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The Digital Product Passport: Scenario-based Recommendations for the Manufacturing Industry

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Abstract:

The impending introduction of Digital Product Passports (DPP) poses a major challenge for companies across and beyond Europe. The set of regulations, kickstarted by the European Green Deal, will require companies to collect sustainability-related data across the lifecycle of their products – something many of them are currently not capable of. Since the final concept for the DPP is still to be developed, accurate and reliable information is not yet available. This puts companies in a difficult spot: Compliance with many of the anticipated features of a DPP might require significant time, effort and investment. In order to set the required actions into motion, decision makers need a basis for their decisions.

This paper uses scenario technique to systematically construct scenarios for the introduction of the DPP in the manufacturing industry. Key factors are identified and prioritised based on their relevance and influence. From there, consistent scenarios are constructed, and recommendations are provided on how industrial stakeholders can deal with possible manifestations of the most important key factors.

Keywords: Digital Product Passport, Manufacturing Industry, Sustainability, Circular Economy, European Green Deal, Scenario Technique

1. INTRODUCTION

The European Commission (EC) has announced its intention to introduce Digital Product Passports (DPP) for products sold in Europe from 2027 onwards (European Commission, 2019). Sustainability-related data will have to be collected and be made available to stakeholders across the product life cycle (PLC). In many ways, this matches the emerging use of Advanced Systems Engineering (ASE) (Riedel, 2023), which also emphasises viewing the system as a whole rather than focusing solely on its individual components, considering the entire lifecycle of the system and integrating knowledge from various fields in an interdisciplinary approach. The integrated system model generated in terms of ASE respectively Model-Based System Engineering (MBSE) with its metamodel and the referenced discipline-specific product models forms the elementary basis for the DPP, as it represents the starting point for a data model that grows over the PLC. The integrated system model will be enriched with further partial models and data sets from the operational, usage and end-of-life phase. This lifecycle-wide collection of models and data sets must in turn be managed in a superordinate metamodel, from which the DPP can make use of sustainability-related data and information – realised in a standardised way, e.g., via the Asset Administration Shell (AAS) (Adisorn et al., 2021). Even though these technological foundations and paradigms such as ASE with MBSE and AAS already exist, the announcement of the EC has greatly unsettled many companies doing business in Europe (Jensen et al., 2023). This is mainly caused by the lack of information regarding its implementation fuelling fears of impending overregulation, administrative burden and the possible loss of intellectual property. Since the final concept for the DPP has yet to be developed within the CIRPASS 2 project starting April 2024 (CIRPASS, 2024), accurate and reliable information is not yet available. Still, a careful analysis of current legislation, scientific literature and recent projects and related initiatives can serve as a basis for likely scenarios for the introduction of the DPP.

In chapter 2.1, the available information on the DPP is discussed, starting with the legal background and the political intent behind it, especially the European Green Deal, Ecodesign for Sustainable Products Regulation (ESPR), Battery Regulation and the proposed Supply Chain Law. Chapter 2.2 paints a picture of the likely concept of the DPP based on scientific literature as well as an understanding of the information gathered by CIRPASS and similar initiatives until this point. In chapter 3, the methodology used to create the scenarios is introduced. Chapter 4.1 presents the results of the application of scenario technique on the subject of DPP and discusses recommendations in chapter 4.2. Chapter 5 draws conclusions including limitations of this work and shows the need for further research.

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2. BACKGROUND

2.1 Legal background

The European Union's (EU) Green Deal (European Commission, 2019) was launched in December 2019 against the backdrop of a variety of economic and political conditions. One of the key drivers for this initiative was the significant environmental impact of industrial production in the EU. The EU has recognised that depending on linear economic models that rely on disposable products and a throwaway mentality is not sustainable. Overall, the promotion of a circular economy in the EU is at the heart of efforts not only to achieve environmental and economic goals, but also to strengthen strategic interests in terms of resource security and resilience to global uncertainties. It is a transformation that takes effect at various levels, from reducing waste to ensuring strategic autonomy in relation to critical raw materials (van Engelenburg et al., 2022). Regarding the DPP, the European Green Deal can be seen as the foundation which sets both the goals to be achieved and the macro-economic framework by which to achieve them.

The Ecodesign for Sustainable Products Regulation (ESPR) is an EU legal initiative that was adopted in March 2022 and aims to minimise the environmental impact of products from the outset and thus make a decisive contribution to promoting a sustainable circular economy (European Commission, 2022b). At early stages of Product development, product characteristics such as the material used, the product shape, the manufacturing process and much more are determined. The ESPR sets clear minimum requirements for the environmental performance of products placed on the EU market. The focus is on considering the environmental impact over the entire PLC – from raw material extraction to production and disposal. The regulation supports the EU strategy in several key areas: It helps to promote resource efficiency and the circular economy by extending the life of products, promoting recycling and limiting the use of environmentally harmful materials. In addition, the ESPR promotes innovation and competitiveness by creating incentives for environmentally friendly product developments (European Commission, 2022b). The ESPR ensures that products are designed to be more transparent, making it easier for consumers to understand how sustainable a product is and what its environmental impact is. This helps to increase consumer awareness of sustainable purchasing decisions. Since accurate data is required to calculate and report this impact, the ESPR already includes requirements for any future DPP in its annexes (European Commission, 2022b). Overall, the ESPR represents a product focused perspective of the DPP with an emphasis on transparency.

The Battery Regulation (Council of the EU, 2023) represents another significant legal initiative of the EU aimed at minimising the environmental impact of batteries and promoting their sustainable use. This framework came into force in its initial version in September 2008 and has since been expanded multiple times. Particularly, the latest version, which came into effect in August 2023 plays a crucial role in the EU's strategy to promote a sustainable circular economy and is closely linked to the goals of the European Green Deal. The Battery Regulation sets clear standards for the design, production, and recycling of batteries to ensure that they are as environmentally friendly as possible throughout their lifecycle. This includes clear guidelines on how sustainability-related product information, such as the carbon footprint, as well as topics like minimum durability and performance requirements, minimum recycled material content, the collection of portable batteries and waste batteries from appliances, and removability and replaceability, must be handled. In many ways, the Battery Regulation can be seen as a blueprint for other product categories which will be affected by the DPP (Kinnunen et al., 2022) (Timms & King, 2023).

The Supply Chain Law (European Commission, 2022a) as it is currently being discussed by lawmakers in Brussels, obligates large and medium sized companies to observe certain human rights and environmental due diligence obligations throughout their entire supply chains. These requirements are intended to strengthen values of social and environmental sustainability worldwide by compelling companies, even those located outside the EU but in a direct or indirect supply relationship with an obligated company, to provide statements regarding the protection of human rights and environmental regulations. Obligated companies cannot rely solely on these statements but must take active measures to monitor compliance with these obligations and promote adherence through risk analysis, prevention, and remediation measures. The Supply Chain Law is of interest for the DPP because it holds companies responsible for compliance along the value chain in addition to more general requirements regarding ecological and social sustainability. Across all EU strategies and initiatives, a high degree of transparency is required for their implementation.

2.2 The Digital Product Passport – Status quo

»The European Commission (EC) defines DPPs as an electronically accessed data set containing product-specific information. It is expected that DPPs would provide details on the origin, composition and repair/disassembly possibilities of a given product, including how its components can be recycled or disposed at end of life.« (Kebede et al., 2023)

In literature, there are several definitions and viewpoints on the DPP. Whilst some define the DPP as a centralised data storage aggregating lifecycle data (Psarommatis & May, 2024) others take a broader view and consider a Digital Product Passport ecosystem (DPPE), which is read, used and changed by stakeholders throughout the entire life cycle (King et al., 2023). A DPPE reflects the complete lifecycle of a product from the different viewpoints of the involved stakeholders and thus can prove their sustainable business practices, enable circular economy by sharing information and provide needed information to legislative authorities. End consumers can use the information collected to make purchasing decisions and, if necessary, differentiate between the environmental performance of different products. By including key performance indicators and continuously recording all relevant manufacturing, transportation, fabrication and usage processes, the concept enables the implementation of the goals of sustainable development and a circular economy. Important concepts are the collection, storage, processing and transfer of information supported by digital technologies. Examples include hazardous, problematic, and valuable materials, the useful life of the product, and how to dispose of it optimally (King et al., 2023). From a practical point of view, the DPP is a digital entity representing various physical products. The DPP is to be used in various industries. Initial applications can be seen in the areas of batteries, buildings, textiles, and electronics (Gallina et al., 2023). The properties of the individual products must be considered in the DPP. Psarommatis & May (2024) distinguish between individual components and products that are made up of several components. A modular form of the DPP allows Product Passports to be created for individual components but can also be aggregated for complex products and integrated into a coherent framework. Several technologies related to the DPP are mentioned for example by van Capelleveen et al. (2023) to support data collection, standardised exchange, or data integrity. Langley et al. (2023) add technologies for data curation, processing and sharing. The AAS and the Reference Architecture Model 4.0 (RAMI 4.0) are considered to collect, store and exchange information (Adisorn et al., 2021).

In terms of content, many different approaches can be identified. In almost all cases, an identification of the physical product is included in the Product Passport. Many authors base the proposed content on the needs of the circular economy. This can be seen in the publications of Mulhall et al. (2022) and Kim et al. (2023). Others like Panza et al. (2023) emphasise the importance of social performance indicators within the DPP. Some authors like Jensen et al. (2023) look at the different stakeholders within the supply chain to define the content of the DPP. A multi-actor perspective is used to gather holistic data needs.

Overall, it must be noted that the conceptual and theoretical basis of the DPP is not yet complete and will continue to progress. The underlying literature is still dynamic, both in terms of content and technology (Panza et al., 2023). Even if the DPP is used as a standardised term, it includes many related and similar concepts such as the material passport, the circular economy passport, the digital life cycle passport and others (Plociennik et al., 2022; Schaubroeck et al., 2022).

Following the announcement of the DPP, some of these concepts along with related processes, methods and tools for the exchange of sustainability-related data within their limited sphere of influence have already been developed and implemented by various individual stakeholders across Europe. By June 2023, at least 114 initiatives dealing with this topic had been launched in Europe (CIRPASS, 2024). In order to use the knowledge gained here and build on proven solutions, the EC announced a coordination action from October 2022 to March 2024 with the aim of creating the conditions for the development of a DPP. Activities were to focus on collecting requirements, existing projects and initiatives, standards and legal frameworks. This call for proposals was implemented in the form of the CIRPASS project. Starting in April 2024, the consortium will build on these results to deliver three prototype DPPs in a 3-year project named CIRPASS 2 (CIRPASS, 2024).

3. METHODOLOGY

The scenario technique can be used to systematically explore future opportunities and potential threats, aiding in the derivation of decisions for strategic product and business planning (Gausemeier, 2009). A scenario funnel is a useful tool for visualising future possibilities. This technique is particularly useful for identifying and coordinating opportunities for technological innovation and market development (Gausemeier et al., 2006). Therefore, it is worth analysing the future for the development of the DPP using the scenario technique (see approach in Figure 1). The analysis pertains to a specific object, such as a product or a business unit, the design field. In the scenario preparation, the project objective and the design field are determined.

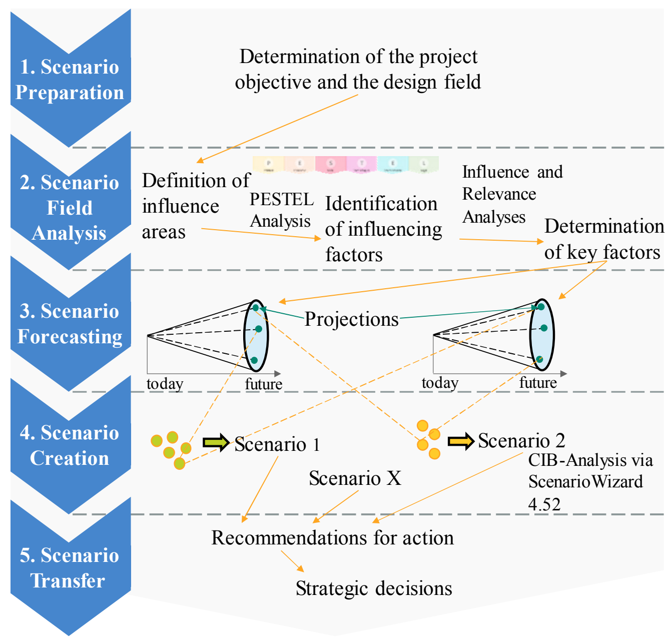

Figure 1: Approach with scenario technique

The developed scenarios are to be used to explain the possibilities of the environment (scenario field) of the object under consideration (Gausemeier et al., 2006). To achieve this, a scenario field analysis is conducted by breaking down the scenario field into suitable areas of influence. In this study, a PESTEL analysis was used to divide the scenario field into political, economic, social, technological, environmental and legal areas. The PESTEL analysis, which is used to investigate the contextual environment, has since become a central element of scenario planning, so that it is already included in the steps (Cordova-Pozo & Rouwette, 2023).

The future of the object of investigation is affected by various influencing factors. An initial set of such influence factors must be determined through general research of the subject at hand. In order to determine the key factors, influence and relevance analyses are conducted. The influence analysis examines the extent to which the influencing factors affect each other, resulting in an active and a passive sum for each factor. The relevance analysis evaluates the influencing factors against each other based on their importance for the object of investigation, resulting in a relevance sum. (Gausemeier et al., 2006)

Scenario forecasting determines potential developments for a certain time horizon in the future, representing the projections per key factor. During scenario creation, the actual scenarios are developed based on the determined future projections by carrying out a pairwise assessment of the impact relationship of the future projections (Cross-Impact Balances, CIB) (Gausemeier et al., 2006). This analysis can be performed using the ScenarioWizard software. The results are combinations of future projections that can be summarised into different scenarios. The internal consistency of these scenarios is measured by a numerical value called impact total, allowing the user to roughly assess how realistic a scenario is in comparison to others. This does not however directly translate into a likelihood of occurrence. In a final scenario transfer phase, the results are translated into strategic decisions. This article aims to derive recommendations for action based on the scenarios developed, which companies can use as a basis for such strategic decisions.

4. RESULTS

4.1 Forecasting influences for DPP with scenarios

The DPP in the context of the manufacturing industry is the design field for the scenario analysis. The purpose of this analysis was to evaluate potential future conditions and developments in the implementation of a DPP in the manufacturing industry in order to assess the impact now and to be able to make strategic decisions, exert influence and mitigate risks. The following conditions were applied:

- Legislation is complied with within its scope.
- DPP requirements are based on the »attribute long list« from the Battery Pass project. (Battery Pass, 2023)
- The DPP will be introduced based on the CIRPASS model, including its infrastructure and timeline, etc.
- Status as of January 2024 is used as a basis.

28 influencing factors for the individual influence areas were determined based on extensive literature research and expert knowledge, see Figure 2. A disproportionate number of factors fell into the categories of economics and technology as these subjects were intensely discussed in the relevant literature. 16 key factors with high relevance and strong influence on other factors were identified based on the analysis as described in Chapter 3 (refer to 'Key' in Figure 2). Again, a disproportionate number of factors from the categories of economics, technology and this time social can be observed, winning out over the other categories, as the technological feasibility determines whether the DPP can be implemented at all, and economical and social factors determine whether they will be adapted by end users. Political and legal factors are also often way out of the scope of influence of the target group.

The resulting scenario forecast determines developments for the time horizon 2026-2030. The three projections for each key factor are described in-depth in Appendix A. The CIB analysis delivers 29 scenarios with strong consistency, showing a range of impact totals from 140 – 279.

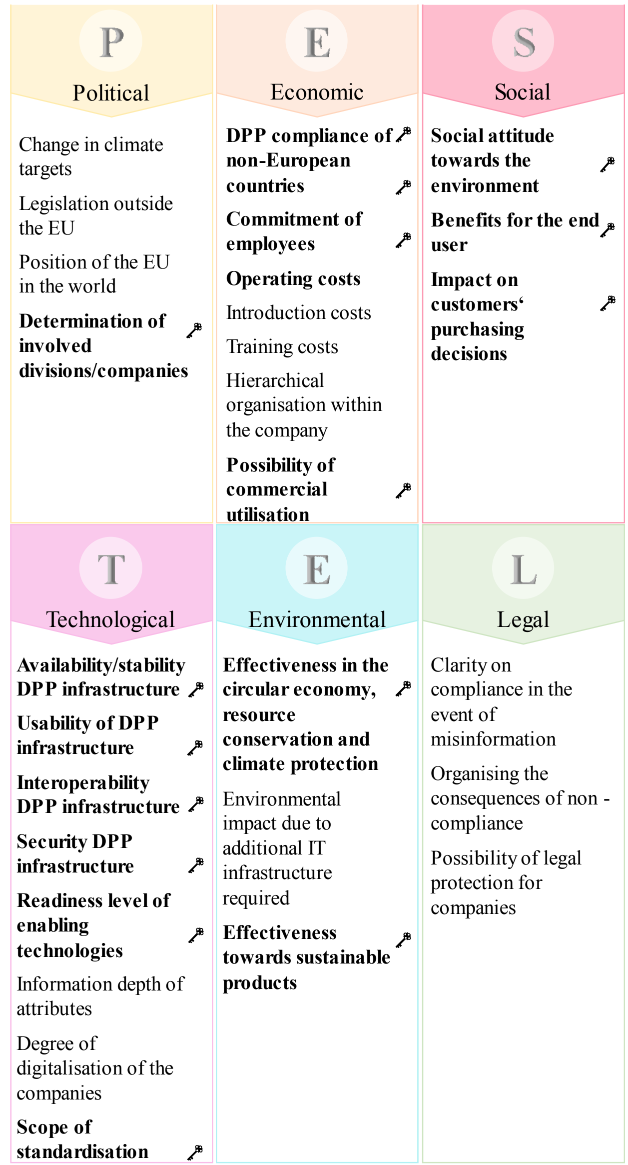

Figure 2: PESTEL analysis for the collection of impact factors

The analysis shows that extreme scenarios are often very consistent as positive/negative projections in one key factor are often causally linked with good/bad projections in another. For example, as Figure 3 shows, the effectiveness of the DPP in improving the circular economy is positively linked with almost every other key factor. This makes sense, as it implies that all these factors play a role in making the DPP impactful.

The impact total is the sum of the impact sums of all selected variants and thus a global measure of the plausibility of a scenario. The three scenarios with the highest impact totals were chosen for further consideration (impact totals scenario 1: 279, scenario 2: 236, scenario 3: 234). In order to identify the most critical factors in the area of influence, the difference between the influence sums of the two opposing scenarios was calculated, which thus forms a measure of the variance of the scenarios. Furthermore, the number of influencing factors was counted, and the arithmetic mean was calculated across the three scenarios. Those values – arithmetic mean over the number of influencing factors and impact sum over all projections – have been plotted in a diagram, see Figure 3. The blue highlighted area (first quadrant) thus depicts the seven most critical (key) influencing factors, as these factors show the highest variance and on average have the most influencing factors.

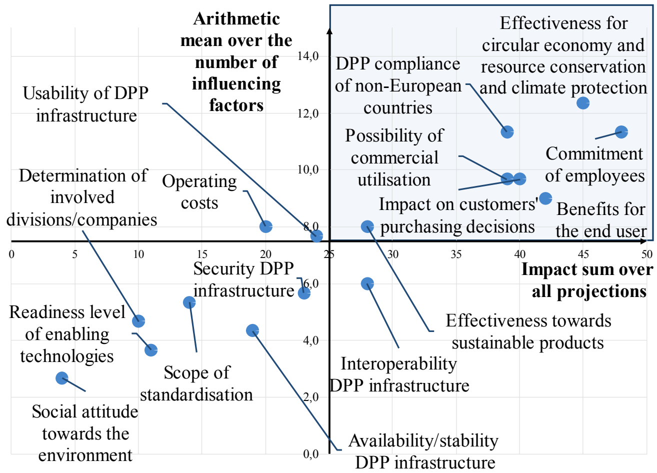

Figure 3: Overview over criticality of influencing factors

4.2 Recommendations for action based on developed scenarios for strategic decision making

The intention of this paper is to derive recommendations for action from the scenarios developed, which companies can use as a basis for strategic decisions. Recommendations for the most critical factors were developed and are presented below:

Effectiveness for circular economy and resource conservation and climate protection

- Embrace transparency regarding environmental impact of products. Provision of accurate and comprehensive data (also within supply chains).
- Utilise DPP to further reduce the companies' environmental impact to receive added benefits, such as incentives.

DPP compliance of non-European countries

- Adapt Supply Chains to improve sustainability by e.g., incentivising suppliers to adopt sustainable practices, sourcing materials locally and implementing traceability measures to ensure transparency.
- Provide guidance to important suppliers on how to comply to EU standards to decrease their reluctancy.
- Where necessary, fill in the blanks with own data, based on estimations. Exchange knowledge with peers from other companies to improve these estimations.

Commitment of employees

- Clarify the topic's relevance, provide comprehensive training, encourage ownership, and offer incentives to enhance employee commitment.
- Communicate importance of DPP for company's sustainability goals, market competitiveness and mission.
- Provide education and training on how to gather information and data for DPP and how to accurately input information into DPP.
- Recognise and reward success of employees with commitment, perhaps monetary rewards, public recognition, career advancement opportunities etc.

Benefits for the end user

- Incorporate feedback from customers, stakeholders and industry experts to enhance reputation and maintain consumer trust.
- Help end user understand the environmental impact of products and make more sustainable purchasing decisions, provide them with advice and resources for reducing environmental impact and living more sustainable.

Impact on customers' purchasing decisions

- Educate customers on how to use DPP effectively by providing information how to interpret information, data and importance of making environmentally responsible purchasing decisions and therefore build trust with customers and position the company as a leader in sustainability.
- Collaborate with Certification Bodies to ensure that products meet sustainability standards. By using certifications, companies can enhance credibility within DPP and differentiate from competitors.

Possibility of commercial utilisation

- Use DPP as part of marketing strategy whereby highlighting products sustainability credentials in marketing materials, on packaging, websites, etc., which can attract environmentally conscious consumers.
- Collaborate with Certification Bodies (see above)

Effectiveness towards sustainable products

- Utilise additionally provided data (upstream of the PLC) to make informed choices regarding suppliers.
- Utilise additionally gathered data to improve internal processes. Identify weaknesses, waste and inefficiencies to increase economical, ecological and social sustainability.
- Utilise additional provided data (downstream of the PLC) to improve the design for repairability/recyclability of products. Establish ASE during the product development process, which takes DPP-data of use-phase and end-of-life into consideration for revised product generations.

5. CONCLUSIONS

The purpose of this paper was to evaluate potential future conditions and developments in the implementation of a DPP in the manufacturing industry in order to assess the impact now and to derive recommendations for action from the scenarios developed, which companies can use as a basis for strategic decisions to mitigate risks. The most critical influencing factors on the DPP implementation were to be found in economics, technology and social areas since the literature extensively discusses these impacts. Technological factors influence the extent to which a DPP can be technically implemented and are generally influenced by the competence of the stakeholders implementing the DPP. Economic and social factors influence the degree of acceptance among end users and by society in general. Fortunately, these can often be positively influenced by the involved companies compared to political and legal factors. Limitations exist in this work regarding the derived recommendations for action, since they can of course only be fairly generic, as every company will face specific challenges when introducing the DPP, depending on the basic conditions already in place. However, they can provide guidance for strategic decision-makers to plan for the inevitable introduction of DPP and avoid being overwhelmed. In addition, this work had to make assumptions about the introduction of the DPP, as several decisions are still pending. It is therefore recommended that the scenario technique is reapplied once the information basis for the analysis has shifted in some way – for example through the development of the first DPP prototypes by the CIRPASS 2 project. ASE as a novel engineering paradigm enables a functioning DPP ecosystem, as it provides the basis for a lifecycle-wide collection of models and data, representing a single source of truth for sustainability-related data and information. In this respect, further research needs to address the efficient integration of system models from the design phase into a lifecycle-wide metamodel – realised in a standardised way, e.g., via the AAS.

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