential of 40 to 100 kg CO_2e – only a fraction of which can be recovered through recycling. Modular smartphones have the potential to both reflect technical progress through upgrades and meet changing consumer needs. This enables a longer useful life, reducing the number of devices and their environmental impact. To unleash positive potentials of modular design and minimize undesirable consequences, "MoDeSt" developed technical, social, and economic prerequisites and solutions for modular concepts.

Project goals and procedure

In addition to acceptance and interest, modular smartphones also require specific user skills on the part of the user, such as knowledge of repair options and upgrades. This enables longer periods of use. In order to leverage the positive potential of modular construction and minimize negative effects such as additional consumption, the "MoDeSt" project investigated the technical, social and economic prerequisites for modular concepts and developed approaches to solutions for recyclable and socio-ecologically sound modular technologies.

The innovative project comprised a broad, transdisciplinary consortium. The integration of research and practice as well as technical and socio-scientific competences formed the basis for a holistic approach to the research task. First, conventional, and modular smartphones were examined in the technical analysis with regard to various Circular Economy aspects. In the next step, life cycle assessments were created to map different usage, repair and disposal practices through scenario building and evaluate them in terms of material and resource efficiency. Existing business models for modular products were analysed and new approaches developed. Based on these joint findings, the modular approach was further developed, aiming at both concrete technical revisions and the development of general eco-design criteria.

"MoDeSt" – Product circularity through modular design – strategies for long-lasting smartphones

Project participants:
Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (IZM); SHIFT GmbH; TU Berlin, Fachgebiet Transdisziplinäre Nachhaltigkeitsforschung in der Elektronik; Leuphana Universität Lüneburg, Centre for Sustainability Management; AfB gemeinnützige GmbH; Johannes-Kepler-Universität Linz (JKU), Institute for Integrated Quality Design (assoziierter Partner)

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Project duration:
01.07.2019–31.12.2022

Project website:
www.modest-projekt.de

Funding code:
033R231

Research results and measures of transfer and transmission

A review of the smartphone market up to 2000 showed the enormous variety of models and manufacturers on the market. The peak in 2014 was 839 new models. Despite this large number of different devices, there is a clear trend in technical features. In addition to the increasingly better equipment with (working) memory, higher display resolution and battery capacity, the market has developed toward significantly larger displays through better utilization of the front (screen-to-body ratio) as well as through larger, but flatter devices. Removable batteries have gone from being a standard to a niche product. Smartphones are increasingly taking over functions from other objects (e.g., alarm clock, stereo system, cameras). They thus already integrate many modules, but these cannot be varied; it is a static modularity. Even sufficient users discover more and more new functions, which they integrate into their everyday practices. The expectations for functions and performance are generally high. Even ecologically oriented users replace their devices as soon as the performance is no longer optimal. Therefore, value-based communication of durable devices is not enough. Modular product service systems (PSS) should focus on the functional expectations and usage patterns of different user groups. Based on this, a survey with SHIFT users shows that a circular attitude influences the repair experience with instructions and thus previous experience should also be included in the provision of services.

Different types of modular smartphones are conceivable and must be tailored to the selected business model and usage scenario. Analogously, suitable complementary services (such as repair services or take-back systems) must be offered for PSS to extend the service life. Modular smartphones, for example, are more often repaired themselves with the help of repair instructions. Modularity offers numerous advantages for all players in the value chain. However, the positive ecological effect is not a given, but must become part of the strategy. Policymakers should create incentives to tax material consumption to create the conditions for greater modularization of devices in supply chains and value creation models. Environmental assessments show that repairs, upgrades, and module replacements pay for themselves when they lead to longer useful life. This requires the technical enabling of such replacements, the provision of (new or used) spare parts by means of suitable business models, and acceptance on the part of users.

The results of the project will be used to increase the market penetration of modular devices. They can serve as important development indicators for smartphone manufacturers. The results of the business model design can be used by producers, distributors, and circular service providers to implement economic potentials of modularization strategies and to set impulses for a longer service life. The applied methods can provide important impulses for the technology and promote the development of integrative Circular Economy strategies. Within the framework of scientific publications, the results will be made available for the further development of the discourse on the transition to an integrative Circular Economy.

Contribution to resource efficiency and sustainability

The main environmental aspects of smartphones – and mobile ICT in general - are linked to the manufacturing phase. Of the many raw materials used, the largest proportions (iron, copper, aluminium, and precious metals) can currently be largely recovered. However, (profitable) recycling routes are still lacking for many materials, and some of the raw materials are lost due to misallocation during processing. In addition, the high manufacturing costs in the production of electronic components cannot be recovered by recycling. This is where the extension of useful life comes in, so that fewer devices must be produced. There are many ways to achieve this - better utilization of the technical service life through replaceable batteries and long-lasting software support, business models that take repairs, second and third uses into account from the outset, and active users who select devices tailored to their needs and use them for as long as possible.

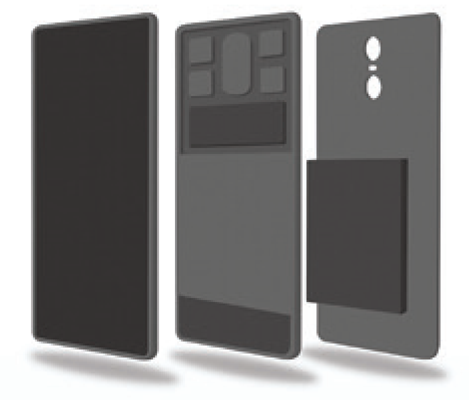

Fig. 33: A look into the future – modular smartphone (Source: SHIFT)

Fig. 34: Discussion on modular business models (Source: CSM)

On the path towards establishing reusable packaging in e-commerce

Re-use, online e-commerce, packaging, waste, e-commerce, reusable box, reusable shipping bag

Zimmermann,T. (Ökopol Institut für Ökologie und Politik GmbH)

“Praxpack” – User-integrated development and testing of business models for reusable packaging solutions in online retailing

Project participants:
Ökopol; Tchibo; OTTO; Avocadostore; GVM; Cargoplast; RePack

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Project duration:
01.06.2019 – 31.12.2022

Project website:
www.praxpack.de

Funding code:
033R243

Context and problems

E-commerce in Germany and Europe has been growing steadily for years. The Corona pandemic has given this development an additional acceleration. The products sold through e-commerce are typically packed in disposable shipping packaging such as cardboard boxes or plastic bags, which are then disposed of by the end consumers after receiving the goods. This results in high resource consumption and high waste volumes; in 2021, waste from shipping packaging amounted to over one million tons. However, these developments must be seen in the context of the efforts made by the e-commerce industry in recent years to reduce the amount of packaging and the resulting consumption of resources. This includes the reduction of average packaging weights through optimised paper and board packaging materials as well as the increasing avoidance of multi-material composites. This means that the specific optimisation potentials at the level of individual packaging have already been largely exhausted. Therefore, innovative solutions at the packaging system level and adjustments to the business models are required to break the trend of steadily increasing resource consumption in this area.

Project goals and procedure

Against this background, the “praxpack” project aimed to contribute to the establishment and spread of reusable systems in e-commerce to significantly reduce packaging-related resource consumption – and the associated waste volumes.

For this purpose, practical reusable concepts were developed, tested, and environmentally and economically assessed. The central element of “praxpack” was the “cooperation laboratory”, in which the project partners developed concrete solution elements for setting up practical and self-supporting reusable systems. Based on the solution elements developed jointly by the partners, reusable systems were tested and further developed in concrete pilot projects at the participating online retailers. The results of the pilot tests were subsequently evaluated. In parallel, environmental, and economic evaluations of different designs of reusable systems were carried out. In various workshops, which were attended not only by the project partners but also by numerous other actors from different stakeholder groups, feedback on the results of the work was obtained on an ongoing basis and the project results were continuously disseminated.

The processing and dissemination of the generated knowledge in the context of events and through numerous publications was another important building block to contribute to the establishment and dissemination of reusable systems in online e-commerce. So far, more than 25 documents (reports, articles, profiles, factsheets, ...) have been made available on the project website. A filtering option based on stakeholder groups and thematic information needs makes it possible to access the relevant information in a target-oriented manner.

Research results and measures of transfer and transmission

The ecological advantages of reusable packaging have been proven in various cases in which single-use packaging was compared with reusable packaging in terms of the resulting CO_2 emissions and resource consumption. Accordingly, it can be concluded that the establishment of reusable packaging in e-commerce has the potential to contribute to resource and climate protection.

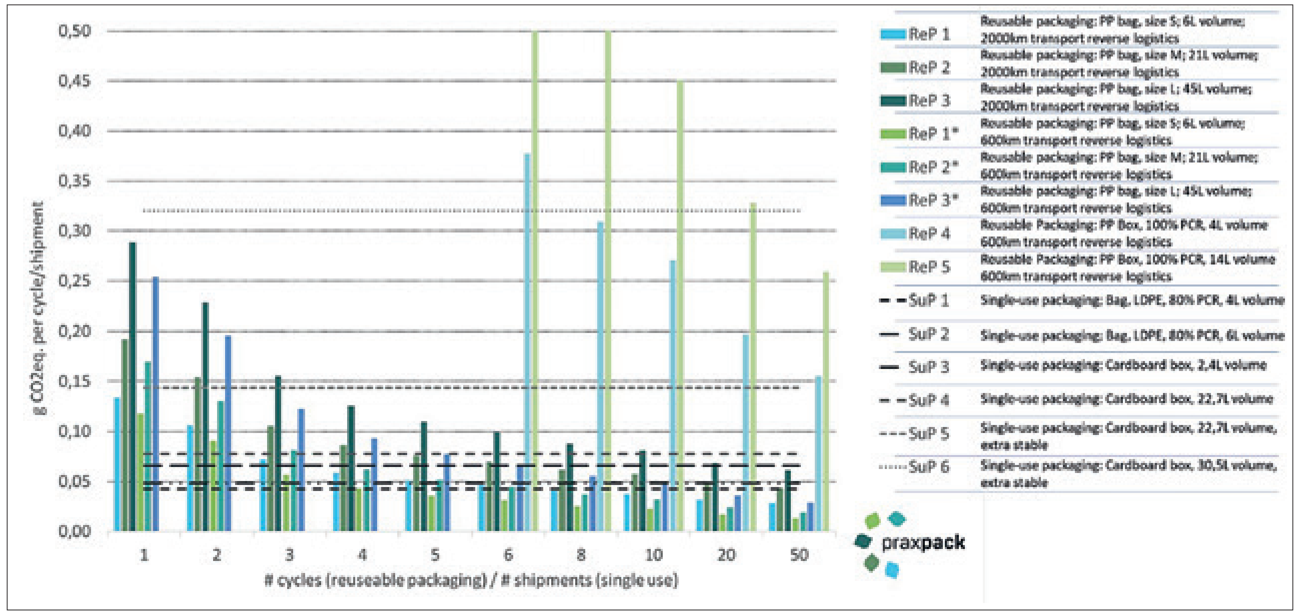

Fig. 35: Comparative analysis of CO2 emissions in the use of single-use and reusable shipping packaging
(Source: “praxpack”/Ökopol)

Contribution to resource efficiency and sustainability

In the framework of the evaluation of the pilot tests, various barriers to the transition to reusable packaging were identified and possible solutions outlined. A key factor – also about achieving a high number of cycles – is the involvement of customers. However, there is no universal formula for this, and possible suitable approaches vary from one online retailer to the other. In addition, various possible measures for optimising packaging design were identified. The additional economic effort, which results from the lack of an efficient and cost-effective return solution, was clearly identified as a central barrier to the broader establishment of reusable shipping packaging. Regarding the cost situation of reusable shipping packaging, various scenarios were examined. The additional costs that currently result per shipment from the use of reusable packaging compared to single-use packaging amount to 1.50 to 3 euros. Although customer surveys show a basic willingness to bear additional costs, in most cases they are not this high. The reduction of costs – for example through the establishment of open pool systems for reusable shipping packaging – represents a central remaining challenge for the establishment of reusable packaging in online e-commerce.

Fig. 36: Reusable shipping bag: RePack
(Source: RePack)

Fig. 37: Reusable box: HeyCircle
(Source: HeyCircle)


Source: vm- Getty Images/iStockphoto

Cluster 3: Remanufacturing

Schielke, C. (DECHEMA e.V.)

The aim of a resource-efficient Circular Economy is, among other things, to maintain the value of existing materials and products for as long as possible and thus to save primary resources. Remanufacturing is an approach to keep products in circulation for as long as possible by restoring the value of all relevant materials and components and thus avoiding an “end-of-life” or waste status. These materials and components can be used to produce new products of equivalent value or even higher-quality products, thereby enabling a completely new utilization cycle. Such value-regenerating processes values should require far fewer resources and energy compared to the production of a new product. This results in an improved environmental performance and helps avoid waste.

Within the funding measure “ReziProK”, four research teams investigated the conservation of the value of components from various application areas using remanufacturing, considering the ecological and economic potentials of the remanufacturing measures. The AddRE-Mo project team investigated value retention scenarios for urban electric mobility for transporting people and loads by remanufacturing of electric motors through additive manufacturing, e.g., to produce individual gear wheel geometries. The “ReLIFE” project focused on optimizing the life cycle of capital goods connected through a digital network by means of an adaptive maintenance strategy that determines the optimal time and scope of maintenance measures based on sensor evaluations. In the “EIBA” project, specific skills of people and machines were combined to improve the identification and evaluation of used parts. The aim of the “RePARE” project was to regenerate product and production systems using additive manufacturing processes.

The project teams were able to demonstrate the potential reductions in environmental impacts of the (adaptive) remanufacturing measures. The results of the life cycle assessments showed that the selected approaches enable significant savings in raw materials and greenhouse gases compared to new production and thus represent innovative solutions for more sustainability, both in plant engineering and in electromobility. The success of the commercial implementation of the research results now largely depends on several (sometimes limiting) factors, such as legal hurdles or a lack of design for recyclability, but also on the respective business model, in which the innovative process must generate cost benefits for all those involved in the value chain. Here, as well as for products that are manufactured using components that have already been used and for reprocessed components, liability issues must be considered. In the case of B2C business models, acceptance on the part of the users also plays an important role: Refurbished and repaired products must be regarded as equivalent to new products.

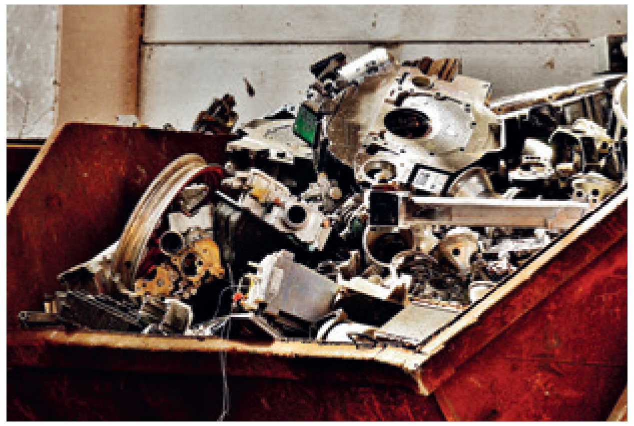

Fig. 38: Remanufacturing is one approach to implementing a Circular Economy (Source: pixabay)**.**

Resource-efficient value networks for urban electromobility

Electromobility, remanufacturing, Value retention, business models, Additive manufacturing, Machine learning, LCA

Döpper, F. (Fraunhofer-Institut für Produktionstechnik und Automatisierung)

Context and problems

A transformation of the transportation system is increasingly being discussed, with innovative mobility concepts playing an important role. In particular, the increased volume of traffic for transporting people and loads and the limited traffic areas in urban areas pose new challenges for municipalities. The electric bicycle once viewed critically, has become increasingly popular in the bicycle market in recent years. In 2020, 1.95 million electric bicycles were sold in Germany, corresponding to a sales growth of 43.4 % compared to 2019. The share of electric bicycles in the total sales of the bicycle industry was thus 38.7 %. However, electric bicycles must be considered holistically from production to disposal to determine whether they can be considered an environmentally friendly and resource-efficient form of mobility.

Project goals and procedure

In the "AddRE-Mo" project, a network of companies and research institutions was pursuing the goal of developing resource-efficient value retention networks for urban electromobility. Through a needs-based analysis and development, local value retention networks for urban electromobility components were being tested with the inclusion of remanufacturing and additive manufacturing. These components of mobility carriers (e-bikes, e-cargo bikes, etc.) were transferred from currently linear product life cycles to closed product cycles through additive remanufacturing. This increased resource efficiency over the entire product life cycle, decoupling resource consumption (raw materials, energy, labor, etc.) and growing product demand.

Research results and measures of transfer and transmission

Market analysis and business models: In the context of market analysis, various stakeholders' requirements from the urban electromobility field were collected. Potentials and barriers of current and future stakeholders (users, manufacturers, workshops, politics, associations, and organizations) were identified. Finally, the market analysis results were used to develop four circular business models (sales models and product-service systems) for the additive remanufacturing of electric bicycles.

"AddRE-Mo" – Value retention scenarios for the urban electromobility of people and goods through additive manufacturing and remanufacturing

Project participants:
Electric-Bike Solutions GmbH; cirp GmbH; Trägerverein Umwelttechnologie-Cluster Bayern e.V.; Wuppertal Institut für Klima; Umwelt; Energie gGmbH; Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA

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Project duration:
01.07.2019 – 30.09.2022

Project website:
www.addre-mo.de

Funding code:
033R234

Concept development and environmental evaluation: The implementation of additive remanufacturing was conceptually described for two reference motors, the mid-mounted motor "Bafang BBS01B" and hub motor "SGI Climber V2". In addition to disassembly, all further processes of remanufacturing (cleaning, testing, reconditioning, and reassembly) were considered. Furthermore, an environmental evaluation of a conventionally manufactured and a remanufactured electric bicycle motor was carried out. For the motors investigated, the savings potential through remanufacturing ranges from 75 % to 92 % under the assumptions made concerning the global warming potential according to the IPCC method.

Product development for additive remanufacturing: 21 gear variants (variation of gear type, additive manufacturing process, and material) were selected as an application example for additive remanufacturing using various additive manufacturing processes. Among the tested gear variants manufactured by the additive manufacturing process fused layer modeling (FLM), the gears made of polycarbonate PC survived the stress tests without damage.

Digital technologies: An image data-based machine learning (ML) algorithm was developed for object classification of the reference motors. Based on the developed algorithm, it was possible to achieve an accuracy of 96.8 % after ten epochs on the test data set.

Contribution to resource efficiency and sustainability

The "AddRE-Mo" project was not only concerned with the recycling of products but also combined the reduction of resource use in production and remanufacturing to increase resource efficiency by incorporating additive manufacturing. Remanufacturing increased resource productivity by enabling a new cycle of product use. As a result, economic growth and rising demand can be partially decoupled from resource consumption. Additive manufacturing also offers the potential to reduce resource consumption per product compared to conventional manufacturing processes and thus improve the eco-balance over the product's life cycle. Especially when considering urban electromobility, ecology, economy, and social aspects as dimensions of sustainability are at the center of developments. Through the joint development of innovative concepts for the transport of people and goods in urban areas, the acceptance of these concepts by the users was also at the center of the research. The consideration and assessment were achieved through integrating corresponding associations during the project, modeling the value network, and the system dynamics simulation.

Fig. 36: Inference in demonstrator
(Source: Fraunhofer IPA)

Fig. 40: Additively manufactured gear wheel of an electric bicycle motor (Source: Pi HQ-Kamera, "AddRE-Mo")

Human-machine interaction for a second product life

Artificial intelligence, self-learning technology, Circular Economy, automation, data utilization, remanufacturing, end-of-life sorting, human-machine interaction

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Context and problems

At the end of a product's use phase, there are various disposal or reprocessing strategies. Depending on their type and condition, products can, for example, be recycled or remanufactured and used again. To do this, they must be clearly identified and evaluated. The challenge here is that many product models differ only slightly from one another and are difficult to identify due to contamination and wear. In addition, the experts have only a few seconds for the identification and evaluation of each part. To support their work, "EIBA" wanted to provide them with a machine that co-assesses the product with the human operator. Data collected by sensors is evaluated with the help of artificial intelligence in conjunction with further information and formulated into a decision recommendation. Thanks to the four-eye principle of human and machine, the error rate during identification is to be reduced and the workload for humans relieved.

Project goals and procedure

The aim of the "EIBA" project was to develop a system for identifying and evaluating the condition of used parts. This will make an important contribution to closing the loop through digital technologies. With the use of artificial intelligence methods – such as machine learning and deep learning – products should be recognized and compared with further information. Continuous expansion of the data should also enable adaptation to new products and requirements. One of the project's innovations was to combine the specific competencies of humans and machines in a complementary manner, thus enabling greater efficiency and process reliability. The resulting system was analyzed according to aspects of sustainability: What has changed for humans? What additional environmental impact is caused by the use of machines compared to the environmental benefits gained through increased efficiency?

Research results and measures of transfer and transmission

One focus of the project was digital image evaluation using artificial intelligence. In a proof-of-concept under laboratory conditions, based on image data of about 1400 different used parts, more than 98 % of these parts were clearly identified correctly in performance tests. Based on this approach, all workstations at a C-ECO location were equipped with depth cameras and scales and the identification software was connected to the digital sensors. In this way, the data availability for images, depth images and weight data was continuously increased in the operational process, based on which neuronal networks are trained to specifically recognize used vehicle parts. Already 3,500 different used car parts with 21,000 data sets (124,000 images) have been digitized in the project and more are being digitized every day, which makes it possible to adapt the image AI better and better to the real conditions through new and more extensive training data. In addition to image recognition, statistical evaluation methods and machine learning models were implemented and tested, which generate identification suggestions for the workers from the historical delivery data, the measurements of the scale applied to the workstation and the shipment information. In performance tests, the statistical models were able to identify unambiguously correctly 66 % of the used parts from 213,879 real readings (including previously unseen old part classes). Performance tests of different machine learning models based on the delivery and business data showed unambiguously correct identifications for 60 to 70 % of the real selection (incl. previously unseen used part classes). Another challenge in human-AI interaction lies in the efficient integration of sensor technology into the work process. For this purpose, the current process was investigated and a concept for its redesign as well as for the presentation of the AI results in the human-machine interface was developed. These concepts were implemented in clickable digital demonstrators and prepared for integration into real operations at C-ECO locations. The results of sensor data interpretation, statistical methods, and worker input are fused to optimally combine their specific competencies for the identification and evaluation of used parts. As part of the development-process, expert interviews were conducted in organizations from various industries and companies having challenges in reverse logistics with the aim to validate and expand the requirements catalog for an AI system. One of the key findings from these interviews was the requirement for an AI application to be able to detect used parts even when they are highly contaminated with dirt, rust or similar. The interviews also served to determine the potential of automated and standardized identification and evaluation of used parts. Among other things, the interviewees saw potential in the possibility that an AI system could define data for business rules in decision matrices.

"EIBA" – Sensory acquisition, automated identification and evaluation of used parts on the basis of product data as well as information about previous deliveries

Project participants:
Circular Economy Solutions GmbH; TU Berlin; Acatech; Fraunhofer IPK

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Project duration:
01.09.2019 – 31.05.2023

Project website:
www.linkedin.com/company/eibaprojekt

Funding code:
033R226

Fig. 41: Human and machine interaction (Source: C-ECO/Bosch)

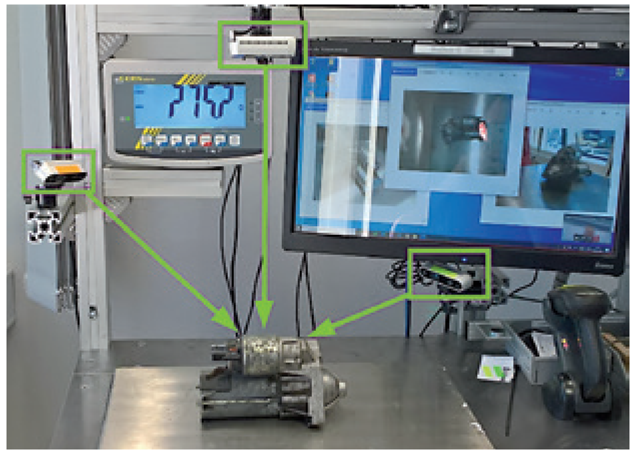

Fig. 42: Camera & scale complement the workplace (Source: C-ECO)

Contribution to resource efficiency and sustainability

Based on the improved recognition rates, the potential effects on CO_2 emissions from sorting were calculated for the example product Starter. For this purpose, the additional emissions due to the use of AI and the necessary hardware were compared with the savings from additional parts that are remanufactured. This showed that the savings are significantly higher than the additional emissions. For the starter product group, after only 15 parts or less than one day of sorting, the potential savings are higher than the additional energy consumption. The potential annual savings using AI at C-ECO for starter motors alone, for example, calculate to 27.5 metric tons of CO_2 equivalents.

Adaptive Remanufacturing for Lifecycle Optimization of Capital Goods

Adaptive Remanufacturing, resource efficiency, Life cycle extension, Maintenance strategy

Dackweiler, J. (Werkzeugmaschinenlabor der RWTH Aachen)

“ReLIFE” – Adaptive Remanufacturing for Lifecycle Optimization of Capital Goods

Project participants:
Werkzeugmaschinenlabor der RWTH Aachen (WZL); Lehrstuhl für International Production Engineering and Management (IPEM) der Universität Siegen; Achenbach Buschhütten GmbH & Co.KG

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Project duration:
01.07.2019–30.06.2022

Project website:
www.relife.wzl.rwth-aachen.de

Funding code:
033R238

Context and problems

The global challenge of resource scarcity due to increasing demand and unsustainable resource consumption of the growing world population requires the decoupling of economic growth and resource consumption. Closing product cycles through the transformation from a linear economy to a Circular Economy is an important step towards achieving this objective. Remanufacturing as a key idea of the Circular Economy increases the resource efficiency of products by extending their life cycle. Especially in industrialised countries, the application of maintenance and remanufacturing measures to capital goods offers great potential for increasing resource efficiency. In this context, the concept of Adaptive Remanufacturing (AdR) was developed within the framework of the research project “ReLIFE” to close the identified gap for intelligent remanufacturing strategies with a focus on capital goods.

Project goals and procedure

AdR describes a proactive and intelligent maintenance strategy with the aim of ensuring an agreed minimum performance of capital goods over an extended period. An essential component of AdR is a decision model that supports users in deciding on the optimal time and scope of maintenance and remanufacturing measures. The model decides on the prioritisation and timing of the various options of measures based on economic, ecological, and technical aspects. For this purpose, based on the principle of condition monitoring, real-time sensor data is used to monitor and analyse the wear and tear of the capital goods and process it in the decision model with further information to produce a recommendation for action. The timely announcement of upcoming measures ensures the maintenance of the agreed minimum performance and enables the long-term and productive use of the capital goods while reducing or avoiding unplanned downtimes.

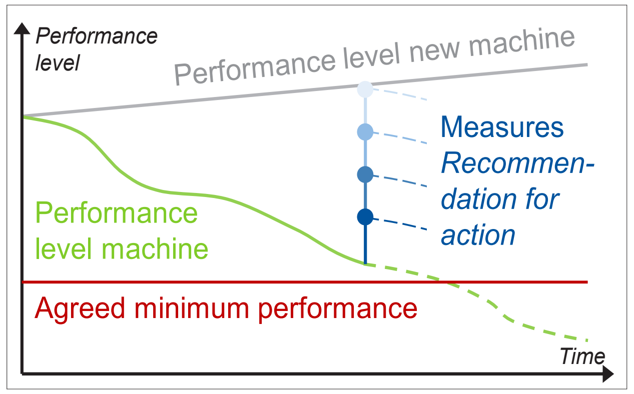

Fig. 43: Target image of adaptive remanufacturing
(Source: “ReLIFE”)

Research results and measures of transfer and transmission

AAs an essential result of the project, the decision model was conceptualised, developed, and implemented in a user-friendly way within a browser-based software application. During the project, a capital good was equipped with selected sensor technology as a demonstrator machine and connected to the developed software application for validation purposes. For this purpose, guidelines for the product design of capital goods were developed with a focus on integrated, digital sensor technologies. At its core, the software application works with input information consisting of sensor data, a catalogue of maintenance and remanufacturing measures as well as product structure and component information. The sensor data of various, different measured variables allow statements to be made about the historical and current condition of the capital goods. Enhanced by prognosis algorithms, the data enables the prediction of critical states of monitored components. If sensor values reach predefined warning limits, application users are informed via the notification centre and a recommendation for action is generated, including suggested measures and the corresponding implementation date. The proposed measures include the selection of technically suitable measures from a catalogue of over 500 individual measures.

By means of the decision model logic, alternatives of technically suitable measures are presented in a prioritised manner with ecological, economic, and technical parameters. This enables the user to select the most suitable and preferred measures specific to the company. For validation purposes, specific measures were selected for each critical component of the demonstrator machine and the characteristic values for the ecological and economic implementation costs of the measures as well as the technical effective benefit were determined. Expert interviews with the demonstrator operator revealed positive feedback regarding the functional scope as well as the user and operator friendliness of the software application. In addition to ensuring the minimum performance level, further potentials were also identified in the reduction of resources for machine supervision as well as the reduction of spare parts storage capacities. On the part of the machine manufacturer, offering the software application in addition to the physical product also enables the realisation of new business models for operators or owners. For this reason, possible business models were developed within the project and validated in terms of economic and ecological effectiveness.

The implementation of the design framework developed in the project resulted in several product service system (PSS)-oriented business model blueprints. These are subdivided according to the typical PSS characteristics into product-oriented, use-oriented, and result-oriented models. The differences between the models focus primarily on the ownership and responsibility structure for the investment good as well as the value creation architecture. They cover a range from classic asset sales to the provision of a specific service with an ascending level of service. However, especially in the case of the use-oriented and results-oriented models, the financial risk due to long-term payments predominated, which is why the focus was placed on the more classic, product-oriented model. The economic validations show that the software application as an additional product to the physical capital good promises success especially when scaling with direct integration of most similar capital goods. With the project results achieved, it will be possible in the future to ensure more in-depth basic research in Adaptive Remanufacturing and to further develop the methodology. The broad applicability of the methodology contributes, for example, to comprehensive market development when applying the methodology to other products, sectors, and industries. The increased resource efficiency in turn ensures the competitiveness of companies in the long term.

Contribution to resource efficiency and sustainability

Adaptive Remanufacturing contributes to resource efficiency and sustainability by returning components to the economic cycle and extending the life cycle of capital goods and their individual components. Exemplary maintenance and remanufacturing measures cover the spectrum from component cleaning to complete component replacement with remanufacturing and functional, performance-enhancing additions. The results of the life cycle assessment show that, depending on the remanufacturing rate of the components, the application of the AdR approach results in a significant reduction of emissions determined in CO_2 equivalents.

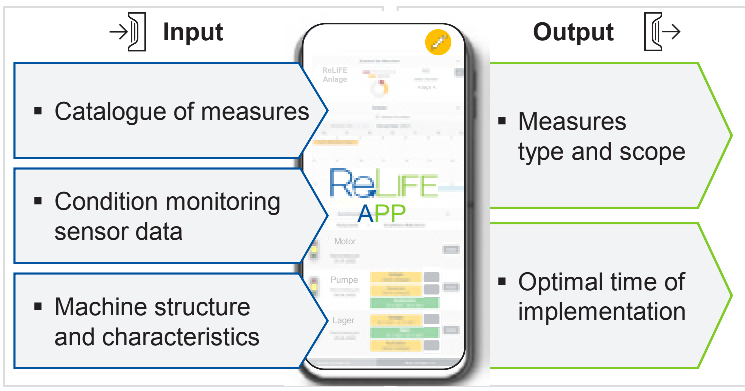

Fig. 44: Input and output information of the “ReLIFE” app
(Source: “ReLIFE”)

Additive Repair & Refurbishment of metallic components

Additive Repair, Additive Refurbishment, Additive Remanufacturing, Laser Powder Bed Fusion

Brinker, J. and Thomas, O. (Deutsches Forschungszentrum für Künstliche Intelligenz GmbH)

"RePARE" – Regeneration von Produkt- und Produktionssystemen durch Additive Repair und Refurbishment

Project participants:
Deutsches Forschungszentrum für Künstliche Intelligenz GmbH; Leibniz Universität Hannover; Institut für Produktentwicklung und Gerätebau; DMG MORI Spare Parts GmbH; Windmöller & Hölscher KG

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Project duration:
01.07.2019 – 31.10.2022

Funding code:
033R299

Context and problems

Unplanned maintenance measures are a challenge in mechanical and plant engineering, as they can be associated with high follow-up costs. For this reason, various solution strategies are being explored with which the reliability of machines and plants can be increased, but also the lead time of maintenance measures can be reduced. Especially the short-term provision of spare parts is a challenge that is currently addressed by cost-intensive stockpiling. However, the choice of suitable storage locations and delivery routes from the supplier and to the customer. This is especially the case for components that are, for example, only rarely needed and thus cause a high capital investment.

Up to now, remanufacturing has only been used for high-priced and usually non-metallic components. The use of additive manufacturing processes enables the repair of damaged metallic components with a high level of process reliability and reproducibility and offers the potential to improve the component in the reworking process. In the future, it will be possible to remanufacture and upgrade selected components close to the customer, which offers added value compared to conventional new parts from both an economic and an ecological perspective. Many companies lack the necessary know-how to identify suitable components, develop process chains and operationalize them.

Project goals and procedure

The "RePARE" project dealt with the use of additive repair processes for metallic components. On the engineering side, the focus was on technical feasibility and the definition and testing of process chains. On the business side, the embedding of repair process chains in existing after-sales structures and the economic and ecological effects of the repair strategy were investigated. To this end, existing use cases and additive manufacturing processes were first compiled in a case base during the project and characteristics for suitable components were identified. Using demonstrator components, process chains were developed, repairs carried out and subsequently evaluated with the aid of test beds. The data collected in the process was used for a process cost analysis and life cycle assessment. At the same time, a service catalog was developed to record in a structured manner the necessary accompanying activities and existing service offerings, such as installation/removal of the component and failure analysis, to derive dependencies and information requirements. To enable the widespread application of additive repair and refurbishment, tools were developed during the project that capture the required expert knowledge and facilitate automation of the process. By using methods from the field of artificial intelligence, it is possible to simplify particularly data-driven process sections, such as the analysis of defect states or the processing of component scans. The main goal was to be able to shift as much of the activities as possible to the customer to be able to carry out repairs on site – without the need for trained technicians to travel to the site and the shipping of spare parts – so that ecological savings potentials can be realized.

Research results and measures of transfer and transmission

With the repair of the demonstrator components, it was successfully proven during the project that additive repair is also possible beyond capital goods. A methodical procedure was devised for developing the process chain for both additive repair and additive refurbishment, i.e., upgrading a component to a newer state of the art or changed requirements. It was found that the decision for or against repairing a damaged component depends on both technical and economic criteria in each individual case. With the help of a prototypically implemented assistance system, a suitable process chain can be identified based on component characteristics, so that companies can independently evaluate the possible applications for these individual cases. With a process cost calculator, a cutting plane generator to facilitate component preparation as well as an optimization model for the planning of spare parts and repair locations, further tools were developed that also facilitate operational implementation. Within the scope of a life cycle assessment, a tool was developed to collect life cycle inventory data of the repair process in a process step-specific manner and to calculate them holistically in the form of an impact assessment. The resulting generalized "cradle-to-gate" process chain enables a cross-demonstrator analysis of repairable components using the LPBF method.

Contribution to resource efficiency and sustainability

During the project, it was shown that additive repair processes can be a resource-efficient alternative to the provision of new spare parts. With the vision of repair at the customer's premises, the shipping of components can also be digitized - in addition to the already established remote services. Furthermore, new insights could be gained into how a circular design of products can be undertaken by facilitating the use of repair processes. Although the complexity of additive repair and refurbishment is still a challenge for widespread use, the tools developed show how expert knowledge can be digitally transferred and processes automated. Although sustainability has so far played a subordinate role in mechanical and plant engineering, it has been shown that the use of additive repair can also bring economic benefits. It can therefore be a sustainable alternative to classic spare parts strategies.

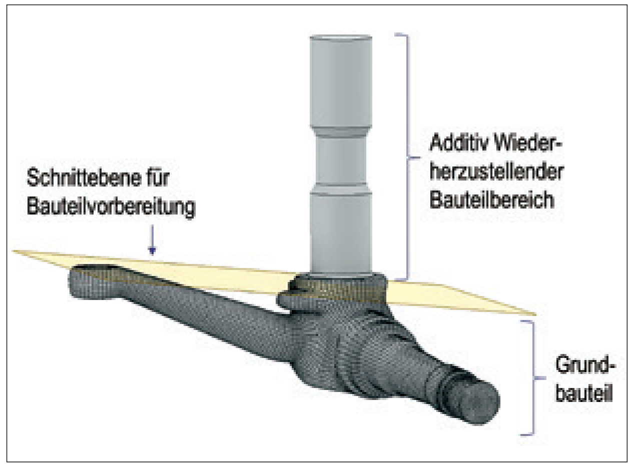

Fig. 45: Data preparation for additive repair using selective laser beam melting on the demonstrator component steering knuckle
(Source: IPeG, Leibniz Universität Hannover)

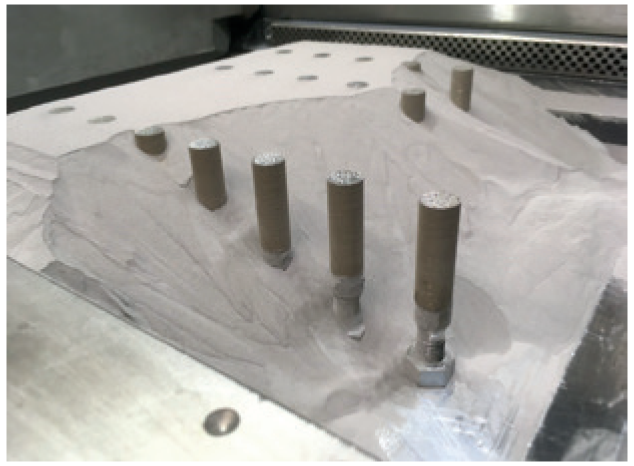

Fig. 46: Fabrication of traction samples to assess the mechanical properties of additively repaired components
(Source: IPeG, Leibniz Universität Hannover).

Source: Framestock - stock.adobe.com

Cluster 4: Circular electric vehicles

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The growth of the world's population and prosperity are demanding natural resources. The OECD and the World Resources Council predict that global resource consumption will more than double by 2050 if current trends continue. A large part of global resource consumption is accounted for by passenger and freight transport. A continuous increase in the volume of traffic for individual mobility and goods disposition can be observed worldwide due to the growing world population and online trade. Due to these developments, the resources required for mobility are increasing considerably, despite the increased efficiency of internal combustion engines. Resource efficiency is thus becoming a key objective in the development of future mobility concepts. This presupposes that, in addition to low environmental impacts during operation, as few resources as possible are used in the production of vehicles and that resources once used, e.g., for individual components, can be efficiently (re-)used and recycled. New vehicle concepts, longer service life of cars through the development of particularly durable modules, new, advantageous business models, reconfiguration, refurbishing or remanufacturing – the scope for solutions that support the recyclability and sustainability of electric vehicles is large, but so is the scope for challenges. One of the biggest challenges is acceptance. For as long as they do not meet with acceptance, none of the measures can be effectively implemented. Acceptance can be lacking among any of the various stakeholders, whether on the side of the manufacturer, the sharing provider, or the end-user, and can be diminished by, for example, comparatively large responsibility, large initial investment, or lack of education. It is therefore not uncommon for projects on circular electric vehicles to increasingly include acceptance research.


Fig. 47: Electromobility forms an important pillar of the Circular Economy (Source: pixabay).

Modular and circular e-vehicle platform

Circular Economy, electromobility, fibre composite, vehicle platform, CFRP, Re-Use, Circular Electric Vehicles

Caba, S. (EDAG Engineering GmbH)

Context and problems

Automotive manufacturing is energy- and resource-intensive along the international value chain. A longer service life of vehicles is therefore of great ecological and economic benefit. The innovative solution of the cycle-oriented open-source construction kit for electricallypowered pool vehicles of the “KOSEL” project contributes significantly to resource conservation and Circular Economy through remanufacturing and reuse. On average, passenger cars are exported or scrapped after less than 15 years of use. By doubling the mileage, automotive customers could significantly reduce emissions from vehicle production and the depletion of raw materials. For this reason, “KOSEL” aimed to develop particularly durable modules, for example by using low-corrosion and low-fatigue materials such as fiber-plastic composites. Against this background, the project has ambitious technical, economic, and ecological goals.

Project goals and procedure

The main objective of the “KOSEL” project was to develop a vehicle platform that enables the re-use of durable components. For this purpose, fixed interfaces have been defined at which components can be exchanged as easily as possible not only for the purpose of repair but also to change the vehicle’s application (see Fig. 48). The target overall service life of the platform is 30 years. For individual components, specific considerations were made for the expected service life. The aim was to keep the large, expensive components in operation for as long as possible. Wear parts such as rubber bearings in the undercarriage will be replaced and recycled once their service life has been reached. In the technical area, the design and prototypical imple-mentation of a modular, recyclable e-vehicle platform for periods of use of up to 30 years with mileages of up to one million kilometers will be carried out. In the economic area, the identification of advantageous business models for fleet operation with new types of vehicles from recyclable modules and proof of cost savings potential compared to classic models. In the ecological field, significant resource savings are to be demonstrated through remanufacturing and the reuse of complex vehicle modules.

“KOSEL” – Reusable open source design kit for electrically powered pool vehicles

Project participants:
Fraunhofer IWU; INVENT GmbH; BSMRG GmbH; Röchling Engineering Plastics SE & Co. KG; TU Dresden – Betriebliche Umweltökonomie; Hochschule Emden/Leer

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Project duration:
01.07.2019 – 30.09.2022

Project website:
https://innovative-produktkreislaeufe.de/Projekte/KOSEL.html

Funding code:
033R242

Research results and measures of transfer and transmission

Work on the modular system is progressing continuously. Particular attention was being paid to durable struc¬tures and open-source interfaces. New types of fibre composite crash absorbers developed at Fraunhofer IWU were being used that can absorb a lot of kinetic energy while being lightweight. These, as well as the structure-determining rocker panel, were manufactured using a cost-effective pultrusion process. Different approaches were being taken to the chassis and drivetrain. A central electric motor was used on the front axle to drive the wheels, which are mounted on a leaf spring. The rear axle used a swing-arm axle with adjustable leaf spring, for which a patent application has recently been filed. The consideration of business models showed that economic efficiency is given due to the long service life. From an ecological point of view, resource consumption was reduced. The Environmental Economics Department of the Technical University of Dresden was developing a method for ecological and economic optimization using life cycle assessment for the new vehicle and mobility concept. The results to be achieved in this project, including the crash protection structure in the form of a sill, were an important intermediate step for the Fraunhofer IWU on the way from basic research-oriented work to concrete implementation in practice, the technology transfer.

Contribution to resource efficiency and sustainability

Carbon fibre reinforced plastics (CFRP) have several advantages that make them ideal for the reuse of components. In addition to corrosion resistance, they have a particularly high mechanical vibration resistance. This means that loads can be carried over longer life cycles than is possible with metallic materials. In addition, drive energy is saved due to the low mass. Like the entire vehicle platform, the side crash protection, here in the form of a sill structure, is modular and offers the possibility of replacing damaged components or reusing intact components. To do this, simply remove the sill cover and loosen a screw connection. After disassembly, the components are inspected and, if necessary, reprocessed before they can be reused. If irreparable damage is found, the components are recycled according to type.

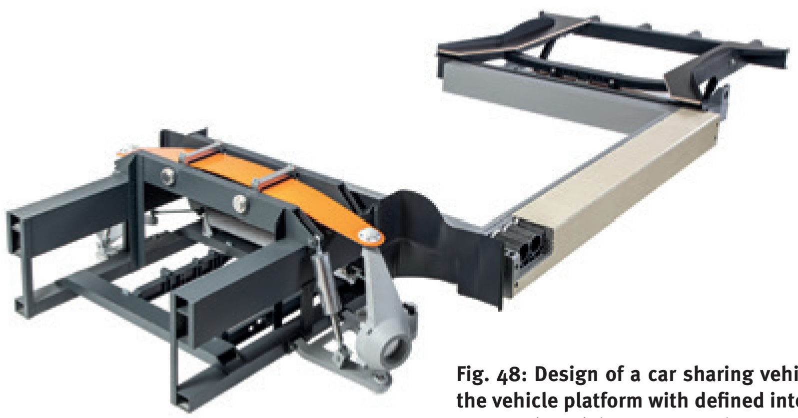

Fig. 48: Design of a car sharing vehicle based on the “KOSEL” platform (top); concept of the vehicle platform with defined interfaces (left); crash absorber made of pultruded CFRP profiles (right) (Source: EDAG).

Light and long-lasting – Light Electric Vehicle for future-proof mobility

Light Electric Vehicle, New Forms of Mobility, Emission-reduced Last Mile, Circular Electric Vehicles

Wüstenhagen, S. (Fraunhofer IMWS)

Context and problems

Structural light weighting in mobility holds out the prospect of a significant increase in energy efficiency, coupled with a reduction in environmental emissions, in the use phase of vehicles. However, established vehicle classes for land-based transport, but also usage habits, limit the potential for drastic weight reduction. Light electric vehicle (LEV) concepts, however, can differ radically from established vehicle concepts - not only in the need for operating energy and resources, but also in production, use and recyclability.

The change to electric mobility means changes for the German automotive industry, as the supplier industry must restructure itself in some cases, but it also opens further access to a resource-efficient Circular Economy through "new mobility". For this purpose, new materials, construction methods and peripheral systems for LEVs were developed in preliminary projects at the Fraunhofer IMWS in cooperation with medium-sized companies. On this technological and material-scientific basis, new market segments are to be enabled for companies in the automotive supply industry in combination with approaches to the Circular Economy.

Project goals and procedure

The aim of the project was to investigate the recyclability of light vehicles that can be industrially manufactured by the supplier industry of the mobility sector. Therefore, two construction methods were prepared which, on the one hand, allow the derivation of all relevant vehicle variants and, on the other hand, allow the comparative investigation of the environmental impact and recyclability of light vehicles compared to conventional vehicle construction methods.

Based on an existing prototype in mixed construction, design models were extended using the finite element method to develop the mechanical component design for a vehicle in fibre composite construction. Innovation methods are to be used to ensure the derivation of vehicle variants for various purposes. The conditions of the vehicle class EU L7e were chosen as a legally secured framework for the vehicle construction and component design, since vehicle mass, payload and drive power hold out the prospect of a solution that is not dependent on the traffic space of the cycle path and

"LEVmodular" – Light Electric Vehicle modular – With new mobility to a resource-efficient Circular Economy

Project participants:
FVK GmbH; Olaf Lange & Co GbR

Coordinator:
Sven Wüstenhagen
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sven.wuestenhage@imws.fraunhofer.de
Tel.: 0345 5589-228

Project duration:
01.07.2019 – 31.12.2022

Project website:
https://innovative-produktkreislaeufe.de/Projekte/LEVmodular.html

Funding code:
033R245

minimises possible acceptance problems. For the comparative evaluation of the identified design methods, the Life Cycle Assessment method was used to holistically include the environmental impacts in all product life phases in the evaluation and to enable a scientifically sound investigation of the environmental impact of LEVs compared to conventional vehicle types. The French repair index was used as a guideline for investigating the recyclability of light vehicles. A novel sensor system was identified to verify the operational reliability of composite fibre components during the use phase. Ergonomic studies were evaluated using practical driving tests to support user acceptance.

Research results and measures of transfer and transmission

Based on real driving consumption data, which was determined on the prototype vehicle, a life cycle assessment could be successfully created in the "cradle to grave" balancing framework over all phases of use. The selection of a suitable functional unit enabled a comparative study with conventional vehicle systems. For the transport of parcels on the last mile, significant reductions in the environmental impact of LEVs compared to conventional vehicle types were

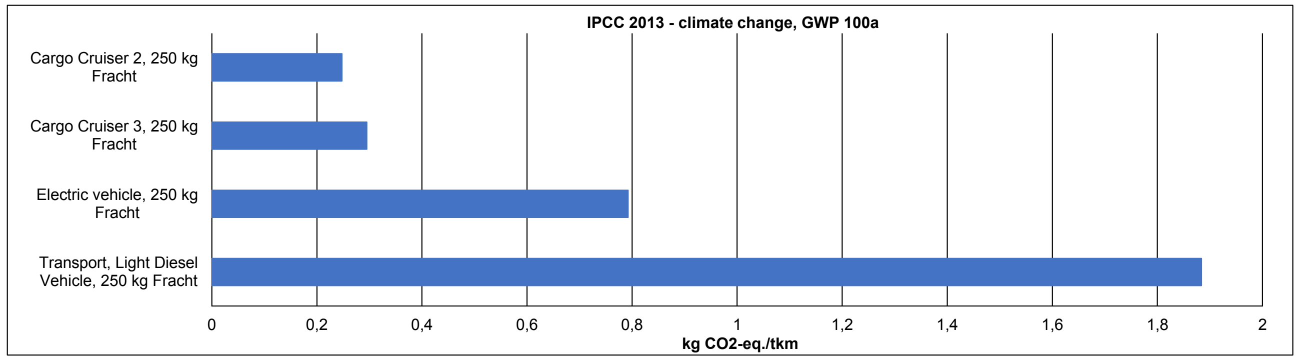

Fig. 49: Exemple of environmental impact, here in comparison of the global warming potential [kg CO_2-eq according to IPCC 2013, 100 a] of light electric vehicles with conventional vehicles, for the reference value 1 tkm, in the "cradle to grave" balance framework
(Source: Fraunhofer IMWS).

determined (Fig. 49). The novel sensor system for structural health monitoring of fibre composite components provides information on overloads in operation in almost real time and thus offers important options for business models for the operation of light electric vehicles.

Contribution to resource efficiency and sustainability

The proof of the significantly reduced environmental impact of LEVs has expanded the solution space for vehicles and "new mobility". Based on the research results, the supplier

Fig. 50: Practical evaluation of the ergonomics in the muscle-powered electric light vehicle Cargo Cruiser 2
(Source: Olaf Lange Dreiradbau, Berlin).

industry can produce light vehicles for niche applications in the "last mile" sector on an industrial scale. In a follow-up project, the project consortium plans direct transfer to industrial practice, coupled with the further development of already identified business models.

Reconfigurable design concepts and services for the resource-efficient (continued) use of e-cargobikes

Acceptance Research, App, Battery, E-cargobikes, sustainable business models, product design, recycling, Circular Electric Vehicles

Vietor, T. (TU Braunschweig)

“LifeCycling^2” – Reconfigurable design concepts and services for the resource-efficient (continued) use of e-cargobikes

Project participants:
TU Braunschweig, Institut für Konstruktionstechnik, Institut für Soziologie; TU Clausthal, Institut für Software Systems Engineering; baron mobility service GmbH, Stöbich technology GmbH, ELECTROCYCLING GmbH, Sense4Future GmbH

Coordinator:
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Tel.: 0531 391-66670

Project duration:
01.08.2019 – 31.01.2023

Project website:
https://lifecycling2.de

Funding code:
033R232

Context and problems

The volume of traffic for individual mobility and goods disposition is increasing worldwide. E-bikes and e-cargo bikes are suitable for reducing emissions, especially in inner-city mobility. However, the lower resource input during the use phase of pedelecs and e-cargo bikes is currently countered by a lack of solutions for the continued use of resource-intensive components such as batteries and the recycling of the complete bicycle.

Since e-bikes and e-cargobikes will be considered electronic waste in the future, concepts must be developed to recycle individual components in a targeted manner or to transfer them to secondary uses. To increase the resource efficiency of e-cargo bikes beyond their initial use, the partners in the joint project “LifeCycling^2” were researching and testing solutions for the targeted further use and upgrading of products and components as well as for material recycling. Effectiveness and innovations should result from interdisciplinary cooperation and the strong linking of services and products.

Project goals and procedure

Against the background of the increasing spread of e-cargobikes, the joint project “LifeCycling^2” aimed to improve resource efficiency across the life cycle. Technical concepts for extending the useful life through product updates and upgrades and for optimising the intensity of use through sharing solutions were developed. In addition, measures for the life-cycle-oriented design of e-cargobikes and methods for the definition of life-cycle strategies were developed, and organisational measures for the targeted recycling of electronic components were investigated. The developed design concepts for hardware and software systems were realised and practically tested in the form of demonstrators for pilot projects. Furthermore, technical solutions and services were developed and tested as software-based services to improve usage behaviour and resource efficiency during initial use through upgrades to enable resource-efficient further use of the entire bike or individual components. The four fields of action considered were:

- **Product:** upgrading, residual value assessment and second use of e-cargobikes.
- **Components:** Recycling and reuse of accumulators and drive components.
- **Material:** Separation and recycling of materials.
- **Information and control:** Collection and provision of information to increase resource efficiency.

Research results and measures of transfer and transmission

Through design thinking workshops, various use cases and corresponding personas for the use of e-cargo bikes were created. The use cases are the central element in the development of the systems e-cargo, battery, business model, information services and recycling processes. With the help of structured influence environments and the derivation, weighting, and detailed description of influencing factors, it was already possible to collect initial requirements and thus lay the foundation for the design concepts. In another strand of research, an analysis of commercial battery systems and cells for e-bike drives was carried out. The recycler was able to collect and provide old batteries and battery systems from various manufacturers. By analysing them, it was possible to establish that there are no uniform standards with regard to the cell designs used (cylindrical cells, prismatic cells, pouch cells) and the mechanical and electrical system structure (including housing, sensor technology). Subsequently, the development of an app was pushed forward, which gives the user the possibility to rent e-cargobikes in his vicinity and to rent them himself. In addition to the app, an e-cargobike is equipped with various sensors to draw conclusions about its use.

Contribution to resource efficiency and sustainability

The data collected in the various pilot projects from the sensors on the e-cargo bike and from the app were processed and used for various purposes. On the one hand, they should be used by the project participants to ascertain requirements and evaluate future application scenarios for e-cargobikes. On On the other hand, they should be made available to manufacturers later and used to generate improved, resource-efficient, and future-proof product architectures. Reconfiguration and upgrading strategies for products during the use phase and in the transition between first and second use were developed and evaluated using the example of e-cargo bikes. Furthermore, initial approaches with regard to commercial sharing, reconfiguration and refurbishing of e-cargo bikes were validated by the pilot projects. The app will be operated as an accompanying service beyond the duration of the project to increase the intensity of use, e.g., by sharing e-cargo bikes.

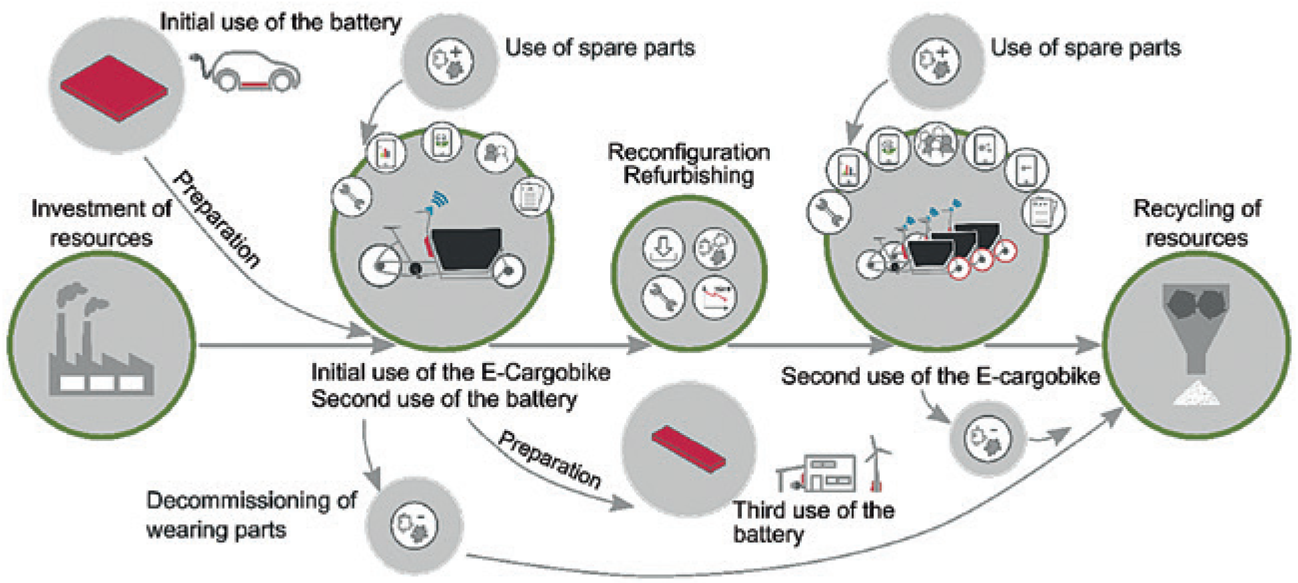

Fig. 51: Vision in the “Lifecycling^2” project (Source: “Lifecycling2”).

Source: Studio Romantic - stock.adobe.com

Cross-project issues of the funding measure

Acceptance

The importance of acceptance in the context of circular value creation

Kreft, O. (Xella Technologie- und Forschungsgesellschaft mbH)

What is the meaning of "acceptance" in the context of innovative product cycles? And how is "acceptance" addressed in the projects?
Acceptance is a crucial prerequisite for the success of business models in the Circular Economy. To better understand the acceptance phenomenon in the context of the Circular Economy, the stress field between acceptance-subject, -object and the underlying evaluation processes was examined more closely. By means of a questionnaire, target groups and actors in the value chains were identified within the "ReziProK" projects, and factors influencing acceptance and their steering approaches in the project context were determined. Experiences made were examined as well as the question of what the term "acceptance" means in the respective project context.

The focus of the "ReziProK" -projects is on active acceptance, for example the integration of different target groups into circular value creation.
Due to the variety of thematic, sectoral, and material focuses of the projects, important facets of the Circular Economy could be analyzed. Most projects focus on several stages of the value chain as well as different actors and target groups. Circular Economy is thus not thought of selectively and monolithically, but in a networked way. Acceptance is generally seen as a positive perception, which still has to be created in part and is a basic condition for successful circular value creation.

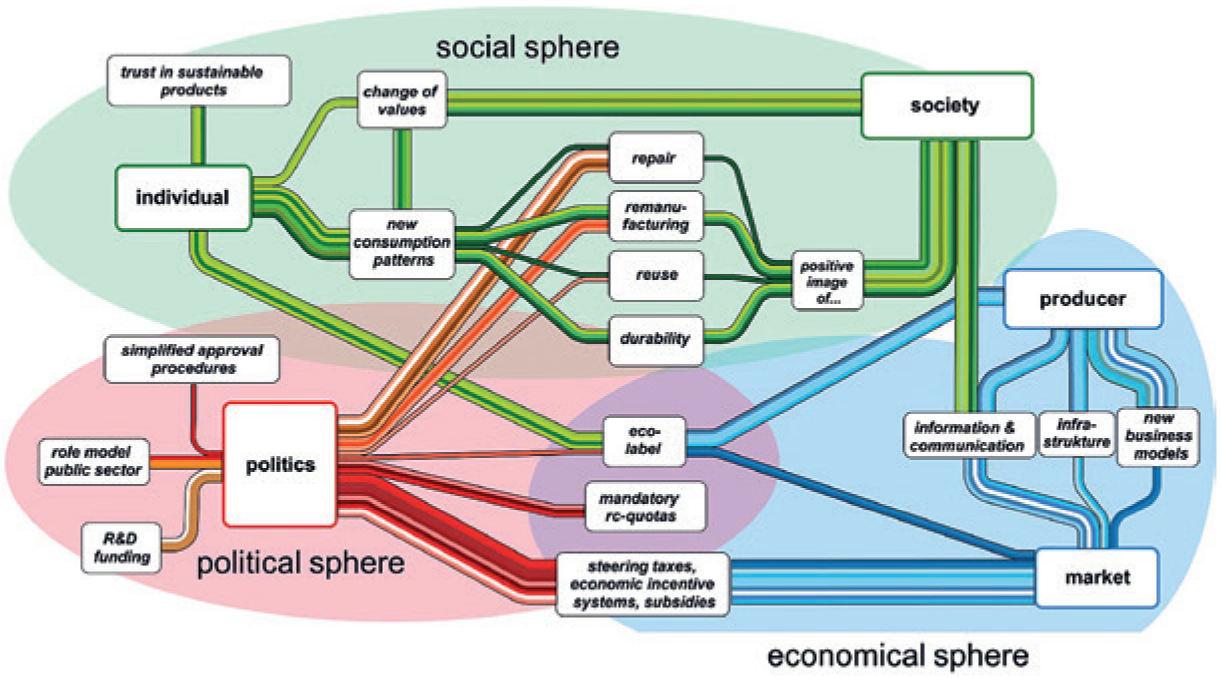

Fig.52: Measures to promote acceptance, here using the example of the answers to the question: "What pre- and framework-conditions would be necessary to enable the ideal integration of the project goals into the application area?" (Multilevel perspective, the thickness of the arrows corresponds to the weighting of the answers).
(Source: Kreft, O., Xella Technologie- und Forschungsgesellschaft mbH, 2022)

Conclusion
The analysis showed that the transformation into a sustainable society requires competitive – or better – business models that are superior to the linear economy. This requires economic and legal steering instruments such as binding substitution quotas, the introduction and consistent implementation of "circular public procurement" to tie the awarding of public contracts to the use of recycled or secondary raw materials, as well as legal certainty with regard to product liability and waste law issues. Only this enables planning security for reprocessors and downstream users for investments in facilities and business models for the Circular Economy. A decisive prerequisite for the success of circular value creation is market-relevant demand. Reservations and uncertainties of the target groups in the selection and use of recycling products must be eliminated. This supports a fundamental change in values towards a new consumer behavior characterized by the desire for durable, repair-friendly, and recyclable products. An elementary instrument for strengthening trust, acceptance and sensitization towards the circular product is active and transparent communication along the entire value chain: Targeted public relations and educational work with information about resource dissipation and conscious consumption as well as reliable environmental labels offering orientation when comparing products. The targeted promotion of research and development can provide support here. Figure 52 shows the distribution and weighting of the identified catalogue of measures based on an example from the survey evaluation.

Case-Study "UPZENT"

The aim of the research project "UPZENT" is to establish a participatory business model to raise awareness about and implement a resource-efficient Circular Economy, which enables the participation of social factory workshops nationwide. "UPZENT" combines Circular Economy and social engagement through professional product development. It focuses on the creation of a closed material loop through the cascading use of industrial residual materials. The combination of design and the use of regionally available residual materials creates something new: *socially integrative and resource-saving design products*.

"UPZENT" has identified various target groups for its project environment, which are addressed specifically. The target groups include, for example, cooperating companies from which UPZENT obtains raw materials (residual material). These companies often also become customers within the Upcycling Service (a service that aims to develop new products from the company's own residual material). Furthermore, the focus is on end consumers who come into contact with "UPZENT" via the web shop, social media and retail (e.g., package-free store). Product design students are also addressed via university workshops.

In this framework, it is important to determine the current level of acceptance for recycled products and, if necessary, to develop strategies to increase the level among the different target groups. The cooperation within the cross-sectional topic of "acceptance research", the related discussions, as well as the developed questionnaire drove the process forward significantly. "UPZENT" defined the specific meaning of acceptance for its project purpose as follows:

‹‹*Acceptance means that consumers recognise recycled/upcycled products as a fully-fledged alternative to new products. Upcycling should be freed from its purely handicraft character, which is to be achieved, among other things, through professional product design. The comparatively high prices are due to regional production in social factory workshops; they must be understood and perceived as normal by consumers.*››

"UPZENT" has developed measures to achieve this level of acceptance within its defined target groups. For example, to ensure that resource-saving product design will be accepted as a standard, workshops were held at universities to train future product designers in the field of *Circular Economy* and of the *recyclability of different materials*. Existing inefficiencies are also highlighted so that the core problem, a true circular product design, can be addressed. Product designers must take into consideration their product responsibility because that is where the Circular Economy begins. A cascading usage of our resources must not remain a coincidence but must be integrated in a planned manner.

Even if consumer awareness is increasing, sustainability alone is not a decisive factor in purchasing decisions. The consumer focus lies still on product benefits, price-performance ratio, and aesthetics. These basic criteria must be fulfilled for a purchase to be considered. If this is the case, higher prices will be accepted since the additional ecological and social benefits keep the price-performance ratio appropriate. The combination of informative communication, sympathetic storytelling and transparent structures is the key to success in increasing consumer acceptance.

Assessment tools/LCA

Life Cycle Assessments in the context of the Circular Economy

Proske, M. (Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration) and Friege, H. (N³ Nachhaltigkeitsberatung Dr. Friege & Partner)

Context / background

The cross-sectional group "Assessment tools / LCA" served as a platform for the technical exchange around the topic of environmental assessments conducted in the individual projects. The diversity of the projects was reflected not only in the products considered, but also in the different approaches to solutions in the context of the Circular Economy (extension of useful life through different product design, repair, business models, recycling, etc. as shown in Figure 53). For LCA, this raises complex questions that go beyond the traditional assessments of products: Do we need our own circularity indicators? How can a large variety of usage cycles be modelled? How can quality aspects of the products be considered in the evaluation and how can adjusted business models be represented in a life cycle assessment? How can a technical potential be evaluated if the level of acceptance by the users is still unclear? All these aspects pose new challenges in the definition of system boundaries, functional units, and scenarios. The evaluation procedure is as individual as the solutions developed by the projects and always needs to be adapted to the specific objective of the evaluation. The cross-sectional group therefore did not come together to define a uniform procedure, but rather to exchange between the projects on (common) technical issues. During the meetings of the cross-sectional group, the projects had the opportunity to present interim results, but also discuss procedures undertaken to achieve the tasks related to life cycle assessments, and to get input from other project colleagues. The topics, procedures, and professional contacts from all projects were collected and made available to the group, thus enabling bilateral exchanges between projects with similar issues.

Results / Barriers

The sustainability assessments conducted by the project teams ranged from simplified environmental assessments based on a small number of KPIs to complete life cycle assessment studies and the inclusion of social aspects in the life cycle assessment studies. The solutions developed could thus be evaluated and classified in the context of the Circular Economy. The results predominantly show that the solutions have great potential, but that depending on the concrete implementation, these potentials can be unlocked. In the following paragraph, an overview of the project results, grouped according to the clusters, is provided:

Cluster 1: Promoting the use of recyclates

Findings: Currently, there is a lack of product designs and infrastructure suitable for a Circular Economy. Using a data-driven approach, current recyclates are analyzed and improved formulations for e.g., clothing fibers (project "Di-Tex") and smelters (project "OptiRoDig") are developed with regards to different aspects such as energy and quality. Relevant amounts of CO_2 can be saved by extending product lifetimes and closing product and material loops. To give an example, the REPOST project developed solutions for the recycling of porous concrete, which is being landfilled to date. Markets for the product made from secondary raw materials are often yet to be established. Barriers to a successful set-up of the markets include higher costs for sorting (of e.g., alloyed scrap), insufficient quantities of recyclates, and legal uncertainties. Resource reduction is not a self-runner; products must also be able to compete with conventional products in other aspects (e.g., wearing comfort, price and durability for textiles, costs and quality for alloys).

Cluster 2: Extending product use and intensifying use

Findings: Many products/components are currently not used until their technical end of life. At the same time, the amount of resources required for their production is high. An extension of use can therefore lead to a significant reduction in greenhouse gas emissions and resources, often after only a short extension of the use phase (e.g., "MoDeSt"). In some cases, however, higher circulation rates are necessary for to achieve a reduction (e.g., "praxPack").

An extension of a service life does not automatically entail a reduction of resources used. The right framework conditions must be created for the products to be attractive to customers, concerning e.g., the price-performance ratio for the project "Wear2Share", enough flexibility for "RessProKA" and additional functions for "MoDeSt"). Additional expenses for transport or other purposes can quickly nullify the savings achieved (e.g., "Wear2Share" and Circle of Tools). Higher costs (e.g., for the additional efforts associated with picking up reusable packaging) can also have negative impacts on both customer acceptance and market penetration.

Cluster 3: Remanufacturing

Remanufacturing, i.e., the reconditioning / refurbishment of used products - even on a small scale - can lead to resource savings. Processes which can be put in place to identify products and - parts suitable for remanufacturing, as well as procedures which help make this happen for a larger number of products, are therefore beneficial and should become a standard part of companies' business models. Limitations arise from a lack of user acceptance for remanufactured products/ parts and a high innovation speed of the products to be refurbished or retrofitted. In some cases, legal requirements for industrial infrastructure differ depending on the region (as was the case for the exhaust air purification system in the project "ReLIFE"), which can make a uniform global implementation of remanufacturing difficult.

Conclusion & Outlook

Results achieved by the cross-sectional group "Assessment tools / LCA" provide the following two insights concerning two different aspects: The environmental assessment must be able to map the specific circumstances of the circular solutions, which requires both a deeper understanding of the methods and a good knowledge of the product-service system being analyzed. The results from the projects show that (product) acceptance and legal framework conditions are critical factors for potentials to come to fruition. Here, regulatory framework conditions are needed that specifically support resource-efficient solutions.

Group "Assessment tools/LCA" – Case study "Wear2Share"

How well a solution performs always depends on the specific framework conditions

"The saving potentials for the modeled case of women's outerwear (a cotton t-shirt) with empirical data amounts to around 30 percent of the overall greenhouse gas emissions and to almost 40 percent of the overall water consumption. Savings are possible as early as the second rental cycle. However, the sensitivity analyses also show that savings can be lost due to disadvantageous behavior, such as long car journeys when shipping, frequent washing and the use of dryers." ("Wear2Share")

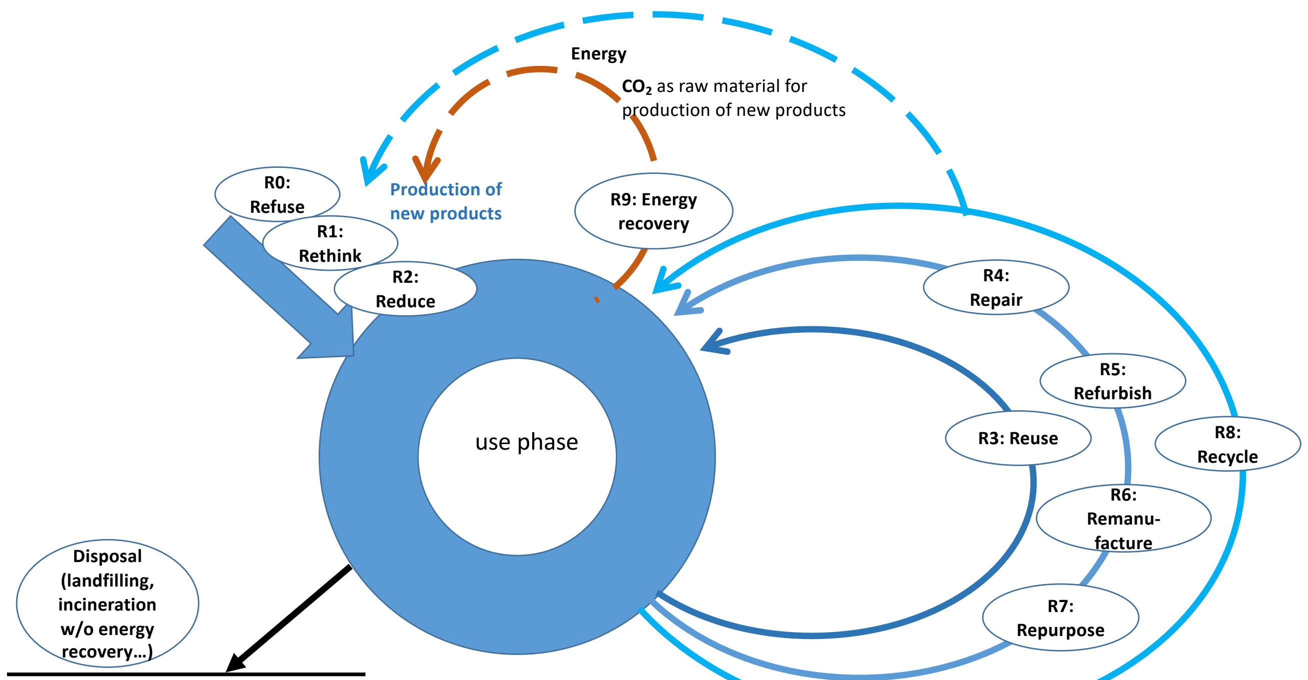

Abbildung 53: Nach einer Graphik aus „Circular economy: What we want to know and can measure" (Eds.: José Potting, Aldert Hanemaaijer, PBL Netherlands Environmental Assessment Agency, Den Haag 2018); modifiziert von Henning Friege und Katja Wendler

Table 2: Classifying the project topics according to basic strategies of circularity (Strategies R0 to R9, see Figure 53).

	Extended use	Reuse of products / modules	Utilization/recovery of products after use	Use of secondary materials	Other
AddRE-Mo R1,R2,R3,R5	Remanufacturing of electric bicycle motors	Reuse of electro-mobility components			Business model for optimal utilization; additive manufacturing of spare parts for remanufacturing
All-Polymer R2,R8			Aim: High-quality recovery after use	From secondary raw materials with added fibres	
Circular by Design R0,R2,R8			Determination of recycling potentials		Design optimization for longer service life and recycling/material recovery
Circle of Tools (CoT) R2,R7,R8			Remanufacturing and repurposing of worn metal products		Organization of the retrieval of tools
ConCirMy „Enabler“					Product Configurator for tyres (e.g. increase of the recyclate proportion, longer service life)
DIBICHAIN „Enabler“					Digital mapping of complex product cycles by blockchain
Di-Link R2,R8				Increasing the recyclate content in high-value plastic products	Sensors for measuring. Quality of recyclates and digital information transfer in the chain
DiTex R1,R2,R3,R4,R8	More frequent use of commercially used textiles, incl. repair services		Use of used textile fibres (fibre-to-fibre recycling)	Use of recyclate to produce textiles	Testing of B2B business models, use of tracking ID to record usage cycles
EIBA R3,R6		Remanufacturing of used car parts			Remanufacturing with the help of AI-supported identification and evaluation of used parts
EffizientNutzen R4	Longer service life of electrical devices through repair				Test of a business model for manufacturer-independent repairs
KOSEL R1,R4	Extending the service life of motor vehicle through high quality materials	open-source design kit for electrically powered pool vehicles	(Simplified use of spare parts due to modularity)		Sensor-based condition monitoring of vehicle components in operation
LEVmodular R1,R4	Extending the service life of light electric vehicles (LEV)	Improvement of reparability (e.g. low voltage in battery and motor)	Open interfaces to battery/motor for repurpose		New business models for the automotive supply industry; sensor-based condition monitoring of fibre composites
LifeCycling^2 R1,R3,R4,R8	Extending service life and intensity of electric cargo bikes	Organizational measures for targeted circulation of e-components	Reclamation of used modules or materials		Design concepts for hard- and software; comparison of business models
LongLife R1,R4	Extension of the use of technical components from industrial buildings				Sensor-based condition monitoring of components; AI to determine remaining service life; development of a business model

	Extended use	Reuse of products / modules	Utilization/recovery of products after use	Use of secondary materials	Other
MoDesT R1,R4,R5	Extension of the service life of smartphones or tablets through exchangeable modules („upgrade“)				Improvement of eco-design and optimization of business models for modular smartphones
OptiRoDig R2,R8				Increase in the proportion of scrap in the foundry and steel industry	AI-assisted characterization and selection of scrap
PERMA R1,R3,R7	Longer use of furniture and other equipment for office buildings	Repurposing (lower value) after use			Open platform for users. Test of business models
praxPACK R1,R3,R8	Replacement of disposable packaging in online retailing (reusable)			Examination of applications for packaging with a high recyclate content and evaluation of the ecological effects	Testing acceptance among customers; piloting with online retailers to test economic viability
ReLIFE R4,R6	Life cycle extension of capital-intensive goods through targeted application of „adaptive remanufacturing“ - and maintenance measures	Return of recycled components of a capital good			Product-oriented business model (capital good and associated application); application-based recommendation for action based on sensor data and decision-making logics
RePare R1,R4,R5	Runtime extension of machines/ vehicles through additive repair of individual parts				Dynamic configuration of value-added networks; automation of component preparation and material application
RePOST R8			Sorting out of aerated concrete waste...	... and preparation to produce new AAC blocks	Existing business model; promoting acceptance in the market for high secondary content
ResmaP R1,R4,R5,R6	Lifetime- Extension through remote diagnosis and repair		Improving the recyclability of pump parts		Extension of an existing business model
RessProKa R1,R3,R6		Reuse of components in office buildings (conversions)	Recirculation and remanufacturing of components		Manufacturers remain owners of the components; business model tested in business game
UpZent R2,R8				Use of industrial waste to produce simple consumer goods	Networking of analogue social enterprises
Wear2Share R1	Longer use due to higher intensity of use (rental)	Reuse of textiles through renting			Economic and ecological optimization of business models

Business models

Opportunities and Challenges of Circular Business Models

Brinker, J. (Deutsches Forschungszentrum für Künstliche Intelligenz GmbH)

Context / background

Limited resources, the resulting price increases, as well as new requirements regarding compliance with sustainability goals, demand a change from linear value creation structures to closed economic cycles. For companies, this results in the necessity to deal with new business models on the one hand, but on the other hand also in the potential to be able to differentiate themselves on the market in the long term. In practice, the conception and implementation of circular business models is associated with challenges: Due to completely new or additional activities of the underlying processes, the complexity within the value creation networks increases. Often, these cannot be covered economically by individual companies. If additional know-how is required, it must first be built up or new players must be considered in the business models, which makes implementation more difficult, especially in the case of divergent interests. Furthermore, consumers, who are aware of sustainability or price, depending on the industry, must also be considered by creating corresponding added value. So far, there are only a few generally applicable standards and frameworks that address these challenges and support companies in realizing circular business models. In the context of this working group, the topic of circular and resource-efficient business models was accompanied and discussed across projects to identify and advance interdisciplinary solutions.

Results / Barriers

Most projects are concerned with the extended use of products (see Fig. 54), for example by monitoring the condition of products, modularization or remanufacturing of components and products. This focus is understandable both from the point of view of resource efficiency and against the background of the business models since the residual value of a product is always higher than that of individual components or recycled materials and can be based on existing business model structures. If one looks at the relationship of the business models to existing ones, complementary and competing offers are of particular interest: Complementary offers expand the value proposition of a company, for example in the form of take-back agreements for raw material recovery, and thus make the existing offer more attractive. In contrast, competing offers form an alternative for the customer, e.g., when a remanufactured component is sold instead of a new part. While on the one hand this is associated with a lower value creation potential due to the existing solution, these business models are also characterized by lower risk and can establish themselves as a sustainable alternative in the long term depending on acceptance and feasibility.

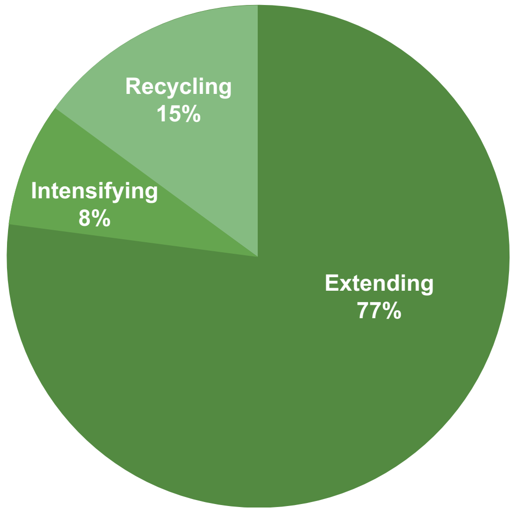

Fig. 54: Classification of projects according to Geissdoerfer et al. (2018)

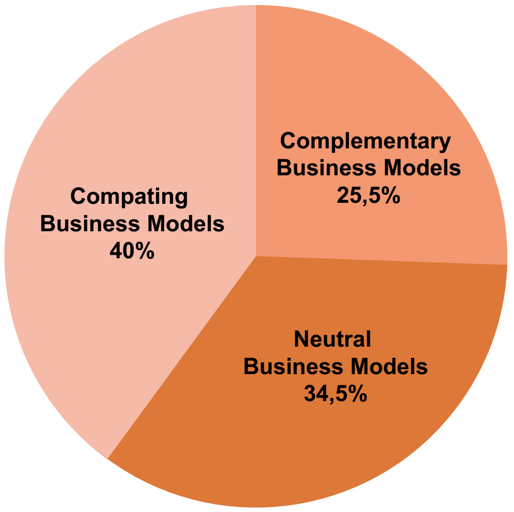

Fig. 55: Relationship to existing Business Models.

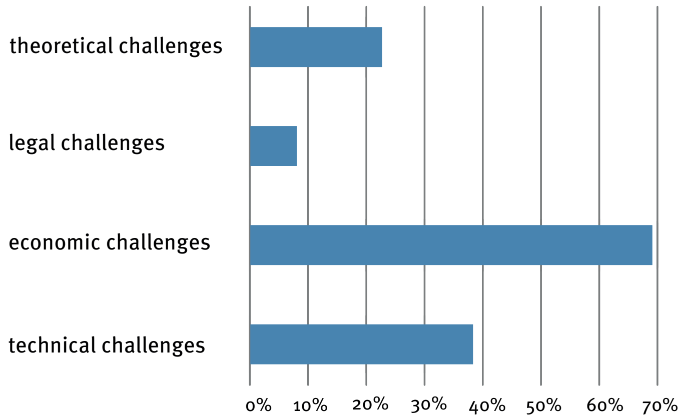

Fig. 56: Challenges in the development of business models.

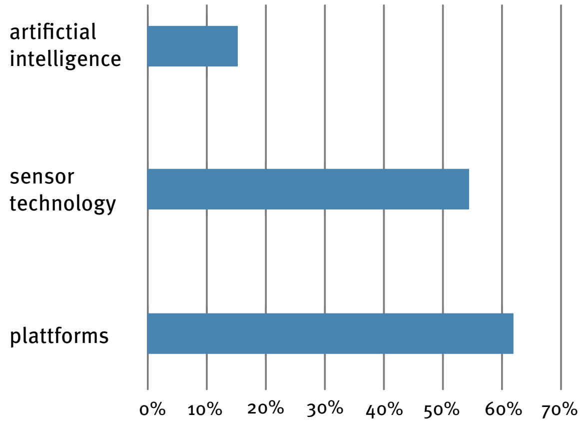

Fig.57: Use of IT.

The challenges identified by the projects lie primarily in business and technical areas. Economic viability is a particular challenge due to the increased expense and dependence on partners in the value network. Technical aspects are particularly challenging due to the change in process and production workflows, the use of new solutions, and also due to the necessary know-how. The implications of these aspects were identified during the project and addressed by means of generalizable solutions. This is also reflected in the IT tools used to realize the business models. Especially the new partner structures and the associated coordination were taken into account in the funding line by using (digital) platforms. Sensor technology and AI processes are used analogously to the goal of longer product use, for example by enabling closer monitoring of the products over the life cycle and the prediction of changes in condition.

Conclusion & Outlook

The participating projects cover a wide range of domains and vary in the focused phases of business model development. During the interdisciplinary exchange in the cross-cutting issue, it became apparent that despite theoretical groundwork in the literature and initial implementations in practice, the realization of a resource-efficient Circular Economy is accompanied by individual issues and challenges such as consumer acceptance or the economic viability of alternative business models. At the same time, the projects have designed and tested new tools in addition to individual solution strategies (see attached publications). Successful implementations, such as in the “DiTex“, “EffizientNutzen”, “UPZENT” or “LongLife” projects, show how such circular business models can be designed in different domains and how economic and ecological potentials can be leveraged. The findings from these projects must be further generated in a close exchange between science and practice and transferred into suitable tools.

Selected publications

- Brinker, J., Gembarski, P.C., Hagen, S., Thomas, O. (2020). *Anwendungspotenziale von Additive Repair und Refurbishment für Service-orientierte Geschäftsmodelle*. In: Lachmayer, R., Rettschlag, K., Kaierle, S. (eds) Konstruktion für die Additive Fertigung 2019. Springer Vieweg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-61149-4_4
- Niemeyer, Jan Felix; Rudolf, Sina; Kvaratskhelia, Lika; Mennenga, Mark; Herrmann, Christoph (2022): *A creativity-driven Case-Based Reasoning Approach for the systematic Engineering of Sustainable Business Models*. In: Procedia CIRP 105, S. 470–475. DOI: 10.1016/j.procir.2022.02.078.
- Rudolf, Sina; Blömeke, Steffen; Niemeyer, Jan Felix; Lawrenz, Sebastian; Sharma, Priyanka; Hemminghaus, Sven et al. (2022): *Extending the Life Cycle of EEE—Findings from a Repair Study in Germany: Repair Challenges and Recommendations for Action*. In: Sustainability 14 (5), S. 2993. DOI: 10.3390/su14052993.
- Koop C, Grosse Erdmann J, Koller J and Döpper F (2021) *Circular Business Models for Remanufacturing in the Electric Bicycle Industry*. Front. Sustain. 2:785036. doi: 10.3389/frsus.2021.785036

Legal Framework

Legal barriers to a resource-efficient economy

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"Legal framework conditions" were identified as a topic of common interest, which is why a joint exchange took place on various legal issues surrounding the implementation of a "Circular Economy (CE)", also involving external experts. The following challenges for the design of the legal framework were identified:

No uniform understanding of "Circular Economy": Neither in European nor in German waste law has the term been introduced so far. "Circular Economy" comprises more than the Circular Economy as defined by the "Kreislaufwirtschaftsgesetz (KrWG)". Although the EU has been using the term "Circular Economy" for many years, it was not until 2020 that a legal definition was included in the Taxonomy Regulation (EU) 2020/852 (Art. 2 No. 9). This also refers to waste legislation: "An economic system in which the value of products, materials and other resources is maintained as long as possible in the economy and their efficient use in production and consumption is improved, thereby reducing the impact of their use on the environment and minimizing the generation of waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy". This definition aims at a more efficient and economical management of resources. As there is no general law sector of "resource protection", corresponding alignments should be made in European and national environmental and product law.

Difficulties with the recognition of the end-of-waste (EoW) status: General requirements for end-of-waste are laid down in the (European and German) "Abfallrahmenrichtlinie" (Waste Framework Directive, WFD, Art. 6) and in the German Circular Economy Act (KrWG (§ 5)). These criteria include the usability, marketability, compliance with technical standards and environmental compatibility of the material or product. In addition, the waste must first have undergone a separation or treatment process or similar. The legal path from waste back to product is complicated. A simplified treatment of the EoW issue is only possible for three types of wastes, namely steel scrap, copper scrap and waste glass, for which material-specific regulations exist at EU level.

The following concrete problems were identified

- An exchange of production waste (e.g., plastic - see "DiLink") between different producers for the purpose of material recycling is currently not possible because treatment by a third party (recycling plant) is required first (§ 3 and with § 5 KrWG).
- Recyclates do not necessarily fulfill "all the technical requirements [...] and applicable standards" on the product side on quality (§ 5 (1) 3 KrWG) but can be used for simple products, as in the "UPZENT" project.

Re-import of defective appliances for repair: Cross-border trade of defective electrically operated appliances is problematic due to the Basel Convention in connection with the waste definition (linked to the owner's intention to discard the product). A practical issue arising in "ResmaP" is as follows: the non-European user sends a defective pump to Germany, where it is repaired and overhauled for resale. If the pump is considered as waste in cross-border traffic with corresponding transport restrictions, labelling obligations, etc., the business model is at risk.

Interface between chemicals and waste legislation: The EU Commission has recognized that greater recycling and reuse after repair require good knowledge of the composition of end-of-life products. Based on Article 9 (1) (i) of the WFD, a database - SCIP (Substances of concern in articles as such or in complex objects (products)) - was therefore created, in which manufacturers enter substances of very high concern (SVHC) used above 0.1% (weight by weight) in their products However, EOL-products are often not identified in waste streams due to a lack of expertise and the necessary equipment on site. In addition to hazardous substances, there are also numerous substance combinations (e.g., composite materials) or connection types (e.g., adhesive instead of plug-in connections) that hinder recycling processes. The considerable information deficit at recycling facilities is thus hardly reduced by SCIP.

Another problem concerning this interface is the exclusion of recyclates from use in a new product (e.g., plastics to be used in the interior of refrigerators/freezers, see "CbD" project) due to the possible presence of pollutants (§ 5 para. 1 no. 4 KrWG), including

- Persistent organic pollutants (POPs) in certain concentrations (EU POP regulation)
- Substances of very high concern (SVHCs) in concentrations above 0.1%
- Flame retardants in plastics (various brominated aromatics)

Where these substances cannot be separated, large quantities of materials currently in use are either disposed of or fed into energy recovery routes. This removes them from the intended cycle of resources. With the continuous tightening of REACH announced in the Chemicals Strategy for Sustainability, the number of SVHC and thus also the quantities of corresponding materials are increasing. At the interface of waste and chemicals legislation, use cases should therefore be defined for such materials, where a release of the contained pollutants during use is avoided.

Quality assurance: Problems of data exchange: A decisive prerequisite for the success of business models along the product life cycle is the exchange of data between producers, customers, and waste management in both directions and with the involvement of stakeholders who organize repair, refurbishment, reuse, etc. There are often conflicting interests regarding

- Data protection (of personal data)
- The protection of intellectual property (e.g., CAD plan for 3D spare parts - IP protection)
- The further use of artificial intelligence (AI) data (e.g., may an AI "pre-trained" with the data of one company be used for applications in another company?)

This is where legal boundaries and management problems along the product life cycle intermingle. The topic of data security in the sense of "cyber security" increases in importance with the size of the value network in the sense of a Circular Economy. Definitional and legal clarifications are required here.

Quality assurance: All business models between R3 ("Re-Use") and R7 ("Re-Purpose" -see Fig. 53) must deal intensively with questions of quality assurance. This includes liability when using second-hand products, recourse security when using artificial intelligence, etc. Protocols or standards to produce secondary raw materials and further activities in the Circular Economy are needed. With these aspects in mind, DIN, DKE and VDI are working together with experts on a "Circular Economy standardization roadmap" to identify the need for standardization in this area.

Because of the challenges identified in "ReziProK", the following additions and/or changes to the legal framework are necessary to give business models for a resource-efficient economy and society better chances for success:

- Mandatory labelling of materials contained in products (such as types of alloys), e.g., a digital twin as a building passport, and for electrical or electronic as well as plastic products and textiles, information via a stable QR codes, fluorescent tracers for tracer-based sorting, or RFID (radio-frequency identification).
- Extension of the requirements of the Eco-design Directive to other products with requirements for repairability and stocking of spare parts
- Investigating options for economic incentive systems for returning used items
- Automated recording and evaluation of conditions of critical components, which can either provide information on the need for a R4 ("repair") or give a green light for a non-critical continued operation of e.g., safety-relevant lightweight components, even after misuse/overload.
- To counteract the misguided incentive to purchase cheap primary materials (e.g., plastic), secondary materials should be made financially more attractive in comparison to the respective primary materials. For example, secondary materials could be taxed at a lower rate or not at all, or an additional levy could be imposed on primary materials.

Outlook and recommendations

Outlook: Barriers to implementation and recommendations for action

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The results from the 25 research projects presented in this publication show promising and innovative approaches on how the transformation of the predominantly linear economy to a resource-efficient, Circular Economy can succeed and thus reduce the consumption of valuable raw materials and products, such as plastics, metals, textiles or building materials. The next step is now to transfer these research results into economic practice as quickly as possible and to strengthen the transformation towards a more resource-efficient Circular Economy in Germany. However, during implementation, these approaches come up against legal as well as economic and technical hurdles. Therefore, several policy recommendations were compiled: - These are listed below and are essential for the politically demanded change of course towards a Circular Economy.

Legal barriers and recommendations for action

Lack of definitions and concretization of the "Kreislaufwirtschaftsgesetz" (KrWG)

A resource-efficient Circular Economy requires a concrete definition of goals and a legal framework. So far, there is only one legal definition of a Circular Economy (in the European Taxonomy Regulation), but none in German law. This leads to uncertainty as to how a Circular Economy is defined and what it aims to achieve. The sometimes very broad use of the term facilitates "greenwashing" by providers. Therefore

- a binding definition of the Circular Economy is needed, which should also be introduced into German law and used uniformly..

The high hurdles for the EoW status constitute another legal barrier. A direct exchange of production waste between different producers for the purpose of recycling is therefore currently not possible. The risk of the by-product status of a material being withdrawn and it being classified as "waste" was also mentioned as a hurdle to implementation. It is therefore recommended to:

- Amend § 3 KrWG to the effect that, despite the classification of a material as waste, it is easier for potential waste recyclers to continue using this material without prior treatment by a third party (i.e., in a recycling plant) and to introduce it into a new product life cycle.
- define § 4 para. 1 no. 2 more precisely and amend it in a way that waste recyclers do not run the risk of having their materials deprived of the status of by-product, e.g., through special purification of a material for further use.

Furthermore, the low-value use of recycled materials is more difficult, as recyclates do not necessarily meet all standards, but can be used for simple products.

- § Section 5 (1) no. 3 KrWG: Requirement to fulfill "all technical requirements and applicable standards" for products made from waste. Here, exceptions should be legally enabled for the retrievable and environmentally safe use of contaminated recyclates, of course in line with the requirements specified in the EU framework.

High carbon footprint due to deficient design in terms of repairability, reusability, recyclability and insufficient use of renewable energy

Products and their components are often manufactured in such a way that material recycling is difficult and there are no known approaches for reprocessing or reuse. For example, due to the way products are constructed, remanufacturing is often more harmful to the environment or more expensive than remanufacturing, as the original properties can only be restored with a disproportionately high effort. However, remanufacturing, repair, and material recycling are prerequisites for saving material and energy resources. The following legal framework conditions would be helpful:

- Legal framework conditions which are integrated into the "classical" product development and provide incentives for design for recyclability, repairability and reusability,
- legal framework conditions which promote the switch to renewable energies in energy-intensive manufacturing processes, thereby contributing to a drastic reduction in CO_2 emissions.

Lack of data

Besides special laws, the labelling of the essential ingredients of products is only mandatory for substances of very high concern (SVHC). However, for recycling, and sometimes even for repair, information on the composition of the products on how they can be disassembled are urgently needed (however, a full declaration of the composition is not usually necessary). Moreover, the use of SVHC is steadily increasing, whilst, at the same time, the use of recyclates containing pollutants according to § 5 para. 1 no. 4 KrWG is banned. This leads to a constant tightening of the chemicals law (REACH) and an increasing amount of waste that can only be energetically exploited.

The above points lead to the following recommendations for action:

- Introduction of a digital twin as a building passport and, for plastic products and textiles, a compulsory disclosure of the composition, e.g., via a stable QR code, fluorescent indicators, or RFID (radio frequency identification).

Furthermore, there are serious deficiencies in the exchange of data between producers, users, and the waste management sector. This lack of data availability is, amongst other things, due to the different interests of the participants in a value chain (protection of personal data) and the protection of intellectual property (e.g., CAD plan for 3D spare parts - IP protection) or also the lack of trust in data security. However, these barriers pose challenges for all CE business models, as cooperative data exchange along the product life cycle between producers, customers and waste management is required in both directions and with the involvement of stakeholders organizing repair, equipment refurbishment, reuse, etc.

It is thus recommended to

- create an incentive to provide data in a way that the data basis and the flows of information between the individual participants in the value chain are optimized and the data format (for the collection of data) is standardized and can thus contribute to a functional network of value creation and - conservation and to a reduced energy- and primary raw material consumption.

Technical barriers and recommendations for action

Furthermore, to increase the comparability and transparency of results,

- a standardization of methodological approaches for environmental assessments should be introduced, which goes beyond the requirements of the relevant standards and provides guidelines for environmental assessment.
  - In the area of plastic recyclates, a guaranteed minimum quality (according to standardized measurement conditions through standardization on the part of the associations) would be helpful.

Complexity of the digitization of existing plants and processes

Suppliers sometimes do not have the technical know-how to bundle information digitally and share it with external parties. This means that the necessary information to calculate various optimizations might be missing. Accordingly, it is recommended

- to promote IT support
- to ensure that the Digital Product Passport is implemented in such a way that as many stakeholders as possible can participate in it. The necessary digital prerequisites are to be created.

Social and economic barriers and recommendations for action

Raising awareness

The use of products that have already been used once or are made from recyclates depends indispensably on their market acceptance. Consumers often have reservations about used and recycled products. The lack of trust in circular products is due, among other things, to non-transparent communication or the lack of public awareness among consumers and leads to low demand for many product groups (e.g., textiles, building materials). This impairs the competitiveness of these products. Therefore,

- through information campaigns, PR and educational work, consumers should be made aware of the benefits of the circular products, so that recycling and the use of recycled materials, upcycling or remanufacturing are recognized as being of equal value and thus, circular products are preferentially produced and consumed.

Research and innovation funding

In addition to the lack of acceptance, the lack of further funding for research projects forms an additional hurdle to the implementation of the results achieved, because after the end of the funding phase, there are no suitable funding opportunities to further develop the results or to increase the level of technological maturity to ensure that they can be transferred into practice.

- To overcome this, the provision of financial support to increase the acceptance of recycled products or sustainable business models is recommended.
- The funding of communication measures to raise awareness among the citizens and the business community and the creation of a "stage" to give successful research projects visibility to bring promising project results to market are desirable.
- In public procurement, a pilot tender (pilot project) or long-term promotion of business models that have a positive impact on sustainability and society should be encouraged to support the roll-out of sustainable products.

The results from "ReziProK" show that circularity-oriented processes, products, and business models have considerable advantages in terms of achieving a sustainable economic activity. However, in some cases, these innovative approaches come up against limits, which the German Federal Government and the Parliament (Bundestag), as well as the business associations, are called upon to overcome.

Keyword register

Keyword register

Related links

“ReziProK” website: https://innovative-produktkreislaeufe.de/resswinn/en/

Publications: https://innovative-produktkreislaeufe.de/resswinn/en/Publications.html