CHALMERS
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Digital Product Passport for a Circular Economy

Designing and testing a readiness tool for SMEs

Master's thesis in Industrial Ecology

STURLA BECK, ALFRED HAGGREN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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External Supervisor: Sophie Charpentier, Chalmers Industriteknik
Supervisor: Arpita Chari, Department of Industrial and Materials science
Examiner: Mélanie Despeisse, Department of Industrial and Materials science

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Department of Industrial and Materials science
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 31 772 1000

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Abstract

The European Union's Ecodesign for Sustainable Products Regulation (ESPR) introduces the Digital Product Passport (DPP) as a mandatory requirement to foster a circular economy by ensuring end-to-end traceability and data transparency. While large enterprises are better prepared for this shift, Small and Medium-sized Enterprises (SMEs) which constitute 99% of European enterprises face significant barriers regarding financial resources, technical expertise, and strategic readiness. A review of existing maturity models reveals a critical gap: current frameworks largely assume starting conditions that smaller firms do not possess, leaving SMEs without tailored diagnostic instruments to navigate DPP implementation. To address this gap, this study aims to design, test, and document a DPP readiness assessment tool tailored specifically for SMEs, providing a low-threshold, web-based instrument that outputs a visual maturity profile and a prioritized improvement plan. The study employs a qualitative research design combining inductive and abductive reasoning. Data were collected through semi-structured interviews with 11 subject matter experts across nine companies. Data were analyzed using the Gioia methodology to inductively derive readiness dimensions, which were then mapped against the Socio-Technical Systems Theory (STST) framework. The analysis identified six critical dimensions of DPP readiness: Leadership & Strategy, Human & Organization, Processes & Data Management, Technical Infrastructure, Ecosystem & External Support, and Value Chain & Integration. Among these, Value Chain & Integration emerged as the most critical hurdle, driven by SMEs' limited purchasing power and the difficulty of enforcing data transparency upstream. Based on these findings, a functional HTML-based self-assessment tool was developed and iteratively refined through pilot testing with six industry practitioners. The results indicate that technical infrastructure alone is insufficient for successful DPP implementation; organizational alignment and strategic ecosystem collaboration are equally vital. Ultimately, the developed readiness tool provides SMEs with an accessible starting point to independently evaluate their baseline preparedness, allowing them to make informed decisions before engaging external service providers.

Keywords: Digital Product Passport (DPP), Circular Economy (CE), Small and Medium-sized Enterprises (SMEs), Readiness assessment, Industry 4.0, Socio-Technical-Systems Theory (STST).

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

API	Application Programming Interface
CE	Circular Economy
CEAP	Circular Economy Action Plan
CIT	Chalmers Industriteknik
CMS	Content Management System
CSO	Chief Sustainability Officer
DMM	Digital Maturity Model
DPP	Digital Product Passport
DRL 4.0	Digital Readiness Level 4.0
DT	Digital Twin
EGD	European Green Deal
ERP	Enterprise Resource Planning
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
EWM	Enterprise Warehouse Management
I4.0	Industry 4.0
IoT	Internet of Things
IT	Information technology
LE	Large Enterprise
MES	Manufacturing Execution System
RFID	Radio-Frequency Identification
SME	Small and Medium-sized Enterprise
STST	Socio-Technical Systems Theory
TAM	Technology Acceptance Model
TOE	Technology-Organization-Environment

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1
Introduction

1.1 Background

Recent European Union (EU) directives such as the Circular Economy Action Plan (CEAP) [2] and the European Green Deal (EGD) [3] aim to make the European economic system more resource-efficient and sustainable through decoupling growth from resource use. Simultaneously a shift towards industry 4.0 (I4.0) can be observed, characterized by cyber-physical systems where products' physical and digital representations are starting to merge and become inseparable [4]. On this subject, Digital Twins (DTs) are being discussed and applied as a way of integrating a products physical and virtual data throughout its life-cycle, often in combination with big data, aiming to improve analytical assessment, predictive diagnosis and performance optimization [5]. A recent example of the transition towards I4.0 is the Digital Product Passport (DPP) included in EU's Ecodesign for Sustainable Products Regulation (ESPR) [6]. DPPs will store individual product life-cycle data, similar to DTs, to enhance the end-to-end traceability of products throughout their value-chains. Kagermann [7] argues that I4.0 and the digitization of manufacturing enables full visibility into product value chains for the first time, and the ESPR together with the introduction of DPPs can be seen as a step toward realizing this vision of data transparency in practice. In the first ESPR working plan, the following products will be prioritized: textiles, iron, steel, aluminum, furniture, tyres, detergents, paints, lubricants, chemicals, energy-related products, ICT products and other electronics [8]. Adoption of DPPs will roll out for each product separately, starting with iron and steel in 2026 followed by textiles, tyres and aluminum in 2027 [8]. DPPs will be mandatory for these sectors on the European market regardless of company size [6]. This will require European manufacturers and economic operators to collect information through their value chain.

Small and medium-sized enterprises (SMEs) account for 99 % of European enterprises and provide more than two thirds of private sector employment [9]. However, when it comes to I4.0 readiness, large enterprises (LEs) tend to feel significantly better prepared than their smaller counterparts [10], with SMEs showing considerable shortages compared to LEs [11]. Primarily driven by a lack of financial resources [12]. A noticeable gap is evident between SMEs and LEs in their readiness towards implementations of I4.0 technologies. Seeing as DPP relies on digitalization and I4.0 concepts, the same gap between SMEs and LEs readiness can be assumed for DPP implementation.

1.2 Research Gaps

The existing literature on DPP readiness and maturity is nascent, with only a handful of relevant studies available at the date of conducting this study. Petrik et al. [13] propose a DPP maturity model defining nine independent maturation paths, but explicitly acknowledge that the model is not aimed towards SMEs, including maturity levels that may be unmanageable for smaller companies. Dake and Ahuja [14] assess DPP readiness in the textile industry across firm sizes using the Technology-Organization-Environment (TOE) framework, identifying several technological and organizational gaps. However, the study does not produce a reusable readiness assessment tool and does not adopt an SME-specific perspective, leaving the question of what particular challenges and success factors SMEs face when adopting DPP unanswered [14]. More broadly, Mittal et al. [15] reviewed fifteen existing I4.0 maturity models from an SME's perspective and found that the vast majority fail to reflect the specific challenges and needs of smaller firms. Collectively, these studies point to a clear gap in the academic literature: no published, research-based tool currently exists targeted towards SMEs, which they can use to assess and improve their readiness for DPP implementation.

1.3 Use Case

Chalmers Industriteknik (CIT) serves as the collaborative partner for this thesis. Operating at the intersection of academic research and industrial application, CIT holds a strong position in guiding companies through digital and circular transitions. A pre-study conducted by CIT in 2025 found that DPP awareness among SMEs in Sweden is generally low and that digital maturity varies widely [16]. The study further found that the needs for support differ substantially depending on a firm's current maturity level. However, the pre-study stops short of providing a instrument through which SMEs can assess their own readiness or identify prioritized next steps [16]. CIT is also a partner in the ongoing EU-funded project CIRPASS2 [17], which works to deploy and validate DPPs at scale across thirteen pilot implementations in four industry value chains, spanning textiles, electronics, tyres and construction [18]. One of the project's explicit goals is to assist SMEs in their DPP adoption, recognizing that smaller firms face distinct challenges in meeting the demands that DPP implementation requires [18]. Based on these projects, CIT has identified a need for a DPP readiness assessment tool tailored for SMEs, which has motivated the development of the readiness model proposed in this thesis.

1.4 Aim

The goal of this thesis is to design, test, and document a DPP readiness assessment tool targeted at SMEs, producing a radar plot and a recommended steps forward. To achieve this end, the study will define the dimensions of the tool, draft and validate a questionnaire, develop a prototype web-based tool, and conduct a pilot

test with experts. The tool will output a radar plot visualizing the user's readiness across each dimension alongside a concise summary report with recommended next steps linked to increased readiness levels.

1.5 Research questions

Based on the gaps identified in sections 1.2 and 1.3, the following research questions were formulated:

> *RQ 1: Which readiness dimensions most strongly predict DPP implementation success?*
>
> *RQ 2: How can the identified readiness dimensions be operationalized into a structured self-assessment tool for SMEs?*

1.6 Delimitations

This study limits itself to DPPs in the ESPR context. Therefore the tool is designed exclusively around the product categories covered by it. Products exempted under ESPR, or subject to separate but similar regulations, are not taken into consideration. Given the SME-focused aim of the study, LEs will not be considered an intended target audience for the tool developed in this study. Furthermore, the study focuses on the Swedish industrial landscape, and the tool is designed towards Swedish SMEs.

2
Theory

This chapter establishes the theoretical foundation of the study. First, the concept of DPPs is described. Second, Socio-Technical Systems Theory (STST) is presented as the analytical framework used to structure the barriers SMEs face in DPP implementation, followed by a review of those barriers organized across the framework's social, technical and environmental dimensions. Finally, existing maturity models and readiness assessments are reviewed critically, with particular attention to their fit with the specific requirements of SMEs and the nascent body of DPP-specific models.

2.1 Digital Product Passports

The DPP is a key part of the ESPR [6] and represents the EU's means of establishing a digital backbone allowing Circular Economy (CE) practices across European value chains [19]. A product passport can be described as a data-set connected to a unique physical product, that can be accessed digitally through a data carrier [20]. Under the ESPR, the data carrier must be physically present on the product itself, its packaging, or accompanying documentation [6]. Both the data carrier and the unique identifier must comply with the international ISO standards, ensuring a consistent identification framework across products and industries. DPPs must also be fully interoperable across technical, semantic and organizational dimensions, meaning that data must be structured and communicated in ways that allow different systems to exchange and interpret it consistently [6]. Rather than functioning as a static product label, DPPs are envisioned as dynamic platforms through which multiple supply chain actors can both insert and extract data depending on their role [21]. The DPP's data set will be able to contain a broad range of information, including product identification, material composition, environmental data, usage and maintenance records, and guidance on recycling and disposal [21], making DPPs promising instruments for promoting a CE [20]. As some of this data carries commercial sensitivity, DPPs are also expected to incorporate multiple levels of data accessibility [21]. Realizing these aspects in practice places significant demands on companies, as discussed in section 2.3.

2.2 STST framework

To structure the barriers that SMEs face in implementing DPPs, and to later validate the dimensions emerging from the expert interview data, this study draws on

the framework of STST. The framework proposes that an organization consists of technical and social components that are affected by its surrounding environment [22], giving rise to three dimensions through which organizational challenges can be understood: social, technical and environmental. The social dimension covers the organizational structures, including roles, culture, communication and reporting hierarchies, as well as the actors who execute or influence work, such as management and employees [23]. The technical dimension comprises the tools and resources used to carry out work activities, including hardware, software, equipment and information systems, as well as the actual processes through which organizational goals are pursued [23]. The environmental dimension refers to external factors, including economic, regulatory and external entities such as suppliers and customers [23]. In previous studies on digital transformation and DPPs, frameworks such as the TOE framework and the Technology Acceptance Model (TAM) have been used [24] [14]. However, these frameworks have been criticized for treating technological, organizational and environmental dimensions as separate and additive, as well as for focusing mainly on the initial decision to adopt rather than the dynamic implementation process and its performance outcomes [25] [24]. By instead focusing on the constant interrelationship between the technological, social and environmental dimensions [22], STST addresses this gap [24].

2.3 STST barriers in the SME-DPP context

The following sections present barriers that SMEs face in the context of DPP implementation, I4.0 and digital transformation, organized according to the STST dimensions: social, technical and environmental.

2.3.1 Social

Among the barriers companies face in digital transformation, the absence of a clear digital strategy combined with limited resources consistently emerges as the most prominent challenge across different economic contexts [26]. At the management level, a lot of businesses haven't found a good enough financial reason to spend money on the large data systems needed to fully run I4.0 [27]. A significant contributing factor is that the advantages from I4.0 are hard for companies to quantify, making it difficult to persuade management into digital investments [28]. Meanwhile, at the organizational level, a persistent barrier for SMEs is the lack of internal knowledge and expertise needed to navigate digital transformation [29] [30]. Furthermore, SMEs frequently struggle to find the time and resources needed for digital implementation, as the pressure of day-to-day operations consistently takes priority over longer-term technology development efforts [31] [32]. A further barrier is the tendency for departments within organizations to operate in isolation from one another, limiting internal data exchange and hindering the cross-functional integration that digital implementation requires [33].

2.3.2 Technical

In the context of I4.0, establishing data-driven processes and services remains a primary gap for all types of Swedish manufacturers [29]. For DPPs specifically, a fundamental barrier is that the infrastructure needed to enable the kind of data exchange required is still underdeveloped across most industries [21]. This is reflected empirically in a study of textile supply chain firms, where only 8% confirmed using technical standards that were interoperable and capable of integrating separate systems, and only 46% possessed the infrastructure needed for DPP implementation [14]. Given that these figures were driven primarily by medium and large enterprises, the technical readiness gap among SMEs specifically is likely even more pronounced [14]. Their main technical challenges include integrating DPP systems with existing legacy IT infrastructure, the complexity of collecting and ensuring data quality, applying relevant data standards, ensuring secure data access and addressing privacy concerns surrounding tracking technologies [34]. Meeting these demands requires substantial technological capabilities, including sophisticated track-and-trace software, physical Internet of Things (IoT) devices throughout the supply chain, and potentially technologies such as Data Spaces and Blockchain networks to facilitate secure external data exchange [35]. Finally, the overall scale of the technical challenge an SME faces will largely depend on whether it chooses to develop and host a DPP solution internally or rely on external providers, a decision that carries significant implications for the level of IT expertise and infrastructure required [34].

2.3.3 Environmental

Research indicates that external support is often a necessary prerequisite for ensuring successful I4.0 adoption among SMEs [36] [37]. However, many organizations struggle to determine which I4.0 activities should be retained in-house as core competencies and which would benefit from external outsourcing [27]. Furthermore, there is a lack of awareness regarding the broader ecosystem of potential external partners available for I4.0 collaboration [27]. Whether a company manages its DPP implementation internally or will have to rely on external 'DPP-as-a-Service' providers ultimately depends on the technical and financial resources available in the company [34]. In the case of SMEs, however, research indicates that they generally have insufficient resources to engage in in-house software development and research activities [38] [30]. Beyond resource constraints, SMEs also face significant challenges in the external relationships that DPP implementation depends upon. Unlike LEs, which typically maintain a broad supplier base, SMEs tend to work with a limited number of suppliers and customers, resulting in a stronger dependence on individual relationships within their value chain [15]. Research suggests that communication and openness to sharing information between value chain actors is a critical factor for successful DPP adoption [39]. However, companies frequently withhold product information unless legally required to share it, limiting data flows to what regulators mandate [14]. In a study of textile supply chains it was found that traceability declined progressively among upstream actors, suggesting that value chain integration challenges are particularly acute at the tiers furthest from the end market [14]. This lack of data exchange between actors in the product supply chain in its turn leads

to incomplete information, ultimately hindering DPP implementation [35].

2.4 On existing Maturity Models

This section reviews existing maturity models and readiness assessments relevant to the context of this study. Section 2.4.1 introduces the distinction between maturity models and readiness assessments and discusses the methodological requirements for their development and their applicability to SMEs. Sections 2.4.2 and 2.4.3 review existing models in the context of Industry 4.0 and DPP respectively. Finally, Section 2.4.4 synthesizes the identified research gaps that motivate the present study.

2.4.1 Characteristics and Limitations of Maturity Models and Readiness Assessments

Before reviewing existing models, it is worth distinguishing between maturity models and readiness assessments. Maturity models provide a structured pathway through which organizations can progressively develop their capabilities across people, processes and technologies [15]. Readiness assessments, on the other hand, act as diagnostic instruments that evaluate how well-positioned an organization currently is to achieve a specific goal, examining the attitudes, conditions and resources present across the system [15]. Maturity models vary considerably in their thoroughness, scope, and intended audience, making a critical approach to reviewing them essential. Becker et al. [40] propose eight requirements for methodologically rigorous maturity model development, grounded in design science principles. These include iterative development, embedded evaluation, multi-methodological design, and transparent documentation. Reviewing 51 models, they found that the majority fell short of full scientific documentation [40]. This finding is echoed by Röglinger et al. [41], whose systematic review of ten business process management maturity models found that while most successfully served a descriptive purpose of use, enabling organizations to assess their current state, few provided meaningful prescriptive guidance on how to prioritize or implement improvement measures. A further structural limitation emerges from Mittal et al. [15], whose critical review of fifteen I4.0 maturity models found that none fully addressed the specific requirements of SMEs. Instead, most maturity models assumed starting conditions that many smaller firms do not possess such as: integrated IT systems, dedicated digitalization resources and organizational culture oriented toward change [15].

2.4.2 I4.0 and digital transformation models

Pirola et al. [33] propose the Digital Readiness Level 4.0 (DRL 4.0) model, a modular assessment tool specifically designed for manufacturing SMEs to evaluate their current readiness with respect to I4.0 adoption. The model was developed through an empirical, multiple case-study methodology, beginning with a literature review of existing maturity and readiness models, followed by iterative validation through two pilot case studies with innovation managers. The model comprises five dimensions: strategy, people, processes, technology, and integration, assessed through 24

five-point Likert-scale questions, supplemented by a company profiling section and investment-intent questions that can adjust the final dimension scores. These inputs are combined into a single index that positions the assessed company on one of five Digital Readiness Levels (DRL 1–5), ranging from no engagement with I4.0 to full digitalization and value chain integration. A defining feature of the DRL 4.0 is its modularity. Questions related to technologies or processes considered inapplicable to a given company's context are excluded from scoring, preventing irrelevant criteria from falsely lessening results, a limitation the authors identify in prior maturity models [33]. Njah et al. [42] propose a Digital Maturity Model (DMM), which, similarly to the DRL 4.0 model, intends to assist SMEs in their I4.0 implementation. The model was developed through the six-phase methodology established by de Bruin et al. [43], covering scope, design, populate, test, deploy and maintain. Specifically, a systematic literature review together with qualitative multiple case studies was conducted across three Canadian manufacturing SMEs. The model is structured around five different dimensions: 'Strategy and governance', 'Human Resources and digital skills', 'Information technology (IT), data and security', 'Industrial systems and value chain' and 'Portfolio, products and services'. Within these dimensions there are a total of 34 subdimensions and 49 indicators which together form a survey of 38 questions [42]. Whilst these mentioned models represent two of the few maturity models explicitly tailored to the organizational structure and resource constraints of SMEs, they are geographically bounded to Italian and Canadian industrial context, respectively. Furthermore, they do not address regulatory or compliance-driven dimensions of digitalization, such as those introduced by DPP regulations.

2.4.3 DPP maturity models

Petrik et al. [13] propose a maturity model specifically designed to support organizations in launching and operating DPPs, developed through design science research. The model comprises three dimensions: data supply, data management, and supply chain integration. In total, these dimensions contain nine independent maturation paths across five levels (0–4), where Level 0 represents a pre launch phase and Level 4 indicates complete automation and a fully circular value chain. Its knowledge base was derived from a multivocal literature review of 115 sources, refined through two rounds of semi-structured expert interviews with 14 practitioners and researchers, and validated through three workshops with companies from the plastics, machine tooling, and automotive industries. Notably, the model is the first to explicitly address data management capabilities as a prerequisite for DPP implementation, filling a gap that prior DPP research — which focused predominantly on architecture and data categories — had left open. However, the authors acknowledge that the model primarily targets economic operators with sufficient IT resources, and explicitly flag that higher maturity levels may be unmanageable for SMEs, limiting its generalizability in that context [13].

2.4.4 Summary of identified research gaps

1. **Existing maturity models broadly fail to address SME-specific needs.** As described in section 2.4.1, Mittal et al. [15] identifies an underrepresentation in SME perspectives in current existing maturity models. Together with the fact that 99% of European enterprises are SMEs [9], this gap is seen as critical and a large focus in this thesis.
2. **Existing SME-focused I4.0 readiness models do not address DPPs.** As mentioned in section 2.4.2, I4.0 readiness models that adopt an SME perspective, although representing a small portion of maturity models, do exist [33] [42]. However, as these models were not designed with DPPs in mind, it remains an open question whether they are applicable in the context of this study.
3. **No SME-targeted DPP readiness tool exists.** As described in Section 2.4.3, a DPP-specific maturity model already exists [13]. However, the authors acknowledge that the model was not designed with SMEs in mind and is likely unfit for smaller firms. Given that DPP compliance will be mandatory for all economic operators regardless of company size [6], and that SMEs account for 99% of European enterprises [9], the absence of an SME-targeted tool represents a particularly critical gap which this study aims to address.

3
Methodology

3.1 Research Design

This study employs a qualitative research design rooted in a pragmatic philosophical worldview [44], in which methods were selected based on the research problem itself rather than following a predetermined methodological system. Drawing on some aspects of grounded theory principles [44], the study obtains its key concepts from the perspectives of participants through multiple stages of data collection, including expert interviews and pilot testing. The research process integrates an initial literature review, semi-structured expert interviews, and tool development, with interview data analyzed using the Gioia methodology [1], ultimately transitioning from an inductive exploration of qualitative data to an abductive validation against existing theory [45]. Section 3.2 presents the data collection, section 3.3 presents the data analysis and section 3.4 presents the tool development.

3.2 Data Collection

This section describes the data collection processes of this study. Section 3.2.1 details the methodological approach used for the literature review, and Section 3.2.2 describes how the expert interviews were conducted.

3.2.1 Literature Review

The literature review began with a set of core keywords derived from the central concepts of the research aim, including: DPP, circularity, I4.0, digital transformation, digitalization, SME, readiness and maturity. These were combined into Boolean search strings, such as "digital product passport" AND "readiness" and "maturity model" AND "I4.0", and applied in the academic database Scopus, with results filtered to the engineering, environmental science and business, management and accounting subject areas. All academic sources included in the study are in English. No strict publication date filter was applied, reflecting the nascent state of DPP-specific literature, though sources were evaluated for continued relevance given the rapidly evolving regulatory context.

The Scopus searches yielded an initial set of articles, which served as the starting point for a backward snowballing process [46]. References cited in these papers were systematically reviewed, with sources retained if they addressed one or more of the study's core keywords. Grey literature, such as industry reports found in

the reference lists of academic papers, was included during this phase. Promising sources identified through snowballing were themselves snowballed further in the same manner. Saturation was considered reached when the snowballing process began returning previously identified sources and no new relevant material emerged from newly reviewed references. Following this process, a final review of the gathered sources was conducted, and papers judged to be insufficiently connected to the study's core topics after deeper reading were excluded.

In addition to the systematic search, two further categories of sources were incorporated. First, key EU policy and regulatory documents, including the ESPR, the CEAP, and the EGD, were included directly, given their foundational role in defining the research context of DPPs. Second, project documentation relevant to CIT's projects was also included in the study in order to explain the use case.

It should be noted that the literature review was conducted in two phases. The initial systematic search described above established the theoretical foundation of the study prior to data collection. A second, targeted literature search was subsequently conducted following the analysis of expert interview data, in which specific literature was sought to validate and contextualize the dimensions that had emerged inductively. This approach is consistent with the abductive reasoning [45] described in Section 3.3, and with the recommendations of the Gioia methodology [1] also explained further in section 3.3.

3.2.2 Expert Interviews

Experts were contacted through the professional network of the collaborative partner CIT. For the purposes of this study, an expert was defined as a person with professional experience within one or more of the following areas: DPP, digitalisation, or I4.0. In total, 9 interview sessions were conducted with 11 participants (Table 3.1). Eight interviews were conducted digitally via Microsoft Teams and one was conducted in person. All participants were informed prior to the interview that the session would be recorded and confirmed their consent. All participants are treated anonymously in the study.

The sample size of 11 experts was seen as adequate for the study's purpose. This is further supported by the concept of information power proposed by Malterud et. al. [47]. Since the selected participants had specialized expertise on the subject matter yielding rich and concentrated data, this reduced the need for a larger sample size [47]. Moreover, it became evident during the end phase of interviews that data saturation had been reached, with core concepts and insights being repeated and later interviews rather reinforcing the consensus that was forming. Combining these conditions with the practical time constraint of a master's thesis, the depth and quality of the data provided by the 9 interviews was deemed sufficient to fulfill the aim of the study of designing a functional readiness assessment tool.

Eight interviews were conducted in Swedish and one in English. Quotes drawn from Swedish interviews were translated into English for presentation in this study, with care taken to preserve the meaning and phrasing of the original statements. The eight Teams-based interviews were recorded and transcribed using its integrated

AI transcription tool, after which the authors listened through each recording and looked through the transcripts to identify and correct errors and ensure consistent formatting. The in-person interview was audio recorded and transcribed fully by hand. Each session lasted approximately one hour and followed a semi-structured format supported by a predefined interview guide (Appendix A). This approach was chosen to maintain focus on the primary subject while providing sufficient flexibility to explore unforeseen perspectives that a more rigid questionnaire might otherwise overlook [44].

Table 3.1: Overview of interviewee profiles

Experts	**Role**	**Occupation**
Expert 1	CEO	Consulting company
Expert 2	Production Manager	Electronics manufacturer
Expert 3	Founder/CEO	DPP service-provider
Expert 4	Consultant	IT-consulting company
Expert 5	Consultant	
Expert 6	Engineer	Sustainability certification
Expert 7	Head of public affairs	Standardization organization
Expert 8	System professor	University
Expert 9	Digital innovation leader	Recycling
Expert 10	Quality & Sustainability officer	Materials manufacturing
Expert 11	Developer	

3.3 Data Analysis

To analyze the expert interview data and develop the dimensions of the readiness assessment tool, this study used the systematic inductive approach defined by Gioia et al. [1], commonly referred to as the Gioia Methodology. This methodology was selected because it is designed specifically to support the development of new concepts from qualitative data while maintaining analytical rigor, a balance that is well suited to the exploratory nature of this study. Central to the approach is the treatment of informants as experts whose language and framing are preserved and prioritized in the early stages of analysis. The analysis was carried out in three steps. First, interview transcripts were coded using the participants own terminology, producing a broad set of first-order concepts. These were then examined for patterns and grouped into six second-order themes, which form the dimensions of the readiness assessment tool developed in this study. In a final step, these dimensions were aggregated against the three dimensions of STST, demonstrating theoretical consistency with an established framework. The complete progression from raw data to tool dimensions is shown in Figure 4.1. In order to allow dimensions to emerge organically from the data rather than confirming prior assumptions, the study followed the recommendation by Gioia et al. [1] of limiting engagement with existing literature during the analysis of expert interview data. Once the second-order themes had stabilized, the study moved to an abductive approach. Abductive reasoning

moves between data and existing theory, combining elements of both induction and deduction [45]. During this phase, existing literature was examined to identify theoretical support for the emerged dimensions, allowing the findings to be compared with prior research, which is presented in the results chapter.

3.4 Tool development and pilot testing

The development of the readiness assessment tool followed the procedure model proposed by Becker et al. [40] for methodologically grounded design of maturity models for IT management. Specifically, the study followed the phases of problem definition, comparison of existing models, determination of development strategy, iterative model development, and initial evaluation. The need for a new model was established through a comparison of existing maturity models in the theory chapter, which identified a gap in DPP-specific readiness tools targeted at SMEs. Dimensions and readiness indicators were, as mentioned previously, derived from analysis of expert interviews and subsequently validated against the existing literature. The tool was implemented as a web-based HTML application, coded using generative AI, to ensure accessibility for the target user group. A pilot test was conducted with six users, their profiles are presented in Table 3.2, five of the users were the experts from previous interviews. Expert 12 was contacted through a DPP focus-group event that the non-profit organization 'CSR Västsverige' held. Testing was conducted remotely, participants were provided with a link to the webpage, enabling them to evaluate the tool from their preferred location.

Table 3.2: Overview of Pilot profiles

Experts	**Role**	**Occupation**
Expert 1	CEO	Consulting company
Expert 4	Consultant	IT-consulting company
Expert 6	Engineer	Sustainability certification
Expert 7	Head of public affairs	Standardization organization
Expert 9	Digital innovation leader	Recycling
Expert 12	Sustainability director	Furniture manufacturer

To provide users with immediate and dynamic feedback, two core requirements of the self-assessment tool were the instant generation of a radar plot displaying readiness levels and the automated presentation of maturity steps upon form submission. Existing survey platforms lacked this capability, relying on them would have resulted in extra administrative steps of manually creating and distributing results back to testers in order to receive feedback. By developing a custom HTML application, we were able to tailor the tool to our needs. This approach enabled testers to view and analyze their results immediately after testing, and subsequently allowed them to provide feedback directly after using the tool.

4
Results

4.1 Tool dimensions and scoring framework

This section presents the dimensions of the DPP readiness assessment tool and the scoring framework through which they are operationalized. Sub-section 4.1 describes how the dimensions were derived through thematic coding of expert interview data using the Gioia methodology [1], and how these dimensions were further aggregated into the STST dimensions demonstrating theoretical coherence between the inductively emerged dimensions and the theoretical lens. An illustration of this process can be seen in figure 4.1. The sub-sections 4.1.2 through 4.1.7 describes each dimensions in detail, including expert statements, validation against existing literature, followed by the corresponding questions, readiness levels and recommendations incorporated into the tool. For a summary of the dimensions, questions, scoring levels and recommendations, see figure 4.2.

4.1.1 Thematic Coding Results

Figure 4.1 shows the thematic coding process following the Gioia methodology [1]. In line with the recommendations of Gioia et al., the first-order concepts were preserved in the language of the experts themselves. These were subsequently grouped into six second-order themes, which form the dimensions of the readiness assessment tool, and finally aggregated into the three dimensions of the STST framework.

The "Leadership & Strategy" and "Human & Organization" dimensions fit well within the social dimension of STST, sharing its emphasis on organizational management coupled with work roles, culture and internal communication [23].The dimensions "Processes & Data management" and "Technical infrastructure" conversely mapped well onto the technical dimension of STST, which similarly to the two dimensions center around the tools available to the company, both hardware and software, together with the company processes [23]. The "Ecosystem & External support" dimension naturally fitted into the environmental dimension of STST, given that the dimension focuses directly on external factors. While the Value Chain & Integration dimension has a clear technical component concerning the granularity and standardization of supplier data, it was placed within the environmental dimension of the STST framework on the basis that its core challenges are fundamentally contextual and relational rather than technical. As the expert interviews emphasized, the primary barrier is not the absence of technical solutions but rather suppliers' limited awareness of DPP requirements, low willingness to share data, and the constrained

purchasing power of SMEs to enforce transparency demands [15]. These are contextual factors shaped by the external environment in which the SME operates, and are therefore more accurately captured by the environmental dimension of STST.

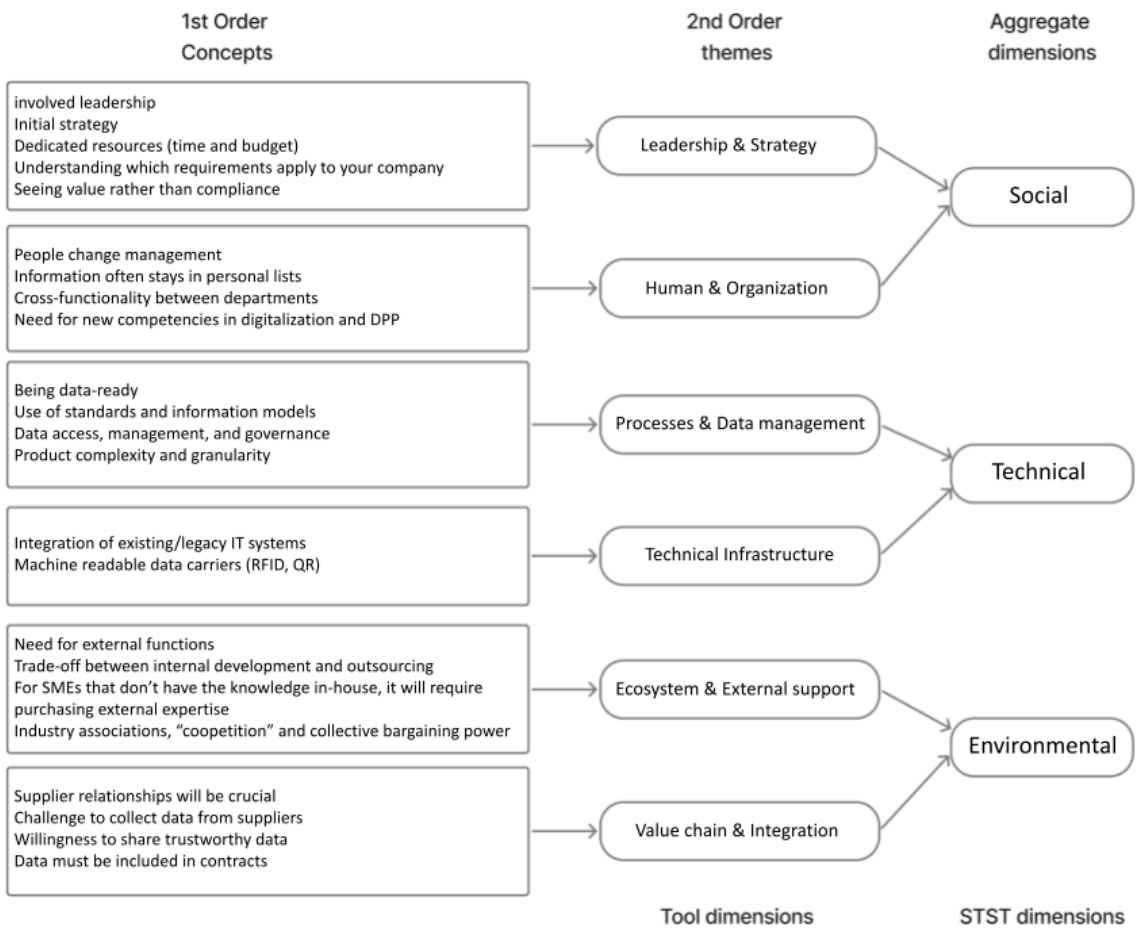

Figure 4.1: Thematic coding using Gioia methodology [1]

Table 4.1 summarizes the identified dimensions from the thematic coding of the 11 expert interviews along with the share of experts who provided empirical support for each dimension

Dimension	Share of experts supporting dimension
Leadership & Strategy	73%
Human & Organization	73%
Process & Data management	91%
Technological infrastructure	73%
Ecosystem & external support	73%
Supply chain & integration	91%

Table 4.1: Dimensions from Expert interviews

4.1.2 Leadership & Strategy

According to the experts interviewed, this dimension is crucial for determining an SME's ability to prepare for DPP implementation. Regarding SMEs and their knowledge of the specific requirements imposed by the ESPR, experts note that maturity levels vary significantly. Understanding these requirements is the essential first step toward fulfillment. There is a strong correlation between a company's general ambition and its maturity level—or its capacity to improve. As Expert 5 noted: "If a company's leadership decides to extract value from the DPP rather than just seeking compliance, you are looking at a mature company." One critical factor identified is how companies allocate internal resources and authority. While a Chief Sustainability Officer (CSO) typically manages these regulations in larger firms, SMEs often lack such dedicated roles, necessitating a shift in leadership strategy.

Because the launch of a DPP affects multiple departments, experts highlight the absolute necessity of top-management involvement. To be regarded as mature in the context of a DPP launch, experts identify decisive leadership, a dedicated budget, and allocated resources as the key enablers. A clear insight from the interviews is that a company's perception of the DPP's purpose heavily influences its strategic readiness. The lowest level of maturity is characterized by a complete lack of knowledge, where the regulation is viewed solely as a non-beneficial administrative burden. Conversely, companies with more developed strategies integrate DPPs into their business development. These companies view the regulation as an opportunity to create new business models, strengthen customer relationships, and gain a competitive advantage as less sustainable actors are phased out of the European market. Ultimately, a basic strategic analysis is required to understand one's position: "It is important to perform a strategic analysis and understand exactly which requirements apply to you." (Expert 8)

Literature suggests that digital maturity is less a function of which technologies a

firm adopts than how well it integrates them through clear strategy and committed leadership [48]. Firms that establish a defined digital strategy consistently achieve higher implementation outcomes, indicating that strategic prioritization is itself a driver of successful transformation [28]. Beyond simply having a strategy, firms that view digital transformation as a strategic opportunity rather than a compliance requirement also tend to engage more thoroughly in the preparatory work it demands, including defining performance targets and selecting appropriate technologies before implementation begins [49] [30]. In the context of DPP specifically, it is not sufficient for firms to merely be aware of regulatory requirements, they must actively translate these into concrete requirements and assess their own capacity to meet them [50].

Based on the expert opinions and the supporting literature, Questions 1 and 2 were derived (see Figure 4.2). Question 1 assesses regulatory knowledge, which was identified as essential for successful DPP implementation by both experts and the existing literature. The lowest level of readiness is characterized by merely having heard of the DPP. In contrast, higher maturity represents a comprehensive understanding of the DPP regulatory landscape, coupled with established routines to ensure the company stays updated on future regulatory additions. The recommendations align with the experts advice on strategic positioning, including allocating more time towards learning about current DPP regulations. Question 2 measures to what extent the company puts resources into DPP implementation, which was also highlighted by the experts as a success factor.

4.1.3 Human & Organization

The interviews demonstrate that DPP adoption creates significant challenges for internal cooperation and demands specific technical competencies. Fundamentally, it requires robust change management: “People change management is crucial in order to be successful with the DPP.” (Expert 4) A persistent challenge identified by experts is that the data required for the DPP is often fragmented across the company or isolated within individual silos. As Expert 3 noted: “CSOs are usually well-educated and know what is required, but that information often stays in personal lists and spreadsheets within the sustainability department.” For a successful adoption, data must be democratized and utilized by the organization as a whole, requiring different departments to communicate and align toward a common goal. Simultaneously, experts highlight that SMEs may actually possess a competitive advantage in this area, their smaller size and inherent adaptability often allow for more effective and agile cooperation.

However, regarding specific competencies, SMEs typically lack the specialized expertise that DPP implementation demands. “It is very rare to find the specialist knowledge needed for DPP in a small company,” Expert 8 remarked. This issue is largely a byproduct of scale, as SMEs often lack the resources to maintain dedicated departments for "secondary" functions such as complex data collection. Consequently, there is a pressing need for specialists who can identify technical needs, implement the necessary tools, and manage data flows. To increase strategic readiness, experts

recommend that companies begin educating their staff early. The focus should be on training the organization to navigate digitalization and recognize its potential benefits: “In order to be ready, the organization and coworkers need training in how to think about digitalization and how to benefit from it.” (Expert 3)

Echoing what the experts highlighted in the interviews, the literature consistently identifies building internal digital competencies through workforce training as a critical success factor for technology adoption [26] [51]. For SMEs specifically, this is particularly urgent given that they often lack access to in-house technical expertise or dedicated IT specialists [30] [32]. Beyond individual competencies, technology adoption must be accompanied by organizational change at multiple levels, ensuring operational employees are actively involved in implementation and removing the communication barriers between departments that can otherwise create costly bottlenecks [52]. That said, research on SMEs suggests this does not mean building large teams with representatives from every department — smaller dedicated project teams that involve other staff only when needed tend to deliver better results in terms of time, cost, and quality [53].

For this dimension, Questions 3 and 4 were developed (see Figure 4.2). Question 3 focuses on the interdepartmental communication and data sharing—themes highlighted by the experts and the literature. Meanwhile, Question 4 targets internal competencies in the context of DPP, another critical area that was identified. For question 3, the maturity levels move from a low level in which no product data is being shared between departments to a high level characterized by robust cooperation between departments and ultimately automated information sharing. For Question 4, the lowest maturity level reflects a complete absence of DPP-relevant competencies, with higher levels representing progressively greater expertise in data collection and value chain traceability, until the highest level reflects a workforce that is continuously trained in sustainability, data tracking and digitalization. The recommendations for Question 4 build on the experts’ advice regarding internal training, suggesting that companies at lower maturity levels begin by mapping competency gaps and comparing internal and external options.

4.1.4 Processes & Data Management

To launch a DPP, companies must be "data-ready", which implies not only that data exists but that structured workflows are in place to manage it. As Expert 3 noted: “Most companies today are not data-ready; they rely on spreadsheets, email, and Enterprise Resource Planning (ERP) systems, but lack automated data management processes.” Experts observe that while companies often possess a large portion of the information required for a DPP, it is frequently fragmented and unstructured, buried in "paper trails" and manual workflows such as email chains, local PDF files, and spreadsheets. A key distinction was made during the interviews, Expert 5 said “There are very few companies that are truly digitalized; they may be digitized, meaning they possess unstructured digital files, but they lack integrated systems.” Consequently, data quality and structured governance are essential for DPP adoption: “Data access, management, and governance must all be firmly in place.” (Expert 8) To develop a template for the DPP, a company’s information

processes must be standardized. Experts emphasized that companies structuring their data flows is essentially building the foundation for the DPP itself. Master data management is becoming a critical function in its own right, requiring a clear information model and strict policies for how data is defined, collected, and verified before being shared externally. However, this remains a challenge: “It is difficult to create universal data types because there are often several ways of measuring the same data.” (Expert 11)

The complexity of data management is directly dictated by product complexity and the size of the product catalog. “The more materials and parts a product has, the more complex the DPP creation becomes.” (Expert 2) Companies must establish processes to manage information granularity—specifically deciding whether exchangeable components and spare parts are managed as separate information packages. While manual data management might be feasible for a small number of products, it quickly becomes untenable as volumes increase. At scale, machine-readable, fully automated processes are required, utilizing standardized data formats that allow systems to communicate via Application Programming Interfaces (APIs). To begin this transition, several experts recommend conducting a "DPP demo" on a single pilot product. By manually breaking down one product into its constituent parts, a company can map its processes and data flows, providing a blueprint for the future task of generating DPPs for the entire catalog: “Take a sample product to begin with; use it to analyze the requirements and understand how everything is connected.” (Expert 4)

Similar to the experts, literature points out the establishment of routines for actively utilizing already available data within ones’ organization as a success factor, and a prerequisite, for DPP implementation [30]. Since data provided by suppliers often varies in granularity and format, the adoption of common data standards becomes essential for manufacturers seeking to compile the consistent, product-level information that DPPs require [35] [54]. Without such standards in place, implementation efforts risk becoming fragmented and costly, as organizations are forced to duplicate work and navigate incompatible systems independently [55]. In the context of DPPs specifically, Jensen et al. [21] argue that firms should not wait for regulatory mandates to force changes to their data processes, but should instead proactively redesign their data flows to support decision-making across the full product lifecycle, including reverse supply chain activities [21].

The themes from the experts and the literature in this dimension led to the creation of Questions 5 and 6 (see Figure 4.2). Question 5 focuses on the more general needs for standardized and documented processes while question 6 narrows these aspects down towards how far a company has come in developing a blueprint for DPPs. The readiness levels for Question 5 reflect a gradually higher usage of documented standards, with the lowest level indicating no usage. The recommendations focus on the advice from the literature and the experts to establish clear routines and get an overview of the information currently available to the company. In question 6, the readiness levels progress from a low level of structured DPP data to having a full, ready to use data model for creating DPPs. The recommendations in this area align closely with the experts’ strong advice to conduct a practical pilot or demo.

Depending on the company's current maturity level, this pilot can range from a manual mapping exercise of a single product to fully integrating a demo product into a working digital system. These recommendations also promote the proactive mindset recommended by Jensen et al. [21], since this is something companies can start doing before regulations enforce it.

4.1.5 Technical Infrastructure

Many smaller actors currently operate at a low level of digitalization, with IT infrastructure often limited to email, spreadsheets, and basic ERP systems. Despite these shortcomings, experts do not necessarily believe that companies must invest in a "solve-all" digital system specifically for the DPP. Instead, the integration of existing systems is seen as the key to success. As Expert 1 noted: "The key is integration. Previous trends focused on large IT systems that lock you in; today, modular systems that function like components are far more attractive." The primary task involves expanding existing IT environments with new functions that support DPP workflows: "Integration work means taking already available information and creating new columns in the ERP or information objects in the Content Management System (CMS)." (Expert 1) Experts consider it unviable for an SME to single-handedly develop and maintain the custom database structures and cloud solutions required for a DPP. One expert drew a comparison to standard business software: "We do not believe smaller companies will build their own DPP system, in the same sense that they do not usually build their own accounting systems." (Expert 7)

Consequently, the prediction is that most SMEs will adopt third-party market solutions or specialized DPP modules designed to plug into their existing software. Another central component of the technological infrastructure is the "bridge" between software and the physical product. Experts highlight the need for data carriers—such as URL-based QR codes, microchips, or RFID tags—to make information accessible. To ensure scalability for B2B customers and supervisory authorities, these carriers must be machine-readable, allowing external databases to automatically retrieve, validate, and manage information across a vast volume of articles: "For scalable use, you need a machine-readable instance so that the DPP behaves like a database." (Expert 7)

Literature identifies having access to digital technologies unlocking traceability and information transparency throughout product life cycles as a major driver behind DPP implementation [39]. To successfully do this, organizations are faced with a distinct operational ultimatum: they must either invest in physical IoT tracking infrastructure, such as Radio-Frequency Identification (RFID) sensors, or fully automate their existing manual data mapping procedures [35]. Research also indicates that technical systems such as ERP, Manufacturing Execution System (MES) and Enterprise Warehouse Management (EWM) prove essential for DPP implementation in manufacturing companies [35].

From these findings question 7 emerged (see figure 4.2). The readiness levels goes from a lack of digital infrastructure towards having the complete IT infrastructure

required for unique product identification and life cycle data tracking. The recommendations focus on acquiring baseline IT systems, integrating existing systems, and using data carriers-all of which were highlighted by the experts.

4.1.6 Ecosystem & External Support

For small companies, a crucial capability is the ability to navigate and leverage the external ecosystem in which they operate. As Expert 3 noted: “It will be time-consuming to prepare internally; there is a great need for external functions.” When internal competencies are lacking, trusted service providers with specialized knowledge become essential. “For SMEs that don’t have the knowledge in-house, it will require purchasing external expertise.” (Expert 8) The primary challenge lies in evaluating the market to make informed decisions and select reliable and appropriate consultants and providers. Expert 5 warn against silver-bullet solutions: “There are already opportunists claiming to have the definitive DPP tool, but if you haven’t already organized your master data, such tools are useless.” Consequently, companies must seek partners who understand the multifaceted nature of a DPP launch, encompassing the technological and regulatory requirements. Ultimately, the degree of external support is a matter of cost and a strategic trade-off between internal development and outsourcing. “For some, external help is a budgetary consideration, for others, it is a pure necessity.” (Expert 2)

Because the DPP must persist for the entire lifespan of the physical product, long-term recurring costs and administrative maintenance must be factored into the decision-making process. Companies active in sector-specific organizations, clusters, and networks hold a clear advantage, as these hubs are where information regarding new regulations like the DPP is disseminated. “You are notified of DPP-related developments through your industry association, allowing you to act early.” (Expert 2) Experts strongly favor strategic alliances and "coopetition" as effective measures for overcoming resource scarcity and low bargaining power with large suppliers: “By joining others, you gain collective bargaining power, which is highly effective.” (Expert 6) As an initial step toward higher readiness, experts recommend that companies engage with their current IT providers and industry networks immediately: “A vital first step is reaching out to your ERP or IT supplier to ensure an external partner is prepared to support these new requirements.” (Expert 7)

Literature also suggests that SMEs should engage external consultants in order to compensate for lack of internal competencies and provide assistance in formulating clear and effective strategies [56]. Furthermore, research indicates that SMEs would benefit greatly from external financial assistance with digital transformation, particularly highlighting the necessity of government grants and public funding initiatives [32].

For this dimension, questions 8 and 9 were developed (see figure 4.2). Question 8 evaluates awareness of the options for outsourcing the DPP versus managing it in-house, building on the experts’ emphasis on evaluating the market and being able to find the right provider. Following the experts’ advice, the recommendations for lower readiness levels suggest reaching out to current external partners. At higher

levels, companies are advised to compare alternatives financially in order to make an informed decision. Question 9 focuses on leveraging external, regional and sectoral collaboration, as emphasized by the experts, as well as securing financial support as noted in the literature. The recommendations connected to lower readiness levels suggest that companies seek out existing networks and potential regional initiatives and projects.

4.1.7 Value chain & Integration

According to the experts, Value Chain & Integration is the most critical dimension for SMEs. This is primarily because the DPP demands information from far beyond a company's own walls. Traceability and strong supplier relationships are vital: "As a company, you need to be aware that supplier relationships will be crucial." (Expert 6) To create a DPP, products must be mapped down to their smallest components and connected back through multiple tiers of suppliers. Currently, upstream traceability is lackluster. Expert 1 noted "It has been a challenge to collect data from suppliers, especially since if only a few purchasing companies understand the DPP requirements, their suppliers almost certainly do not." This creates a specific challenge when production occurs entirely outside the EU. In these cases, the importer bears the DPP responsibility but often lacks the necessary data access, as the provided data is frequently unstructured. "For production outside the EU, the information lies with the producer, but the responsibility to trace the value chain lies with the importer." (Expert 5) Furthermore, tracing raw materials back to their origin requires absolute transparency, a daunting task. As Expert 8 illustrated: "You might be able to trace critical raw materials to the distributor, but tracing them to the specific mine is a monster for an SME." Ultimately, data collection relies heavily on human cooperation: "When collecting data through the value chain, you need access to someone who is not only willing to share data but also shares trustworthy data." (Expert 10)

Another significant challenge for SMEs is their limited purchasing power. If a small company accounts for only a fraction of a supplier's turnover, it is incredibly difficult to enforce demands for transparency and traceability that require systemic change. "From a non-EU supplier's perspective, if you represent 0.02% of their turnover, it won't be easy to demand transparency." (Expert 11) Consequently, SMEs face the real risk of having to change suppliers, forcing them to strategically select their partners. "If you're a small actor, you might need to shift to suppliers where these standards already exist, because you can't force much change on your own." (Expert 6) Simultaneously, Expert 7 emphasize the importance of deep cooperation to overcome these hurdles. They refer to the "spiral of trust": "A group that trusts each other can solve harder problems, and the same principle applies to a value chain between companies." Experts also note that merely purchasing a physical product is no longer sufficient; product-related data must now be a mandatory part of the transaction. This means companies will have to update their existing supplier agreements. "It is no longer enough to sign contracts regarding physical products; moving forward, the data must be included." (Expert 7) As a practical first step, small businesses should immediately initiate dialogues with their suppliers regarding these

future requirements. Finally, experts point out that companies must clearly define their specific role and position within the value chain to fully understand the unique requirements the DPP will impose upon them.

The literature also reflects that the information exchange required for DPPs depends heavily on stakeholders' willingness to share data [50]. Jensen et al. [21] argue that manufacturers should therefore proactively map data availability across their supply chain relationships, both upstream with suppliers and downstream with service providers, and begin establishing shared data routines before regulatory mandates require them to do so. For SMEs in particular, who typically operate with a narrow supplier base and deep dependence on individual chain relationships [15], cultivating strong technological partnerships with value chain actors becomes especially critical [36].

The themes gathered from the expert interviews and the literature led to questions 10 and 11 being implemented into the tool (See figure 4.2). Question 10 measures the granularity and standardization of data collected from suppliers. Drawing on the literature, the recommendations suggest establishing collaborative routines with suppliers and ultimately digitalizing these processes. Meanwhile, question 11 focuses on visibility into the value chain. Lower readiness levels indicate little to no value chain visibility, whereas the highest level reflects full transparency and complete supplier knowledge. Based on the experts advice, the initial recommendation for lower readiness levels suggest reaching out to direct suppliers to explain DPP needs, and eventually formalizing product data as a required deliverable in vendor contracts and expanding visibility down to raw material suppliers.

Dimension	Question	Level 1	Level 2	Level 3	Level 4	Level 5
Leadership & Strategy	1. How well do you understand the demands the Digital Product Passport (DPP) (ESPR 2024/1781) will impose on your company and your sector?	We have only heard of the DPP, but we have not started reading what the regulation says or how it affects us.	We have started reading about the digital product passport regulation but have not yet gained a general understanding.	We have a general understanding of the requirements for digital product passports.	We have a good understanding of what the requirements are so far for digital product passports in our sector.	We have a complete overview of what the requirements are so far specifically for our sector, and we have an established routine for keeping up-to-date on upcoming additions to digital product passport regulations.
		1 → 2: Familiarize yourselves with the EU regulation Ecodesign for Sustainable Products Regulation (ESPR 2024/1781) which includes digital product passports.	2 → 3: Set aside time to deepen your knowledge of ESPR (2024/1781) and create a general understanding of the requirements placed on digital product passports.	3 → 4: Deepen your knowledge regarding the specific requirements placed on your particular sector in ESPR (2024/1781).	4 → 5: Establish a fixed routine to continuously stay updated on upcoming additions and delegated acts within ESPR (2024/1781).	
	2. To what extent does the company dedicate time and staff to working with the DPP?	No resources are allocated.	Occasional hours are allocated sporadically, and the work is not prioritized.	One person has been given responsibility but lacks the mandate or time to involve the rest of the organization.	Specific time is scheduled for a project group to work on implementing the DPP.	The company has dedicated resources and a clear budget in place to implement the DPP.
		1 → 2: Create an initial awareness of the issue and set aside initial time (even if sporadic) to investigate what Digital Product Passports (DPP) mean for your business.	2 → 3: Appoint a responsible person within the organization tasked with owning the issue, gathering knowledge, and starting a mapping of what is required.	3 → 4: Give the responsible person a clear mandate to anchor the work more broadly, form a project group, and ensure the group receives scheduled time for its work.	4 → 5: Transition from a temporary project structure to an established process by determining a clear budget and allocating dedicated, long-term resources for implementation.	
Human & Organization	3. To what extent do different departments cooperate and share product information?	No product information is shared between departments.	Information is shared only upon direct requests. There are no common systems or routines for data sharing.	Regular meetings are used to coordinate product data.	Shared digital workspaces are used to coordinate product data, but data must be entered manually.	Information regarding processes and products is shared automatically between departments in a common system.
		1 → 2: Establish routines and clear contact paths so that departments can begin requesting and sharing specific product information when needed.	2 → 3: Introduce regular meetings to share and discuss product information.	3 → 4: Establish shared digital spaces where data is collected and made available to everyone.	4 → 5: Automate the information flow of product and process data between departments.	
	4. How well prepared is your organization in terms of the competencies required to collect and manage the information the DPP demands?	The company possesses no specific knowledge regarding data collection or value chain traceability.	The knowledge exists but is isolated to a single employee (e.g., a sole sustainability manager).	The company has started mapping the competency needs and has begun conducting training to build an understanding of the new requirements.	The company has employees with competence in data collection and/or value chain traceability.	Employees have competence in sustainability, data tracking, and digitalization, and are continuously trained.
		1 → 2: Begin mapping which competence needs are missing in your business and compare options such as internal training or outsourcing.	2 → 3: Compare the options of training other employees or bringing in external help (outsourcing competence).	3 → 4: Acquire specific competence in data collection and/or value chain tracking based on the mapping performed.	4 → 5: Introduce a routine for continuous training related to data collection and value chain tracking.	
Processes & Data management	5. To what extent are the company's operational processes standardized and documented?	Processes are not standardized and are not documented.	Some documentation of processes exists on paper or in unstructured files, but routines vary.	Processes are documented, but a standard is not in place.	Processes are standardized and follow uniform routines.	All work follows strict, digitally documented standards that are adapted for external data sharing.
		1 → 2: Begin documenting processes by hand on paper to get an initial overview of the routines currently existing in the business.	2 → 3: Ensure all processes within the business are documented to get a full overview so that you can see which standards can be introduced.	3 → 4: Review the documented processes and introduce a standard that applies to all processes throughout the entire business.	4 → 5: Introduce strict, digitally documented standards that are adapted for external data sharing.	
	6. To what extent has the company defined a structured template for what will be included in your product passport?	We do not know what information is required or how it should be structured.	We have started looking at the legal requirements but have not made our own adaptation or list.	We have a rough list of information (manual or digital), but it is not formatted to be shared.yet gained a general understanding.	We have a finalized template that outlines exactly which data points should be included for each product group in our assortment.	We have a fully developed and digitally implemented data model that is ready to communicate with external DPP platforms.
		1 → 2: Find out which requirements are placed on your specific products in ESPR (2024/1781).	2 → 3: Create a product passport on paper for one or a few of your products to see what exists, what is missing, and where the missing information is located.	3 → 4: Create a template for how each product passport should look and which data points they should contain.	4 → 5: Digitalize the template and ensure it is ready to communicate with future DPP platforms.	
Technical Infrastructure	7. To what extent do you have the digital and physical systems (e.g., RFID, ERP, MES and PLM) required to uniquely identify products and store their lifecycle data?	We lack basic digital systems.	We have some basic digital systems, but they are primarily used for administration and are not connected to production or product identification.	We use standardized technical solutions (e.g., barcodes or a simple ERP system) to track products internally, but the systems are not integrated or ready for external data sharing.	We have a stable digital infrastructure with cloud-based storage and systems that enable external data sharing and unique identification of products (e.g., via QR codes).	We have an IT infrastructure that automatically captures, stores, and can share lifecycle data at the product level.
		1 → 2: Begin investigating systems that allow for the creation of digital product passports (ERP, PLM, MES) and see how these can be woven into your business.	2 → 3: Contact current IT providers and explain your needs regarding DPP; compare potential offers with other IT providers. Acquire technical solutions for internal tracking of products.	3 → 4: Expand existing systems so they allow for external data sharing and unique identification of products (e.g., via QR codes).	4 → 5: Develop your IT structure to be able to automatically handle and externally share data.	

Figure 4.2: Tool Anatomy

4.2 Tool implementation

This section presents the structure of the implemented web-based tool, which represents the version following pilot testing with six users, through which minor refinements to language, interface design and available response options were incorporated based on user feedback. The mechanisms behind the tool output are also described in detail. The full interface of the tool is presented in Appendix B

4.2.1 Tool structure

The tool consists of three pages. The first page provides the user with a brief description of the DPP and the ESPR, establishing the regulatory context before the assessment begins. The second page contains the questionnaire itself, presenting the questions and readiness levels described in Figure 4.2. For a detailed view of

the questionnaire see figures B.3-B.8 in Appendix B. A commenting function is present at every question to allow users to provide contextual notes and feedback. Furthermore, a checkbox is also present at each question, enabling users to indicate whether external help is being used for the function in question. Together, these features make the tool suitable as an instrument for further validation and data collection, enabling the gathering of structured feedback from users at scale. The third page presents the tool output, consisting of a radar plot visualizing the user's readiness across all dimensions, together with an overview of the answered questions and their corresponding recommendations as described in Figure 4.2.

4.2.2 Tool output

Once all questions have been answered, the user is given a score in each dimension presented in a radar plot. The dimension score is calculated as the mean of its constituent question scores using the following equation:

$$S_d = \frac{1}{n_d} \sum_{q=1}^{n_d} s_q \tag{4.1}$$

where S_d is the final score for dimension d, n_d is the number of questions in that dimension (taking into account the modularity option described in section 4.2.1), and s_q is the score given to question q. As no large-scale validation with SMEs was conducted, the study lacks the empirical sample size required for statistical weighting. Therefore, this model employs equal weighting, which, according to the OECD [57], is the standard methodological approach to avoid introducing unjustifiable subjective bias. This equally weighted baseline for the model was also recommended by the experts

5
Discussion

5.1 Answering the research questions

The first research question, "which readiness dimensions most strongly predict DPP implementation success", is addressed through the six dimensions developed in this study. Based on the expert interviews, Value Chain & Integration emerged as the most critical dimension, as experts consistently identified the challenge of collecting structured data from upstream suppliers as the primary barrier to DPP implementation. Leadership & Strategy was identified as an essential prerequisite, given that without management commitment and regulatory awareness no meaningful progress across other dimensions is possible. The remaining dimensions: Human & Organization, Processes & Data Management, Technical Infrastructure, and Ecosystem & External Support were each identified by the majority of experts as significant, as reflected in Table 4.1.

The second research question, "how the identified readiness dimensions can be operationalized into a structured self-assessment tool for SMEs", is answered through the tool developed in this study. Each dimension was translated into one or two questions designed to capture its most critical aspects, accompanied by five-level scoring rubrics grounded in expert testimony and existing literature, and concrete recommendations guiding users toward the next readiness level. Together the questions, scoring levels and recommendations make up the operationalization of each dimension into a format accessible to SMEs. Whether this operationalization produces consistent and reliable results across different users and sectors however remains untested, as the full-scale validation needed to verify this fell outside the scope of the present study.

5.2 Findings compared to literature

The six dimensions that emerged from the expert interviews show a broad correspondence with the barriers identified in the theory chapter. Across the social, technical and environmental dimensions of the STST framework, the tool's dimensions collectively address several key challenges SMEs face in DPP implementation. However, the fit is not uniform, and some barriers identified in the theory chapter are only partially captured by the tool's current design.

Within the social dimension, the Leadership & Strategy dimension directly responds to the barrier of absent digital strategy and limited management commitment.

Where the literature highlights that SMEs frequently lack a clear strategic rationale for digital investment [27], the tool addresses this by assessing both regulatory awareness and resource allocation. However, one barrier from the theory chapter is not fully reflected: the difficulty of quantifying the business case for digital investment [28]. A company may recognize the DPP regulation and have assigned internal responsibility, and thus score well on this dimension, while still being unable to justify the investment financially, a gap the current questions do not capture. Similarly, the Human & Organization dimension responds to the persistent barriers of internal knowledge gaps [29, 30] and departmental siloing [33] mentioned in the theory chapter. Yet the theory also identifies a more operational barrier: the pressure of day-to-day activities consistently being prioritized over longer-term implementation efforts [31] [32]. This time-constraint dynamic is not directly measured by the competency and communication questions in this dimension, meaning a well-organized but operationally strained SME could be underrepresented in its readiness challenges.

Within the technical dimension, the Processes & Data Management dimension addresses the barriers of insufficient use of technical standards [14] and underdeveloped data-driven processes [29]. The Technical Infrastructure dimension responds to barriers around legacy IT systems and data carriers [35, 34]. However, the theory chapter also explicitly identifies data privacy and security concerns as a distinct technical barrier [35]. This aspect is arguably left underrepresented in the tool's questions.

Within the environmental dimension, the Ecosystem & External Support dimension directly addresses the barrier of insufficient awareness of external partners [27] and the need for outside expertise [36, 37]. The Value Chain & Integration dimension responds to the limited purchasing power and dependence on individual supplier relationships that SMEs face [15], and the declining traceability observed among upstream value chain actors [14]. Taken together, the dimensions provide broad coverage of the barriers described in the theory chapter, but the correspondence is stronger for some barriers than others.

5.3 Theoretical implications

This study makes several contributions to the nascent literature on DPP readiness and maturity modeling. First, by developing a readiness assessment tool explicitly targeted at SMEs, this study addresses a gap acknowledged by Petrik et al. [13], who explicitly flag that their DPP maturity model may be unmanageable for SMEs. Furthermore, where Petrik et al. [13] structure their model primarily around data supply, data management, and supply chain integration, the tool developed in this study takes a broader view of DPP readiness. By incorporating dimensions such as Leadership & Strategy, Human & Organization, and Ecosystem & External Support, this study argues that technical and data-related capabilities alone are insufficient to capture the full scope of challenges SMEs face in DPP implementation, a perspective strongly supported by both the expert interviews conducted in this study and a broad body of literature on digital transformation, I4.0 and DPP adoption [48,

49, 36, 30]. Furthermore, this study contributes to the literature on readiness tools tailored to SMEs in the larger context of digitalization and I4.0, addressing a scarcity previously identified by Mittal et al. [15].

This study also contributes to the discussion around theoretical framing in digital transformation research raised by Amanollahnejad et al. [24]. The emergence of six dimensions from the expert interview data, which mapped coherently onto the three STST dimensions, provides support for the framework's applicability in the DPP-SME context. While the Gioia methodology was helpful in mapping the dimensions onto the STST dimensions, it also proved a productive approach for developing maturity model dimensions from qualitative data. The inductive-then-abductive approach allowed dimensions to emerge from practitioner knowledge before being validated against existing theory. This methodological combination may be of interest to future researchers developing similar diagnostic tools in emergent regulatory contexts, where established frameworks are limited and practitioner knowledge is particularly valuable.

5.4 Practical implications

This study delivers a concrete tool that CIT and similar organizations can deploy in their ongoing work with SMEs navigating DPP implementation. As mentioned previously, CIT has been actively involved in mapping DPP readiness among SMEs through projects such as CIRPASS2 [17] and the Halland knowledge node prestudy [16], through which a need for a structured readiness assessment instrument was identified. The tool developed in this study directly responds to this need, providing an accessible and structured means of evaluating SME readiness across the dimensions identified in this study. That said, as the tool has not yet undergone full-scale validation, its results should be interpreted as indicative rather than definitive, and its practical utility across different sectors and company sizes remains to be confirmed through further testing. CIT and other potential organizations deploying the tool are encouraged to treat the results as a basis for dialogue with SMEs rather than as absolute scores, using the radar plot to facilitate conversations about priorities and next steps rather than drawing firm conclusions about a company's readiness. As the regulatory landscape around ESPR and DPPs continues to develop, the tool's dimensions and recommendations will also require periodic review to ensure continued alignment with evolving requirements.

For SMEs themselves, the tool offers a low-threshold entry point into understanding their own readiness. Rather than requiring external consultants or specialist knowledge to interpret, the web-based format and embedded recommendations are designed to be self-administered and yield an instant result, allowing a SME to quickly and independently identify their strongest and weakest dimensions and receive prioritized guidance on where to focus their efforts. This is particularly valuable given that SMEs consistently lack the dedicated resources and time needed for digital transformation efforts [31, 32], making an easy-to-use, self-administered tool more accessible than engaging external consultants, at least as an initial step towards DPP implementation. Furthermore, as the expert interviews highlighted, the

market for DPP solutions is increasingly populated by providers claiming to offer definitive tools, making it difficult for SMEs to evaluate their options objectively. By establishing an independent baseline understanding of their own readiness before engaging external partners, SMEs are better positioned to identify which kind of support they actually need and critically evaluate whether a given provider or solution is genuinely suited to their situation.

5.5 Quality of the thesis

Following the recommendations of Creswell and Creswell [44], multiple strategies were used in order to ensure qualitative validity. Specifically, data triangulation was enabled by utilizing various data sources, including both expert interviews and existing literature. The study's validity was further enhanced through member checking [44]; the same experts who informed the tool's dimensions, questions, readiness levels, and recommendations also pilot-tested the instrument, ensuring their continuous influence on the final output. Furthermore, the study presents discrepant information such as in the critique against one-size-fits-all readiness models raised by experts and literature [15] [41] in section 5.6, which according to Creswell and Creswell [44] adds to the overall credibility of the study. In order to ensure qualitative reliability of the study, several steps recommended by Gibbs [58] were followed, including thorough checking of the interview transcriptions to avoid user and AI errors, as well as cross-checking codes between the authors to minimize biases in the coding process.

5.6 Limitations & Future research

Given the novelty of DPPs and the current scarcity of existing literature, a purposeful sampling strategy was employed. Participants were selected specifically for their deep knowledge and professional expertise regarding the DPP landscape. While this approach was necessary to gather foundational insights, it introduces certain limitations. Notably, there is a risk of selection bias, as all interviewed experts held generally positive or proactive views regarding DPP implementation; no experts fundamentally opposing or highly critical of the regulation were included in the sample. Furthermore, while the participants are highly knowledgeable about the overarching subject, they do not themselves belong to the target demographic of the proposed tool. Consequently, their insights represent an external expert perspective rather than the lived, operational realities of the SMEs that will ultimately utilize the tool.

For the purpose of qualitative, exploratory research design the sample size of 11 experts is adequate, this is supported by the concept of information power mentioned in Malterud et. al. [47]. Because the selected participants had specialized expertise on the subject matter the data yielded from each interview was rich and concentrated, reducing the need for a larger sample size. It is also supported by the nascent nature of the DPP subject limiting the actual population of subject matter experts. Most importantly it became evident during the data analysis phase that practical data saturation was reached, core concepts and insights stopped emerging and the

later interviews instead reinforced the consensus that was forming. Combining these conditions with the practical time constraint of a master's thesis, depth and quality of the data was deemed sufficient to fulfill the aim of the study of designing a functional readiness assessment tool.

Due to a low response rate from contacted SMEs and the thesis constrained time frame, no full-scale validation on a broader sample was conducted. This means that whether the tool performs equally well across different sectors remains an unanswered question. Moreover, experts raised concerns about the feasibility of designing a generalized readiness tool for all sectors, making this question particularly relevant. Although the delegated acts that will specify the detailed DPP requirements for each product category have yet to be finalized, experts anticipate that these will differ across sectors, potentially limiting the practical applicability of a general model. This critique is echoed by Mittal et al. [15], who argue that I4.0 has different meanings and implications for different industries, and that SMEs need to develop their own tailored vision rather than following a generalized model. So, while the tool's dimensions were designed to be broadly applicable across ESPR-covered sectors, the recommendations produced at each maturity level may lack the sector-specific depth needed to be fully actionable. This limitation mirrors the broader issue in maturity model design discussed in the theory chapter, where Röglinger et al. [41] found that models broad enough to be widely applicable tend to lose the prescriptive guidance needed to be truly useful in practice.

The pilot testing also led to several areas for improvement that could not be incorporated into the tool within the scope and time frame of this study. One expert noted that the recommendations embedded in the tool are relatively brief and would benefit from greater detail, as well as links to further reading materials to guide users seeking more in-depth guidance. Another expert highlighted the absence of questions addressing product and portfolio complexity, noting that the number of materials, components and supply chain tiers involved in a product directly increases the challenge of DPP implementation, an area that the current tool does not explicitly capture. The same expert also suggested two additional questions: one measuring the degree of influence a company holds over its value chain, and one targeting data trustworthiness by distinguishing between self-declared data and information verified by an independent third party. Finally, several experts noted that some questions may be difficult for companies to answer with confidence at this stage, given that the delegated acts specifying the detailed DPP requirements for each product category are still under development. These represent valuable directions for future iterations of the tool.

As a direct continuation of this study, the natural next step for CIT is to validate the proposed readiness tool across a cross-sectoral sample of SMEs. Large-scale testing is required to clarify whether sector-specific score weighting is necessary and to determine if a universal 'one-size-fits-all' model is useful in the context of DPP readiness assessment for SMEs. Beyond the scope of this specific instrument, these questions point to a broader gap in the research field which still remains unanswered.

While the readiness tool developed in this study provides a valuable static snapshot of an SME's current capabilities, future research includes understanding how this

readiness evolves dynamically over time. As the delegated acts within the ESPR are released and enforced, observing the maturation curve of SMEs will be crucial for evaluating the long-term effectiveness of various implementation strategies. A critical factor in these strategies is the ability to navigate complex supply chain relationships. This thesis has highlighted the struggle SMEs face in enforcing transparency demands due to their limited purchasing power, consequently, a potential future path for research involves examining the evolving power dynamics between LEs and SMEs, specifically investigating how regulatory tools like the DPP might influence these imbalances. Ultimately, as SMEs move beyond mere compliance, future research should expand to explore the alternative business models enabled by the DPP, analyzing how these emerge and adapt across different industry sectors.

6
Conclusion

This study set out to answer two research questions: which readiness dimensions most strongly predict DPP implementation success, and how the identified readiness dimensions can be operationalized into a structured self-assessment tool for SMEs. In response to the first research question, six readiness dimensions were identified through expert interviews: Leadership & Strategy, Human & Organization, Processes & Data Management, Technical Infrastructure, Ecosystem & External Support, and Value Chain & Integration. Of these, Value Chain & Integration emerged as the most critical by experts, indicating that the collection of data from upstream suppliers is the primary barrier to DPP implementation for SMEs. The remaining dimensions were also each supported by the majority of experts. In response to the second research question, the six dimensions were operationalized into a web-based self-assessment tool consisting of eleven questions, each accompanied by five-level scoring rubrics and recommendations guiding users toward the next readiness level. The tool produces a radar plot visualizing a company's readiness across all dimensions and was pilot tested with five users.

By developing a tool explicitly targeted at SMEs, this study addresses a gap in the research field on DPPs. Methodologically, the study demonstrates the applicability of the Gioia methodology [1] for developing maturity model dimensions from qualitative data in emerging regulatory and technological contexts. In practice, this study delivers a research-based tool that SMEs can use to assess their readiness and which CIT, and similar organizations, can further improve upon and use in their future work with DPP readiness.

Certain limitations must be acknowledged. The tool has not yet undergone full-scale validation on SMEs and should not be seen as definite. Also, experts and literature warn of the limited usability of generalized readiness tools [15] [41]. Furthermore, DPPs exist in a changing regulatory landscape and since the delegated acts for each product category are not yet finalized, the tool will most likely need updates when these are published. Future research should focus on cross-sectoral validation to determine whether sector-specific score weighting is necessary and if a generalized readiness tool is useful for SMEs in the context of DPP implementation.

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A

Interview guide

Introductory information:

We are recording the meeting to facilitate transcription, and anything we use in our report will be kept anonymous. Is this okay with you?

We will, of course, send our report to you when it is finished. If you'd like, we can even send it to you before it is published.

Questions:

Demographics:

1. Tell us a little about your company and your role in it. (What does the company do? What sector? How many employees?)

Prior knowledge ragarding DPP:

1. Do you/does your company work with DPP?
2. Do you work with similar areas, such as digitalization?

DPP:

1. What needs to be in place at a company before it is possible for them to produce DPPs?
2. What challenges in the creation of DPPs do you see as the biggest obstacles for small to medium-sized enterprises (SMEs)?
3. Can these factors be divided into different categories/dimensions? If so, what would they be?
4. What do different readiness levels look like within these dimensions? Not ready, somewhat ready, more ready, and fully ready?
5. Can a company work on increasing readiness across all these dimensions simultaneously? Or are there dimensions that depend on others?
6. What concrete steps can companies take in each dimension to increase their readiness?
7. Will these steps look different depending on the company's sector?
8. Will these steps look different depending on the company's size?
9. Have you measured digital readiness or readiness for DPP?
   (a) Are there any methods you currently use to measure digital readiness or readiness for DPP?
10. What kinds of questions can be used to map out/assess a company's readiness level within the different dimensions?

Concluding questions:

1. Do you know anyone else who you think we would benefit from interviewing?

2. Are you okay with us potentially contacting you again if we have further questions later on?
3. Is there any reason to weight the results differently for different sectors? And for different sizes of companies?

B

Webpage

In this appendix the web-based tool is presented as it is shown to the user on the webpage, the different sections represent different pages and the pictures are ordered as shown on the page.

B.1 Homepage

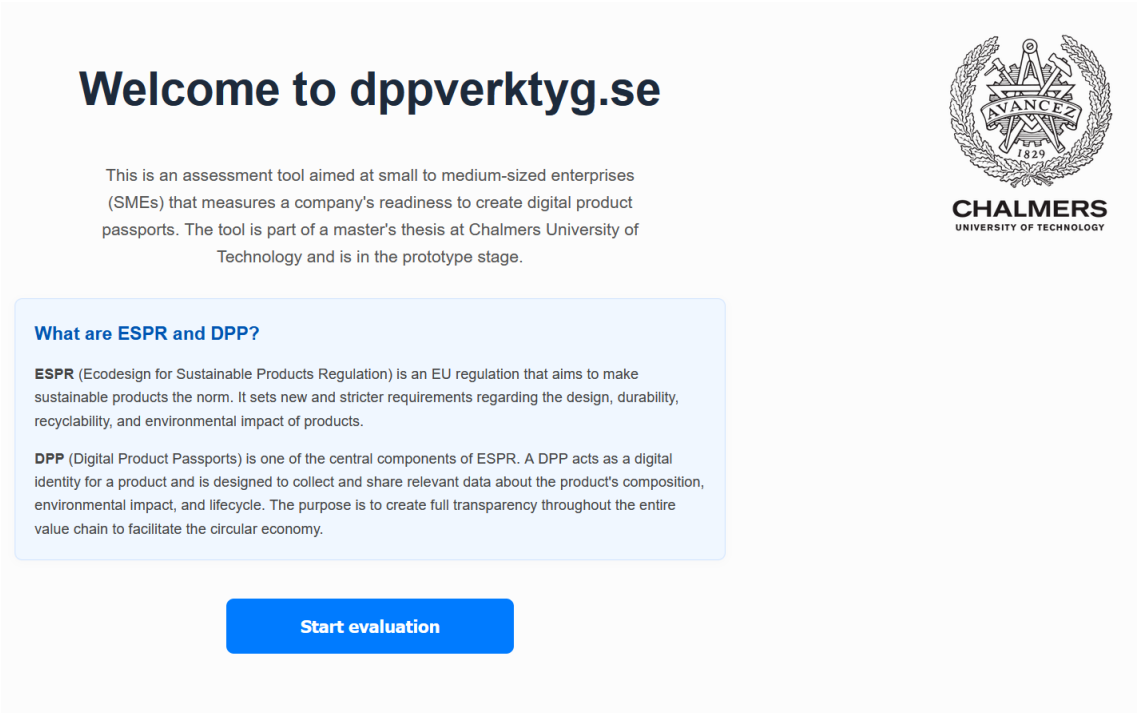

Figure B.1: Homepage

B.2 Survey

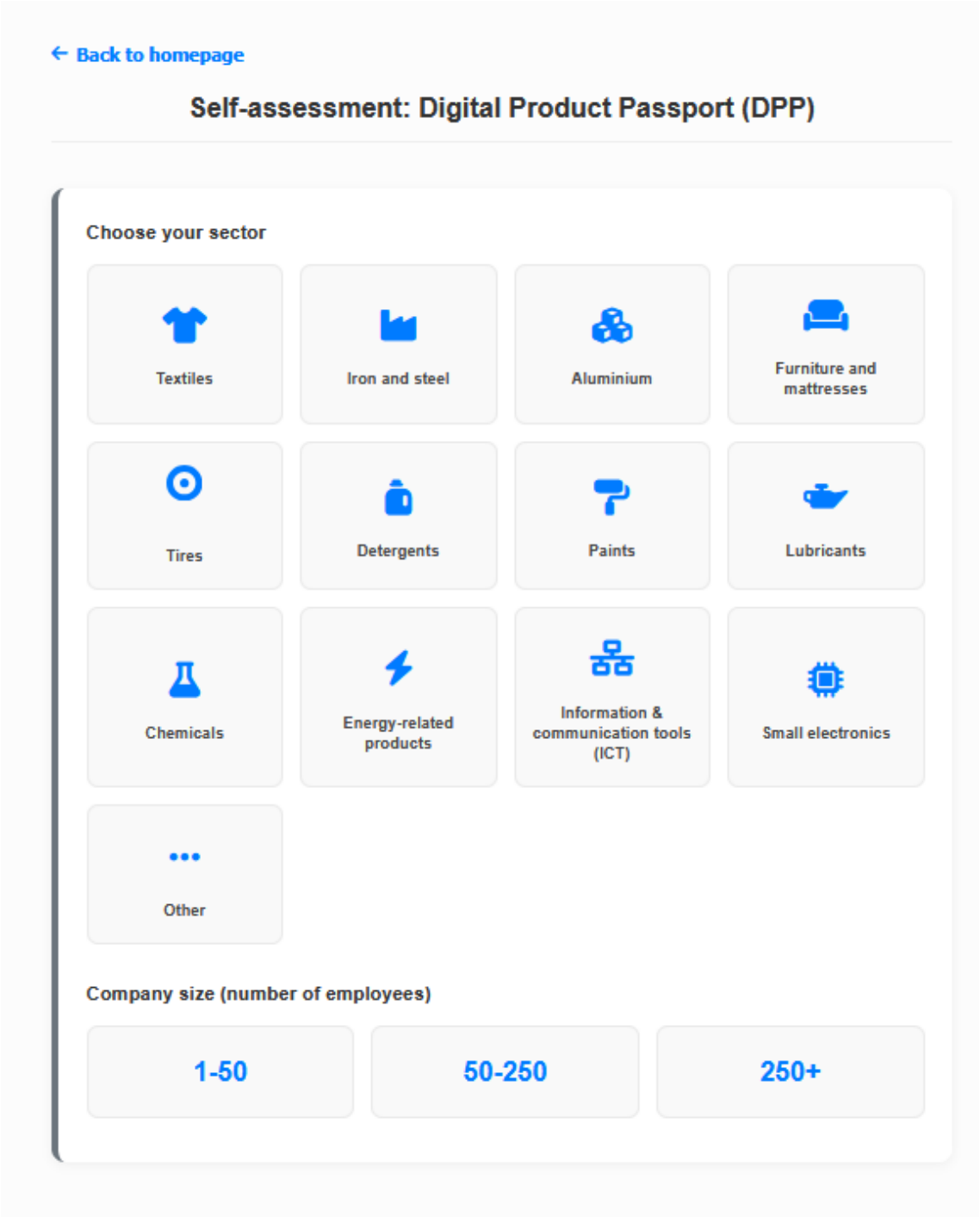

Figure B.2: Choosing sector & size

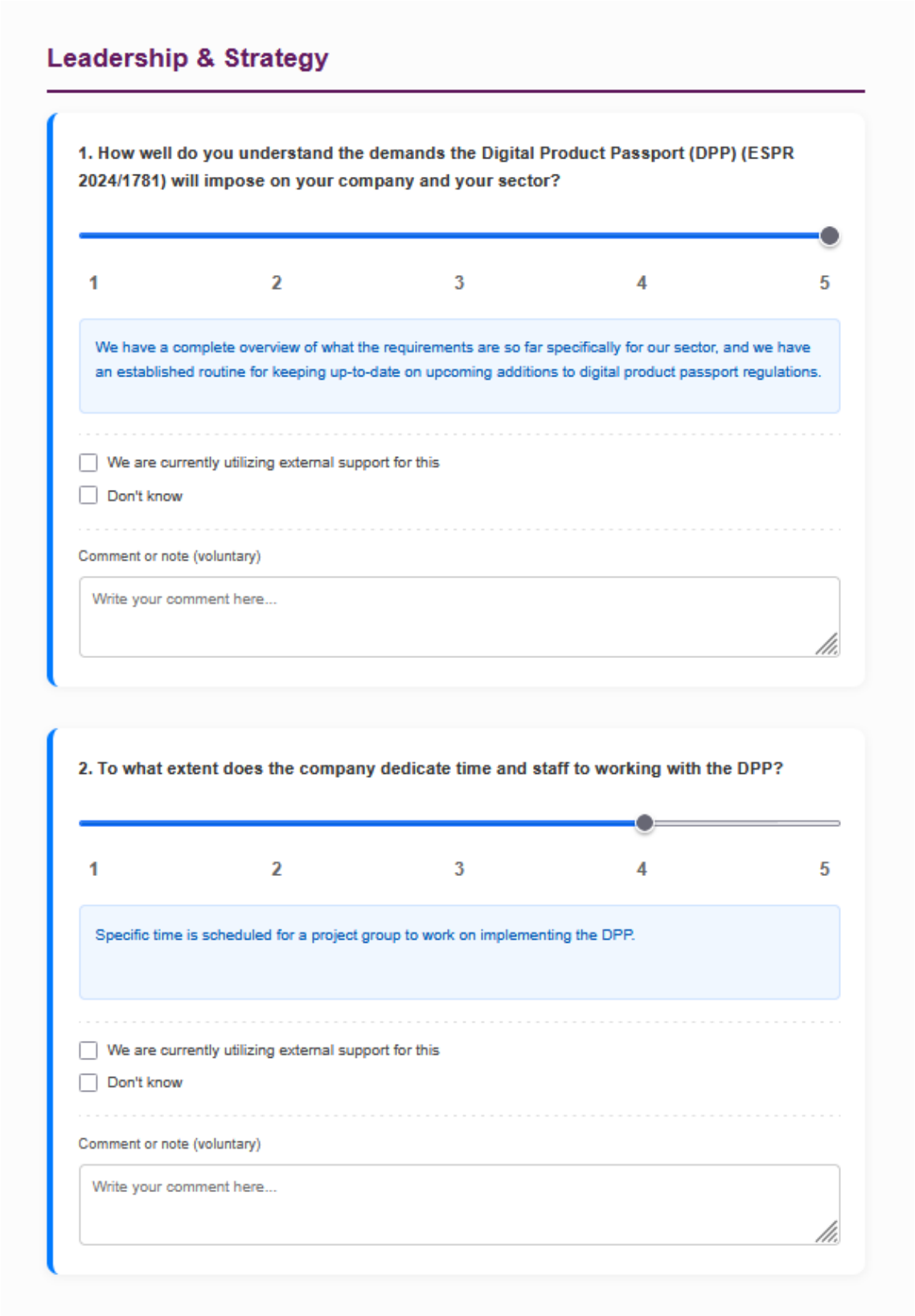

Figure B.3: Leadership & Strategy

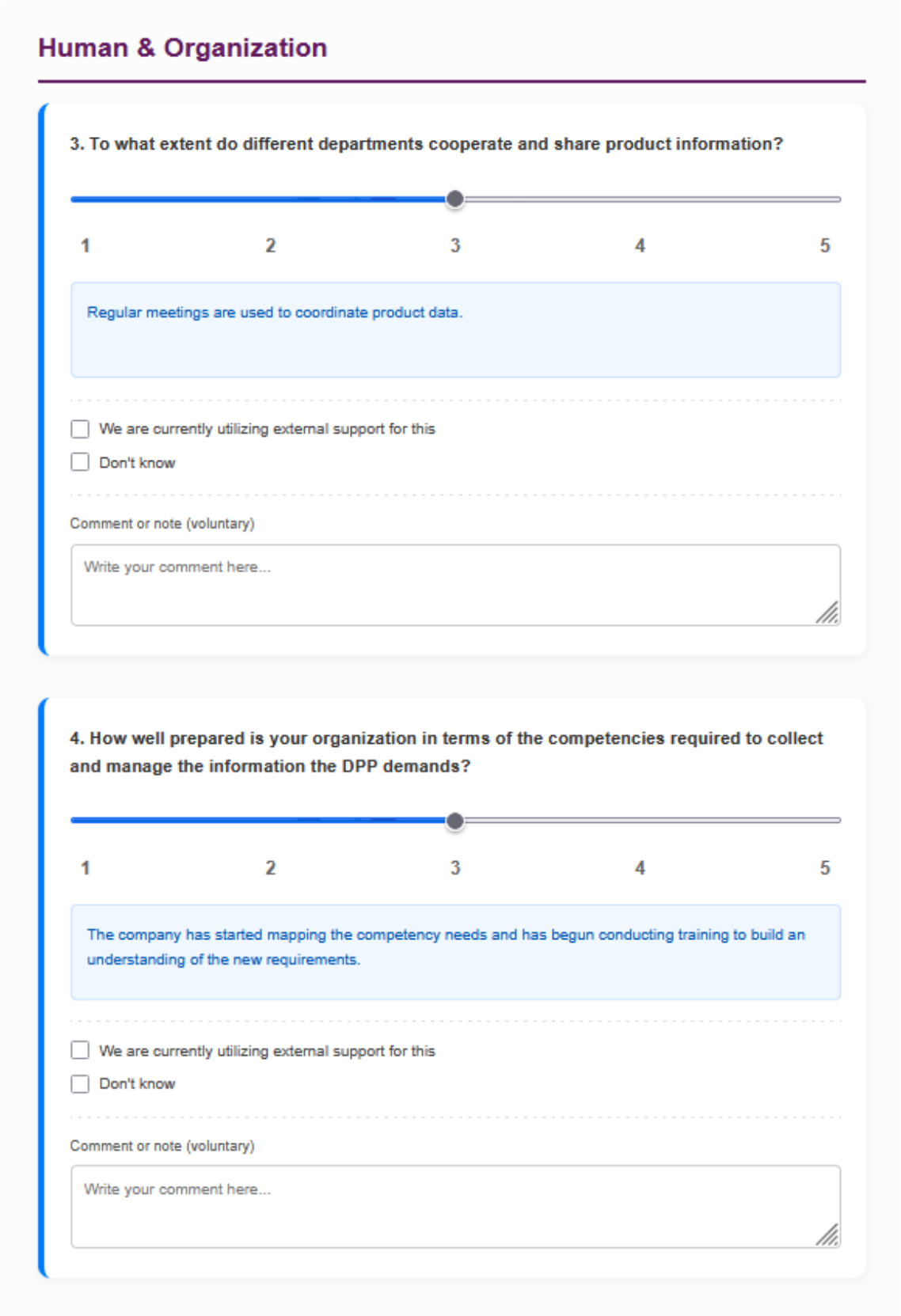

Figure B.4: Human & Organization

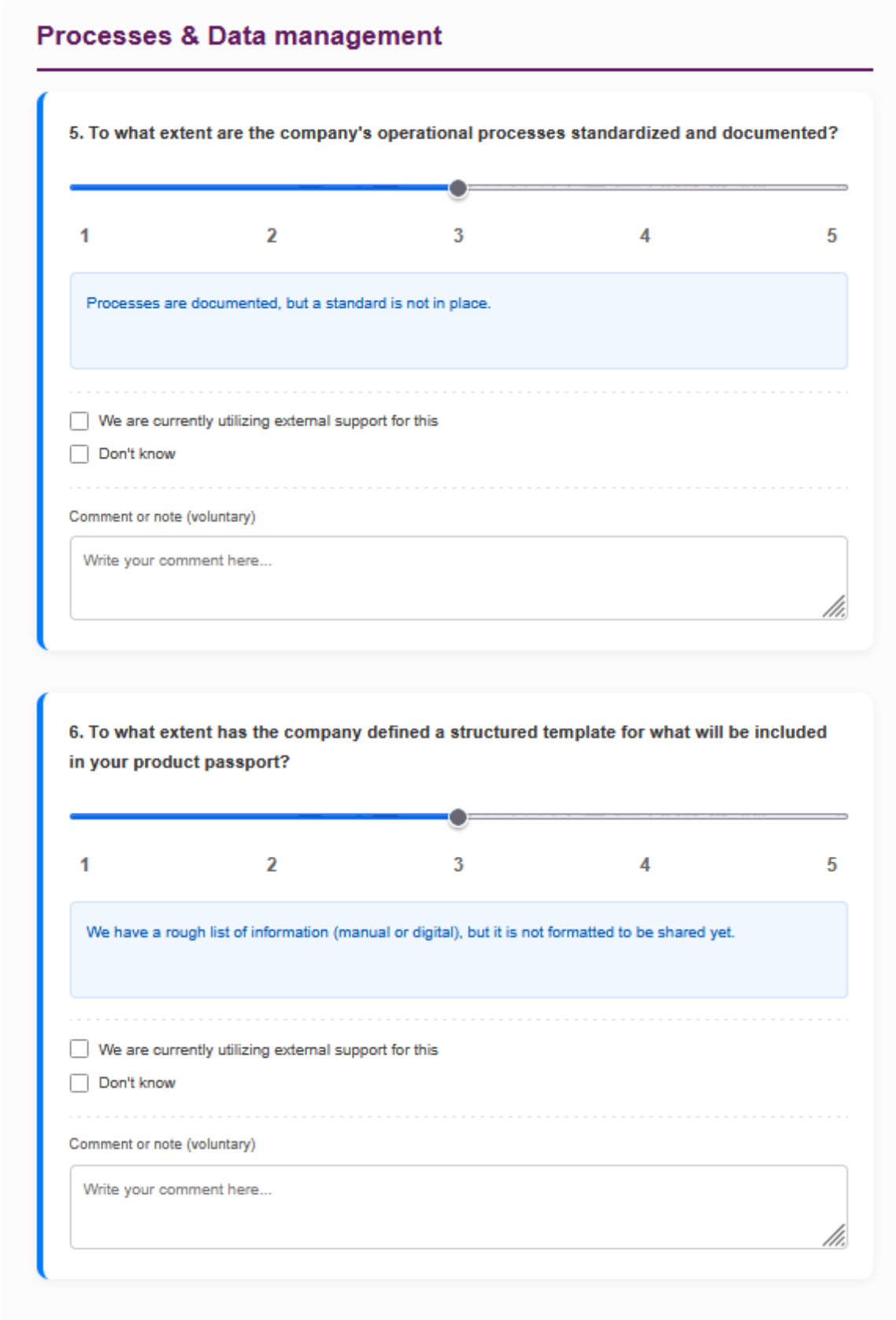

Figure B.5: Processes & Data management

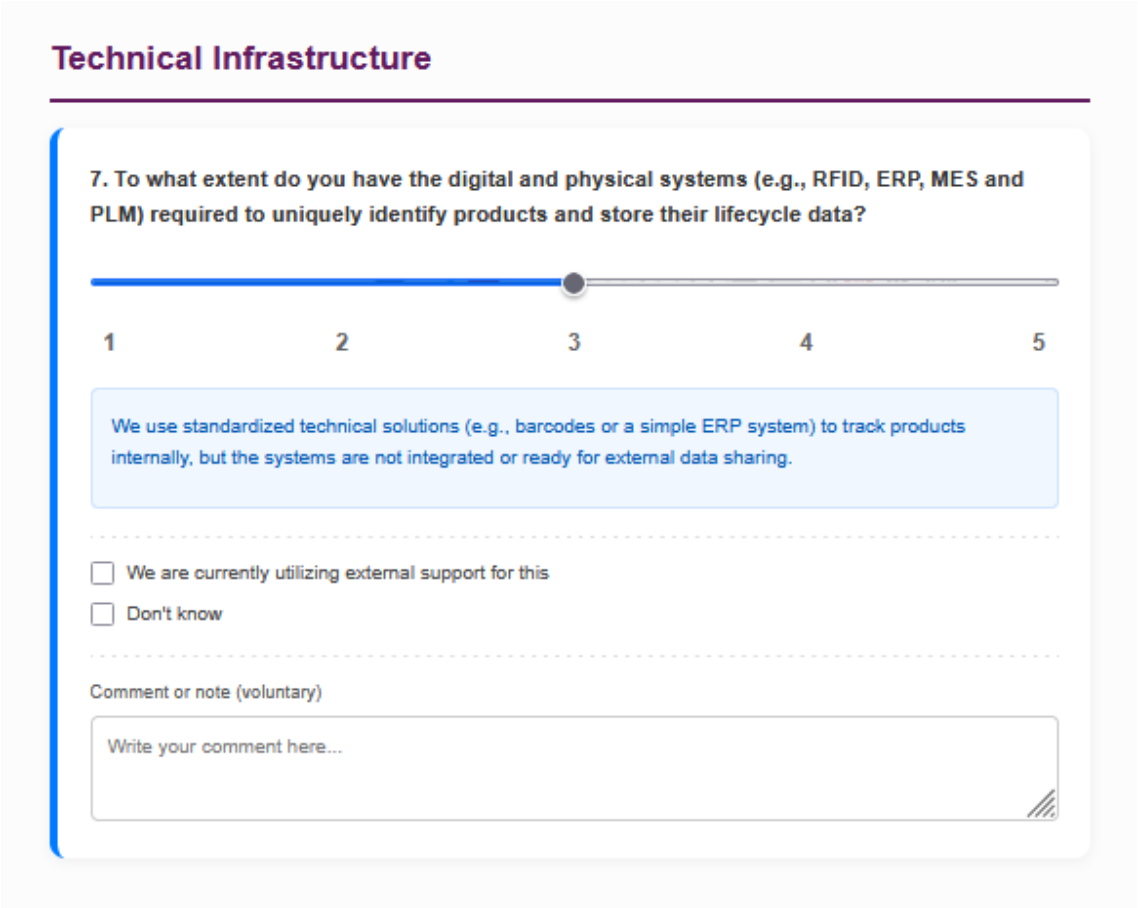

Figure B.6: Technical Infrastructure

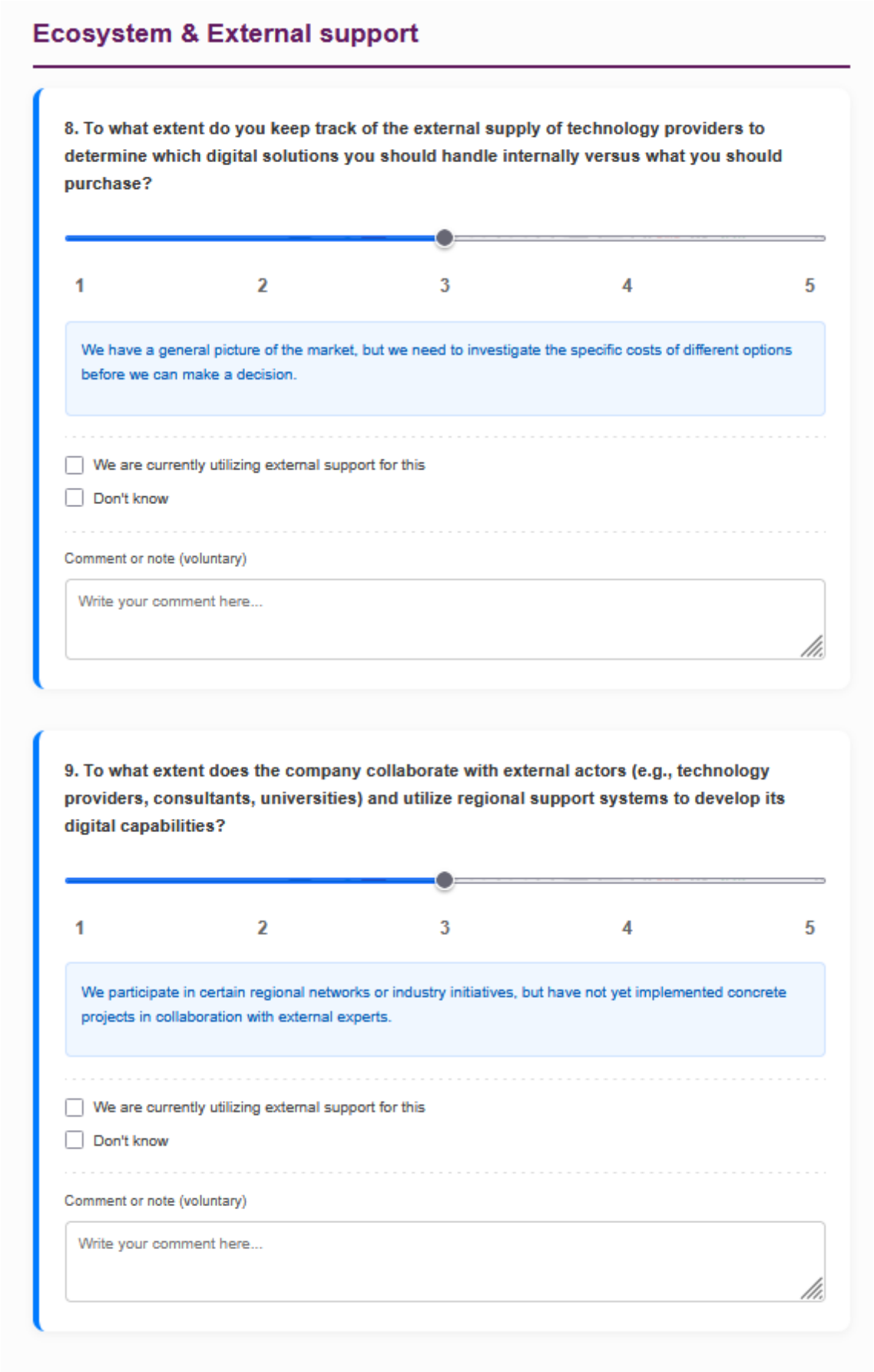

Figure B.7: Ecosystem & External support

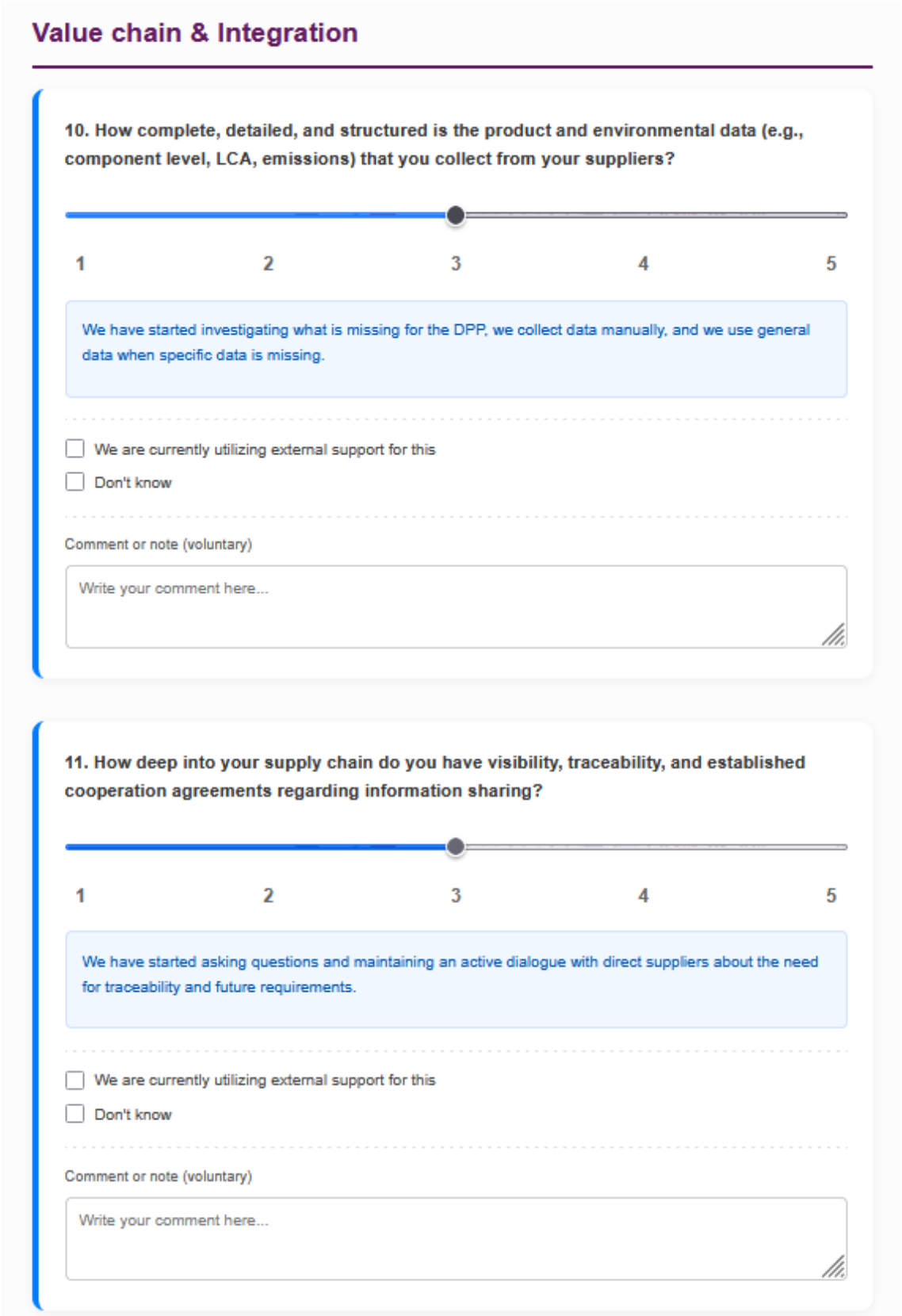

Figure B.8: Value chain & Integration

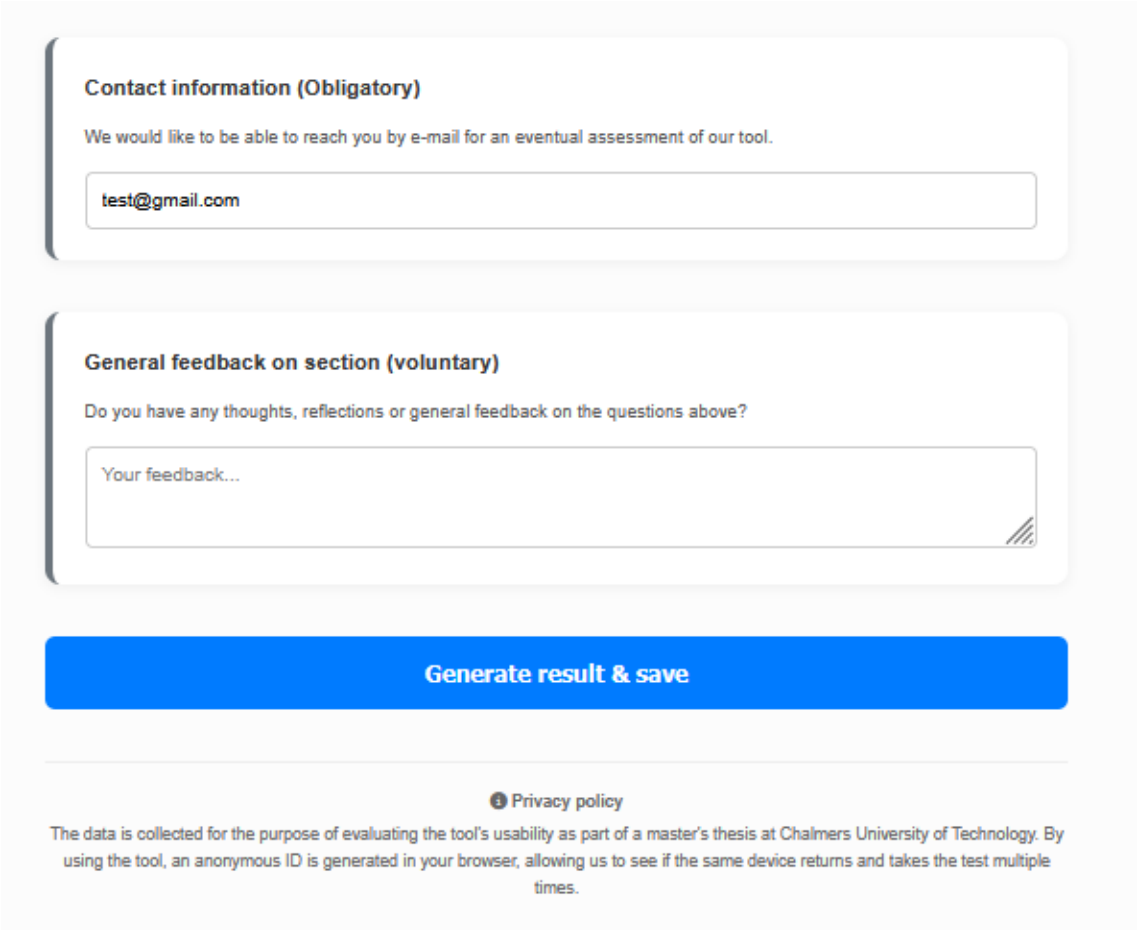

Figure B.9: Contact info & Feedback

B.3 Results and Playbook

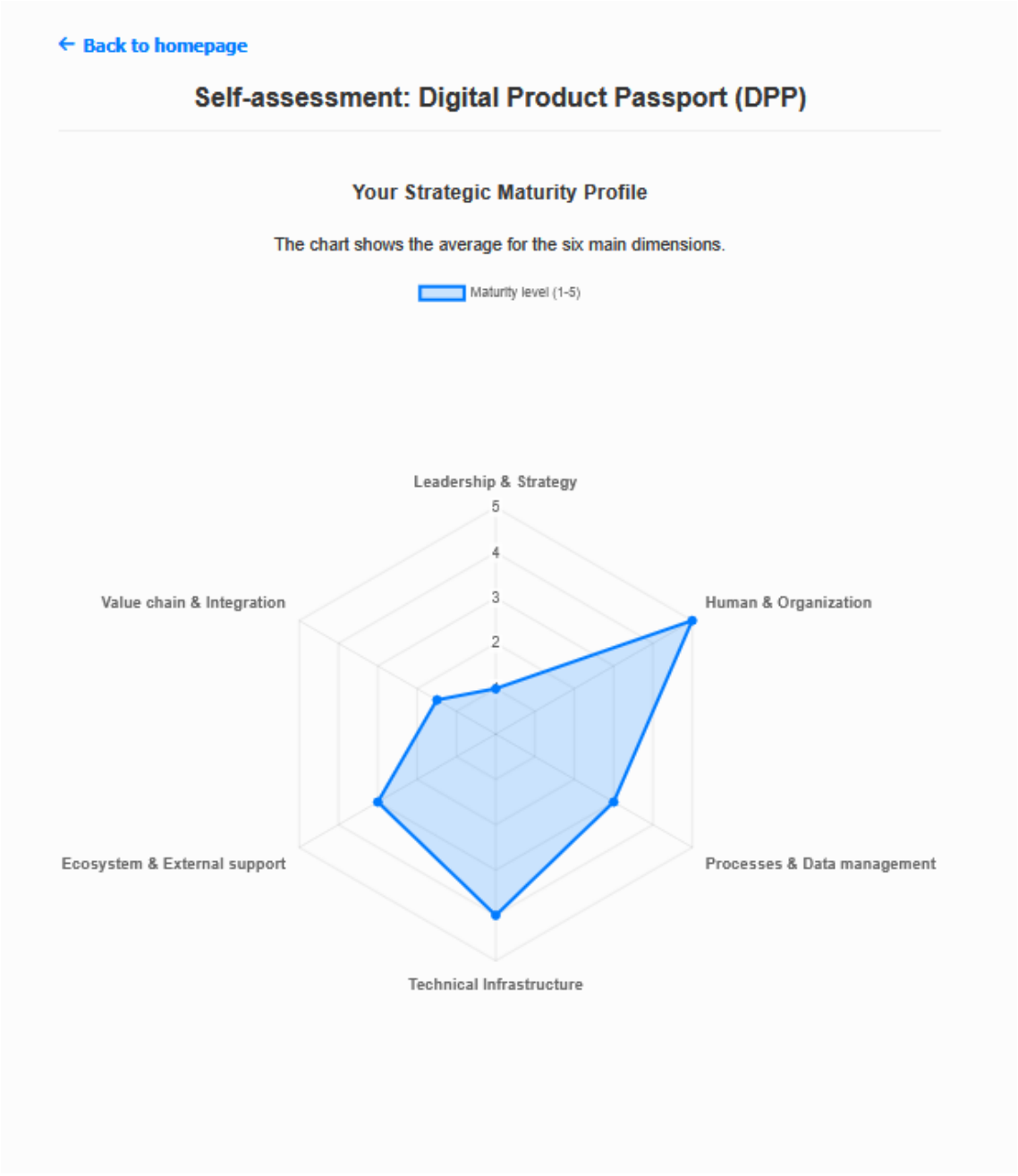

Figure B.10: Radar plot

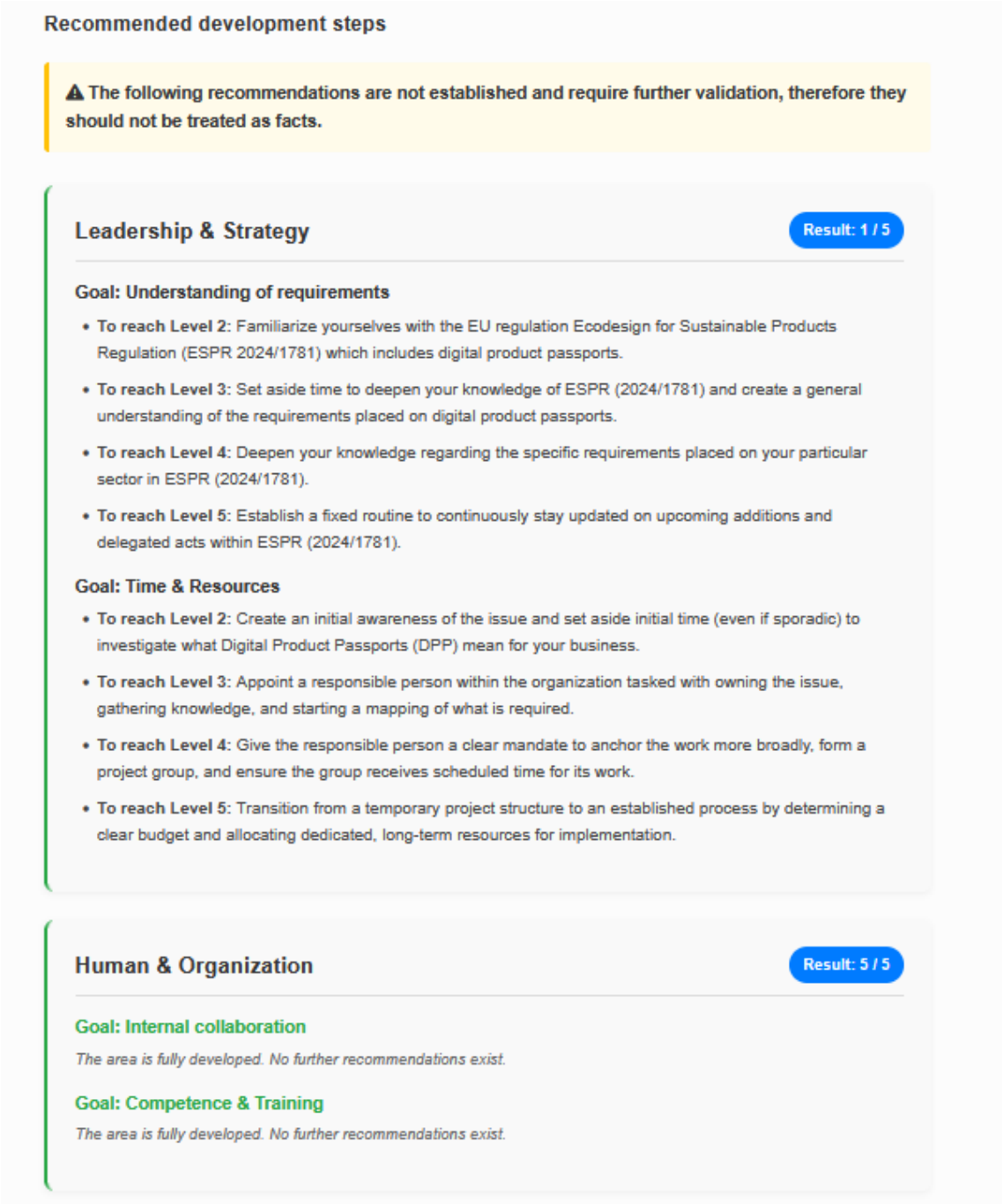

Figure B.11: Recommended steps for different levels (1)

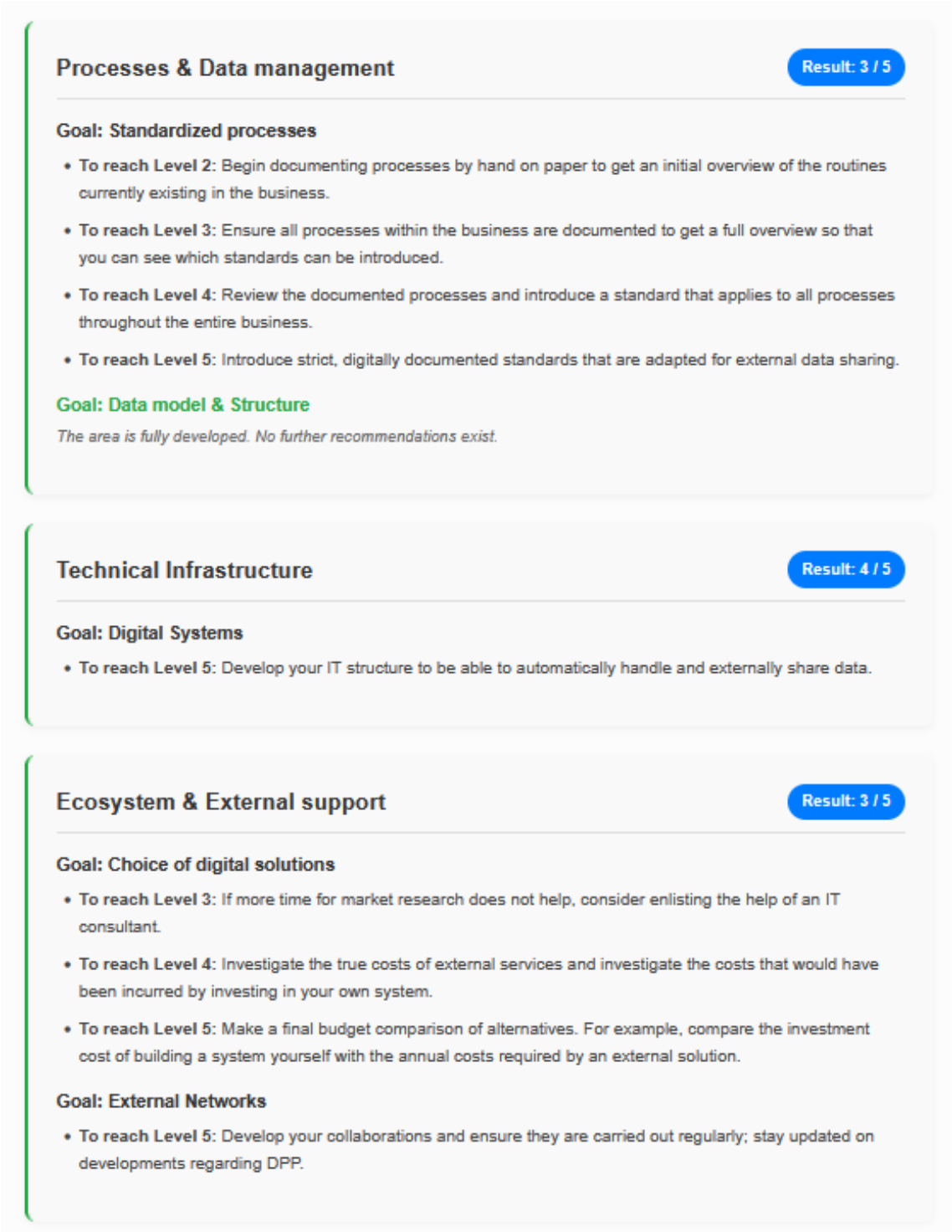

Figure B.12: Recommended steps for different levels (2)

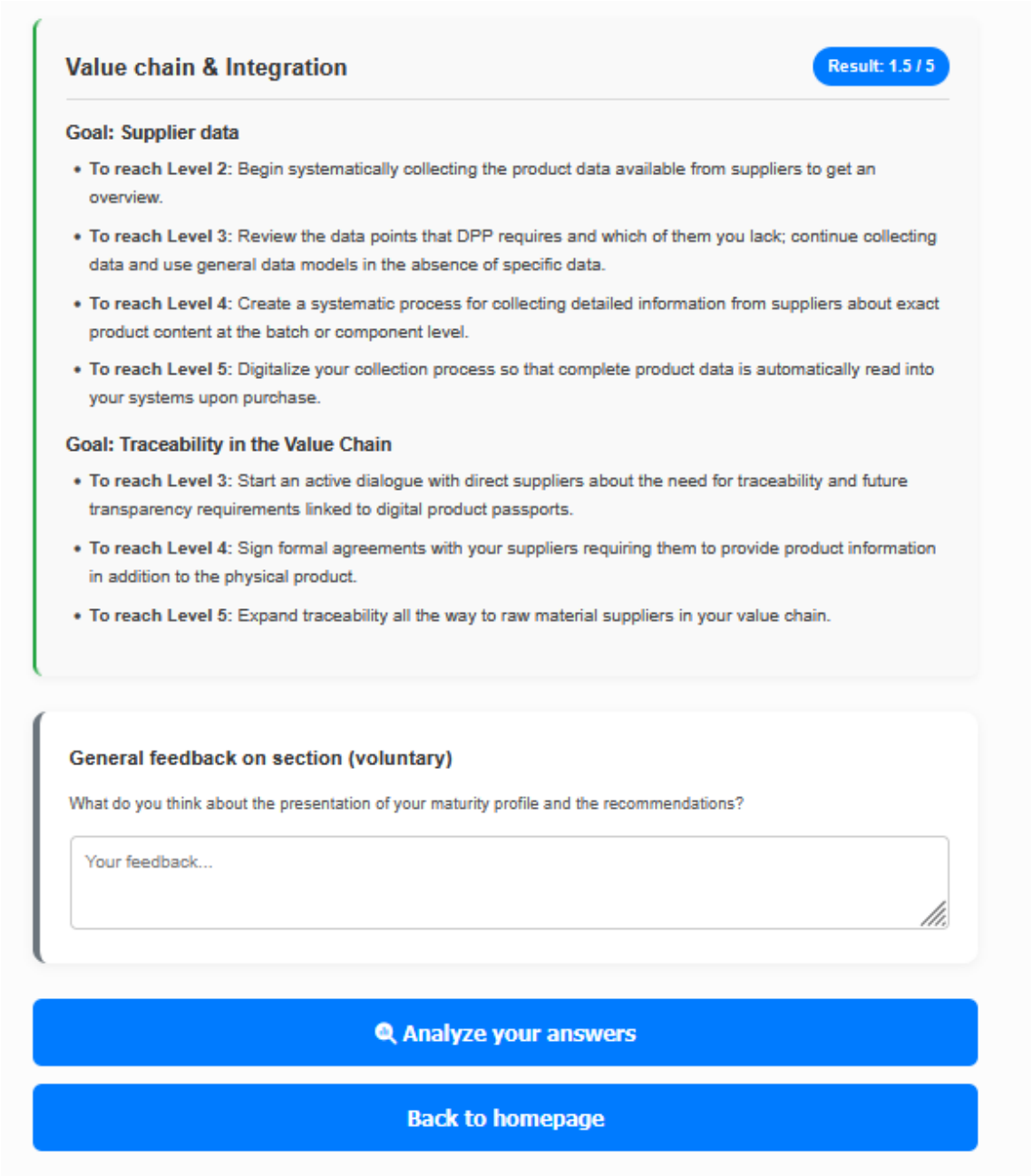

Figure B.13: Recommended steps for different levels (3)

B.4 Analysis

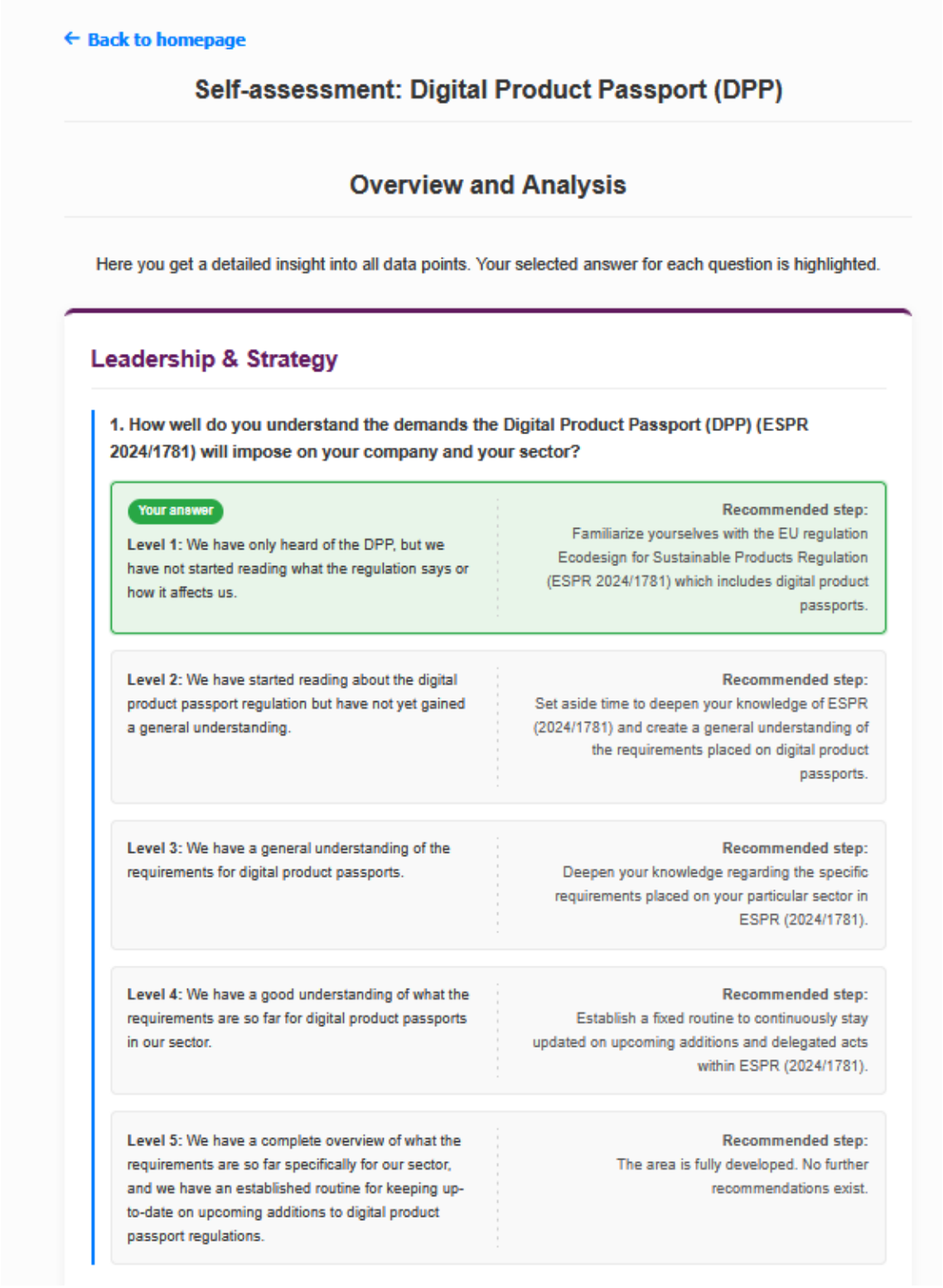

Figure B.14: Analysis of survey results for question 1

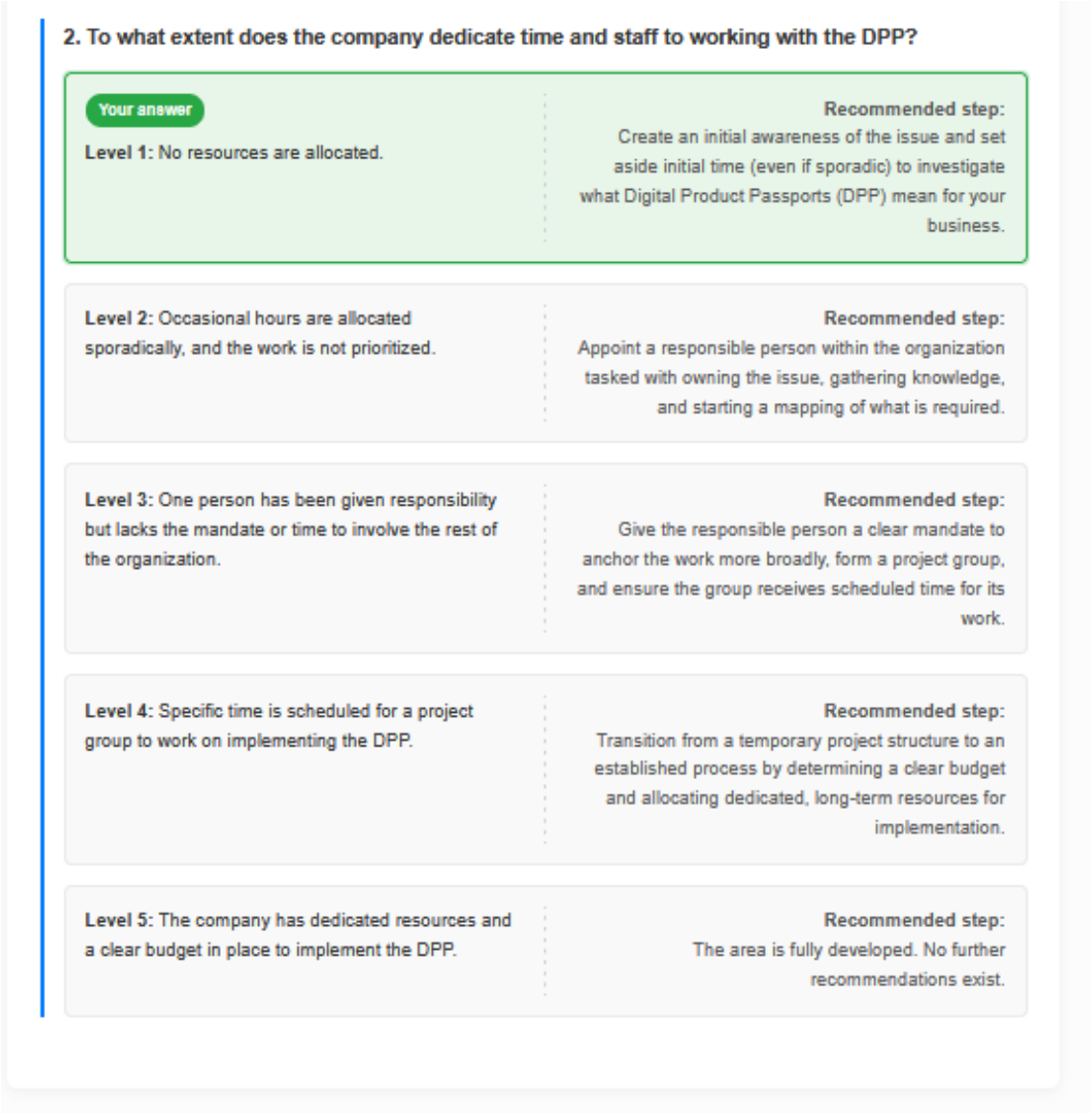

Figure B.15: Analysis of survey results for question 2

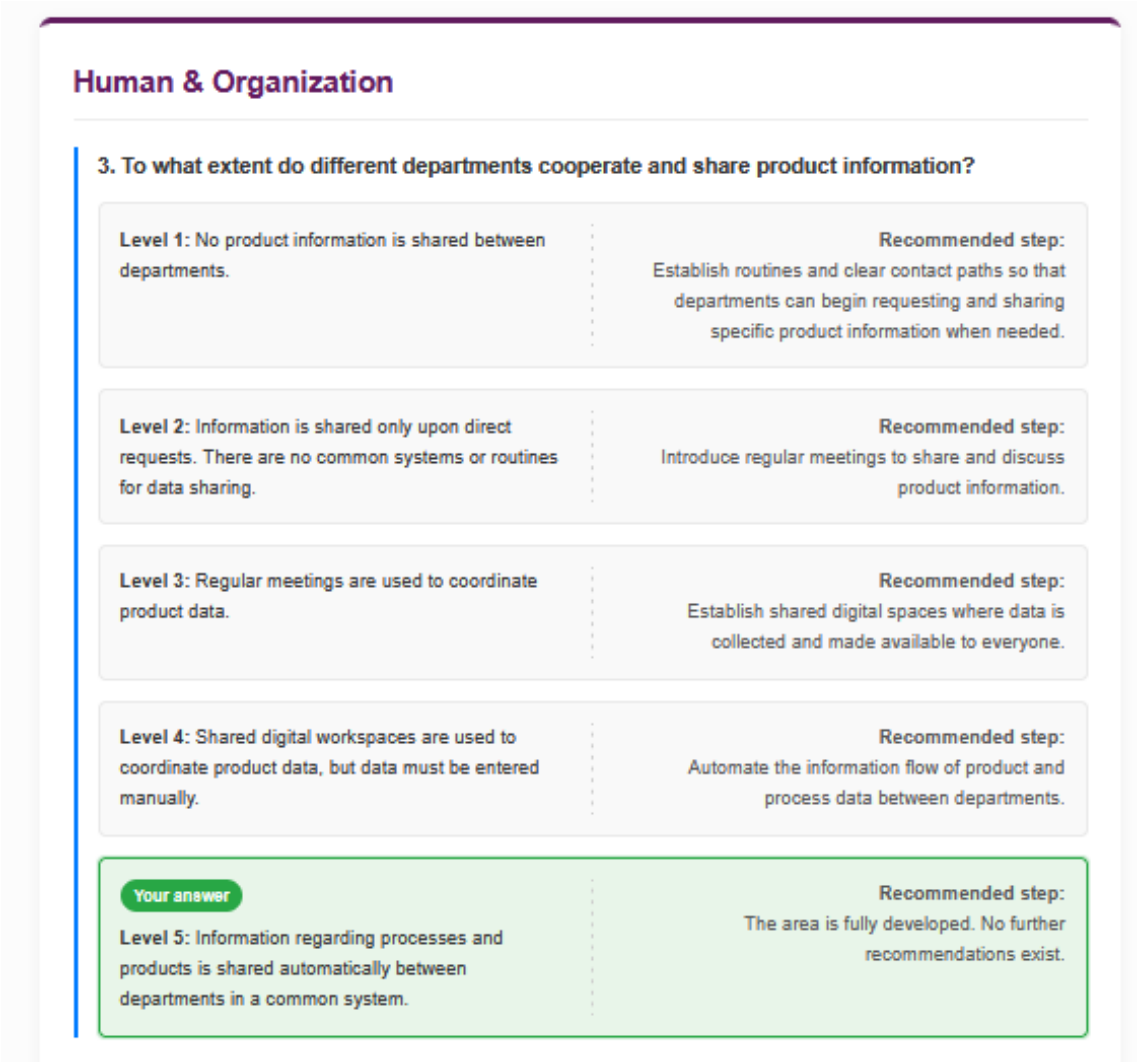

Figure B.16: Analysis of survey results for question 3

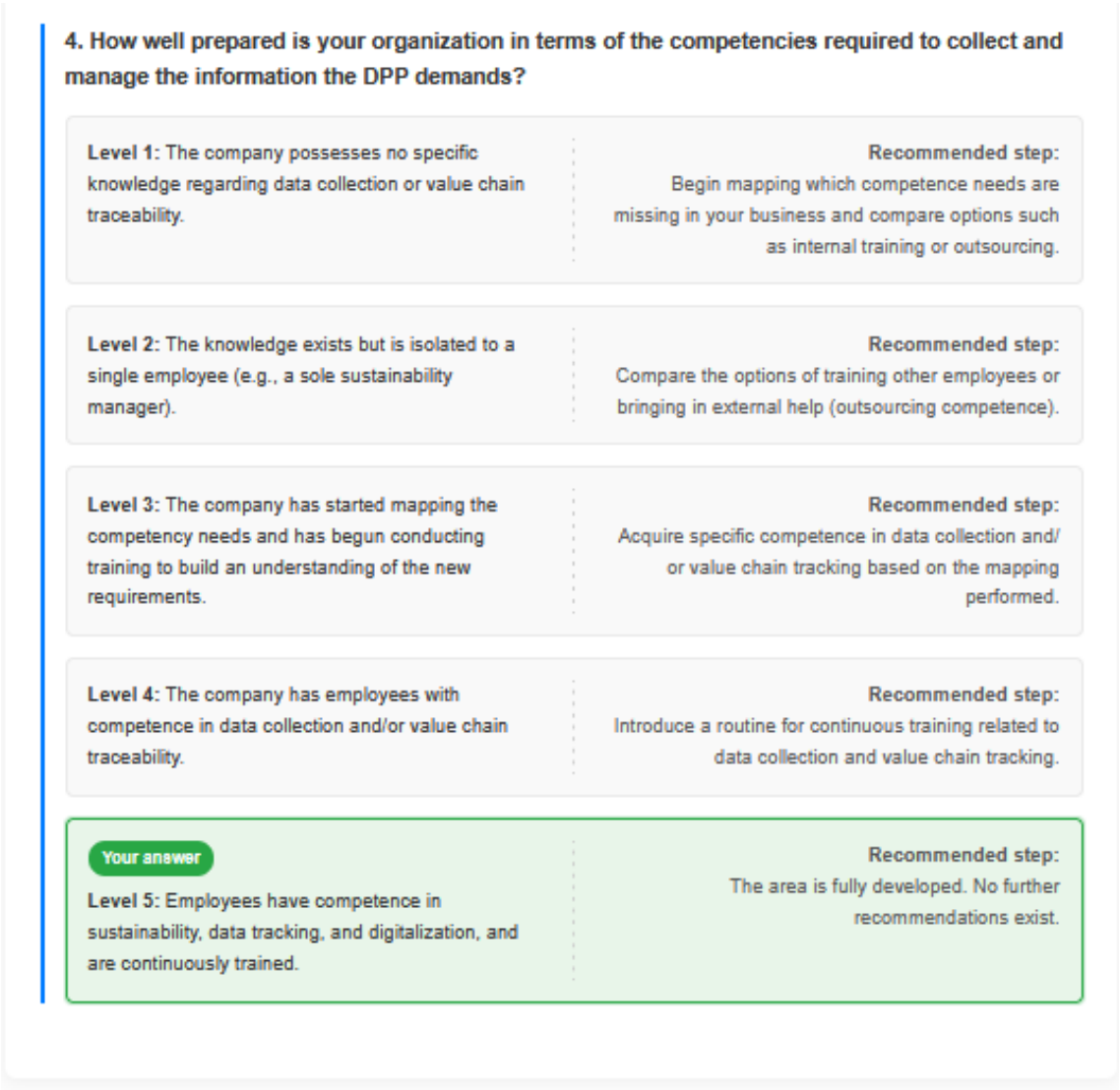

Figure B.17: Analysis of survey results for question 4

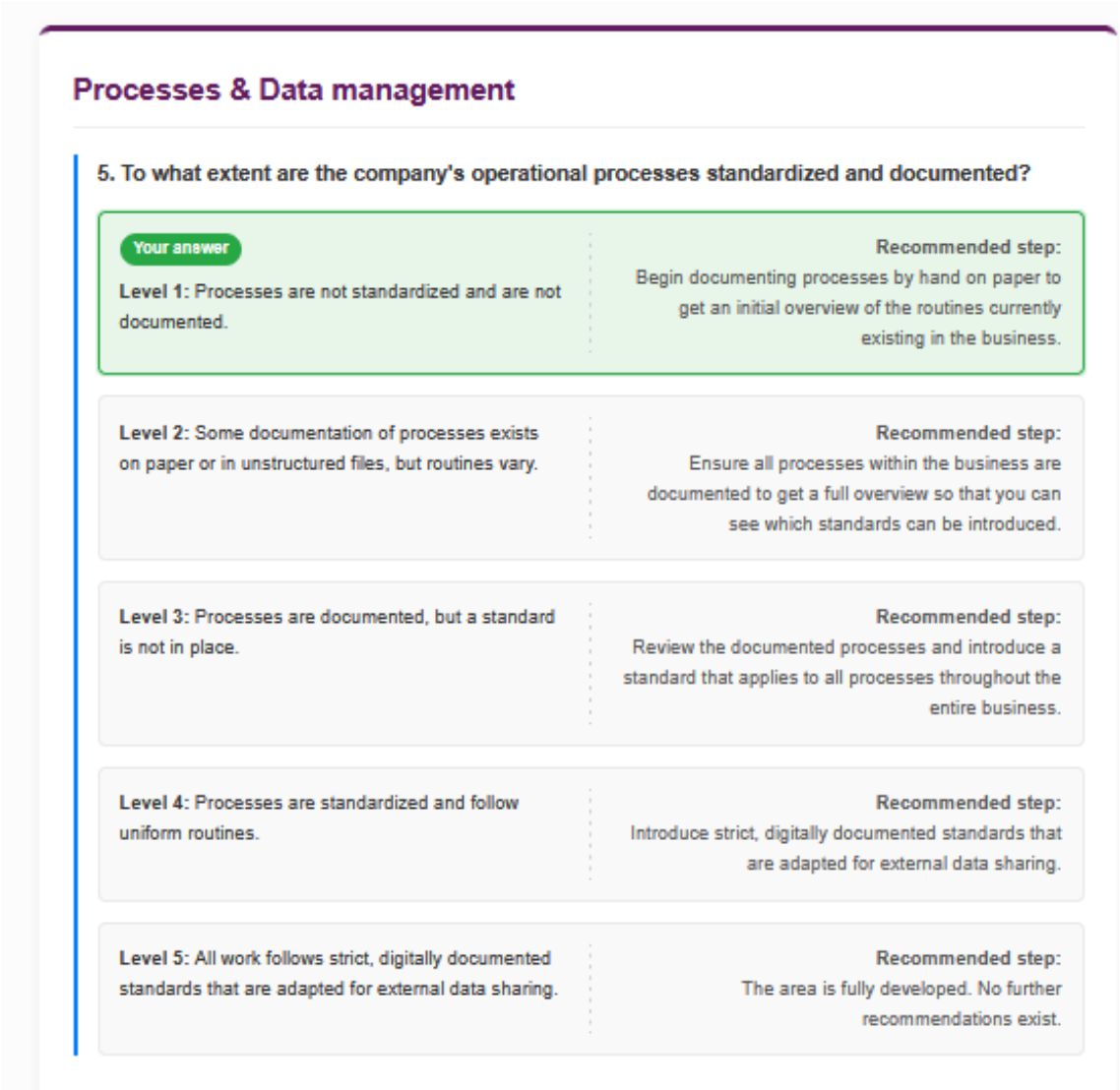

Figure B.18: Analysis of survey results for question 5

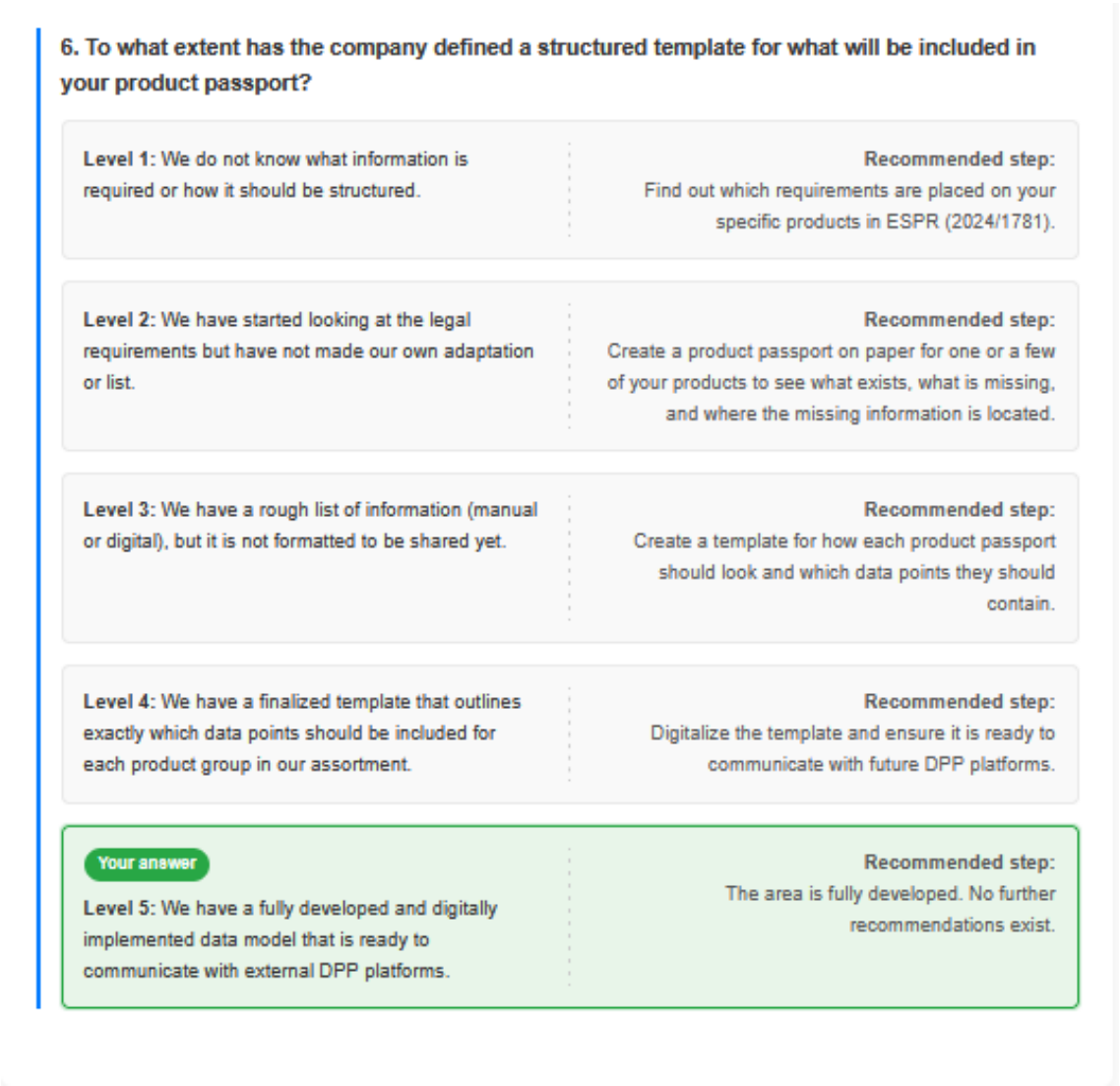

Figure B.19: Analysis of survey results for question 6

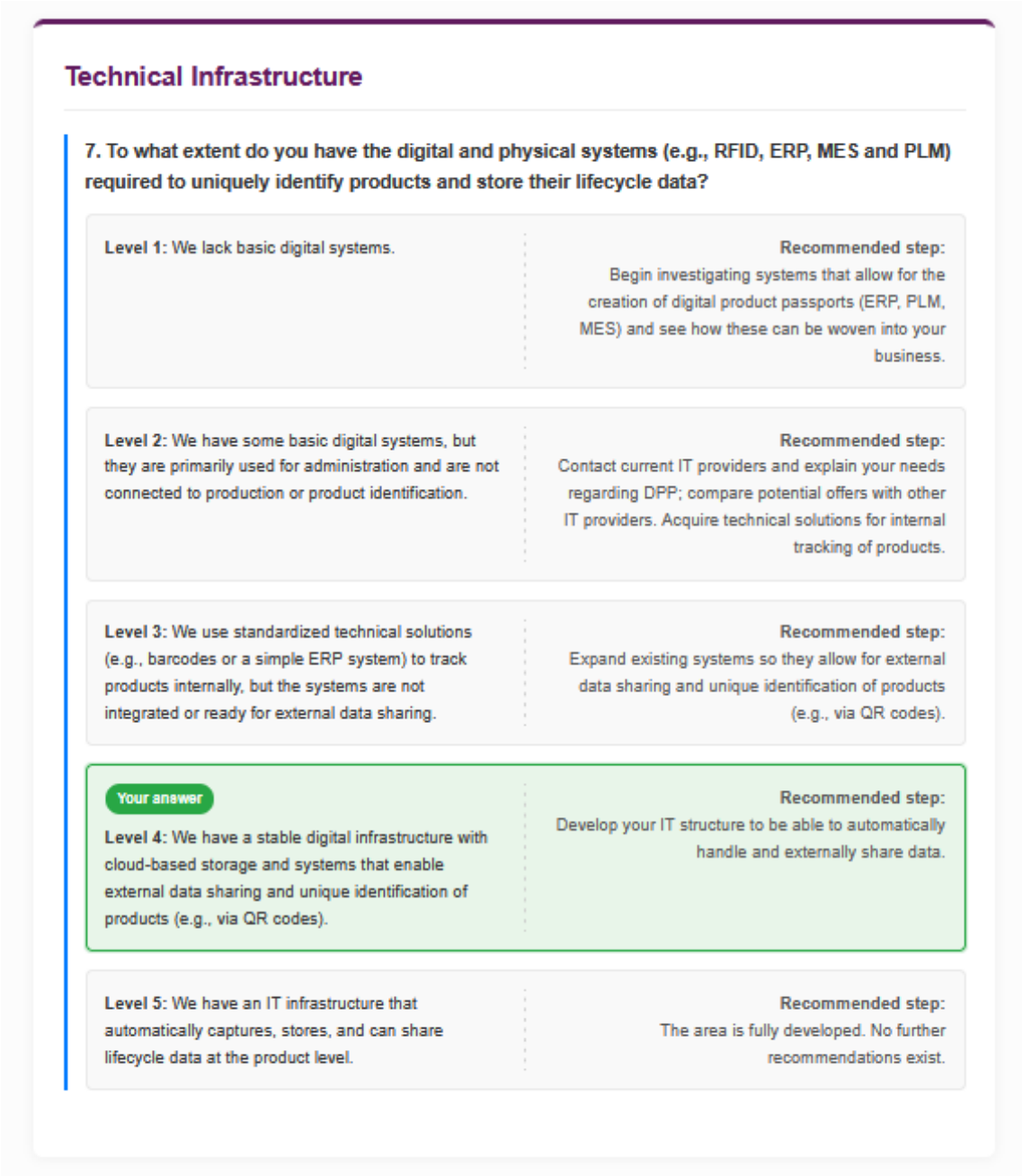

Figure B.20: Analysis of survey results for question 7

Figure B.21: Analysis of survey results for question 8

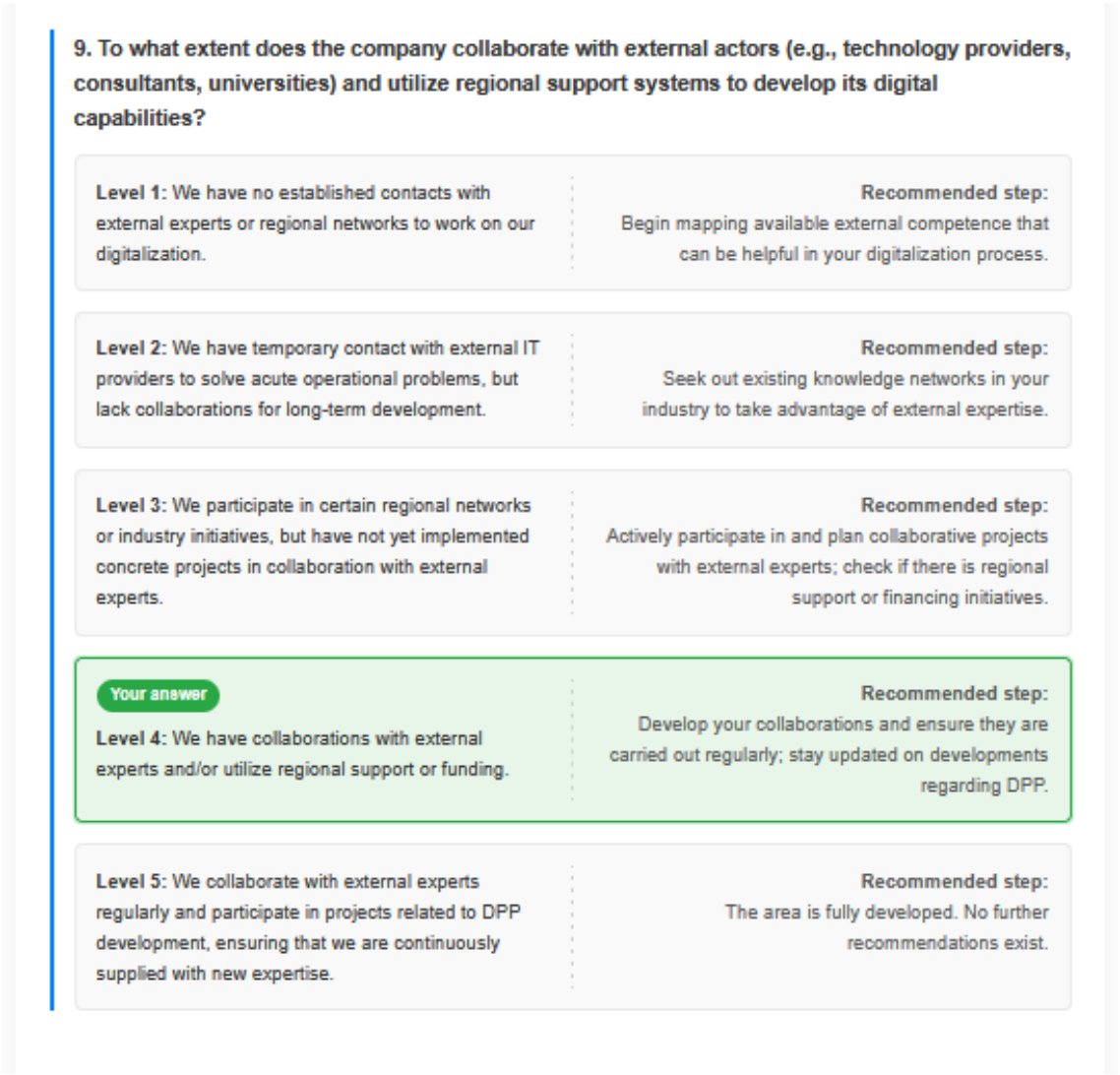

Figure B.22: Analysis of survey results for question 9

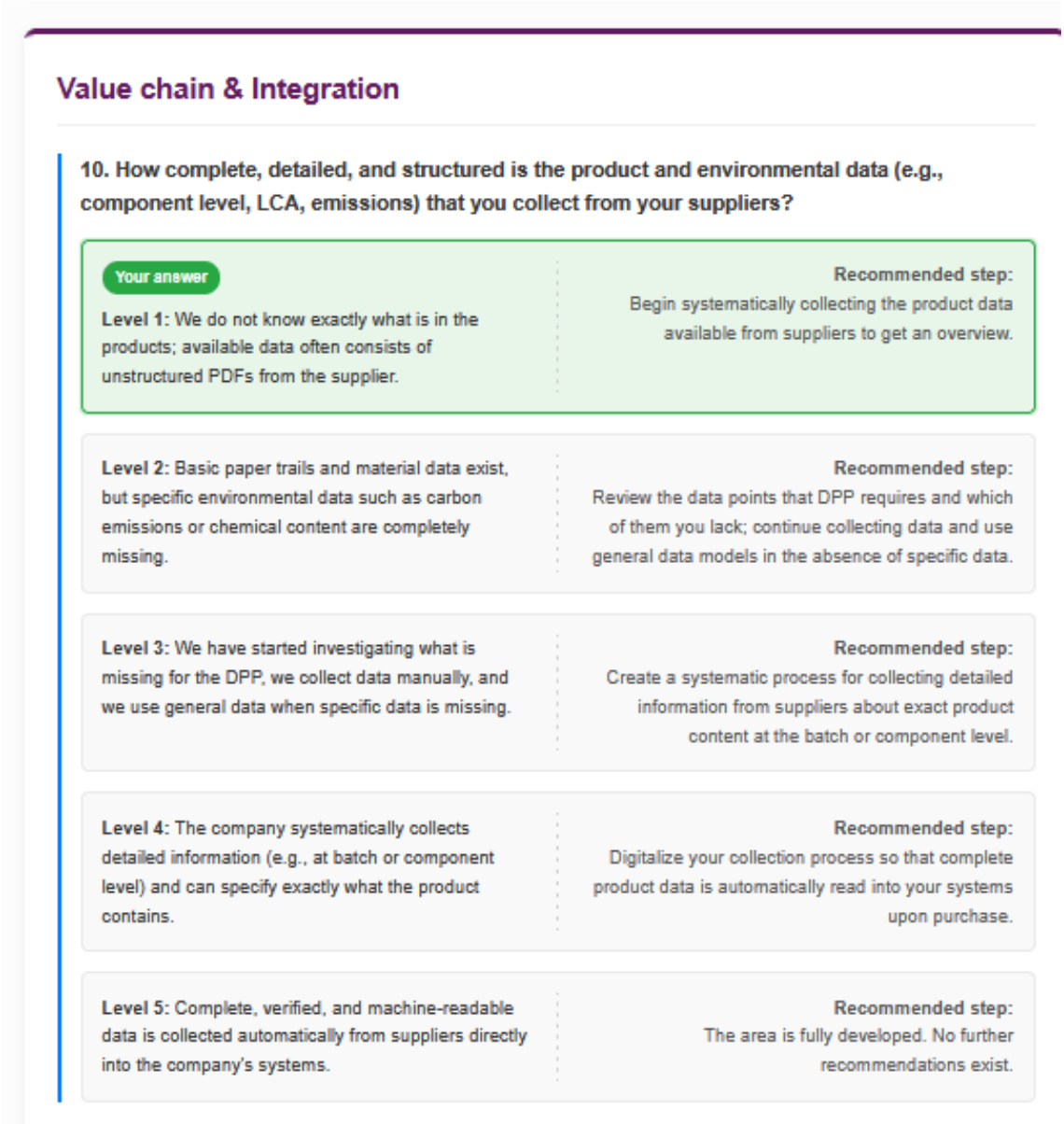

Figure B.23: Analysis of survey results for question 10

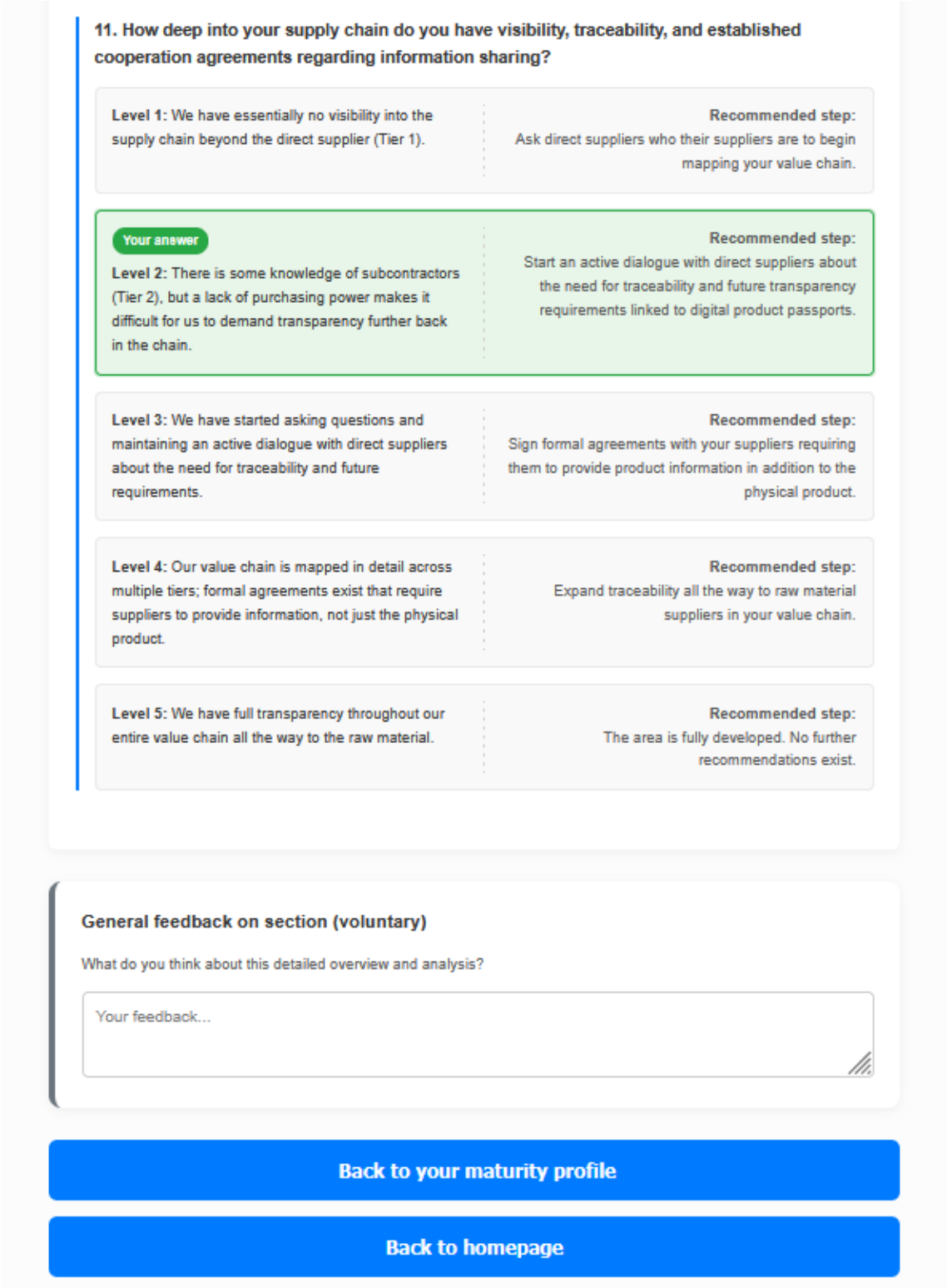

Figure B.24: Analysis of survey results for question 11

IMS - DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
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