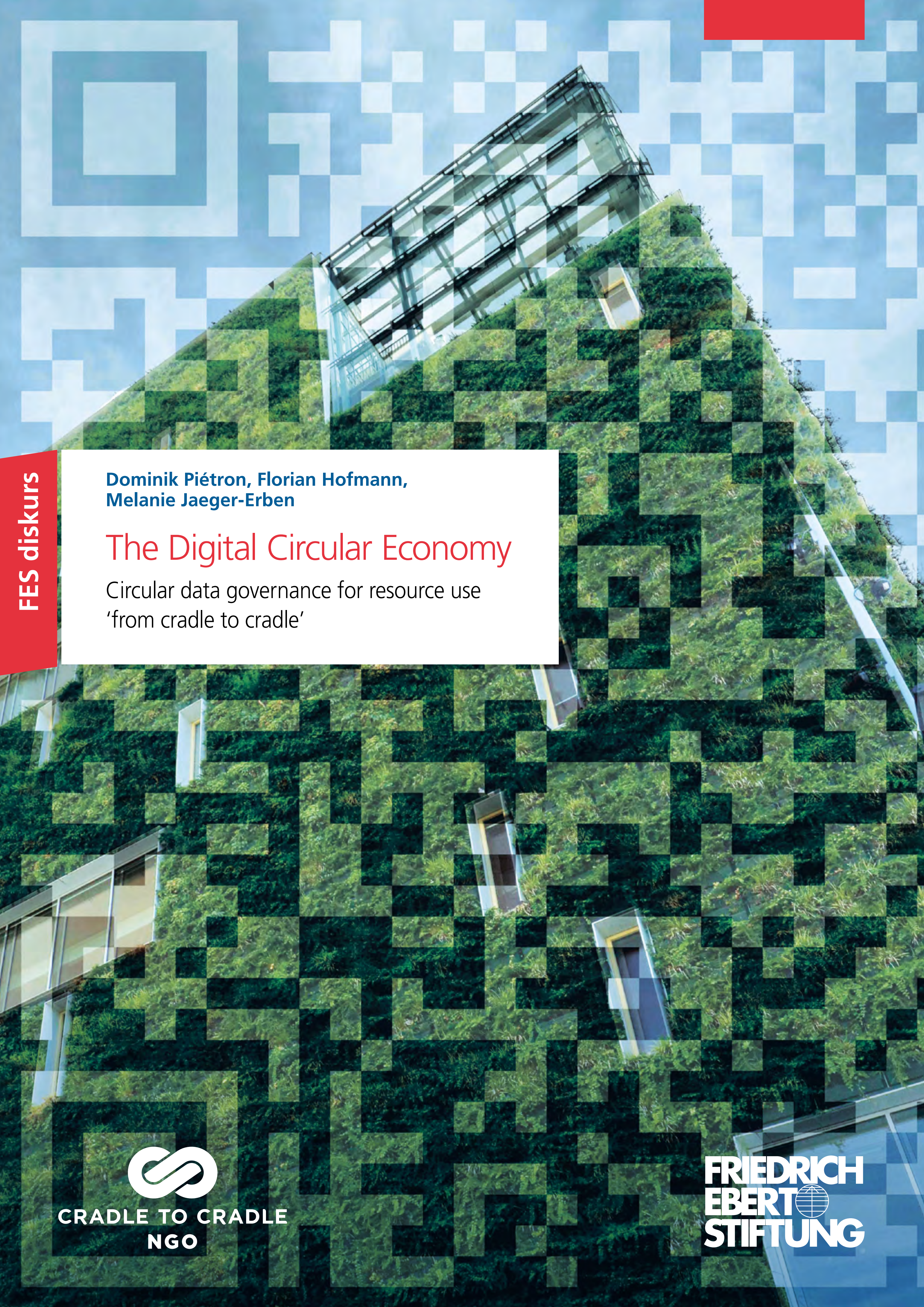

FES diskurs

Dominik Piétron, Florian Hofmann,
Melanie Jaeger-Erben

The Digital Circular Economy

Circular data governance for resource use
'from cradle to cradle'

CRADLE TO CRADLE
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November 2023

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The Digital Circular Economy

Circular data governance for resource use 'from cradle to cradle''

Study commissioned by Friedrich-Ebert-Stiftung and Cradle to Cradle NGO in association with the 'Digitalisation and Circular Value Creation' project

CONTENTS

FOREWORD

Half of all greenhouse gas emissions and 90 per cent of all biodiversity losses are attributable to resource extraction, processing and manufacturing. Our linear economy, in which resources flow relentlessly from factory to incinerator, is a blind alley. Simply producing a little less waste and doing a little more recycling is not going to make any meaningful difference. If we are serious about tackling climate change and resource shortages, we will need a fully circular economy based on the cradle-to-cradle principle. That means products, production and business models designed from the outset to ensure that materials and resources are able to circulate more or less endlessly.

Digitalisation will be a crucial tool in that transformation. Circular value creation will require sophisticated management of material flows throughout the product lifecycle. Data is key: the more information can be digitally collected, processed, analysed and shared about composition, use, and environmental and health effects, the easier it will be to ensure that materials and products circulate optimally, and to scale up circular business models and ecosystems.

The present study presents the findings of the project 'Digitalisation and Circular Value Creation' conducted jointly by the Friedrich-Ebert-Stiftung and the Cradle to Cradle NGO. In a series of five meetings experts analysed the potential of digitalisation for realising a fully circular economy in Germany and Europe, using examples from different branches and product life-cycle phases. The objectives were to understand the (potential) role of data and digital infrastructures in different circular ecosystems, and to identify instruments suited to establishing or expanding a circular economy in different sectors.

The authors of the present study draw on concrete use cases from the different sectors to explore opportunities and obstacles. They identify disclosure and sharing of product information as a key factor for success. That would form the basis for new circular ecosystems and business models throughout the entire product life cycle. The key instrument in terms of implementation is the European Digital Product Passport project, with its comprehensive transparency requirements for businesses. In order for the Digital Product Passport to realise its potential, however, binding rules will be needed on what data is to be collected and by whom, who would be permitted to access it, and what standards are to be observed in the process: in short, circular data governance.

As this is rolled out policymakers must ensure that sector- and product-specific Digital Product Passports are interoperable. The greatest potential for a circular economy lies in cross-sectoral cooperation, for example, the repurposing of decommissioned car batteries for stationary energy storage. The platform economy has demonstrated the crucial importance of data access for new products, business models and markets – but also the danger that data silos may emerge alongside other undesirable developments if data governance is left to the market. If Europe wishes to harness the power of data to drive the circular economy, we must learn from these experiences and ensure that the rules and standards for sharing data – and the associated digital interfaces and infrastructures – are fair and functional. Only then can good markets emerge.

That does not mean that policymakers will be given free rein to devise the rules and specifications. But they must define conceptual and technical minimum standards and ensure that the interests of all stakeholders are acknowledged – from the biggest corporation to the smallest workshop, from 'disruptive' start-ups to Germany's traditional firms. Above all, policymakers must ensure that civil society actors representing the public interest – environmental and consumer organisations, certifiers and the open data and open source movements – also have a firm foothold in these processes. Politicians need to realise the power of the digital product passport to leverage transformation – and acknowledge the many particular interests and objections that may imply.

Of course, there will be no fully circular economy until all products contain only materials that can circulate endlessly in biological and technical cycles and are suitable for a product's particular purpose. But the Digital Product Passport can already lay the groundwork in different branches and life-cycle phases.

As well as the EU, national governments must grasp the potential that lies in collecting, standardising and sharing product data to create a sustainable circular economy. That potential needs to be tapped. Germany's National Circular Economy Strategy, currently under discussion, offers a good framework. Now it needs to be put to work.

Policies for a digital and circular economy must go beyond silo thinking. The key to that is the closer networking of the digital and circular economy communities. We hope that our project and this study can make a positive contribution.

Nora Sophie Griefahn, C2C NGO
Tim Janßen, C2C NGO
Stefanie M. Moser, FES
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GLOSSARY

Circular economy: The concept of the circular economy aims to keep extracted natural resources in use as long as possible and to preserve the maximum value of products through reuse and recovery strategies.

Circular ecosystem: A group of loosely connected actors with their own technologies and institutions that cooperate in different phases of a product's life cycle and exchange information in order to preserve the value of products and materials.

Cradle to Cradle (C2C): A holistic approach responding to the climate and resource crises. Conceived in the 1990s by German chemist Michael Braungart and US architect William McDonough, C2C addresses the product's entire life cycle from design to disposal (recycling). Rather than simply seeking to minimise harm, the C2C school holds that human beings can potentially make positive ecological, economic and social contributions. The C2C design concept describes how products and processes should be designed. The specific purpose for which a product is intended is decisive. On this basis, healthy and suitable materials can be selected for the product to circulate continuously in biological and technical cycles.

Data governance: Practices and processes to define rights and obligations for handling data, and the application of these rules in the collection, storage, processing and sharing of data within and between organisations.

Material quality: The C2C design concept employs only materials that are harmless in the respective use scenario – or ideally add value for both user and environment. Classification into ABCX materials (as used by C2C certifier the Cradle to Cradle Products Innovation Institute) establishes transparent quality standards for components. A materials are optimally suited for a defined purpose; B are optimisable, C tolerable and X unacceptable. Materials classed X need to be replaced by acceptable alternatives. The more A materials a product contains, the higher its (material) quality.

Product-as-a-service: Product-as-a-service (PaaS) is a platform-based business model in which customers purchase access to a product's functionality rather than the (often physical) product itself.

Product data: Recorded digital information about the properties, composition, states and handling of products, components and materials.

Use scenario: Products for a real circular economy need to be designed for a concrete use scenario. The use scenario defines the function(s) a product is required to fulfil in a particular context and whether its components circulate in the biosphere, the technosphere or both. If the product's components enter the environment, they need to be suitable for the biosphere. If they are not, the product must circulate in the technosphere. Copper, for example, can have harmful effects in biological cycles but can be used unreservedly in technical contexts. A realistic service life should be defined to allow manufacturers to predict the flow of returning materials and plan their reuse in production processes.

Value: The social benefit (use value) created by and for human actors in the form of products and services, plus the material value of natural resources embodied therein (raw materials, soil, renewable energy and so on). In the circular economy, actors join together in circular value ecosystems to generate maximum use value from the resources employed.

1
INTRODUCTION

In recent years the circular economy has become a central paradigm for economic sustainability. It entails a structural transformation of patterns of production and consumption, operating within planetary limits. Circular product design seeks to establish a new norm: products and materials that can be reused and recirculated repeatedly in order to reduce resource and energy consumption and avoid harmful waste. It has been calculated that circularity could reduce resource consumption by about one-third (Circle Economy 2023: 31) and keep greenhouse gas emissions below the two-degree target (IPCC 2021: 159).

However, circulating materials and products requires sophisticated management of material flows throughout a product's life. One key instrument for this is digital data. Digitalisation supplies the tools required to efficiently gather, store and share information on products and materials. This allows product data to circulate with products and function as an 'ecological guide' informing actors about the value contained in the product and how it can best be conserved. Digital product data can promote the circular economy by:

— displaying the value of materials and components contained in products and enabling new sustainable business models;

— displaying which materials and components contain unhealthy and environmentally harmful substances, when these substances exceed thresholds, and which substances must therefore be substituted with healthy and circular alternatives;

— improving ecological transparency within the value network and thus promoting sustainable sourcing and product design;

— facilitating evaluation and marketing of used goods (second-hand);

— extending product life by providing repair and servicing information;

— facilitating constant recirculation of material flows and reducing the cost of collecting and sorting products in order to improve recycling rates;

— enabling users to make ecologically aware decisions about purchases, product use and (DIY) repairs;

— supporting agencies that regulate products and materials (for example, controls on hazardous substances);

— enabling researchers to conduct ecological big-data analyses of product markets;

— strengthening collaboration and resonance between actors in circular ecosystems;

— enabling holistic representation of products' worth above and beyond their exchange value.

DIGITALISATION AND THE CIRCULAR ECONOMY: SUSTAINABILITY REQUIRES MULTIPLE TRANSFORMATIONS

The social-ecological sustainability transformation is the political task of the century. A multitude of social-ecological problems and crises obviously have to be addressed, given the increasingly tangible consequences of climate change and resource crises. It is above all also an immense complexity challenge, in which multiple major political projects have to be developed simultaneously and joined up. The circular economy requires digitalisation and digital technologies if it is to meet the demanding information and coordination needs of circular ecosystems and to make processes more economically and ecologically efficient. Without consistent recirculation of products and materials, as well as a significant increase in the lifespan of technologies, digitalisation alone will not reduce the immense long-term ecological footprints of industry. However, the high energy consumption of digitalisation and the circular economy (for example, for servers and data storage, and for reconditioning of products and materials) means they can be sustainable only if they are coordinated and connected with the third major project, the energy transformation. Conversely, the energy transformation's enormous resource demands will themselves necessitate recirculation of materials, and the shift from centralised to decentralised renewable energy systems is virtually inconceivable without a full set of digital management tools. In other words, this is not just a double but a triple transformation challenge, which demands serious coordination. That means public support and buy-in, and an orientation towards inter- and intragenerational justice. The three overarching sustainability strategies need to be central points of reference. In view of the short time remaining to overcome our social-ecological problems, our decisions need to be guided by sufficiency as well as efficiency. For the same reason we need to employ resources more efficiently. Given the high energy consumption of today's digital technologies, we also need digital sufficiency. The goal must be to orientate action towards a consistent strategy that thinks in terms of circulation and ecosystems, incorporating the social dimension and therefore having the potential to resolve the big issues holistically and sustainably.

Cradle to Cradle (C2C) was the vision adopted for the expert discussions on which this contribution is based. C2C begins with the design of all products and is thus not restricted to the question of how existing products can best be reused and recycled. The goal is a world in which all waste becomes the starting point for something new. Under the C2C design concept all materials must be circular and suitable for their use scenario (as well as healthy). Where inevitable wear and tear causes substances to enter the environment, they must be suitable for biological cycles. Materials that do not enter the biosphere must be optimised for circulation in technical systems. Ideally, C2C production uses exclusively circular renewable energy. Additionally, circularity of air, water and soil is sought in all value creation stages. Rather than just polluting the environment a little less, the goal is for human activity to improve the quality of air, water and soil. Working conditions must be fair and humane throughout all value chains.

CHALLENGE: CIRCULAR DATA GOVERNANCE

The present contribution starts from the proposition that digital technologies will be able to realise their full ecological potential only if the collection, maintenance, management and sharing of product data is governed in such a way as to allow access by all involved actors. Only if information about products' properties and the materials they contain is collected systematically and shared through appropriate digital infrastructures will it be possible to rapidly develop and scale sustainable business models and circular ecosystems.

In line with that approach, numerous initiatives have already begun to develop infrastructures for sharing product data: platforms share product repair information, second-hand marketplaces sell used goods, and initiatives such as Catena-X make it easier for businesses to share product data. That is all fundamentally welcome of course, but can have undesirable side-effects: the more different data standards and digital platforms there are for sharing product data, the harder it becomes to ensure interoperability. For example, many private-sector providers operate proprietary ecosystems that ultimately hinder data sharing and thus create new barriers to circular business models.

The European Commission has recognised the problem and has already responded with a draft Ecodesign Regulation, published in 2022. The proposed digital product passport (DPP) will hold the information required to optimally preserve the value contained in all products bought and sold within the EU. The challenge is enormous: The product data required for the transformation to a circular economy will have to be defined for each and every product category. How the data is gathered, where it is stored and who is permitted to access it will also have to be clarified. Coordinated management of economic information flows will have a decisive impact on the future economy (Piétron et al. 2022). All in all, the EU's digital product passport has the potential to be an effective tool to improve transparency concerning material flows and create a level playing field for new, sustainable business models in the circular economy.

THE PROJECT: THE FIVE EXPERT DISCUSSIONS

In order to advance the political project of a data-driven circular economy, the Friedrich-Ebert-Stiftung (FES) and the Cradle to Cradle NGO (C2C NGO) joined forces to organise a series of five expert discussions between January and June 2023. The objective was to investigate the potential of data and digital infrastructures for circular value creation, based on selected use cases in different sectors. The participants were stakeholders from politics, business and academia, with sectoral experts invited to join the core group for individual sessions. Each session examined a different sector and a different phase of the product life cycle:

— 1. (20 January 2023): Digitalisation paves the way for circular ecosystems – political parameters, platforms and digital product passports

— 2. (16 February 2023): Right from the outset – data and infrastructures for circular design and reutilisation in the building sector

— 3. (23 March 2023): Networked and transparent – data and digital infrastructures for circular production in the car industry

— 4. (4 May 2023): (Re)use rather than own – data and digital infrastructures for circular business models in the consumer electrical/electronic goods sector

— 5. (1 June 2023): Data and digital infrastructures for closing material loops in the textile sector

FINDINGS IN BRIEF

The discussions during the expert meetings emphasized that strategic collection, processing and sharing of product information is a necessary but not sufficient condition for the transformation to a circular economy. The shift from linear to circular value creation will inevitably require regulatory intervention for longer product life, circular design, material quality (and health), repairability, and reutilisation of products and materials. If businesses and other actors (government agencies, consumers, repair cafés and so on) are to coordinate material and substance flows through the entire product life cycle, they will certainly require data and digital infrastructures. Strategic data governance will therefore be needed for product data, in the sense of an institutionalised coordination process that precisely defines what product-related information must be generated and how it should be processed and shared. Only if this information on product attributes circulates freely along with the products can the value contained in them – materials, components, energy – be optimally conserved. The European Union's digital product passport is a lighthouse project in this respect, seeking to assemble standardised digital information on all products traded on the European market. The EU member states must oversee and promote the introduction of the digital product passport and expedite circular business models in the fields of second-hand, product-as-a-service (PaaS), repair and recycling, to create sustainable value-creation options and employment opportunities.

STRUCTURE OF THE PUBLICATION

The present publication presents and analyses the central findings of the expert discussions and turns them into policy recommendations. The text is structured as follows: Chapter 2 provides a brief introduction to the scientific state of the art concerning data for the data-driven circular economy. Chapter 3 outlines the findings of the expert discussions, illustrating the needs, opportunities and risks of circular data governance in each of the four investigated sectors: buildings, car industry, electrical/electronic consumer goods, and textiles. Chapter 4 draws the findings together and puts them in the context of the ongoing development of a European digital product passport, while chapter 5 lays out nine central policy recommendations for political actors at the national and EU levels.

2
WHAT IS CIRCULAR DATA GOVERNANCE?

OBJECTIVE: CIRCULAR VALUE CREATION

The goal of the circular economy is to transform value creation processes – and specifically product design – to ensure that resources and materials circulate and product life is extended as far as possible in order to minimise resource consumption and waste. The circular economy concept thus rejects the classic linear logic of 'take-make-dispose' in which most of the value is destroyed at the end of the product's life, to the detriment of natural ecosystems. Instead, the C2C principle proposes circular value creation, in which products and materials are used multiple times and material flows form closed loops (Blomsma/Brennan 2017; Friant et al. 2020; Hofmann 2019). In other words the goal of a circular economy is to employ rather than consume resources, to reduce absolute resource consumption, and thus to lessen the anthropogenic impact on nature (Hofmann/Jaeger-Erben 2020).

Clearly, the circular economy cannot be established by any single economic actor alone. It requires the collaboration of many: manufacturers, users, vendors, repair firms, recyclers and regulators. System innovations will be needed to embed individual business models into circular ecosystems (Hekkert et al. 2020). Such circular ecosystems are needed in all economic sectors, allowing diverse economic actors to collaborate to extend the service life of products, increase intensity of utilisation, and create closed material cycles. This requires the participating economic actors to apply the principles of circularity in all five phases of the product life cycle (Hansen/Revellio 2020):

- **Design:** Product design actors employ materials in ways that ensure that all utilised resources can be returned to their respective biological or technical cycles after use. Products should also be easy to repair and re-use.

- **Production:** Manufacturers supply products that are need-oriented, circular, healthy, repairable and upgradable, using renewable energy and recycled materials whose production protects – and ideally improves – air, water and soil quality and observes social standards.

- **Use:** Product-as-a-service providers enable collective usage in systems that enhance efficiency. They cooperate with users to enable long and need-oriented use.

- **Second life:** Repair and reconditioning organisations extend product life through servicing and repair, reconditioning and resale, and reassembly with new components.

- **Recycling:** The recycling industry collects and separates material flows to avoid waste and generate secondary raw materials.

DIGITAL TECHNOLOGY AS A RELATIONAL TOOL

All relevant actors will need to overcome existing barriers and obstacles if they are to cooperate around products and materials in circular ecosystems. That will mean creating new relationships of collaboration and exchange, for example between designers and recycling firms, manufacturers and users, consumer advocates and service providers, in order to work together. In this context digital technologies and infrastructures function as relational tools creating connections and relationships between actors. Extending far beyond the purely 'technical' transmission of information, their potential encompasses the generation of resonance and trust between actors and reflection of different value judgements concerning products and materials. Under a relational paradigm the potentials of digital technology can be categorised as follows:

- **Bridging gaps** in knowledge by gathering, sharing and managing data fairly and competently; promoting transparency and openness to reduce knowledge disparities and hierarchies.
- **Creating relationships** between actors (business, regulatory, academic, political, civil society and so on) across different product life phases, sectors and hierarchy levels; gathering actors in circular ecosystems; creating a holistic understanding of life cycles.
- **Generating resonance** to improve understanding between actors concerning (information) needs and values.
- **Encouraging a sense of responsibility** among actors in circular ecosystems to operate responsibly within their own sphere and in relation to others.

These relational attributes allow digital technologies to contribute to making value-creation processes altogether more open, transparent and participatory. That is urgently needed, because the circular economy is more than a project to decentralise value creation. In place of linear connections between large market actors in production, distribution and waste management, the circular economy foresees a multitude of large and small cycles and interactions. Emphasising the regional aspect ensures that in particular the 'inner loops' (sharing, exchanging, second-hand purchase, reconditioning, repair) avoid the additional emissions associated with long-distance transport. This will require actors whose solutions, creative services and new business ideas contribute to the success of circular economy systems. The example of the open source movement demonstrates how powerful and transformative – and at the same time safe and low-risk – open design and production processes can be and how participation and knowledge-sharing can coexist productively with economic efficiency and profitability (cf. Brandenburger et al. 2023; Omer et al. 2022).

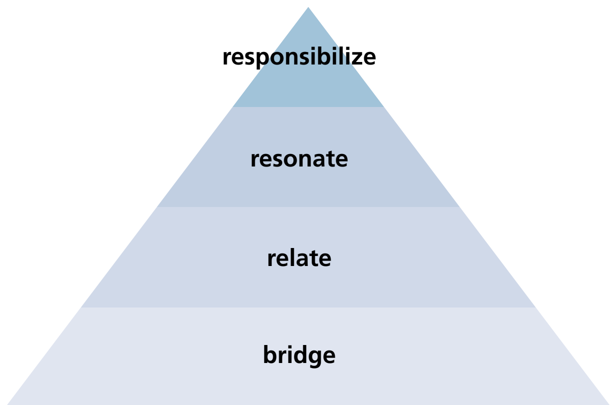
INFORMATION AND COMMUNICATION AS THE BASIS OF THE CIRCULAR ECONOMY

The transformation to an open and decentralised circular economy presupposes a clear regulatory framework. It will require binding rules on material quality and circular product design, extending minimum service life, repairability and reuse of materials.

Businesses must also be actively encouraged to introduce new value networks and production methods. In particular, uncertainties must be addressed and transaction costs for participating in circular ecosystems significantly reduced. The most important measure here is dependable information about the quantity, quality and properties of products and materials circulating in the economy (Jäger-Roschko/Petersen 2022). Here we see the connection between *in*-formation and *trans*-formation: only if economic actors are informed about products' composition, utilisation and environmental impacts will they be able to develop sustainable patterns of production and consumption that effectively reduce resource depletion and greenhouse emissions. Actors must be given the tools to

Potential of digital technology for structuring social relationships

Fig. 1



SOURCE: authors

conserve and preserve the value contained in products and materials.

This broad exchange of information requires preconditions that the market cannot fulfil. As sustainability science points out, the market economy's focus on price as the central product information obscures numerous other aspects that are essential for ecological economic coordination (Berg/Wilts 2019; Agrawal et al. 2021; Hedberg/Šipka 2021):

— The ecological costs associated with initial production are concealed and externalised, creating unjustified price advantages. Reused, repaired and reconditioned products are consequently too costly and the emergence of circular ecosystems is disincentivised.

— Lack of information on quality and suitability of used products and secondary materials (value, price, quantity, quality and so on) creates uncertainty and increases search costs.

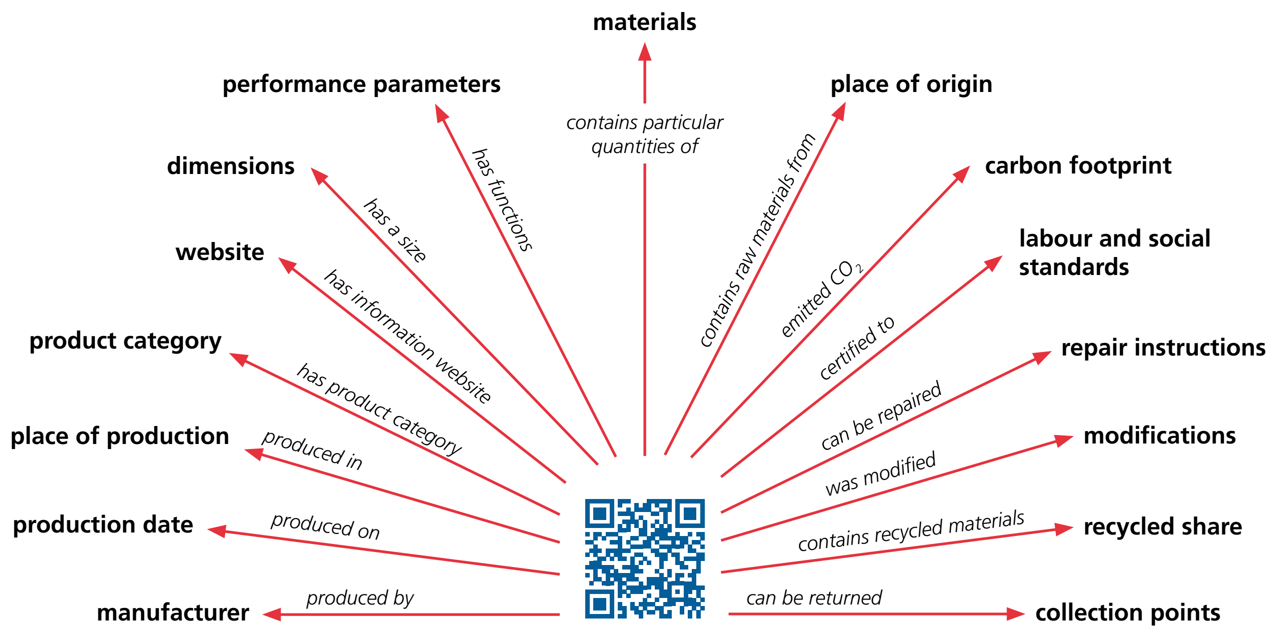
— Inadequate data on material composition prevents product repair, reconditioning and recycling and the recirculation of the resources used in them. This deficit is frequently attributable to a desire to protect business secrets.

Seventy-six different product passports are currently under development in the EU alone (Jansen et al. 2022: 12). Although the large number of initiatives is to be welcomed it can also be counterproductive, for example if competing data formats impede interoperability and restrict data access. A similar restriction of product data is observed in closed ecosystems on proprietary platforms, which tend to lack open interfaces for porting data.

In that context, the European Commission's initiative to create a digital product passport is a welcome development. It sets out to define minimum standards for digital product passports for specific product groups in order to ensure interoperability. The European DPP is also intended to serve to 'electronically register, process and share product-related information amongst supply chain businesses, authorities and consumers' (European Commission 2022a). Businesses operating in the EU market will be required to create a DPP and provide all requisite information and documentation online. The DPP is currently being negotiated at the political level. It is due to enter service in 2026 in the battery sector (on the basis of the Battery Regulation of 2023) (Council of the European Union 2023). In parallel with this, what product data manufacturers (and other economic actors) must share, with whom and for what purposes will need to be defined (at the political level) for numerous other sectors.

The DPP as a graph-structured data model of a product with selected product information

Fig. 2



SOURCE: authors

3 FINDINGS OF THE EXPERT DISCUSSIONS

In what follows we present the findings of the discussions on ‘digitalisation and circular economy’ held between January and June 2023 with experts from politics, business and academia (see list on p. 7). Each of the sessions examined selected use cases in one of four important sectors – buildings, motor vehicles, electrical and electronic goods, and textiles – and each focussed on a different phase of the product life cycle. The systematic analysis was guided by the following questions:

— How can data, digital infrastructures and innovative business models facilitate and promote data-driven circular ecosystems?

— Can promising initiatives to establish data-driven circular ecosystems be identified?

— Which acute challenges might prevent the realisation of data-driven circular ecosystems?

For each sector, we discuss examples of sector-specific initiatives, as well as advances and challenges. Rather than attempting to provide a complete overview of all initiatives for sharing product data, we use the expert discussions to identify sector-specific actor types and coalitions, explore the constellations of cooperation and competition, and analyse the implications for data governance. Each section begins with a general introduction to the sector, with consideration of sustainability challenges and effective principles of the circular economy. Then the role of data and digital infrastructures as a lever for sectoral transformation is examined, and the most acute obstacles to efficient, functioning data governance are outlined.

3.1 BUILDING SECTOR

The term ‘building sector’ encompasses all activities and processes involved in the construction and use of buildings. As well as the construction phase (production of construction materials, planning, construction, logistics services), this also includes services during use as well as expansion, conversion and demolition work. The building sector has a significant role to play in protecting the climate and conserving resources. It is one of the most resource-intensive parts of the economy (Schubert et al. 2023). To name but a few of the issues: growing demand for sand and gravel, steel, aluminium and glass; the CO_2 emissions associated with concrete production; immense energy consumption during the use phase; large volumes of waste; and expanding land use and soil sealing. In view of the numerous negative influences on natural ecosystems, a deep transformation of the sector is urgently needed.

One important starting point is to maintain existing stock. The participating experts agreed that existing buildings needed to be preserved – and used better or differently. Wherever possible, housing and commercial premises must be created through resource-efficient conversion of existing buildings. Systematic maintenance and repurposing of existing buildings would save large amounts of grey energy and primary raw materials (Schubert et al. 2023). One important precondition for repurposing and extending useful life is insulation, given that more than 60 per cent of residential buildings in Germany were built before the first Thermal Insulation Regulation (1977) and fall far short of today’s energy standards (Küstner et al. 2022). A second central starting point is to conceive buildings as circular from the outset. If a new building must be constructed – after thorough and careful consideration – the possibility of multiple use and later conversion should already be considered (and acted upon) in the planning phase (Küstner et al. 2022). The circular economy principles of modularity, repairability, separability of material types, and circularity of materials must be established as sectoral standards. To support this, every new building should have a deconstruction concept for easy access to the materials (urban mining). And the use of healthy and renewable raw materials must naturally be considered and, if ecologically advantageous, prioritised.

DATA AND DIGITAL INFRASTRUCTURES FOR A TRANSFORMATION OF THE BUILDING SECTOR

Building information modelling (BIM), which generates a digital copy of a real building, is increasingly widely used. The digital ‘twin’ allows the building’s dynamic behaviour to be analysed realistically. Creating a digital twin requires comprehensive information about the building, which is increasingly collected in a digital building passport (or a digital product passport for buildings). Digital building passports can be extremely useful in all phases of a building’s life, from planning and construction through successive uses to possible repurposing and (selective) demolition. The beneficiaries include owners, architects, builders, service providers, recycling companies and local administrations.

Information from the digital building passport can be used to market used components and to prepare life-cycle assessments as input for decisions concerning circular construction. In particular, continuous dynamic recording of building performance data (for example, renovation work, residual value of used materials) in combination

Sample content of digital building passport

Fig. 3

General information	Location, year constructed, type, total mass, residual service life …
Materials	Materials used in building (timber and wood products, plastics, electrical and electronics, metals, plaster, mineral construction materials, etc.). Unique and permanent ID numbers for used materials to allow tracking throughout life cycle, monetary value of materials, origin of materials …
Dismantling and circularity	Recoverable mass plus quality classification, separability of materials plus quality classification, connection technologies, separable mass, potentially reusable mass, potentially recyclable mass, reusable material mass, thermally utilisable mass …
Flexibility and adaptability of building structure	Multiple use area, convertibility, expandability …
Hazardous and high-risk materials	Contamination report, toxicity of used materials …
Greenhouse gas emissions across entire life cycle	Production of inputs and materials, construction, use, dismantling, saved emissions with different extended use and conversion options …

SOURCE: authors

with static information (for example, location, connection technologies, materials used, material health) throughout the building's life creates a transparent and documented basis for maintenance work, resource-saving conversion or repurposing, and selective deconstruction (Schubert et al. 2023).

For that to happen, the information contained in the digital building passport must be prepared and presented in such a way as to be relevant, useful and applicable for diverse users. The great complexity and individuality of buildings, however, means that introducing a standardised digital building passport would entail a multitude of open questions that are currently not covered by national and European norms. At present, there is no coherent approach to developing and using digital building passports (DIN/DKE/VDI 2023).

As a result, multiple commercial service providers have emerged offering digital building passports. Prominent examples include Madaster and Concular. Both register buildings and their components digitally, bundle the data in digital building passports, and store these permanently in an online register. In this way they collate important sustainability indicators, such as stored carbon, toxicity and reusability of materials and components, and financial evaluations of buildings and their components. Beyond this, businesses are also experimenting with online marketplaces, through which used components can be marketed on the basis of the stored data. But there are also collaborative efforts to advance the development of digital building passports. One example is the German Sustainable Building Council (DGNB), which has proposed a standardised documentation format in close cooperation with its Committee for Life Cycle and Circular Building (DGNB 2023).

CHALLENGES FOR CIRCULAR DATA GOVERNANCE

The participating experts welcomed the initiatives to establish digital building passports, but agreed that it was unlikely they would become widely established without resolution of the open questions. They noted the lack of harmonised data standards and standardised interfaces. In view of the great diversity of sources and information involved, standardisation of data formats and interfaces (such as Industry Foundation Classes, IFC) will be essential to facilitate the sharing of product data.

The current lack of interfaces and the heterogeneity of data formats is problematic. Information exchange is challenging and sometimes requires very specific expertise. Clear rules on open data formats and standards would reduce market uncertainty, promote the harmonisation of hitherto incompatible initiatives, and enable freer exchange throughout a building's entire life cycle (DIN/DKE/VDI 2023). If the digital building passport is to become the universal standard, the open questions will have to be resolved.

In this connection the experts also noted a lack of data openness and transparency on the part of manufacturers. Important information on properties of materials and components is currently often unavailable and/or incomplete and frequently not machine-readable. An obligation to share material and product data (while guarding trade secrets) could permit reliable evaluation of buildings for purposes of maintenance, servicing, material recyclability and resource and energy consumption. A data-driven circular transformation of the building sector will require the creation of a digital infrastructure that provides material and building data in optimised formats.

3.2 CAR INDUSTRY

The transformation from the internal combustion engine to lower-emission drive technologies is currently progressing in leaps and bounds. Alongside a general reduction in road traffic and an increase in multimodal mobility services, rapid expansion of the number of electric vehicles will be crucial. The shift to electric cars will probably also shift the bulk of social-ecological impacts from the use phase to the production phase. Resource extraction, sometimes under inhumane conditions, will be a significant factor (Kwade et al. 2020). At the same time the car industry will need to find answers to the growing shortages of strategic metals (such as rare earths) which are required in large quantities in the production of electric cars (Buchert et al. 2019).

Consequently, the car industry will have to undergo profound structural changes if it is to realise the circular economy: productivity-increasing multiple use (sharing services), life-extending measures (repair, refurbishment and remanufacturing) and recycling (of batteries and vehicles) are necessary conditions for more ecological motorised personal mobility. Circular vehicle manufacturing begins with circular product design and must cover everything from procurement to more energy-efficient production technologies (Buchert et al. 2019). Cross-sectoral orchestration of manufacturing networks is required, and must build on the free flow of digital information.

DATA AND DIGITAL INFRASTRUCTURES FOR A TRANSFORMATION OF THE CAR INDUSTRY

Two initiatives for sharing product data were discussed in depth in the session on the car industry: the Battery Pass (Acatech 2023), which is a digital product passport for batteries, and Catena-X, a consortium developing a data ecosystem for the car industry.

The Battery Pass consortium is seeking to make the battery life cycle circular in order to reduce the social-ecological costs of resource extraction and CO_2 emissions in complex value chains. The consortium is funded by the German Federal Finance Ministry; its members include manufacturers, research institutes and service providers. It is working to develop cross-sectoral standards for a digital battery passport in line with the requirements of the EU Battery Regulation (Council of the European Union 2023). The passport includes static information on technical specifications, certifications, employed raw materials, toxic substances and CO_2 emissions, as well as dynamic information on battery condition and number of charging cycles completed. The battery passport will also need appropriate data infrastructures, for example an open-access digital platform (Kwade et al. 2020).

Interoperability of product data and seamless documentation of battery service life are vital concerns, and many potential ecosystem actors are therefore participating in development of the battery passport. The project was initiated by the state and includes a broad spectrum of stakeholders (although heavily slanted towards large corporations and consulting firms).

The second German lighthouse project for sharing product data in the car industry is Catena-X, which is led by major manufacturers (Catena-X 2023a). The goal of Catena-X is to create an open data ecosystem for value networks with comprehensive digital documentation of products and materials, for example in order to quantify CO_2 emissions or to document component supply chains in line with the German Supply Chain Act of 2021. Standardised data exchange and shared software will ensure that data can be freely exchanged, processed and analysed. Technically, Catena-X builds on open-source solutions that originate in the work of GAIA-X and the International Data Space Association (IDSA). It puts great weight on data sovereignty and selective transparency: ecosystem actors are permitted to access sensitive information only if authorised to do so by the manufacturers. In the words of the Catena-X consortium: ‘The data’s provider retains control and decides who to share it with, when, how and under what conditions’ (Catena-X 2023b).

CHALLENGES FOR CIRCULAR DATA GOVERNANCE

The session on the car industry revealed differences over the question of openness of data infrastructure. The major car manufacturers at the heart of the Catena-X consortium want comprehensive and largely exclusive control over their product data, which rather relativises the asserted ‘openness’ of the data ecosystem. For example under Catena-X’s rules data exchange would require some form of contract. This is problematic because the strict form of data control pursued by Catena-X can curtail the data access of third parties (for example, independent repair firms offering circular services for electric vehicles). Strict control of data could also prevent the emergence of new circular business models and consolidate barriers to market access. This would subvert the idea of creating new economic incentives for sustainable and ecological businesses through open circular ecosystems.

These criticisms of the exclusive thrust of Catena-X were accompanied by concerns over the asymmetrical structure of the organisation behind it. It was argued that the core consortium of major car manufacturers dominated the 144 smaller participating suppliers and made important decisions about the shared data infrastructure unilaterally behind closed doors. While the discussion participants criticised this two-tier system, they also acknowledged the need for a viable core group to advance the project rapidly.

3.3 ELECTRICAL AND ELECTRONIC CONSUMER GOODS

The third session took up the issue of electrical and electronic consumer goods, in particular household appliances and ICT products, such as washing machines, kitchen equipment, televisions, smartphones and computers. These products incur enormous ecological costs. First of all they require large quantities of critical metals, which are frequently associated with the destruction of complex habitats and exploitation of the Global South. Then there is the ever-shorter service life of electronic goods. Consumers buy new devices even when their current one is still (at least partially) functional and would potentially remain technically serviceable (UBA 2016). The reasons behind such purchasing decisions are manifold: trends are one, the time and expertise required to carry out maintenance and repairs another; inadequate manufacturer service also plays a role. Although recycling processes are continuously improving, important high-value materials are lost during reprocessing due to contamination with other substances and the complexity of product composition. Extracting them and returning them to their original state is technically demanding and energy-intensive (Prakash et al. 2023). Enormous amounts of electronic waste are often illegally exported rather than properly disposed of, exposing populations and the environment to toxic chemicals (Meloni et al. 2018).

The electronics sector is pursuing a number of strategies to reduce its high ecological costs. Resource-effective circular product design is a central starting point for a circular transformation of electronic goods. Optimising design for repairability, modularity and adaptability can contribute to making products easier to repair and allowing components to be used more intensively. Integrating circular design principles into the product development process at an early stage is decisive, because once the product's attributes have been defined and the use scenarios and contexts settled it is possible to make only minor alterations. Another approach is to maximise electronic products' service life, because the greatest harm to natural ecosystems occurs during the manufacturing and disposal phases (Ramesohl et al. 2022). For example, businesses can support careful handling and longer use with tailored services, such as maintenance and repair, availability of spare parts and reconditioned devices, and through skill and knowledge transfer. The intensity of utilisation can also be maximised through innovative models such as PaaS. Business models in the electronics sector that set out to improve product utilisation rates typically revolve around temporary use by multiple users. They are based on leasing, rental, lending and pooling, with ownership no longer a precondition of accessing product functionality. In this way the principle of 'sharing' can bring about an absolute reduction in the material volume of consumption if it reduces the number of purchases of new products (Jaeger-Erben/Hofmann 2019).

DATA AND DIGITAL INFRASTRUCTURES FOR CIRCULAR BUSINESS MODELS IN THE ELECTRICAL/ELECTRONIC SECTOR

Alongside hardware-related challenges, such as built-in obsolescence and expensive or unavailable spare parts, software-based business practices increasingly prevent effective circularity in the electronics sector. Practices such as serialisation, closure of cloud services, cessation of security updates for older devices, and lack of information on repairs and spare parts are detrimental to sustainable use and reuse of electronic products (Runder Tisch Reparatur 2022).

At the same time, increasing digitalisation of products and business models can also help to overcome barriers to circularity in the electronics sector. In particular, digital platforms can be important technological enablers, facilitating the provision and exchange of information and the processing of economic transactions. On one hand, this can bring together suppliers and customers of maintenance and repair services (for example, MeinMacher.de), spare parts (Kleinanzeigen.de, Ifixit.com), and reconditioned second-hand devices (afbshop.de, refurbed.de). On the other, digital sharing platforms encourage collaborative shared use of electrical and electronic devices and thus increase the utilisation factor (nebenan.de). Platform-based online marketplaces are especially important for repair and reconditioning services, matching customers with suppliers, organising new forms of collaboration between independent firms, and orchestrating service capacity, materials and spare parts. For example, the matching platform developed and operated by FixFirst (FixFirst.io) offers customers remote consultation about defective devices, complete with a virtual inspection. It also matches users with regional businesses, processes paperwork and enables lean organisation of repairs and servicing. SHIFT GmbH is a non-profit start-up developing long-lived modular digital devices. It employs circular product design to create social-ecological solutions in the strongly oligopolistic markets for smartphones, tablets and laptops. Users of its products can change the operating system at will, expand the RAM, and replace the battery and display themselves. The firm is committed to long-term availability of spare parts and online tutorials, enabling users to carry out their own repairs. Not least, SHIFT works to improve social-ecological transparency in the production process, supplier networks and company investment decisions (Hofmann et al. 2021).

CHALLENGES FOR CIRCULAR DATA GOVERNANCE

In the electronics sector, defining uniform binding standards for data formats and interfaces is one of the most important challenges when it comes to creating circular ecosystems using product data. The lack of data und interface standards hampers the availability of information about the condition of used, repaired and reconditioned devices, further reducing interest and confidence in used electronic products. Additionally, restrictions on sharing information (about availability of spare parts, knowledge relevant to repairs and reconditioning, and digital models for 3D printing) prevent the scaling up of business models focussing on repair and reconditioning.

Another issue is power asymmetries throughout the electronics value chain, which hinder a sustainable transformation in the sector. There is a fundamental lack of information about the ecological costs of (imported) inputs. As well as problematic discontinuation policies affecting elementary spare parts and the (quasi-) monopolistic market power of global component manufacturers (for example, CPUs and circuit boards), resource extraction in the Global South (ores and metals) is very opaque and hard to monitor. Manufacturers also block an effective transformation towards a circular economy through practices such as serialisation, lack of transparency in value chains, early discontinuation of spare parts, and anti-repair product design. In order to counter the concentration of power in the hands of just a few actors, businesses that orientate their business models towards repair, refurbishment, remanufacturing and/or upgrading of electrical and electronic products and PaaS models (see Hansen et al. 2021 for further innovative business models in these areas) should be enabled to access original spare parts, 3D models for printing components, and software and hardware tools in order to guarantee the full functionality of reconditioned products (González-Varona et al. 2020).

3.4 TEXTILE SECTOR

The session on the textile sector concentrated on garment production, household textiles, and technical textiles for industry and the service sector. Textile production networks are distributed across the globe and have grave negative effects on people and the environment. One main cause identified in the discussion is the ‘fast fashion’/‘ultrafast fashion’ marketing strategy pursued by dominant market actors such as Zara, H&M, Primark, KiK and Shein. Weekly new collections and low prices encourage customers to buy more. The number of garments sold globally more than doubled between 2000 and 2015, while use duration has declined steadily (Greenpeace 2017). The average German buys sixty items of clothing per year (Greenpeace 2020). The consequences of ‘ultrafast fashion’ are well-documented by media reporting and academic research: systematic exploitation of textile workers in the Global South, gigantic CO_2 emissions, enormous water consumption in regions of water shortage, the introduction of toxic and persistent chemicals into natural ecosystems (PFAS, per- and polyfluoroalkyl substances) and the problem of microplastics, which enter the water cycle each time the cheap artificial fibres are washed. One central challenge is thus to close the textile material loop through reverse logistics and recycling. Germany already possesses a comparatively well developed infrastructure that collects an estimated one million tonnes of used textiles each year (Wagner et al. 2022). Only a fraction of the collected garments are sold second-hand. The existing recycling technologies face organisational and technical obstacles. Some of the discarded textiles are downcycled into cleaning cloths, insulation materials, filling materials and fleece, but most are incinerated. The reasons for low recycling rates for textiles are diverse and cannot be reduced to single causes. One significant factor is beyond doubt, though. Most garments are designed in ways that prevent recirculation of their components: heterogeneous material flows are difficult to separate, as are mixtures of natural and artificial fibres; pure cotton and wool cannot be recycled without great loss of quality; inadequate information on material composition presents further obstacles (Gimkiewicz et al. 2022).

DATA AND DIGITAL INFRASTRUCTURES FOR CLOSING MATERIAL LOOPS

The participating experts consider that improving product transparency could significantly increase reuse and recycling rates for textiles. A widely recognised and standardised dataset for garments would help to promote reverse logistics systems and textile recycling on a large scale. For example, the circularity.ID Open Data Standard developed by circular.fashion enables textile manufacturers to communicate their product information in a format that can be read and processed by numerous software applications (circular.fashion 2021). This digital product passport for clothing contains an uneditable dataset with information on material composition and chemical substances, and an editable adaptive dataset used to record reconditioning measures, consumer information for long and sustainable use, and updated product care information. The data can be held on an NFC chip integrated into a button or woven directly into the fabric. Relevant characteristics of the textile can be read out from the chip, for example on a smart sorting table, and evaluated extremely quickly. This makes the entire sorting process more efficient and allows high-quality garments to be separated out for remarketing.

The circularity.ID from FairWertung and circular-fashion is already being trialled on a large scale in a project named Closed Loop Pilot (FairWertung 2021), in collaboration with manufacturers and sorting and recycling firms. In the pilot project, the participating manufacturers are developing and marketing various textile products equipped with the aforementioned circularity.ID. After the use phase, the products are returned to textile sorting firms, which use a special sorting machine to read the chip (containing product history, material composition and dynamic remarketing information) and automatically sort the garments into fractions. The participating ecosystem actors hope to gather generalisable practical experience concerning the success factors for configuring material loops. In conjunction with enhanced sorting processes, the product ID should improve the quality of the fractions identified for reuse and recycling.

Product-specific identification technologies are also increasingly used in work clothing in industry, health care and catering. The approach developed by Sitex is employed above all in internal reverse logistics. Its proprietary textile identification system employs RFID technology for smooth, functional reverse logistics. Sitex supplies reusable textiles to hospitals, care homes, and industrial and commercial users. Comprehensive monitoring and management allow the company to respond to customer requirements in real time, and permits automated handling and reutilisation of work clothing.

CHALLENGES FOR CIRCULAR DATA GOVERNANCE

Digital product passports for textiles are in the early stages of development and facing multiple challenges. There is no sign that any particular initiative is likely to become sufficiently large and widely recognised to establish itself as a universal standard. Instead, there are isolated small-scale solutions based on the work of individual companies (such as Sitex). The relevant software systems lack harmonised data standards and interfaces, making large-scale inter-actor data exchange impossible. The risk is that the existence of multiple unharmonised data standards will subvert the stated goal of data-driven circularity. The existing initiatives to develop product passports for the textile sector therefore need to be opened up and joined together to create data standards for technical parameters and content.

Another longstanding problem in the textile sector is deliberate mislabelling and inadequate controls (Regierungspräsidium Tübingen 2022). Correct labelling of fibre composition is an absolute precondition for automated sorting and effective recycling. Despite the EU's Textile Labelling Regulation (since 2012) and the German Textile Labelling Act of 2016, false and missing information on fibre composition remains more the rule than the exception, notwithstanding the prospect of reprimands and fines. Rapid expansion of market surveillance is required to ensure that the information supplied in the product-specific dataset is in fact correct.

4
ANALYSIS AND POLITICAL CONTEXT

In the following we draw together and compare the findings of the expert discussions. Existing circular economy initiatives promoting use of product data are evaluated and put in the context of European regulation and the digital product passport.

HOW CAN PRODUCT DATA SUPPORT THE TRANSFORMATION?

The sectors under examination share a great deal in common. The most important insight is that there are already groups in all four sectors pursuing the goal of a data-driven circular economy. In particular, data exchange and sharing of product information using digital product passports are seen – across sectors – as central tools for promoting new business models and collaborations between all participating actors in circular ecosystems (suppliers, manufacturers, refurbishers, remanufacturers, repair firms, recyclers and consumers). Overall, the use scenarios are similar across sectors:

- **Ecological transparency throughout the supply chain for sustainable procurement and product design:** businesses receive better information about their inputs, allowing them to devote proper attention to the principles of circularity, material health and sustainability, starting in the planning and product design phase. Machine processing can be vital for assembling the final product's DPPs in particular when complex products have hundreds or even thousands of inputs and components. The objective is a realistic representation of ecological costs and better assessment of the value and condition of repaired and reconditioned products.

- **Improved secondary use (reuse, second-hand):** standardised product information documents the value contained in used products and components. Correct identification of products and the materials they contain is helpful for evaluating and marketing used goods, and building new business models around them.

- **Repair and servicing information for longer product life:** supplying instructions for repair and replacement of individual components enables users and repair firms to conduct servicing and repair work. Providing information on the availability of spare parts and 3D models for printing them (and saving resources) can prolong product life and improve material efficiency.

- **Higher recycling rates:** information on recommended recycling processes and types and quantities of materials and chemical substances contained in products is a precondition for digitally supported separation of mixed materials. This allows recyclers to operate more cost effectively when turning discarded products into secondary raw materials (collection, disassembly, sorting, purification and reprocessing).

- **Enabling ecologically aware consumer decisions and product use:** standardised information on a product's carbon footprint, repairability and recyclability can encourage users to pay more attention to sustainability information (alongside price, design and functionality). E-commerce platforms in particular should prominently display the ecological costs as documented in the DPP. Information on care, servicing and disposal can also enable users to contribute actively to increasing material efficiency.

- **Supporting government agencies in implementing future product regulation:** bundling product information in digital product passports allows manufacturers to fulfil their recordkeeping duties more easily and with less bureaucracy. For example, the observance of statutory material-quality standards, emissions limits and product life requirements can be collated in a dataset and verified independently.

- **Better decision-making through analysis of environment-related product data:** bundling DPPs in a register of product passports will allow a whole new dimension of big-data analysis to improve the ecological transparency of product markets. On one hand, aggregated information on expected secondary materials can expedite the planning and establishment of circular business models. On the other, researchers can evaluate data on utilisation cycles, resource consumption and emissions, and provide feedback on alternative development scenarios and potential for savings.

- **Strengthening collaboration and resonance in the economic ecosystem:** DPPs collect actors around objects, materials and resources in order to improve the efficiency and consistency of economic activity (over and above self-centred profit interests). Even if this means dealing with conflicting interests and intentions, transaction costs and obstacles to collaboration, the long-term impact of DPPs in generating relationships and establishing the principle of sustainability-oriented common ground should not be underestimated.

- **Expanding and transcending value concepts:** the DPP can potentially supply a multitude of information tailored to the intentions and values of the economic actors involved. This produces a holistic picture of the value or 'worth' of products, components and materials that goes far beyond the fixation on exchange value in the contemporary market economy.

WHAT PRODUCT DATA IS REQUIRED?

If these use scenarios are to be realised, product information must be gathered in a standardised format and supplied as digital datasets. The expert discussions focussed on the question of data categories. Building on the comparatively advanced development of the battery passport (Battery Pass Consortium 2023), the following data categories should serve as orientation for further discussion:

- **General product information:** clear and machine-readable product ID (digital identity), product category, manufacturer, date of production.
- **Technical specifications:** dimensions, performance parameters.
- **Conformity, labelling, certifications:** CE, norms, certificates, labels.
- **Material composition:** quantification of raw materials, process chemicals and materials, additives and hazardous substances.
- **Sustainability indicators:** carbon footprint (scope 1, 2, and 3), water consumption, effects on biodiversity, due diligence obligations, reporting duties, origin of critical raw materials, social standards and working conditions.
- **Circularity and resource use:** circularity of materials, repair and servicing instructions, disassembly instructions, spare parts, proportion recycled, care and disposal, recycling processes.
- **Utilisation information (dynamic data):** condition (wear), negative events (temperature), history (charging cycles, service life).

THREE TYPES OF DATA GOVERNANCE MODEL

In all four investigated sectors, numerous actors are already working to develop their own technical data infrastructures and standards to promote the sharing of product data. Three types of product data initiative can be distinguished, each with its own distinctive constellation of actors and data governance structures:

- **Proprietary platforms:** start-ups in the IT branch provide technical infrastructures for sharing product data as a service (for example, Madaster, Concular, Kleinanzeigen, rebuy, FixFirst). These are mainly digital marketplaces in which the participants trade used products, components, secondary raw materials and information. In technical terms, they are based on centralised data governance models with proprietary interfaces under the exclusive control of the platform provider.
- **Commercial development partnerships:** established businesses join forces to create shared data infrastructures for product data in order to open up new strategic fields of business, frequently with state funding and the support of independent research institutes (for example, Catena-X, Batterie Pass). This produces mixed data governance models with centralised software structures and collective administration, but also a strong focus on data sovereignty for the participating companies.
- **Open norming processes:** established standardisation organisations and civil society actors cooperate with businesses and other stakeholders to develop open standards for digital product passports (for example, DIN, Product Circularity Data Sheet). The aim is decentralised collection and sharing of product data while ensuring high functional and semantic interoperability.

All three types of product data initiative are voluntary projects that must rely on manufacturers and owners supplying product data via the corresponding data infrastructure. The product data initiatives differ with regard to how much transparency and participation in data governance they enable for different ecosystem actors. While platform providers dictate the terms and purposes of product data processing, and may alter these at short notice, the development of open data governance involves long-running processes with many stakeholder groups. Commercial development partnerships fall between the two: further businesses may join the consortium and enjoy the same degree of data sovereignty, but the central data governance decisions are taken by an exclusive core group of established actors.

PROBLEM: LACK OF INTEROPERABILITY

The promise of a data-driven circular economy rests on the assumption that product data is permitted to flow freely. Although many actors share that objective, the multitude of product data initiatives, sometimes with incompatible data standards, represent a problem. The more competing standards there are in a sector, the more difficult it will be to realise transfer and aggregation of product data between ecosystem actors and even more so between sectors. The problem is especially clear in proprietary platforms for sharing product data, which are based on closed data ecosystems without open interfaces. This can lead to the emergence of new product data silos, in which particular economic interests threaten to undermine the overarching goal of product data integration. But the flow of information can be interrupted even in product passport standards with decentralised data governance if differences in data formats and collection methods hinder interoperability.

This risks fragmenting the data landscape, creating an artificial data shortage. For several reasons this can be a risk factor for the circular economy:

— **Information loss:** product data cannot be aggregated and information about inputs is lost. Network and synergy effects cannot be exploited and collaboration is hindered.

— **Costs of duplication:** duplication of data gathering and sharing in different formats can incur significant additional costs.

— **Market failure:** product-data ecosystems can fragment markets, create new market entry barriers and hinder the emergence of circular business models.

— **Potential for abuse:** product data initiatives can become powerful gatekeepers, exercising de facto control over market access. In particular, in combination with lock-in effects product data initiatives can demand high fees and impose disadvantageous conditions on participating ecosystem actors.

Basic sectoral standards are needed to prevent the creation of new data silos. These must harmonise technical and transparency standards for collecting and sharing product data. Legislation is required for this purpose.

THE EUROPEAN DIGITAL PRODUCT PASSPORT

The development and introduction of the European Union's digital product passport is a milestone on the road to a circular economy. In recent years the European Commission has stood out as a central advocate of data-driven circular economy and has repeatedly demanded a 'digitalisation of product information' (European Commission 2020) for the circular economy (for example, in the Green New Deal, the Circular Economy Action Plan and the Sustainable Product Initiative). The new draft Ecodesign Regulation of 2020 should now define a 'common set of rules, which include product requirements and the obligation to provide reliable information' (European Commission 2022b: 1) for economic operators operating on the internal market. The most important innovation here is that all manufacturers of physical products marketed in the EU, including components and intermediates, will have to publish a digital product passport (EU-DPP) for each product. Now the EU will have to define minimum standards for exchange of product data.

The technical minimum standards will be defined in the European digital product passport, which is to be the centralised technical format for all necessary product data. Here the EU is pursuing decentralised data governance: the EU-DPP is to be stored locally by the respective businesses and accessed via a data carrier on the product (for example, barcodes, QR codes or NFC chips). In order to ensure interoperability of all digital product passports, the European Commission is developing basic IT norms and data protocols. It aims to complete the technical standardisation of the EU-DPP by the end of 2025, with the expectation that businesses will be able to use the IT from 2027.

In the matter of minimum standards – defining exactly which product data is to be provided – the European Union is pursuing a two-track strategy:

— First, a universal horizontal framework is defined for digital product passports and corporate due diligence obligations. The central instrument here is the new Ecodesign Regulation, but information requirements from other legislation could also be included (for example, from the Corporate Sustainability Reporting Directive)

— Secondly, 'vertical' sectoral requirements will be adopted for individual product categories, laying out concrete obligations for specific product data. For example, the Ecodesign Regulation requires the European Commission to prepare ecodesign requirements for specific products using delegated acts. Information requirements can also be realised in normal legislative processes. The model here is the EU Battery Regulation, which requires a product passport for batteries from 2026.

BARRIERS AND TENSIONS IN DPP DEVELOPMENT

In the course of the expert discussions it became clear that there are several fields in which interests conflict and fears are emerging. The three following spheres in particular have given rise to controversy.

1) INTELLECTUAL PROPERTY VS PUBLIC INTEREST

Manufacturers warn that a statutory duty to share product data may amount to infringement of their trade secrets or intellectual property rights. From a commercial perspective, they argue that the more precise the information on product design, materials and production methods, the greater the risk of losing out to competitors. Accordingly, certain manufacturers demand especially comprehensive data control, where they retain responsibility for granting access rights to individual ecosystem actors and are able to restrict detailed information (for example, product composition) to authorised repair workshops and recycling firms.

Other participants objected that strict data control by manufacturers would lead to underuse of data and hinder the emergence of circular ecosystems. Instead of securing existing market positions through exclusive ownership rights, they said, a new level playing field needed to be created to reduce market entry barriers in circular business models. The objective, they argued, was fair competition in the markets for sustainability services, such as repairs and recycling, as well as improving general freedom of knowledge and participation for users and civil society. To back up their case, they cited the demonstrably positive effects of open-source software and hardware on technological independence, competitiveness and innovation in the European Union (European Commission 2021). European transparency requirements could certainly create competitive disadvantages for European manufacturers, where they compete in foreign markets with foreign businesses that are not subject to comparable transparency requirements. However, the experience with existing transparency standards, for example for hazardous substances (REACH and RoHS), has demonstrated that such reservations are frequently unjustified. In fact, international standards are often rapidly levelled up.

Despite the controversies the participants agreed that a 'mental shift in willingness to share data' is required. That presupposes a secure legal and regulatory framework for the digital product passport that is as open as possible (and as closed as necessary). Fundamentally, they agreed that detailed product information is always in the public interest where it contributes to conserving the value of components and materials in products. They also agreed, however, that manufacturers' trade secrets and intellectual property must be weighed carefully against the rights of users and the interests of society and environment. It should be obligatory to disclose sensitive product information, for example on manufacturing processes, only if this promises significant resource savings.

2) LARGE VS SMALL BUSINESSES

The transformation from linear to circular ecosystems presents particular challenges for small and medium-sized enterprises (SMEs). SME representatives argued that they incur higher data-related costs in relation to total turnover than large companies do. They also fear that the intensified data exchange that comes with DPPs will leave them even more dependent on large manufacturers. In particular, standardisation processes dominated by the private sector have the potential to exacerbate power asymmetries within value chains. Catena-X, for example, exhibits traits of a 'two-class society' between the core consortium and the other members, whose options for participating in the development of the data infrastructure are severely curtailed. But even open standardisation processes may exacerbate inequalities between small and large businesses because the resources at their disposal for influencing standardisation processes differ so widely. SME representatives fear that large companies will exploit the development of open DPP standards to the detriment of the SME sector, for example through expensive data collection processes. The need for special support programmes for SMEs was discussed, along with the question of whether the costs could be reduced for SMEs, for example through asymmetrical data disclosure obligations (requiring larger businesses to disclose more product data).

3) ECOLOGICAL COSTS VS ECOLOGICAL BENEFITS

The application of digital technologies is always associated with some degree of ecological cost. The computers on which product data is stored, processed, communicated and viewed are particularly energy- and resource-consuming. Large-scale use of NFC and RFID chips for electromagnetic identification of products can also significantly increase demand for metals such as silicon and gold. In view of this **conflict of goals between digital data interchange and sustainability** it must always be considered whether the ecological gain – through better availability of product data – outweighs the ecological costs. Fundamentally, the volume of data expected in connection with product data is moderate in comparison with social media and streaming platforms, although a systematic analysis has yet to be conducted. The guiding principle should be digital sufficiency (data minimisation) in order to minimise the amount of physical infrastructure required. In this context, data duplication and the use of blockchain technologies should be subject to critical scrutiny – even if the latter's energy and resource consumption is significantly lower in the context of digital product passports than in crypto-currency applications.

5
POLICY RECOMMENDATIONS

On the basis of the expert discussions and other research we make the following nine recommendations for action at the national, European and international levels.

1) The European Commission should rapidly develop minimum standards for sector-specific transparency of product data.

The current draft of the Ecodesign Regulation already lists a number of 'information requirements' that businesses must supply in a DPP if they wish to market a product in the European Union (European Commission 2022a: Articles 7 and 8). Information is required on performance, hazardous substances, repair, servicing, disassembly, recycling and disposal. The transparency requirements apply to all product groups across all sectors and therefore remain very vague. Certain kinds of product information required for circular business models are not mentioned at all. They include:

— information on quantity and quality of raw materials (including process materials and connection technologies) and their circularity;

— technical specifications for components;

— information on spare parts (availability of original parts, 3D models);

— environmental indicators (CO_2 emissions, water and soil consumption, influence on biodiversity);

— social and labour standards throughout the value chain (starting from resource extraction).

Further sector-specific transparency rules will be necessary in the coming years to define the exact information required for individual product groups. The most important actor here is the European Commission. It will have the power to adopt delegated acts on the basis of the Ecodesign Regulation and is already preparing further-reaching legislation, such as the EU Battery Regulation. The EU member states and other actors should support the Commission as much as possible. The guiding principle when developing transparency rules should be 'as open as possible'. All information about the environmental impacts and recirculation of products and their components should be treated as essential public interest data. (Firm-level) competitive disadvantages in foreign markets need to be weighed against the societal and ecological benefits of better availability of product information.

2) The European Commission should continue working on technical minimum standards to harmonise data collection and ensure interoperability of digital product passports.

The data-driven circular economy can function only if proprietary data silos are opened up and digital product passports are interoperable (can be read and processed across all sectors). There are two preconditions for interoperability: first, manufacturers must use the same methodologies to collect and process product information for the DPP; second, the DPPs must share the same technical data format with harmonised IT norms and protocols, allowing them to be combined and aggregated. The ability to aggregate DPPs is especially important to enable product information to be integrated across sectors throughout the product life cycle and the inclusion of all information about inputs in the digital product passport of the final product.

The European Commission has already underlined the importance of interoperability in Articles 9 and 10 of the proposed Ecodesign Regulation. To this end it has already started the development of a standard data format for DPP systems. This is to be implemented by the end of 2025 by the Directorate-General for Informatics (DG DIGIT). Uniform technical standards for collecting and sharing product data are also needed, as are harmonised methods for collecting product information – especially for repair and servicing instructions, material composition, sustainability indicators and information on recycling processes – in order to ensure that they are comparable and suitable for aggregation.

3) The digital product passport should serve as a centralised dataset for unbureaucratic fulfilment of all information requirements.

In order to keep costs low for small and medium-sized enterprises and to ensure that data collection is efficient, effective and unbureaucratic, the EU product passport should serve as a centralised dataset for all product-related recordkeeping requirements. Comprehensive standardisation and bundling of all required product information could simplify the existing reporting requirements for manufacturers, avoid data duplication and improve the availability of product information for other actors. In particular, the DPP should be able to satisfy the transparency requirements associated with the following instruments:

— Environmental Product Declaration (EPD);
— REACH Regulation;
— Corporate Sustainability Reporting Directive;
— EnergyEffizienz, EU energy label.

Product labels and certificates that are recognised in the EU (including C2C, Blue Angel and Green Button) should also be noted in the DPP, so that they can easily be viewed, processed and compared by other businesses, regulatory agencies, as well as users and (online) vendors.

4) Balanced representation of all stakeholder interests is required, as well as inclusion of the environmental, climate and sustainability sciences in developing standards for DPPs.

The development of standards is usually dominated by large companies, which can draw on generous resources to influence technocratic standardisation processes. If the DPP is to unfold its full potential, the influence of private-sector particular interests in the standard-setting process must be corrected, specifically by promoting the inclusion of non-profit actors. As well as being open and democratic, standardisation processes must also offer explicit participation and quotas for representatives of civil society (in particular, environmental NGOs and consumer organisations) and academia (in particular, the environmental, climate and sustainability sciences). Actors from the open data and open source movements should be included, as should representatives of small businesses and independent contractors (who make up a significant part of the repair sector). That kind of active inclusion should apply to future, as well as current standardisation processes. The process of developing minimum standards for digital product passports will be ongoing. Standards will need to be adapted to account for new product developments, while the data infrastructure will have to keep up with technical progress in the IT sector. It must also be expected that new information requirements will emerge as the circular economy progresses. Comprehensive, inclusive stakeholder dialogues will be vital.

5) The German government should strengthen national regulatory agencies to ensure observance of DPP standards and sanction violations.

The extent to which product information can influence patterns of production and consumption depends to a great extent on its reliability and trustworthiness. Regular verification of the veracity of the data in DPPs and adequate penalties are therefore necessary conditions. As the European Commission emphasises in the draft Ecodesign Regulation: 'Stronger enforcement and market surveillance activities (e.g. inspections or audits) are seen as necessary to accompany implementation of this initiative' (European Commission 2022a: 7).

However, the draft makes the member states responsible for oversight and penalties. First, the national customs authorities will be responsible for verifying that all products marketed in the EU possess correct DPPs (Article 13). Second, the member states will be required to periodically verify the content of DPPs, publishing biennial action plans stating the nature of planned market surveillance activities (Article 59), the frequency of controls (Article 60) and the nature and severity of penalties imposed (Article 61). Third, they will have to put the penalties for infringements of the Ecodesign Regulation into national legislation and ensure that the penalties are applied (Article 68).

Consequently, national governments need to strengthen their customs authorities and create additional control instances that are capable of verifying DPPs quickly and efficiently. At the European level, national governments should press for effective implementation in all EU member states.

6) Establish a public register of product passports to ensure easy access for all stakeholders.

Prior experience with transparency requirements shows that purely decentralised provision of product data can significantly restrict availability. In order to ensure that all actors in a circular ecosystem can access relevant product data therefore a central register of all DPPs is needed. The draft Ecodesign Regulation already proposes that the Commission establish **a central product passport registry** in which manufacturers will enter their product information (Article 12). This centrally collected data will include at least the product identifier and a link to the locally stored DPP, but can be expanded by means of delegated acts. **Centralisation of further product information would be recommendable** in order to further reduce the transaction costs for mass analysis, for example in consumer assistance software, and would improve markets' ecological transparency.

Many stakeholders, including companies with circular business models, consumer organisations, users and regulatory agencies, stand to profit from data centralisation. Full open access to data is ideal; complicated rules that restrict access to selected actors should be used as sparingly as possible (for example, where valuable data, such as 3D models, is offered only to paying customers). It must not be forgotten that monetisation of product data always also means artificial shortage, which can lessen the ecological benefits of a data-driven circular economy.

7) Vendors and online marketplaces should display product sustainability indicators.

Vendors and dedicated online marketplaces are crucial for product distribution. They select products and communicate particular information, which users and businesses use to choose between products. This is an important opportunity to secure exposure for ecological information and environmental costs, alongside price and technical specifications, in particular in online marketplaces. Consequently, the European Commission and the German government should consider whether vendors can be required to display relevant sustainability indicators, such as the proportion of recycled materials, resource consumption, circular design, material health and CO_2 emissions.

8) International harmonisation of minimum standards for digital product passports.

Global value chains present special challenges for collecting and sharing product information. Especially in connection with resource extraction and inputs, it must be ensured that all ecological and social costs are transparent and that no relevant information is lost or falsified. This applies in particular to CO_2 emissions (scope 1, 2, 3) and other sustainability indicators, such as water and soil consumption, effects on biodiversity, due diligence obligations, and reporting and documentation of origin of critical raw materials. Given that the European product passport is required only when products are marketed in the European Union, an international harmonisation of digital product passports is needed. Only if the product information used by Europe's trading partners is interoperable with the European product passport will product-related datasets be able to 'grow' along entire value chains.

Another reason to harmonise transparency requirements between the EU and external markets is to avoid businesses that are subject to strong transparency requirements inside the EU experiencing competitive disadvantages when operating outside it. There are grounds for optimism that the European digital product passport – like the REACH Regulation and the GDPR – will lead to the development of global standards because of the size of the EU economy. At the same time, international coordination of transparency requirements must not lead to a lowering of standards. In certain quarters the international discussion is still at the level of 'waste management' and could tend to hold Europe back.

Initiatives such as the Product Circularity Data Sheet already offer promising incentives at the global level. But overall, states have yet to show much engagement or determination. Increasing efforts are therefore urgently needed to expand and standardise circular governance of product data, for example, through the G7, in the International Organization for Standardization (ISO), bilaterally in trade agreements, or through the German Development Cooperation Agency (GIZ).

9) Assistance for SMEs.
In order to reduce the obstacles to collecting and sharing product data, an enabling programme is needed that is specially designed for small and medium-sized enterprises offering various forms of support. These should be organised by state actors in collaboration with research institutes, chambers of industry and commerce, and guilds. The most important component should be the development of open-source software with which businesses can collate complex product data (such as life-cycle assessments) themselves and put it online. Such software could be modelled on Germany's tax software, with users entering their material rather than financial flows. The state should also provide an online cloud service to which digital product passports can be submitted to meet recordkeeping requirements. This would also avoid making SMEs dependent on service providers specialising in preparing product passports. Training and seminars for SMEs are also needed to disseminate the knowledge required to operate the software and in general to handle the (product) data. Collecting, processing and sharing of product data should be integrated directly into initiatives for knowledge transfer in the fields of AI and data competence (for example, AI skill centres for medium-sized firms).

6
CONCLUSIONS

Governance of product data will play a key strategic role in the transformation from a linear to a circular economy with closed material loops and minimised resource consumption. In the five expert discussions, pioneering companies and actors from different sectors underlined the potential of a data-driven circular economy. As well as improving markets' ecological transparency, sharing product information can also promote new circular ecosystems and business models in the spheres of reuse, repair and recycling, as well as 'sharing'. The wider the availability of information about product design, material health, ecological footprint, accessibility, repairability and reusability, the easier it will be to conserve the materials and values contained in products.

That is why we need circular data governance, in the sense of data policy tailored to the circular economy. The European Union's digital product passport project in particular, with its comprehensive transparency requirement for manufacturers, can become the driving force for digitally managed circular ecosystems at all stages of the product life cycle.

Building a circular economy and avoiding rebound effects will require numerous further regulatory measures as it progresses, for example in the areas of material quality, minimum service life, repairability and reuse of materials. The EU's digital product passport also creates important preconditions for such future regulations. In future, much of the information and documentation required for government agencies, auditing organisations and certifiers can be bundled in a single location. This will prevent data duplication and reduce bureaucracy.

In order for this to succeed, political initiative is required to define the framework and systematically develop the potential of shared product data for a circular und sustainable economy. This will require ongoing development work on minimum standards in a balanced process drawing on sustainability expertise and reflecting the interests of all stakeholders. National surveillance agencies need to be strengthened, international harmonisation of transparency requirements advanced and (online) vendors required to display environmental product information prominently.

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Digitalisation is a powerful tool for the transition to a circular economy. That process will demand sophisticated management of material flows throughout product life cycles. Data is key. The study examines examples from different sectors to illuminate the opportunities and obstacles associated with a data-driven circular economy. It identifies transparency and data sharing as central factors for the success of new circular ecosystems and business models. The European Digital Product Passport (DPP) is the key to implementation.

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