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Towards a Digital Product Passport Fit for Contributing to a Circular Economy

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Abstract: The Digital Product Passport (DPP) is a concept of a policy instrument particularly pushed by policy circles to contribute to a circular economy. The preliminary design of the DPP is supposed to have product-related information compiled mainly by manufactures and, thus, to provide the basis for more circular products. Given the lack of scientific debate on the DPP, this study seeks to work out design options of the DPP and how these options might benefit stakeholders in a product's value chain. In so doing, we introduce the concept of the DPP and, then, describe the existing regime of regulated and voluntary product information tools focusing on the role of stakeholders. These initial results are reflected in an actor-centered analysis on potential advantages gained through the DPP. Data is generated through desk research and a stakeholder workshop. In particular, by having explored the role the DPP for different actors, we find substantial demand for further research on a variety of issues, for instance, on how to reduce red tape and increase incentives for manufacturers to deliver certain information and on how or through what data collection tool (e.g., database) relevant data can be compiled and how such data is provided to which stakeholder group. We call upon other researchers to close the research gaps explored in this paper also to provide better policy direction on the DPP.

Keywords: resource efficiency; product policy; energy efficiency; digitalization; life cycle assessment; easy-to-repair design

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1. Introduction

At the international level, with the Agenda 2030 [1] the global community has defined 17 Sustainable Development Goals (SDGs) for socially, economically and ecologically sustainable development [2]. Sustainable development in general and the SDGs in particular require suitable indicators and corresponding data in order to initiate necessary policy action and to measure progress.

On the level of the European Union (EU) and with regard to product policy, the provision of data and the organization of a comprehensive information flow is promoted, among other things, by the "European Green Deal" [3] and the "Circular Economy Action Plan" [4] of the EU. Another impetus that makes the topic of product policy and data collection/provision even more relevant is the topic of digitalization, which has been heavily discussed for years (cf. [5]). In this context, a concept that is gaining attention in the political agenda is the development of a Digital Product Passport (DPP), which is not only topic in the two already mentioned EU strategies but also confirmed in the "Council conclusions on Making the Recovery Circular and Green" drafted under the German EU Council Presidency [6]. For providing input to the German Council Presidency of the second half of 2020, the authors of this article developed a scoping paper on the DPP, which this article is based on [7]. From the anchoring in high-level policy strategies, one can derive the high expectations on the DPP as an essential new tool for enabling a holistic and comprehensive recording of sustainability aspects in the future. Among other things, the DPP is intended to provide consistent "track and trace" information on the origin, composition, repair and dismantling options of a product, as well as on its handling at the end of its service life. The aim of the DPP is not only to promote a circular economy and thus support a low-carbon transition but also to overcome existing obstacles like the lack of information. The DPP has the potential to provide different actors (such as consumers and waste management companies) with relevant information on a product and thus force decisions towards sustainable development (for consumers during the purchase and use phase, for waste management companies during disassembling and recycling). For this undertaking, e.g., Gligoric et al. have been developing smart tags based on printed sensors to product or object identification on a per item-level [8], while Donetskaya and Gatchin in their conference paper come up with some requirements for the content of a DPP [9]. Depending on its exact design, it may help companies along the value chain to develop sustainable business models. For instance, Longo et al. argue to manufacture batteries and vehicles "with fewer, renewable, recyclable/recycled, and non-hazardous materials and characterized by lower energy and environmental impacts during their life cycle" [10] and Wielgosiński et al. call for a reduction of waste streams by having raw materials circulated in the domestic market [11]. To make businesses deliver to these objectives, the obligation to generate high quality product information can be a valuable contribution in a policy mix for an effective circular approach [12].

At the European level, the DPP is most prominently discussed in the context of the Sustainable Products Initiative (SPI) [13] in combination with the expansion of the EU Ecodesign Directive beyond energy-related products to include as wide a range of products as possible in order to define appropriate minimum sustainability and information requirements for specific product groups. Following this, DPP and SPI are also closely related to other recent EU initiatives such as in particular "Consumer policy-strengthening the role of consumers in the green transition" [14]. The central objective of the latter is to revise EU policy within the framework of the "European Consumer Agenda" [15], to enable consumers to play a more active role in the timely transition to a more sustainable economy ("green transition") by providing reliable and useful product information. Among other things, minimum requirements for sustainability logos and quality labels as well as reliable environmental information, e.g., on service life and repair options, are to prevent claims from being glossed over in the sense of "greenwashing" (i.e., giving a false impression of the actual environmental impact) or products being sold with a shortened service life. In addition, as part of the EU initiative "Environmental performance of products & businesses-substantiating claims" [16], companies will in the future be increasingly required to substantiate information on the environmental footprint of products or services using standardized quantification methods. The aim here is also to make environmental claims more reliable, comparable and verifiable throughout the EU and thus to reduce "greenwashing" and strengthen trust in environmentally relevant information. While DPP's overall contribution to facilitating circularity appears to be relatively clear and policy is currently moving the topic more into the spotlight, a widely applicable and holistic DPP-approach has not yet been established in practice. Accordingly, there are no finalized concepts at the political level as to how a DPP affects different stakeholders. However, there are some approaches and ideas on how the DPP could be implemented.

For instance, at the level of the EU's Member States, the German Government has picked up EU discussions on the DPP. According to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) [17], the digital product passport is defined as a data set that summarizes the components, materials and chemical substances or also information on repairability, spare parts or proper disposal for a product. The data originate from all phases of the product life cycle and are to be used for the optimization of design, production, use and disposal. The structuring of environmentally relevant data in a standardized, comparable format should enable all actors in the value and supply chain to work together towards a circular economy in a goal-oriented manner. At the same time, the digital product passport is intended as an important basis for more reliable consumer information and sustainable consumption decisions in both stationary and online retailing. According to the BMU, the DPP should in principle be applicable to all products and services as well as foodstuffs, with an initial focus on particularly resource- and energy-intensive goods [18]. These would include, for example, information and communications technology (ICT) products or products from other sectors with high energy and material consumption. Another study conducted by the European Policy Centre on behalf of the BMU that sketches possible ways of designing and implementing a DPP was published in late 2020. The aim of the study was to find "better coordination and exchange of information in value chains [to] enhance transparency while creating the basis for smart circular applications". The study suggests that the EU should start developing general guidelines for "tracking and mapping [. . .] products, materials and substances across value chains". A DPP should build on existing databases and information requirements and take into account the experience that companies have already gained in collecting information. The authors of the study propose the Commission to focus on textiles, electronics, construction, packaging, batteries and electric vehicles [5].

Due to the uncertain development of a DPP in the future and the lack of scientific debate on the DPP, this study seeks to work out design options of the DPP and important questions to be answered in the not-too-distant future regarding the implementation of the DPP. In so doing, we first show our step-wise approach (Section 2) and, then, describe the existing regime of regulated and voluntary product information tools focusing on the role of stakeholders (Sections 3.1 and 3.2). Intermediate results presented in Section 3.3 are examined in an actor-centered analysis on potential advantages gained through the DPP factoring in the most relevant stakeholder groups in a product's value chain. Lastly, in Section 4, we discuss our results with respect to the design of the DPP, and we focus on open questions, which need to be addressed in the not-too-distant future.

2. Materials and Methods

This study seeks to identify relevant points of discussion as regards the implementation of the DPP in order to maximize the socio-economic benefits across stakeholder groups. In so doing, we carried out a two-step approach, as shown in Figure 1.

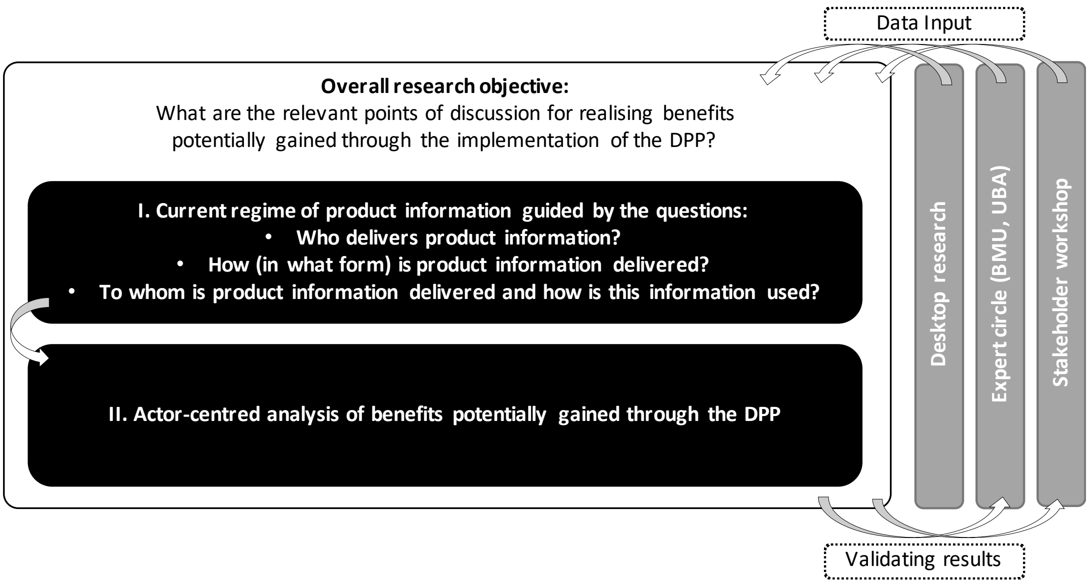

Figure 1. Research design.

First, we looked at the current regime of product information and factored in the following questions:

- Who delivers product information?

- How (in what form) is product information delivered?
- To whom is product information delivered and how is this information used?

By systematically reviewing relevant literature, we screened regulated and voluntary initiatives, which are implemented or developed from a variety of sectors in order to gain a rich overview of relevant factors to be taken into account when implementing the DPP as envisioned in the introduction of this article for the sake of providing more circular information. These findings on central characteristics of state-of-the-art information tools are then reflected in part two of the analysis: the actor-centered analysis. This part of the study will stimulate the discussion on the design of the DPP regarding the most relevant stakeholder types in a product's value chain: manufacturers, market surveillance, retailers, investors, repair shops, waste management companies.

Experts from the BMU and German Federal Environment Agency (UBA) were part of the project's expert circle and validated our findings periodically. In order to gain hands-on perspectives on the DPP, we also carried out a national expert stakeholder workshop in late 2020 as part of the project, this article is based on. More than 20 experts participated in the workshop, and the participants were selected in a way to cover a broad range of areas. This included experts from the BMU, the UBA and from the fields of standardization, digitalization, waste management, engineering and equipment manufacturing as well as academia. For the workshop, first project results were presented and discussed.

3. Results

Today, there are already a number of legal or voluntary information requirements in the area of product policy that determine information and information flows from point A to point B. At the EU level, information requirements exist for all phases of the product lifecycle, such as production, use, repair and disposal, but these requirements are mostly defined in a product-specific way. Results of the project, this article is based on Supplementary Materials.

3.1. Regulated Product Information

An illustrative example for current information flow regimes is the EU's energy labeling framework regulation, which defines a mandatory label and information obligations for selected product groups at the time of "placing on the market" (first time a product is made available on the EU market). With the status of March 2021, 15 product groups require an energy label [19]. Accordingly, product group or model-specific information must be published both on a label and on product data sheets. In the respective product group-specific implementation measures, the contents and information are further specified. For example, the label for refrigerators must include the manufacturer's name, the efficiency class, the electricity consumption per year, the volume of the refrigerator/freezer compartment and the maximum noise level for the corresponding model. The product data sheet, which must also be provided by the supplier, contains further information in addition to the information on the label, such as the exact design or duration of the manufacturer's guarantee. In addition, the Directive obliges suppliers to enter the information in the product data sheet and other data ("technical documentation") into an official digital EU database (EU Product Registration database for Energy Labelling, EPREL) via a special input page. This consists of both, a public part (for end users, among others) and a non-public part, which are only accessible to the European Commission and market surveillance authorities [20]. Apart from market surveillance, investors are a key target group of product information compiled by manufacturers. In particular, the Energy Label helps investors (including the public purse) to make conscious purchasing decisions [21], and the Label's recent revision of the scaling system is supposed to deliver higher efficiency gains through a more comprehensible labeling scheme. Retailers may also use the product information in sales talks, particularly those accompanied by the Energy Label. It should also be acknowledged that retailers do not enter or provide any new information, but they are responsible for ensuring that labels are placed on the respective products. To a very limited extent, repair companies and waste management companies can also benefit from the (limited) information by being able to verify certain aspects of the product.

Registration with the EPREL data is already mandatory as of February 2021 for the following product groups: air conditioners, household cooking appliances, household dishwashers, space heaters and water heaters, light bulbs, individual space heaters, household refrigeration appliances, commercial refrigeration appliances, solid fuel boilers, televisions, tumble dryers, residential ventilation appliances, and household washing machines [20]. In addition, since March 2021, consumers can also use the product database for the relevant public information on energy labels and product data sheets through a QR code that is printed on the label of some first product groups. Figure 2 below schematically illustrates the general structure of the EPREL product database.

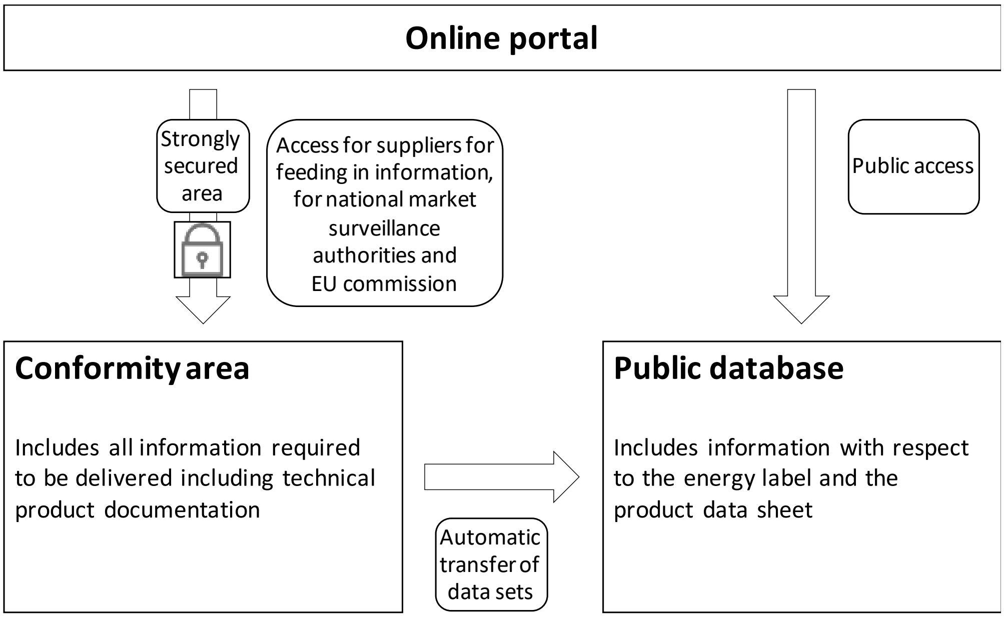

Figure 2. Schematic figure of the EPREL database (based on BMWi 2019 [22]).

The accessibility of the database for (potential) investors via an easy-to-use QR code is important to deliver information immediately at the point of sale, where a conventional website with cumbersome data entry would be of less help to investors.

In addition to the framework regulation on energy labeling, other EU regulations also contain subject-specific information and reporting obligations that differ more or less significantly depending on product and target group. For example, the EU Ecodesign Directive 2009/125/EC for energy-related products and appliances and its product group-specific implementing measures include, as does the closely linked EU framework regulation on energy labeling, information obligations at the time of "placing on the market". While aspects of circular economy and on repair options are increasingly included in the Ecodesign Directive, a central database has not been used for this purpose yet and a systematic data flow has not been prescribed. The information only has to be publicly available on a website of the manufacturer, importer or authorized representative. Another example for information requirements is the REACH Regulation EC 1907/2006 (REACH stands for Registration, Evaluation, Authorisation and Restriction of Chemicals). It includes safety data sheets for chemicals and further information on substances and mixtures and in particular on hazardous ingredients. Chemicals manufactured in the EU or imported into the internal market must be registered. The safety data sheets are primarily intended for persons who are in direct contact with the substances. This information must be provided either in electronic form or printed on paper and is intended to help protect health and the environment. In addition, the SCIP database ("database for information on Substances of Concern In articles as such or in complex objects (Products)") will be set up for SVHC ("substances of very high concern") in 2021 [23]. Suppliers will be required to provide their information to the European Chemicals Agency (ECHA). The aim of the database established is to provide operators of waste treatment plants with information on SVHCs in order to be able to separate them if necessary and to ensure high-quality recycling. Also focusing on chemicals, the Regulation EC/1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures based on the United Nations Globally Harmonized System (GHS) has defined obligations for labeling [24]. Moreover, for this purpose, the European Chemicals Agency (ECHA) maintains a database on the classification and labeling of notified and registered substances. The Waste of Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU is another example for information requirements. The Directive established obligations for electrical and electronic equipment, in particular with regard to the provision of information for recycling companies and operators of treatment facilities. This can be done by means of printed manuals or in electronic form. In addition, EU member states are required to establish a WEEE producer register. The EU Packaging and Packaging Waste Directive EU/2018/852 stipulates that clearly legible markings on materials in the packaging must be attached to the product; the Fertilizer Regulation EU/2019/1009 requires manufacturers to publish information on various product properties (storage conditions, volume, ingredients, etc.) on the product or in an accompanying document. The End-of-Life Vehicles Directive 2000/53/EC specifically regulates the publication of information on the dismantling, storage and testing of reused parts in end-of-life vehicles. In the international dismantling information system IDIS ("International Dismantling Information System"), vehicle manufacturers can deposit data to support disposal companies in the environmentally friendly treatment of end-of-life vehicles [25]. Another data collection system for vehicle manufacturers is the IMDS (International Material Data System), in which all materials used in the manufacture of a vehicle are collected [26]. In this context, the use of the IMDS should make it possible to fulfill the obligations imposed on the automotive industry by national and international standards, laws and regulations [27]. In addition to the examples presented, there are also various other approaches to data collection and presentation, such as the EU-wide standardized food labeling.

3.2. Voluntary Product Information Initiatives

In addition to the regulatory requirements, there are also numerous ideas and concepts on how (parts of) a digital product passport can be implemented. Some of these are already being implemented. One example is the concept of Material Passports. In more recent discussions, MPs have been developed with special focus on the building sector. Even though this concept is not necessarily restricted to construction materials only [28], buildings appear to be the central area of application so far. As part of the EU-funded research project focusing on reversing building design, partners develop an electronic Material Passport Platform as a one-stop-shop for material information provided by manufacturers and suppliers [29]. It is considered as record or documentation of properties of materials in order to facilitate recycling and reuse [30]. Hence, Material Passports increase transparency on the circularity characteristics of building materials and information includes, amongst others, data from technical data sheets or environmental product declarations (EPD). As soon as the a building is decommissioned, information can be made available to contracted deconstruction firms [31].

Technical documentation can be regulated, as for those product groups addressed under the Energy Labelling Directive. EPDs are generally voluntary and based on a life cycle assessment providing extensive quantitative and (third-party) verified information on environmental impacts without evaluating or judging them [32]. In Germany, EPDs have so far been used in practice also in particular for the comprehensive description of the environmental performance of building products. The environmental impacts of production, use and disposal are characterized according to internationally recognized conventions, resulting in key figures such as greenhouse potential in CO_2 equivalents, water consumption, waste production, ozone depletion potential or acidification potential [33]. In this way, EPDs should, for example, specifically facilitate the selection of materials in construction and form a basis for the documentation of the building materials used in the building (e.g., by means of a building passport) [34]. As regards the Material Passport Platform, the cross-referencing to other information tools shows that developers do not want to design new tools from scratch, but they also seek to build on existing information tools and embed this information for their purposes. Due to increased transparency, architects or builders can make use of materials with more circular characteristics.

Building information modeling (BIM) is seen as a vehicle to compile more comprehensive information on the entire building level (in contrast to the material level). BIM is a tool for networked planning, execution and management of buildings and may function also as an inventory database on the building level (in contrast to the component level). According to Honic et al. "the main results obtained from the BIM-supported MP is the total material composition of the building [...], which contrasts the share of recyclable materials with the share of waste created by the building" [35]. A challenge for MPs might be the feeding of material information continuously. For instance [36], state that steel used in buildings can, in general, be re-used without substantial testing in laboratories. However, if steel is exposed to fire, its characteristics may change, which is why the usage history of building materials can become important [36]. Such expositions but also major refurbishments, which could alter materials in buildings, would and could—ideally—be updated [31].

In addition to the MP, other concepts exist such as the cradle-to-cradle passport (C2C-passport). For example, the Danish shipping company Maersk already makes use of a C2C-passport for part of its own fleet of ships. The C-2-C-concept is based on a proprietary approach developed by McDonough Braungart Design Chemistry (MBDC). In 2010, MBDC transferred the certification program to the non-profit Cradle to Cradle Products Innovation Institute (C2CPII), which has since acted as a third-party certification body. The objective is to recycle materials used at the end of a product's life. Maersk's passport shows, for example, which materials are used in which location of a ship and provides, for instance, information about quality differences in the steel used. For Maersk, some of the key tasks were to develop a database for material information and to encourage suppliers to make complex material information (including its composition) available and feed it into the database. Materials should then be able to be located directly in a 3D model of the ship, which is why the passport already plays an important role in the development phase [37]. For ship owners or operators, this increases transparency and allows to identify potentials for reusing existing (and already purchased) materials. In the end, this may decrease material inputs and potentially overall costs for new ships, even though costs for training staff and deconstructing ships as well as testing steel characteristics will have to be added. As regards the C2C-passport, there is a direct (financial) interest in designing ships in a transparent way, which might be a different case for actors in the construction sector.

The comprehensive digitization of industrial production is known under the terminology of *Industrie 4.0*. In this context, the concept of the "asset administration shell" (AAS) was developed to systematically record and retrieve data on manufacturing equipment [38]. The AAS represents a digital image of the real production object, which is often also referred to as a "digital twin". The AAS, thus, opens up the conceptual link between the real and digital worlds. So far, this has been used primarily in progressive industrial companies and above all to optimize internal industrial production processes and procedures. Reference Architecture Model 4.0 (RAMI 4.0) is the (underlying) conceptual basis for data collection, which is based in principle on the Smart Grid Architecture Model (SGAM) established in the energy sector. In principle, the more relevant data is stored in the AAS, the more precise the mapping of the digital twin. Data (if available) can be mapped over the complete product life cycle, from development to the end of the product's life. Industry-internal information and communication technologies and IoT-technologies (Internet of Things) systems can thereby continuously capture and store data in real time so that the AAS can correspond with the real object as best as possible at any time. Data sets can, for example, consist of pre-configurations of production machines, material properties of intermediate products [39], limit values for use (e.g., maximum speed, highest possible operating temperature) or manuals, CAD drawings, key production figures (for example, target and actual values) or maintenance information [40,41]. However, the concepts of RAMI 4.0 and the AAS have so far been geared primarily toward use within highly networked *Industrie 4.0* areas. The AAS has therefore so far been used primarily in the production of complex production objects to create a network between appropriately equipped suppliers, integrators, machine manufacturers and other industrial users (cf. [38]). In theory, suppliers, integrators and manufacturers may benefit from increased information flows from the usage phase in order to improve product performance and for carrying out predictive maintenance.

3.3. Key Takeaways from Regulated and Voluntary Product Information Initiatives

All in all, a relatively clear picture emerges from the status quo analysis and from the different concepts and initiatives:

- Manufacturers and suppliers are, generally, the main actors to provide the specific product information. As regards other actors and, especially, retailers, they only forward relevant information but do not create new product data, which, in the end, means that the data flow in unidirectional.
- An exception of this is discussed for the Asset Administration Shell and also for the Material Passport, both of which, at least, discuss a more multidirectional information flow. In particular, the AAS is a good example that factors in current trends in digitalization (or IoT). Still, based on these findings, it can be assumed that acquiring product information *during* the use phase of a product is challenging in particular.
- Relevant information is supplied in a variety of forms including technical and safety data sheets (hard copies), labels and on the internet through websites or data portals.
- Online databases may contain confidential and non-confidential information, which can be accessible to selected user groups in a product value chain including manufacturers, market surveillance, retailers, investors, repair shops and waste management companies.
- Product information can be relevant to different user groups, but with different levels of detail, while market surveillance authorities need to have a clear overall picture with relatively detailed information, investors need simpler (and less detailed) information for their purchasing decisions.
- The development of business models (in delivering better product data regarding product circularity) is key to create acceptance, especially for manufacturers; should a manufacturer see a business case in product information (such as in the Maersk example), data compilation might be accompanied by an intrinsic motivation of the manufacturer.

These intermediate findings need to be taken into account as regards the potential benefits for each stakeholder group discussed in the next Section. As a summary, an overview of the different approaches compared to the currently discussed design of the DPP is illustrated in Table 1.

Table 1. Comparison of information tools.

	Digital Product Passport	Energy Label	Material Passport	C2C-Passport	AAS
Status	Pre-conceptual phase	Implemented	Demonstration	Implemented	Demonstration
Product Category	In theory, for all products discussed	Energy-related products	Building materials	e.g., Ships	Manufacturing equipment for *Industrie 4.0*

Table 1. *Cont.*

	Digital Product Passport	Energy Label	Material Passport	C2C-Passport	AAS
Key Information Categories	Origin, composition, repair and dismantling, handling at the end of its service life	Energy consumption, technical aspects	Information on reuse of materials; cross-ref. to data sheets, EPDs	Location of material use, material characteristics	Various
Life-Cycle Phase Targeted	Production, repair, disposal to complete life-cycle	Use phase	End-of-life	Production, repair, disposal	Complete life-cycle
Data Tool	unknown	EPREL	Materials Passport Platform, BIM discussed	Database for material information, 3D modelling	RAMI 4.0/AAS
Information Providers	Suppliers, manufacturers	Manufacturers	Manufacturers	Suppliers, manufacturer	Suppliers, manufacturers, (industrial) users
Target Groups	Market surveillance, consumers, repair shops, waste operators	Market surveillance, consumers	Architects, builders, deconstruction companies	For example, ship operator/owner	Suppliers, manufacturers, (industrial) users

3.4. Preliminary Actor-Centred Analysis of Potential Benefits Delivered by the DPP

Moreover, for the Digital Product Passport, manufacturers will likely remain the central suppliers of product information. Hence, additional (transaction) costs incurred due to further information demands (potentially also to be requested from suppliers) need to be kept at a minimum, even though it should be acknowledged that learning effects reduce the administrative costs in the longer run (cf. [42]), and trends in digitization (IoT, blockchain, machine learning) ease information gathering. Synergies should be seen with recent legislative developments, e.g., in Germany on the country's Supply Chain Act and similar initiatives on the EU level [43]. The DPP may help to provide a more consistent and untangled overall framework for manufacturers to deliver product information, but this would require a comprehensive integration of existing regulation and could be regarded as a challenging undertaking given that several of the above-mentioned regulations are administered by different Directorate Generals of the Commission. Still, gradually, the DPP may help to switch from mixed physical and digital information to a digital-only information supply including technical and safety data sheets. However, for this, it would also need to be ensured that target groups have the equipment necessary to really gain information access. In order to increase the motivation of manufacturers to deliver more circular information, attractive circular business models would need to be incentivized as well. This can also include that IoT-equipped products deliver information for manufacturers enabling them to expand their business model (e.g., predictive maintenance) as envisaged for the AAS. The Energy Label is also a success as it offers sustainable manufacturers to showcase their products' advantages in terms of sustainability and circularity and EPREL has high security standards which exacerbate data theft. Given that the DPP is supposed to be available for a variety of products, information requirements would need to be analyzed in a sector- or product-specific way (e.g., through a feasibility study) and manufacturers need to perceive a DPP infrastructure as a reliable and trustworthy system.

Market surveillance authorities can use product information to monitor whether manufacturers meet product standards in practice, also to protect manufacturers complying with standards against unfair competition. For such authorities, a central system, in which all information is organized, might be extremely helpful. In this respect, the EPREL database can be considered a good example as it is designed to contain selected regulated information. In our stakeholder workshop, experts argued that the digital product passport should also be seen as a part of a substance inventory, which takes stock of goods that are a" valuable secondary raw materials reservoir" and a "capital stock of the future" [44].

Retailers can use the improved information provided by a product passport to make their product range more customer-oriented and sustainable and to provide a corresponding range of information at the point of sale. Here, too, it plays a major role, which data retailers receive and to what extent this can be used in customer advice. In addition to retailers, contributors to the common good economy (second hand stores, etc.) should also be considered, as they can offer remanufactured products that are generally still usable. For them, the DPP may help if information from repair shops can be fed into the product documentation. Moreover, information on how a product has been used would also be largely beneficial as it would increase the trust of buyer in second-hand products. However, the question is what type of information can overcome barriers to purchasing second-hand products and how can the information be fed into the DPP. Amongst other, this may require the continuous multidirectional feeding of product-specific (in contrast to model-specific) information resembling the architecture of the AAS (which is largely envisioned for *Industrie 4.0*).

The key potential benefit of the DPP for product users is transparency, and private and institutional customers can make more conscious purchasing decisions. By differentiating between end-users, the role of green or sustainable public procurement should also be acknowledged as the public purse has a huge potential to transform products markets due to its buying power [45]. Products may reveal high social and ecological costs associated with production and customers are given the opportunity to buy products with a low socio-environmental footprint. Further valuable product information for customers may include the repairability and the end-of-life handling. However, it remains to be seen how information or data will be processed and made available to lay people. In order for customers to make sustainable purchasing decisions, information needs to be accessed with least possible effort. For instance, as regards the EU's Energy Label, the well-known scaling system (green to red arrows) visible to customers helps to easily differentiate between efficient and inefficient energy-related products, while disclosing only (standardized) energy consumption data (e.g., in kWh/a) would not be considered helpful by most users. An existing system for simple product identification for retail products, for example, is based on the "Global Trade Item Number" (GTIN), i.e., an identification number that can be used to uniquely identify many types of trade units. It must be mentioned here that this system has not yet been used for product-specific recording but rather for identification at the product group or model level. In any case, it is absolutely essential for a digital product passport that a product group, the model or, in perspective, even each individual product is clearly and easily identifiable. As with the EPREL database, for example, data could then be accessed directly via the individual item, e.g., via bar/QR codes or RFID tags on the product or product label (RFID stands for Radio Frequency Identification; small/tiny chips allow for wireless transfer of data). It would also make sense for consumers to be able to understand the information provided, including the language and meaning of the information, by making product features available via apps, websites or augmented reality, for example.

In contrast to product users, repair shops are dependent on precisely disaggregated information about repairs and spare parts, while information on socio-ecological effects associated with production is hardly a concern for them. Repair information is already required for some products (e.g., cars), and an extension could result in a rise of repair shops for many other products. An essential step will be that EU and national regulations require products to be manufactured in a way that factors in circularity and the right-to-repair. If in parallel, consumers are aware about the repairability of their products, this may strengthen the business model of repair shops.

In addition, companies from the waste management sector may also be interested in highly disaggregated data, which usually plays a minor role for consumers, for example. In particular, materials (and combinations) included in products, dismantling information and end-of-life handling will be of relevance. Through such information, dismantling costs can be reduced, and by selling recycled materials at higher qualities, revenues can be increased. If repair companies exchange certain components in a product, compositions of new materials used may also be relevant for waste companies.

4. Discussion

The Digital Product Passport seeks to facilitate a circular economy and a low carbon transition acknowledged by the EU [4] and the German BMU [17]. It is supposed to deliver information on the origin, composition, repair and dismantling options of a product, as well as on its handling at the end of its service life [3]. However, there are several open questions regarding the DPP's final design and its implementation. For instance, a long-time grown regime of diverse information requirements already exists, in which the DPP needs to be fitted into.

Having looked at certain parts of this existing landscape form a bird's eye perspective, we found that manufacturers are the most important source of product information. This means that any future DPP information requirements should be ideally designed in a way that manufacturers and other stakeholders perceive them as an advantage and not as an additional burden, in order to create business models and intrinsic motivation. If additional information obligations are imposed, they should create as much as possible synergies with other compliance regulation (cf. [43]). Therefore, the initial DPP approach should build-up on existing systems of regulations [5] also acknowledging technology trends as well as learning effects for information supply [42].

For instance, under the Waste Framework Directive, companies supplying products containing SVHC (above certain concentrations) already must supply selected information on these articles to a database made available to waste operators and consumers [23]. Under the Energy Labelling Directive, manufacturers of refrigerators have to supply a variety of information (e.g., efficiency class, electricity consumption per year, the maximum noise level for the corresponding model). However, this information mostly focuses on the use phase of a product and have to be fed into the EPREL database. In contrast to that, the Waste of Electrical and Electronic Equipment goes beyond the Energy Labelling Directive's product scope and mandates manufacturers to deliver information on equipment disposal and handling at the end of its life, while the End-of-Life Vehicles Directives focuses on similar information types (e.g., dismantling information) but for a particular product group. For the DPP, a key question will be how to organize an optimized and synergetic data flow with the existing framework of regulatory efforts for manufacturers, which really are the core stakeholder group, at the moment. In contrast to the regulated information flows, there are also voluntary initiatives on the market or in development. In our study, we selected some information tools, which seek to contribute to a circular economy. They also differ from each other. Similar to EPREL or SVHC, they make use of a digital system to compile, feed in and retrieve data or information.

It might be helpful to investigate further on the existing information tools in order to find out what information are technically feasible to be supplied for a DPP. An option to reduce the administrative burden of manufacturers can be to, initially, develop an approach that integrates existing information requirements in a smart way, where a single point of information brings together all existing information with high security standards and provides them according to different access rights to specific stakeholder groups (cf. [7]).

Thus, this single point of information will be fed by manufacturers with minimal transaction costs for changing information supply. In other words, the information requirements (mandated in various regulations and directives) remain the same, so there is not additional effort to compile new information for manufactures, only the point to enter the relevant information might differ.

As regards the basic technical infrastructure necessary to implement the DPP, the experiences from the EPREL database as well as the Asset Administration Shell deserve some more attention. One of the basic key features of EPREL is that confidential information and non-confidential information can be fed into the database, which is relevant if information may be mandatory from the perspective of a market surveillance agency but not for other stakeholders; some information might also have to be shielded from competitors (e.g., extraction/production location of certain inputs for consumer goods). The AAS, considered largely for advancing *Industrie 4.0* and addressing respective equipment, could even provide a basis for multidirectional data exchange regarding single products. This would be interesting e.g., for the information exchange between repair shops and waste operators, especially if the concept of the AAS could be transferred and adjusted for non-industrial purposes. For instance, if particular spare parts are used differing from the original product set up, waste operators could require adjusted product information for recycling purposes. Other opportunities for the multidirectional information flow might also exist and, thus, information feedbacks between different stakeholders should be explored factoring in, e.g., advances in the field of digitization, in general, and IoT, in particular.

All in all, how to generate data during the use phase will remain extraordinarily challenging. It would give not only investors the opportunity to exchange components in advance before more serious damage occur, but is also offers equipment providers to extent business models for instance through predictive maintenance and receiving data in order to improve technology. At present, in most traditional sectors where a manufacturer "just sells" a product to an investor, there is hardly any business case for the manufacturer further down in their product's value chain. So conventional and linear business models still dominate in most sectors. However, the example of the company Maersk suggests that the company hopes to identify corporate sustainability information and new revenue streams or reduce costs at the same time through being better able to identify certain products in ships built. Likewise, the Material Passport factoring in Building Information Modelling may help to break the existing paradigm in construction works helping to generate information during the use phase.

Apart from questions around the existing (regulatory and also voluntary) information landscape and the technical infrastructure, an essential aspect is to focus also on the question how to increase general attractiveness of the DPP to users/investors. For instance, the Energy Label also enjoys broad stakeholder support as it offers manufacturers to illustrate the uniqueness and benefits of their certain product's characteristics to investors (apart from energy efficiency, also noise pollution). However, how can the DPP create similar transparency as regards the circularity of products in order to contribute to the objectives of the European Consumer Agenda [15]? In other words: How will customers know and easily understand which refrigerator belongs to the most "circular" or sustainable ones? Product information only available to stakeholders further down the value chain (repair shops, waste operators) is important for a circular economy but not necessarily to persuade investors to invest in a certain product. Hence, in order to make sustainable choices, consumers need transparent, simple information. If the DPP seeks to raise the awareness of a product's circularity characteristics, the EU needs to find out how this can be achieved (again, without increasing the administrative burden, in parallel).

With the discussion on a digital product passport gaining momentum, there is currently an ideal window of opportunity to bundle ideas at the European level and derive initial options for action as well as further research approaches [3,4]. Scientific feasibility studies should be carried out as soon as possible on how to implement a digital product passport [5]. The German Environmental Agency began to initiate such a study on textiles and energy-related products, but further research will also have to scrutinize EU-wide conditions in various pilot projects. An analysis of the data needs of various stakeholder groups is essential but also whether these wishes can be realistically met and how taking into account different manufacturers. Since the concept of a digital product passport is still relatively new, there are currently several aspects to be clarified promptly by additional research activities for rapid and concrete implementation. These include, for example, the more precise selection of product groups to be prioritized and thus the question of which products are particularly suitable for the fastest possible introduction of a product passport system. The assessment of various experts and interest groups also still differs greatly in some cases on the question which criteria and precise data requirements should be addressed by a digital product passport. Therefore, a detailed stakeholder analysis including a differentiation, at least, regarding certain subtypes (e.g., SME vs. large companies) should be conducted and is also necessary at the beginning of further research activities in order to determine the respective information needs and acceptance factors more precisely.

In order to involve the relevant stakeholders in this process and promote acceptance, an early exchange within the framework of a scientifically accompanied consultation process is therefore recommended so that opportunities, interests, obstacles and challenges can be identified through active participation. Stating the obvious, the DPP will not be a silver bullet for achieving a circular economy alone, but its realization might make particular sense to form a key instrument in a well-orchestrated policy mix [12].

5. Conclusions

In order to identify the relevant points of discussion regarding the implementation of the Digital Product Passport, we first screened the current landscape of existing information tools. From the tools scrutinized we were able to draw some key lessons:

- Manufacturers and suppliers are, generally, the main actors to provide the specific product information;
- The Asset Administration Shell and the Material Passport are interesting use cases and examples for the management of multidirectional information flows;
- Relevant and comprehensive product information is supplied already today but in a variety of formats;
- Online databases with dedicated access control may contain and handle confidential and non-confidential information;
- Product information can be relevant to different user groups but with different levels of detail;
- The development of business models (in delivering better product data regarding product circularity) is key to create acceptance, especially for manufacturers.

In a second step, these lessons were fed into our actor-centered analysis helping to carve out achievable benefits by the DPP, which depend on the overall implementation design of the instrument. In the previous chapter, we discussed that the DPP may be integrated into existing systems of information regulations but that it will be relevant to organize synergetic data flows with the existing framework. In so doing, a single point of information could bring together all existing information with high security standards and provide them according to different access rights to specific stakeholder groups. This single point of information could be fed by manufacturers with minimal transaction costs for changing information supply. Apart from that, the multidirectional information flow is highly interesting as this, e.g., would enable the information exchange between repair shops and waste operators. However, the collection of data during the use phase will remain extraordinarily challenging, though probably more relevant and feasible for some products (e.g., high value products with longer product lifetime) compared to others. Besides, the role of investors must be factored in, and the DPP should ideally help investors to better understand which products belong to the most sustainable ones in their respective product group. However, as described, all those potential design options still need further scientific investigation concerning their suitability for real-life use.

Considering all gained perspectives and results, the DPP is a very promising policy instrument that is correspondingly linked with high expectations by many stakeholders. However, being at an early stage of the discussion, several open issues need to be addressed before a Digital Product Passport can be implemented on a large scale. With this paper, we hope to initiate a broader scientific discussion and that further research take on these challenging questions to provide orientation for the DPP's design. If implemented carefully in a sense that visibly increases the benefits for different actor types and ideally also reduces costs or efforts, there is a strong potential to drive sustainable product policy in a more circular direction. Closing the material loop in the sense of a more holistic ecodesign can mean that the EU's demand for new raw materials can be reduced while increasing independence of the EU from less trustworthy suppliers at the same time (also increasing leverage in other policy fields). Information on better product usage and repair may result in innovative new circular business models in the EU extending the lifetime of products and creating also new efficiency and job opportunities. Within the EU market, the DPP in combination with complementary regulation may help innovative manufactures to stand out from competitors that hardly care about circularity. At the same time, given the EU market's strong international role in and influence on manufacturing worldwide, the DPP (in combination with other instruments, such as ecodesign) may also function as a further starting signal to transform production systems globally towards more sustainability. In this context, the DPP could be seen also as part of a complex puzzle to lower the divide between more industrialized and less industrialized countries in the sense of the SDGs.

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Abbreviations

AAS	Asset Administration Shell
BIM	Building Information Modeling
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
C2C	Cradle to Cradle
CLP	Regulation on Classification, Labelling and Packaging
DPP	Digital Product Passport

ECHA	European Chemicals Agency
EPD	Environmental Product Declaration
EPREL	EU Product Registration database for Energy Labelling
GLS	Globally Harmonized System
GTIN	Global Trade Item Number
ICT	information and communication technology
IDIS	International Dismantling Information System
IMDS	International Material Data System
IoT	Internet of Things
RAMI	Reference Architecture Model
REACH	Regulation concerning Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio Frequency Identification
SCIP	Substances of Concern In articles as such or in complex objects (Products)
SDG	Sustainable Development Goals
SGAM	Smart Grid Architecture Model
SPI	Sustainable Product Initiative
SVHC	Substances of very high concern
WEEE	Waste of Electrical and Electronic Equipment Directive

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