ReziProK
Resource-efficient Circular Economy – Innovative Product Cycles

SPONSORED BY THE
Federal Ministry of Education and Research

FONA
Research for sustainability

BMBF-funding measure "Resource-efficient Circular Economy – Innovative Product Cycles (ReziProK)"

Results

Preface

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

In Germany, the annual consumption of raw materials amounts to approximately 17 metric tons per capita, which is twice as high as the global average. To preserve a world worth living in for future generations, our highest priority must be to protect our climate – in conjunction with a decoupling of economic growth from resource consumption to the largest possible extent.

For this, we need, above all, a fundamental transformation of our current, often linear economic system (production, usage, disposal) towards a resource-efficient circular economy, in which, for example, 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 and contribute to making Germany as a business location more independent of raw material imports and thus more resilient.

The promotion of the circular economy is therefore a priority of Germany's Federal Government. 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 25 "ReziProK" projects focused on common R&D themes such as new business models for the circular economy in conjunction with the increase of resource efficiency through a sustainable, repair- and recycling-friendly product design, innovative technology developments for high-quality raw material recovery, as well as digital technologies.

Only if all involved parties can be convinced of both the economic and the longterm ecological benefits of the circular economy, the necessary implementation will succeed.

Your Federal Ministry of Education and Research

"ReziProK" – Results from 25 research projects

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.

Within the 25 projects of the funding measure "ReziProK", numerous new insights for a more sustainable use of resources were gained. In the projects, experts from business, science and industry developed sustainable solutions for innovative product cycles. 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.

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 and at the same time significantly reduce energy consumption and associated greenhouse gas emissions over the "product life cycle".

The BMBF funding measure "Resource-efficient Circular Economy – Innovative Product Cycles (ReziProK)"	
Aim of the funding measure	Contribution to the implementation of a resource-efficient circular economy by closing product cycles
Funded projects	25 research projects, 1 networking and transfer project
Funding Volume	~ 30 Mio. Euro
Funding Volume	~ 3.5 years from June 2019

Table 1: Overview of the research topics of the funded “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

Cluster 1: Optimized use of recyclates

Recycling remains one of the central strategies of sustainable resource management. Although established regulations exist for most of the separately collected waste fractions at national and EU level and technologies are constantly being developed, the recovery of secondary raw materials such as plastics, textile fibres and special metals still falls short of expectations. The provision of high-quality recyclates is a great challenge due to the contamination of waste fractions or the complex separation of the desired material from numerous additives. With the impulses from the "Green Deal" and the implementation of measures from the "Circular Economy Action Plan" of the European Commission, the EU is providing incentives for increased resource savings, the development of better technologies and the establishment of business models for circular processes.

Cluster 1 "Optimized use of recyclates", consisting of eight projects, comprised new technologies for the processing of separately collected waste ("REPOST": aerated concrete, "OptiRoDig": metal scrap, "DiLink": waste from plastics production, "UpZent": manufacture for consumer products from commercial waste), new product designs with the aim of better recyclability after use ("AllPolymer": increasing the recycled content through fibre reinforcement, "DiTex": workwear that is easy to recycle) as well as the use of digital information for the separation and recycling of waste ("DiTex": textiles equipped with active RFID (Radio Frequency Identification) tags, "OptiRoDig": digital network between the recycling industry and metal smelters, "DiLink": intelligent networking of production plants, "DIBICHAIN": blockchain as a dynamic carrier of information along the value chain, "ConCirMy": product configurator based on the example of used tires).

Fig. 2: Workwear made from recycled polyester (rPES) used in the textile service (© MEWA 2022)

For most of the projects, it has already been shown through the evaluation of available key figures that they make an additional contribution to sustainable development compared to previous recycling processes, above all through an increase in the substitution of primary materials by secondary materials, higher quality recyclates and a reduction in energy consumption. Digital information and identification tools have played a prominent role in achieving this. Without them, the recognition of materials in complex end-of-life products or the extensive networking of secondary raw material producers with recyclers would not be possible.

The costs incurred for digital support must be generated through higher revenues from recyclates, which must be considered when implementing the research results in existing markets.

To utilize the opportunities for a more sustainable use of resources identified in this cluster, changes to individual legal regulations are also required, for example at the waste/product interface, as well as suitable legal frameworks for circular business models. Legal solutions are needed that ensure cooperation between all participants along the value chain, e.g., for the protection of intellectual property, when results from optimization based on artificial intelligence are jointly used and, for the problemoriented handling of personal data.

Fig. 3: Upcycling: stacking stool "Volker" (© "UPZENT" 2021)

Cluster 2: Extended product use

A resource-efficient circular economy includes not only the recovery of raw materials but also the extension of the lifespan of products or individual components.

In various "ReziProK" projects, it was shown that extended product use can increase resource efficiency in a wide variety of application fields in manufacturing, private consumption, and the service economy.

Ten projects focused on reusing products, i.e., an extension of the product life span. This ranged from the extension of the use phase of electrical and electronic products through the repair and trade of secondhand equipment ("EffizientNutzen"), the comparison of rental models for clothing ("Wear2Share") and the reuse of furniture and equipment ("PERMA") to the further processing of used cutting tools ("CoT").

Fig. 4: Reusable shipping bag "RePack" (© RePack)

The foundations that enable reuse, repair or even value-added recycling are already laid in the product design phase. Some project teams therefore investigated the influence of design, e.g., on repair and recycling friendliness. How can the functionality and sustainability of mobile phones be increased through a modular design ("MoDeSt") or how does the reduction of material diversity in large electrical appliances contribute to an increase in repair-friendliness and to an improved raw material quality of the derived recyclates ("CbD")? Options of using reusable packaging in online trade were also investigated ("Praxpack"). In addition, it was investigated how the remaining useful life of technical systems can be best determined ("LongLife") and how the electronic components of modern heating pumps can be used, for example, for remote maintenance ("ResmaP").

The development of new business models also played a decisive role in the projects of this cluster. In the "RessProKA" project, for example, the economic, ecological, and legal effects of concrete business models were examined, using the example of the finishing trade.

Results have shown that there is no uniform business model for the extension of product lifetimes. Some projects focused their business models on the data collected during the use phase of the products; in others, standardized repair manuals or the ownership of the products were placed at the center of the new business models.

In addition to good technical solutions and viable business models, customer acceptance also plays a central role. The market studies carried out by the project teams of the cluster have revealed deficits here, whose elimination, in many cases, requires special efforts. The attitude and mindset of our society must change fundamentally. This remains both a task for those involved in the individual value chains and for policy-makers.

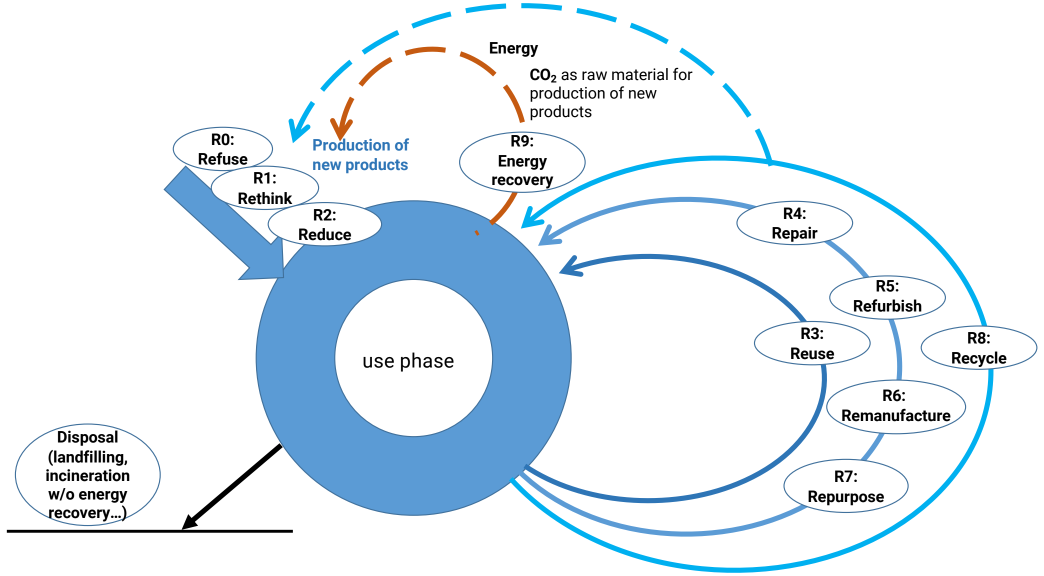

Fig. 5: Based on a graphic from "Circular economy: What we want to know and can measure" (Eds.: José Potting, Aldert Hanemaaijer, PBL Netherlands Environmental Assessment Agency, The Hague 2018); modified by Henning Friege and Katja Wendler.

Cluster 3: Remanufacturing

Remanufacturing is an approach to keep products in circulation for as long as possible. In an industrial process, used or defective products are restored to an as-new – or even better-than-new condition.

Within the funding measure "ReziProK", four research teams investigated the conservation of the value of components from various application areas using remanufacturing, taking into account the ecological and economic potentials of the remanufacturing measures.

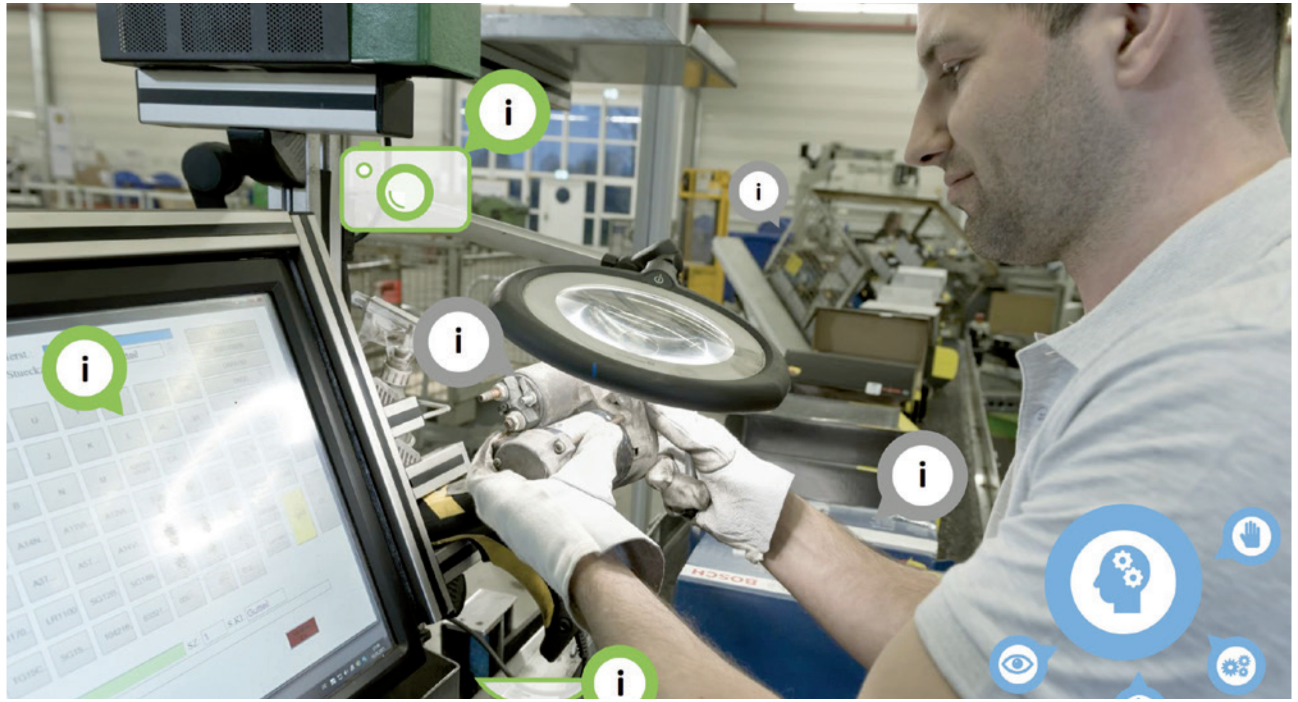

Fig. 6: Humans and AI complement each other (© C-ECO/Bosch)

The "AddRE-Mo" project team dealt with value retention scenarios for urban electric mobility for people and loads by additive remanufacturing, 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, the 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 ecological potential of (adaptive) remanufacturing could be demonstrated in the projects. 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 implementation of the research results in commercial practice now largely depends on 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.

"Business models" were identified as a topic of common interest, i.e., a crosscutting issue relevant to several projects. In this context, use cases as well as challenges and findings from the development of business models in the projects were recorded and published.

Fig. 7: Additively manufactured gear wheel of an electric bicycle motor (© Fraunhofer IPA)

Cluster 4: Recyclable electric vehicles

A large part of the world's resource consumption is caused by passenger and freight transport. A continuous increase in the volume of traffic for individual mobility and merchandise planning can be observed worldwide due to the growing world population and increasing online trade.

Due to these developments, the resource consumption for mobility is increasing considerably, despite the increased efficiency of combustion engines. Resource efficiency is thus becoming a key objective in the development of future mobility concepts. In addition to low environmental impacts during operation, a minimization of the amount of resources used for the production of vehicles and an efficient (re)use of resources; e.g. by recycling individual components and performing material recycling for others, is required.

Fig. 8: Practical evaluation of ergonomics, light vehicle Cargo Cruiser 2 (© Olaf Lange Dreiradbau, Berlin)

New vehicle concepts, a longer lifespan of passenger cars through the development of particularly durable modules, innovative, advantageous and economically viable business models, reconfiguration, refurbishing or remanufacturing – there are many different approaches supporting the recyclability and sustainability of electric vehicles, and which were addressed by the three "Rezi-ProK" projects "KOSEL", "LEVmodular" and "LifeCycling2":

In the "KOSEL" project, a recycling-friendly opensource construction kit with durable components made of low-corrosion and low-fatigue materials such as carbon fibre-reinforced plastics was developed for electrically powered pool vehicles. The "LEVmodular" project focused on the evaluation of the suitability of conventional electric vehicles for recycling or reuse compared to a light electric vehicle (LEV) constructed in the project through life cycle assessment. The analyses showed an increased energy efficiency and thus a reduction of environmental emissions for LEVs. Pilot tests also support the realistic use of light vehicles for private and commercial purposes. In the "LifeCycling2" project, critical subsystems of e-cargobikes, such as batteries, were identified and solutions for the targeted reuse and upgrading of products and components were investigated.

One of the biggest challenges here is also acceptance, because without acceptance on the part of the manufacturer, the sharing provider, and the end user, none of the solutions can be effectively implemented.

Therefore, a cross-project exchange on the topic of "acceptance research" took place within the framework of the "ReziProK" funding measure. Via a questionnaire, various target groups and participants along the value chains were identified, as well as factors influencing acceptance and their steering approaches in the project context (see Figure 9).

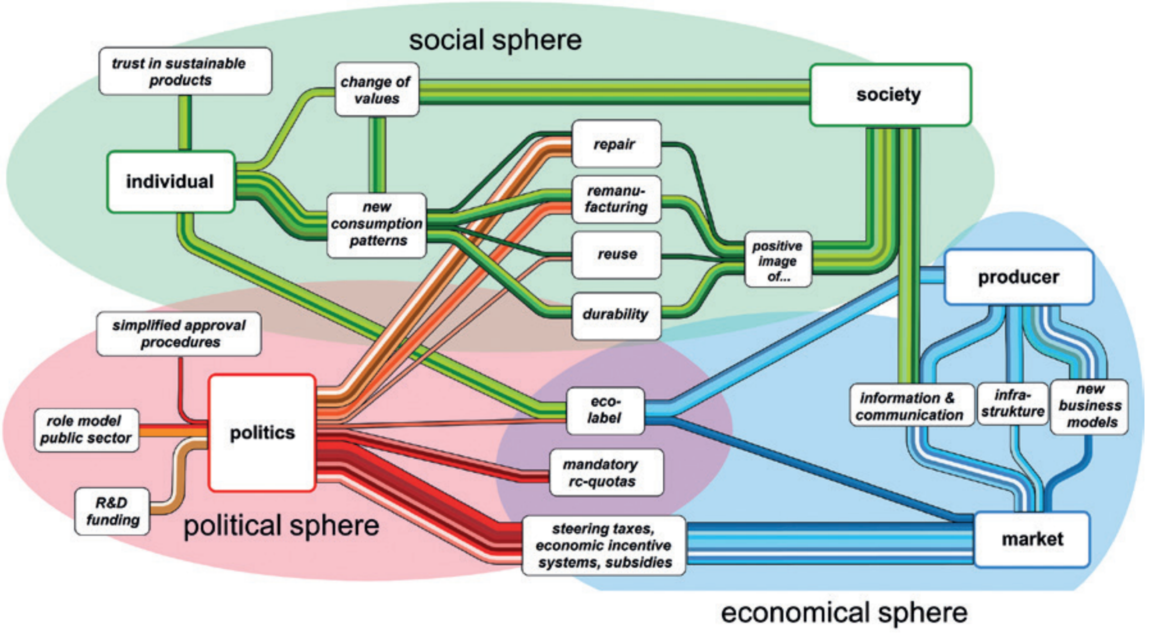

Fig. 9: Measures to promote acceptance, here using the example of the answers to the question: "What preconditions and framework conditions would be required to enable the ideal integration of the project objectives into the field of application?" (multilevel perspective, the arrow thickness corresponds to the weighting of the mentions) (© Kreft, O., Xella Technologie- und Forschungsgesellschaft mbH, 2022).

Outlook and Recommendations

The results from the 25 resarch projects show promising and innovative approaches on how the transformation to a circular economy can succeed and how resource efficiency can be increased. In some cases, however, during implementation, these approaches come up against legal as well as economic and technical limits. This is a challenge not only for science and industry, but also for politics.

A resource-efficient circular economy requires above all a concrete definition of goals and a legal framework, which is why a binding definition of the circular economy is needed in

German law. The high hurdles for the end of the waste status pose another barrier. It should be possible to use production waste which does not pose a risk, e.g., from cutting, directly as an input into other companies‘ production processes without prior treatment in a recycling plant. The status of a “by-product” through additional treatment steps should not lead to this material being classified as waste.

To facilitate the low-value use of recyclates in controlled applications, a regulation of the use of waste containing harmful substances is also recommended, provided this does not incur a risk to the users.

Products and their components are often manufactured in such a way that recycling is difficult (e.g., glued), and reprocessing is often expensive and associated with high material losses. Legal framework conditions that create incentives for reparability, reuse and design for recyclability would be helpful.

In addition, the switch to renewable energies in energy-intensive manufacturing and treatment processes leads to a drastic reduction in CO_2 emissions and should therefore be the focus of efforts.

Furthermore, a stronger orientation towards resilient economic and logistics structures is required, for example by shortening and regionalizing value chains. One challenge is the lack of data, since besides special laws, there is only an obligation to label the main ingredients of products for substances of very high concern.


© Larisa Koshkina - Pixabay

Therefore, the introduction of a digital product passport, e.g., as a building passport and for plastic products and textiles, is a sensible and urgently needed measure for which corresponding incentives should be created. At the same time, a standardization of methodological approaches for sustainability assessments should be introduced to increase the comparability and transparency of results.

The lack of automation and digitalization of existing facilities and processes were identified as technical barriers. To overcome those, the creation of the necessary pre-requisites and a stronger promotion of IT support for employees are recommended.

In addition to the aspects already mentioned, there are also social and economic barriers: Consumers often have reservations about used and refurbished products. Through information campaigns, public relations, and educational work, as well as increasing awareness in society, a market acceptance of circular products can be created, and the competitiveness of the products can thereby be increased.

In addition, the market entry of innovative approaches for a resource-efficient circular economy can be supported by suitable funding and innovation programs, especially to increase the acceptance of products with a high recycled content and for the piloting of sustainable business models.

Editor

DECHEMA

DECHEMA Gesellschaft für Chemische Technik
und Biotechnologie e.V.
Theodor-Heuss-Allee 25
60486 Frankfurt am Main
Germany
www.dechema.de

Contact DECHEMA e.V.
Dipl. Ing. Katja Wendler
E-Mail: katja.wendler@dechema.de

Dr. Celine Schielke
E-Mail: celine.schielke@dechema.de

Contact Federal Ministry of Education and Research
Thomas Bartelt
Referat 726 - Resources, Circular Economy; Geosciences
E-Mail: Thomas.Bartelt@bmbf.bund.de

Contact Projektträger Jülich
Dr. Andreas Jacobi
E-Mail: a.jacobi@fz-juelich.de

https://innovative-produktkreislaeufe.de/en