STRUCTURE OF DATA-DRIVEN BUSINESS MODELS FOR THE CIRCULAR AUTOMOTIVE SECTOR: A TAXONOMY

HANNAH SCHEERER,[1] HENDRIK VAN DER VALK[1,2]

[1] TU Dortmund University, Chair of Industrial Information Management, Dortmund, Germany
hannah.scheerer@tu-dortmund.de, hendrik.van-der-valk@tu-dortmund.de
[2] Fraunhofer Institute for Software and Systems Engineering, Dortmund, Germany
hendrik.van-der-valk@tu-dortmund.de

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Companies in the automotive sector are under increasing pressure from stricter regulations, shifting customer expectations, and ambitious sustainability goals. The circular economy (CE) provides a promising pathway to address these challenges by promoting resource efficiency, lifecycle extension, and closed material loops. Meanwhile, data-driven business models (DDBM) enable enhanced transparency, optimization, and innovative value creation through digital technologies (DT). While the integration of circular strategies and data-driven approaches has significant transformative potential, circular DDBMs remain scarce in the automotive industry and lack systematic conceptualization. To address this gap, this study develops a taxonomy that structures the current landscape of circular DDBMs using a rigorous, iterative methodology. The resulting taxonomy, based on 42 empirical cases, comprises six meta-dimensions, 16 dimensions, and 68 characteristics, offering a comprehensive framework for analyzing, comparing, and designing circular DDBMs in the automotive sector.

Keywords:
data-driven business models,
circular economy,
automotive,
taxonomy,
digital technologies

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1 Introduction

The automotive industry is undergoing continuous transformation driven by regulatory pressure, shifting customer demand, and technological innovation, such as electric vehicles, which challenge traditional linear business models (BM) with high environmental impacts (Grimm & Pfass, 2022; Urbinati et al., 2021). The European Green Deal further intensifies this shift by constraining linear value creation, particularly in a sector responsible for substantial life-cycle greenhouse gas emissions (Pichler et al., 2021). The CE concept offers a pathway to reduce these impacts through circular product and process design, with initial applications such as alternative drivetrains, battery systems, and component reuse already emerging (ACEA, 2018; Urbinati et al., 2021). However, high investment costs, organizational complexity, and supply chain adaptations still hinder large-scale adoption (Hoppe et al., 2025). In this context, digitalization and DTs, including data analytics, tracking, and monitoring, are key enablers of CBMs by enhancing transparency, resource efficiency, and data-driven decision-making (Luoma et al., 2021; One Planet Network, 2025), as they enable systematic supply chain data analysis, sustainability indicators, and improved stakeholder transparency (One Planet Network, 2025).

In the automotive sector, companies have recognized that data must be part of their BM, reflecting a shift from manufacturing to software offerings (Ecorys, 2021). In the CE, DDBMs are already established, but their use is still limited (Circular Republic et al., 2025; Danish Business Authority & EMF, 2021). Currently, a small percentage of circular start-ups use data and DT as the basis for their BM. For example, the report Circular Economy Start-up Landscape 2025 identifies that only 109 European circular start-ups out of 2,525 use artificial intelligence (AI) and data analytics for resource efficiency. The report also found that circular start-ups are represented in the battery, energy, and vehicles and mobility sectors (Circular Republic et al., 2025). Therefore, there is a research gap regarding the potential of circular DDBMs in the automotive sector. Against this background, this study aims to understand DDBMs that support CE implementation for the automotive industry, leading to the research question: **What is the current state of DDBMs for enabling the CE for the automotive industry?**

To answer this question, we created a taxonomy that provides a structured overview of the current state of DDBMs supporting CE implementation in the automotive sector. The paper is structured as follows: We first outline the state of the art in DDBMs and CE, followed by the research method in chapter 3. Chapter 4 presents the taxonomy results, and Chapter 5 evaluates them using three real-world objects. The final chapter concludes with key findings, research opportunities, and limitations.

2 State of the Art

2.1 Business Models

The increasing interest in BMs began in the 90s with the onset of digitalization (Zott et al., 2011), and in recent years, researchers have examined various types of BMs (e.g., Möller et al., 2020). In general, BMs describe how a company operates and organizes itself to create value for its customers, as well as how financial changes occur (Osterwalder & Pigneur, 2010). DDBMs are a subterm of digital BMs that specifically focus on data as the key resource (Engelbrecht et al., 2016; Hartmann et al., 2016). Therefore, companies offer raw data or analyzed results for sale or as a service. Digital BMs refer to digital offerings such as digital services or products (Möller et al., 2019).

To optimize the development and description of BMs, tools, and methods support the process by defining the differences and dynamics (Al-Debei & Avison, 2010). Often cited examples include the Business Model Canvas by Osterwalder and Pigneur (2010) and the methodology by Gassmann et al. (2013). However, these are too superficial to develop DDBMS (Engelbrecht et al., 2016). Therefore, further tools and methods were developed, such as the VISOR framework by El Sawy and Pereira (2013).

DDBMs are present in different areas, i.e., in logistics (e.g, Möller et al., 2020), manufacturing (e.g., Stahl et al., 2023), or mobility (e.g., Sterck et al., 2022). Generally, they help companies with decision-making and strategic planning. In the context of sustainability and CE, DBBMs are specialized, particularly in insights into various data to close the circle. For example, DDBMs are used for circular contexts by tracking material flows to identify potential CO_2 hotspots and adjust accordingly

(Luoma et al., 2021). In addition, companies can upgrade their old products with sensors to monitor their condition and implement circular strategies such as »repair« (Ghoreishi, 2023; Ingemarsdotter et al., 2020). Another example of a circular BM based on data or digital components is the dematerialization. Digital components replace physical products to reduce material and to achieve resource efficiency (Geissdoerfer et al., 2018; One Planet Network, 2025).

2.2 Circular Economy Concept

The concept of a CE is widely accepted. In recent years, the awareness, interest, and research on CE have increased because its application is a new phenomenon (Rosa et al., 2019), although the original idea was developed in the 1960s (Boulding, 1966). The main idea of this concept is that global systems become sustainable (ecological, economic, and social) by keeping products and materials in use as long as possible throughout their life cycle (EMF, 2013; Kirchherr et al., 2023). Further advantages are new job creations and growing revenues (OECD, 2025). The CE concept is operationalized through different circular strategies. The 10R framework by Potting et al. (2017) describes various opportunities, such as Refuse, Reduce, Repair, Remanufacturing, or Recycle, to implement circular strategies. Consequently, the EMF also developed a framework, ReSOLVE, to describe the implementation steps for the circular transition (EMF, 2015), although it primarily focuses on BM elements. In the literature, taxonomies and typologies of CBMs exist to describe their patterns and current characteristics(e.g., Lüdeke-Freund et al., 2019; Rosa et al., 2019). However, these studies primarily focus on the technical implementation of CE and largely omit the role of DDBMs as an integral component of CBMs.

DTs and data are key enablers of CBMs, as they support both BM innovation and the implementation of circular strategies (Rosa et al., 2020). However, research remains fragmented, particularly in the automotive sector. Existing studies either focus on specific data types of BMs (e.g., Luoma et al., 2021) or isolated DT use cases of CBMs (e.g., Ingemarsdotter et al., 2020). A holistic perspective on DDBMs is still missing, revealing a clear research gap.

3 Taxonomy Design and Approach

Taxonomies classify objects into dimensions and characteristics, enabling systematic comparison and analysis, and are widely used in BM research to describe and structure BMs, thereby supporting the understanding of complex landscapes (Möller et al., 2022; Szopinski et al., 2019).

This study applies the taxonomy development approach by Kundisch et al. (2022), building on Nickerson et al. (2013), comprising six phases from problem identification to communication.

First, the target users and problem are defined, as they shape the meta-characteristic and subsequent development steps. In our case, we identified two target users of the taxonomy. The taxonomy targets researchers and practitioners interested in a deeper understanding of DDBMs in the circular automotive sector and in innovating new BMs. It supports both the structuring of these emerging BM types and the development of new DDBMs for circularity by serving as an inspiration source, particularly when future work derives patterns from these models (Möller et al., 2022). It thereby responds to the identified gap between the high potential of data for enabling CE and its limited exploitation in the automotive industry (Urbinati et al., 2021). Accordingly, the meta-characteristic is defined as »elements of DDBMs for the circular automotive sector«.

Taxonomy development followed an iterative process that combined conceptual-to-empirical and empirical-to-conceptual approaches. The empirical sample concluded 350 companies identified through *StatrUp Autobahn*[1] and *Catena-X* [2](November 2023 – January 2024), of which 58 underwent detailed analysis using publicly available sources such as websites, articles, videos, and news reports. Eligible companies operated data-driven and CE-oriented BMs in the automotive sector. The sample predominantly consisted of start-ups, which were chosen as the primary database due to their innovation-oriented nature (Möller et al., 2022). Due to insufficient information, we excluded 16 companies, leaving 42 for taxonomy development. Based on the VISOR framework, we conduct four iterations (1. conceptual-to-empirical; 2.-4. empirical-to-conceptual) to refine dimensions and characteristics,

[1] https://startup-autobahn.com/
[2] https://catena-x.net/

introduce a CE-specific meta-dimension, and improve conceptual fit. The process starts inductively and is later complemented by empirical analysis of the selected objects.

After the iterations, all objective and subjective stopping conditions according to Nickerson et al. (2013) are met, resulting in a final taxonomy comprising 16 dimensions and 68 characteristics (cf. Table 1). These conditions ensure completeness (objective) and quality (subjective) of the taxonomy development process (Szopinski et al., 2019). To further validate usefulness, we applied three real-world objects as it is suggested in the study by Szopinski et al. (2019). The remaining phases focus on evaluating completeness, demonstrating applicability, and communicating the taxonomy.

Table 3: Business model taxonomy for circular transformation for the automotive sector

Meta-Dim.	Dimension	Characteristics						
Value Proposition	Service Offering	End-to-End Solutions	Digital Marketplace	Analytics and Montoring	Management Tasks	Process Digitalization	Digital Object / Process Mapping	Database
	Purpose	Transparency	Optimization	Collaboration	Traceability	Compliance	Efficiency Improvement	
	Actors Group	Automobile Manufacturer / OEM	Commercial Vehicle Manufacturer	Battery Manufacturer	Automotive Suppliers	Car Dismantler / Recycler	Industry Neutral	
Interface	Customer Interface	Web-based Platform	Mobile App	Plugin App				
	Data Integration Interface	GUI	API	(IoT) Sensors				
Service Platform	Technology	AI / ML	Cloud Technology	Blockchain				
	Data Ressource	Process Data	Vehicle Data	Battery Data	Sensor/ Machine Data	Supply Chain Data	Material Data	External Data
	Data Source	Internal Source	External Source					
	Data Collection	Manuel	Dynamic	Both				
	Data Activity	Data Generation	Data Acquisition	Data Aggregation	Data Processing	Data Analytics	Data Visualization	Data Distribution
Organizational Model	Partnership Network	Ecosystem	Technology Company	Consultancy Company	Association	University / Research Institution	Other	
	Integration of Other Actors	Supplier	Authority	Customer	Partner	None		
Revenue Model	Offer Options	Subscription	Asset Sale	Freemium				
	Price Structure	Fixed Prices	Variable Prices					
Circular Economy	Design Option	Share	Optimize	Loop	Virtualize			
	Focus Object	(Critical) Raw Material	Vehicle Component	Machinery & Production Plants	Value Chain			

Legend: • TWAICE (Use Case 1) • material.one (Use Case 2) • i.Point (Use Case 3)

Source: Own

4 Results

This chapter presents the characteristics and dimensions resulting from taxonomy development. Some of these dimensions and characteristics are defined for DDBMs, such as the dimensions and characteristics from the »Interface« and »Service Platform«. The data components »Data Resource«, »Data Source, »Data Activity«

and »Data Integration Interface« are BM characteristics based on generic DDBMs. The representative characteristics of the circular DDBMs for the automotive sector become clear in the meta dimension »Value Proposition« and especially in the sixth meta-dimension »Circular Economy«. These elements highlight the distinguishing features of BMs compared to generic DDBMs and among themselves. The variety of characteristics demonstrates the uniqueness of circular DDBMs.

4.1 Meta-Dimension: Value Proposition

The meta-dimension *Value Proposition* comprises the dimensions *Service Offering*, *Purpose*, and *Customer Group* with 19 characteristics in total.

1st Dimension: Service Offering

This dimension describes the functionalities offered by circular DDBMs. Identified characteristics include: *End-to-End Solution* (integration of cross-departmental processes), *Digital Marketplace* (digital interaction platform for suppliers and customers), *Analysis and Monitoring* (e.g., emissions calculation, predictive maintenance), *Management Tasks* (decision and communication support), *Process Digitalization* (replacement of manual documentation by digital workflows), *Object Mapping/Digital Process* (digital representation of objects and processes, e.g., digital product passport), and *Database* (data collection and provision).

2nd Dimension: Purpose

This dimension captures the problems addressed by the offering: *Transparency* (e.g., identifying CO_2 hotspots), *Optimization* (product and process improvement through analytics), *Collaboration* (coordination across actors), *Traceability* (tracking products, materials, suppliers), Compliance (legal and ESG requirements), and *Efficiency Improvement* (operational and cost optimization).

3rd Dimension: Customer Group

Target groups within the automotive ecosystem include *OEMs* (e.g., BMW, or Audi), *Commercial Vehicle Manufacturers*, *Battery Manufacturers*, *Automotive Suppliers* (e.g., n-tier suppliers in value chain), *Car Dismantlers/Recyclers*, and *Industry-Neutral Companies* (e.g., other industries such as pharmaceutical or railway sectors).

4.2 Meta-Dimension: Interface

The Interface meta-dimension deals with the digital and physical interfaces between the provider and the customer. In the context of circular DDBMs, the interface serves as a technological component that facilitates transactions (Möller et al., 2020).

4th Dimension: Delivery Mechanism

Three delivery modes were identified: Web-based *Platform*, *Mobile App*, and *Plugin* (e.g., SAP integration).

5th Dimension: Data Integration Interface

Data can be integrated through *Application Programming Interface* (*API)* or *Graphical User Interface* (GUI), Manual Entry (e.g., questionnaires, Excel uploads), or *Internet of Things (IoT) sensors* for real-time machine and component data acquisition.

4.3 Meta-Dimension: Service Platform

The *Service Platform* focuses on technological and data-related components and includes five dimensions.

6th Dimension: Technology

Relevant enabling technologies are *AI / Machine Learning (ML)* (e.g., predictive analytics, data cleansing), *Cloud Technology* (centralized storage and accessibility), and *Blockchain* (traceability and data reliability).

7th Dimension: Data Resource

Primary resources include *Process Data*, *Vehicle Data*, *Battery Data*, *Supply Chain Data*, and *Material Data*; *External Data* serves as secondary data.

8th Dimension: Data Source

Data originates from *Internal Sources* (e.g., Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP), and Customer Relationship Management) or *External Sources* (e.g., supplier databases, ecoinvent, the International Material Data System (IMDS)). Many of these reference databases serve as a basis for secondary data analysis.

9th Dimension: Data Collection

Companies enable *Manual Upload*, *Automated Collection*, or *Both.*

10th Dimension: Data Activity

Seven activities were identified, based on Hartmann et al. (2016) taxonomy: *Data Generation* (data creation by sensors attached to machines and products), *Data Acquisition* (gather external information, e.g., identify supply chain disruptions), *Data Aggregation* (providing customer with, i.e., life cycle information), *Data Processing* (Translating data into one unified language), *Data Analytics* (data calculations, as well as predictive analytics), *Data Visualization* (dashboard reports, i.e., product carbon footprint), and *Data Distribution* (distribution of information to another stakeholder).

4.4 Meta-Dimension: Organizational Model

This meta-dimension describes actor relationships and collaboration structures within circular data ecosystems.

11th Dimension: Partnership Network

Partnerships support knowledge exchange and ecosystem development. Six partner types were identified: *Technology Companies*, *Consulting Companies*, *Associations*, *Universities/Research Institutions*, *Ecosystems* (e.g., Catena-X), and *Others*.

12th Dimension: Integration of Other Actors

Platforms integrate *Suppliers/Vendors*, *Authorities*, *Customers*, *Partners*, or *No Additional Actor Group*.

4.5 Revenue Model

This dimension is divided into two dimensions, with the characteristics referring to the definitions provided by Hartmann et al. (2016) and Bock and Wiener (2017).

13th Dimension: Revenue Model

Three monetization logics were identified: *Subscription fee* (predetermined schedule)**,** *Asset Sale* (fixed price, i.e., hardware or data generation), and *Freemium* (can be used by customers free of charge or at low cost based on user volume)**.**

14th Dimension: Pricing Structure

Offerings follow either *Fixed Pricing* or *Variable Pricing*, depending on service scope and customization.

4.6 Meta-Dimension: Circular Economy

This meta-dimension was added during the second iteration to emphasize the importance of the CE. It is differentiated into two dimensions: *Design Options* and *Focus Object.*

15th Dimension: Design Options

This dimension refers to possible design strategies supporting CE principles and BMs. Four of six ReSOLVE options according to EMF (2015) are met: *Share* (reuse, maintenance, secondary markets), *Optimize* (waste and CO_2 reduction through data-driven improvements), *Loop* (recycling and material circulation), and *Virtualize* (replacement of physical processes through digital solutions).

16th Dimension: Focus Object

Circular initiatives target *(Critical) Raw Materials* (e.g., raw material for the production of electric battery), *Vehicle Components* (e.g., electric battery or mechanical component), *Machinery and Production Plants*, or the broader *Value Chain* (supply chain or reverse logistics).

5 Evaluation

Following of Kundisch et al. (2022) and Szopinski et al. (2019), we evaluate the taxonomy's utility through three automotive real-world use objects. By decomposing DDBMs into their constituent components, the application provides a modular framework for understanding CE implementation. Additionally, we chose these three objects to show the variety of circular DDBMs for the automotive sector. While the qualitative analysis confirms the taxonomy's descriptive power, a detailed assessment of revenue streams and pricing structures is limited by corporate non-disclosure, despite the observed prevalence of subscription-based models. Overall, the application supports researchers and practitioners in understanding the variety of DDBMs in the circular automotive sector and serves as an inspiration source for innovating new BMs. Additionally, we confirm our evaluation goal of systematically describing the current state of these BMs and identifying their specific, circular, data-driven characteristics.

1. Case Example: TWAICE[3]

TWAICE offers a software-as-a-service (SaaS) platform that optimizes electronic battery health performance and reduces risks by analyzing and monitoring battery status. The software provides continuous, reliable information about the battery's status, eliminating the need for costly, time-consuming physical tests. Through data-driven analysis and simulation, TWAICE supports optimized battery design and improved performance, as well as transparent battery health assessment. Improved efficiency is achieved by reducing development, production, and operating costs. TWAICE's main target customers are battery manufacturers and OEMs, who benefit from faster development cycles, improved cell qualification, and a shared understanding of battery aging. The solution leverages cloud and ML technologies, integrating data from battery management systems and other customer databases via API interfaces for real-time monitoring. Key data activities include collection, processing, analysis, and dashboard visualization. The results of continuous analysis and monitoring are demonstrated in Key Performance Indicators. TWAICE's offerings support CE goals by enabling improved battery design, extended battery lifetime, and battery reuse through battery certification, addressing the Loop and Share options of the ReSOLVE framework.

2. Case Example: material.one[4]

material.one is a subsidiary of the big German IT consulting company Arvato. material.one is specialized for ensuring sustainable compliance of materials and supply chains by simplifying the implementation of quality and environmental requirements of products and supply chains, such as verification of recycled materials or CO_2 emissions. The category *Process digitalization* refers to digitizing and networking business processes related to these requirements.

A digital platform functions as a centralized digital database in which all product and material data are stored and is accessible anytime and anywhere to exchange the data with suppliers, for example. material.one's platform and data exchange, and continuous, data- and information-based exchange between the involved actors, enable transparency and collaboration that are important to achieving sustainability.

[3] https://www.twaice.com/
[4] https://material.one/

material.one's function of digitized and automatically executed business processes improved efficiency by reducing the manual effort of these processes.

The platform fosters collaboration among manufacturers, laboratories, and suppliers by connecting these actors within one system. Typical customers include OEMs such as BMW and Mercedes-Benz, as well as automotive suppliers, while the solution itself is industry-neutral. The SaaS platform uses cloud technology, processes mainly material and process data from ERP, PLM, or Quality Management systems, and standardizes them into comparable proofs. Data analysis is primarily descriptive, with automated comparisons of requirements and test results that are visually prepared and shared. The platform integrates suppliers and partners, cooperates with ecosystems like Catena-X, and relies on Microsoft Azure for secure cloud infrastructure. By digitally managing compliance proofs such as recycled content, CO_2 footprint, and hazardous substances, material.one supports CE implementation, with the value chain as the primary focus object and a strong link to product and material data across the lifecycle.

3. Case Example: IPOINT[5]

The case example IPOINT offers a comprehensive portfolio of software solutions that can be classified as an *End-to-End Solution* for implementing the CE across the entire product life cycle. Its offerings cover digital product passports, management solutions, and analysis and monitoring tools, enabling CO_2 footprint calculation, ESG-compliant reporting, risk management, and strategic consulting. By analyzing material flows and value chains, IPOINT promotes transparency, traceability, and compliance, helping companies identify CO_2 hotspots and supply chain risks. The customer target group is industry-neutral but also includes OEMs such as BMW and Audi, as well as tier-1 suppliers. The solutions rely on cloud technology for data collection, processing, storage, and visualization, supported by AI/ML for automated environmental calculations and blockchain for the digital product passport. Data from internal systems (ERP, PLM) and external databases such as IMDS and ecoinvent are integrated via APIs. IPOINT operates on a subscription-based SaaS model complemented by consulting and training services. Collaboration with suppliers, partners, and ecosystems like Catena-X supports CE implementation.

[5] https://www.ipoint-systems.com/

Overall, IPOINT addresses the EMF design options *Optimize* and *Virtualize* by enabling data-driven eco-design, life cycle assessment, and value chain optimization focused on sustainability and circularity.

Overall, these three real-world objects demonstrate the complexity of circular implementation barriers in the automotive industry. TWAICE's use case is limited to a new type of vehicle: electric vehicles. In this case, a significant degree of competition characterizes the European automotive industry, which fosters the development of vehicles comparable to those produced by competitors (Ecorys, 2021). Electric battery development is still in the early stages, leading to outages and unprofitability (Plotnikov et al., 2023). Therefore, TWAICE developed a BM to overcome barriers in the development process and drive innovation. They enable more insights, reaching safety and a higher lifetime of electric batteries through their use of data and digital technologies. Consequently, material.one indirectly influences the circular economy in this sector. A major challenge to successfully implementing circular strategies is the lack of transparency and information. However, supply chain documentation is increasing because legal requirements are becoming more stringent. Consequently, stakeholders must confirm and share important documentation and guidelines. Compliance with CO_2 emissions and recycling material reporting requirements is especially important. Their platform enables contactless and manual data and information exchange. By connecting digital technologies and reducing manual processes through digitalization, they enable transparent information exchange among supply chain partners. The third real-world object, IPOINT, is different from the others. Originally an IT material compliance company, they have recently expanded to sustainability. They enable material compliance, as does material.one, but they also calculate CO_2 emissions for entire supply chains or specialized products. With its wide range of solutions, IPOINT software is a significant step forward in solving individual circular barriers and challenges for its customers.

6 Conclusion, Limitations, and Outlook

This study presents a taxonomy of 42 empirical objects of DDBMs in the automotive industry, demonstrating the current variety of circular DDBMs in the sector. The resulting taxonomy comprises six meta-dimensions, 16 dimensions, and 68 characteristics, capturing service offerings, value propositions, stakeholder groups, data resources, and applied technologies. The analysis shows that companies frequently use DTs such as cloud technology and AI to deliver CE–related value propositions, mainly through data analytics, environmental calculations, and data provision.

From a scientific perspective, the findings highlight the positive role of data and DTs in promoting CE and sustainability, while also revealing significant untapped potential due to the still limited variety of DDBMs. For practitioners, the taxonomy provides a structured approach to analyzing, adapting, and innovating BMs to close or extend the life cycles of materials and products in the automotive sector. Limitations include the restricted sample size, the focus on two automotive platforms, and the subjective interpretation of characteristics. Future research should expand the empirical basis, examine barriers to DDBM adoption, and further explore how data and digitalization can accelerate the transition toward a circular automotive industry.

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About the authors

Hannah Scheerer is a research assistant at the chair of Industrial Information Management at the TU Dortmund University in Dortmund, Germany. She currently researches circular economy business models and their relation with data as well as the general transformation of incumbents from linear to circular business models. She holds a M. Sc. in Industrial Information Management from the TU Dortmund University.

Hendrik van der Valk is the chief engineer at the chair of Industrial Information Management at the TU Dortmund University in Dortmund, Germany. He also works as a part-time job as scientific coordinator at the Fraunhofer Institute for Software and Systems Engineering, Dortmund. He holds a PhD in Mechanical Engineering from TU Dortmund University