ASSESSING ORGANISATIONAL READINESS FOR DIGITAL BATTERY PASSPORT IMPLEMENTATION: A DESIGN SCIENCE APPROACH

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Abstract

The Digital Battery Passport (DBP), introduced by Regulation (EU) 2023/1542, will become mandatory from February 2027 for Electric Vehicle Batteries (EVB), Light Means of Transport (LMT) batteries, and industrial batteries above 2 kWh. Its implementation requires organisations to generate, manage, verify and exchange extensive data across the battery lifecycle. However, existing literature provides limited operational guidance for assessing organisational readiness, particularly at the level of individual data attributes and interorganisational dependencies.

This dissertation develops the Digital Battery Passport Maturity Assessment Framework (DBP-MAF) using a Design Science Research (DSR) approach. The framework integrates a model, a method and an instantiation, grounded in Regulation (EU) 2023/1542, DIN DKE SPEC 99100:2025-02 and the Digital Product Passport (DPP) literature. It assesses internally generated or maintained attributes through Availability, Quality, Digitalisation and Internal Process, while externally dependent attributes are evaluated through Receive and Integrate. A Responsibility Matrix maps data responsibilities across five battery value chain actor profiles. The assessment produces attribute-, category- and organisation-level results, identifies critical gaps, and translates the diagnosis into an implementation roadmap.

The DBP-MAF was applied to a Portuguese small or medium-sized battery Original Equipment Manufacturer (OEM). The assessment covered 72 applicable data attributes and produced an overall readiness score of 1.76 out of 5.00 (Level 2 — Developing). It identified 47 critical gaps, comprising 41 capability gaps and 6 integration gaps. Results showed high readiness in Battery Materials and Composition but significant limitations in Battery Carbon Footprint and Dynamic data. Practitioner evaluation provided positive formative evidence of the framework's Utility, Quality and Efficacy, while highlighting resource constraints, technological infrastructure and supplier data availability as key implementation barriers.

This study contributes an attribute-oriented, regulatory-anchored and actor-sensitive approach to DBP readiness assessment by integrating organisational capabilities with interorganisational data dependencies and translating the diagnosis into an implementation roadmap. Although validated through a single OEM case study, the findings indicate that the DBP-MAF provides a differentiated organisational diagnosis and actionable guidance for DBP implementation.

Keywords: Digital Battery Passport; Organisational Readiness; Maturity Assessment Framework; Design Science Research; Battery Value Chain.

Resumo

O Passaporte Digital da Bateria (*Digital Battery Passport* – DBP), introduzido pelo Regulamento (UE) 2023/1542, tornar-se-á obrigatório a partir de fevereiro de 2027 para baterias de veículos elétricos (*Electric Vehicle Batterie*s – EVB), baterias para meios de transporte ligeiros (*Light Means of Transport* – LMT) e baterias industriais com capacidade superior a 2 kWh. A sua implementação exige que as organizações gerem, administrem, verifiquem e partilhem um volume significativo de dados ao longo de todo o ciclo de vida da bateria. No entanto, a literatura existente fornece orientação operacional limitada para avaliar a preparação das organizações, em particular ao nível dos atributos individuais de dados e das dependências interorganizacionais.

Esta dissertação desenvolve o *Digital Battery Passport Maturity Assessment Framework* (DBP-MAF) recorrendo à metodologia *Design Science Research* (DSR). O *framework* integra um modelo, um método e uma instanciação, fundamentados no Regulamento (UE) 2023/1542, na norma DIN DKE SPEC 99100:2025-02 e na literatura sobre o *Digital Product Passport* (DPP). Os atributos de dados gerados ou mantidos internamente são avaliados através das dimensões Disponibilidade, Qualidade, Digitalização e Processo Interno, enquanto os atributos dependentes de entidades externas são avaliados através das dimensões Receber e Integrar. Uma Matriz de Responsabilidades estabelece o mapeamento das responsabilidades pelos dados entre cinco perfis de intervenientes da cadeia de valor da bateria. A avaliação produz resultados ao nível do atributo, da categoria e da organização, identifica lacunas críticas e traduz o diagnóstico num roteiro de implementação.

O DBP-MAF foi aplicado a um fabricante português de baterias de pequena ou média dimensão (*Original Equipment Manufacturer* – OEM). A avaliação abrangeu 72 atributos de dados aplicáveis e produziu uma pontuação global de preparação de 1,76 em 5,00 (Nível 2 — Em Desenvolvimento). Foram identificadas 47 lacunas críticas, correspondendo a 41 lacunas de capacidade e 6 lacunas de integração. Os resultados evidenciaram um elevado nível de preparação na categoria Materiais e Composição da Bateria, mas limitações significativas nas categorias Pegada de Carbono da Bateria e Dados Dinâmicos. A avaliação por profissionais forneceu evidência formativa positiva relativamente à Utilidade, Qualidade e Eficácia do *framework*, destacando simultaneamente as restrições de recursos, a infraestrutura tecnológica e a disponibilidade de dados por parte dos fornecedores como os principais obstáculos à implementação.

Este estudo contribui com uma abordagem orientada aos atributos de dados, ancorada na regulamentação e sensível aos diferentes intervenientes da cadeia de valor, para a avaliação

da preparação das organizações para o DBP, integrando capacidades organizacionais com dependências interorganizacionais de dados e traduzindo o diagnóstico obtido num roteiro de implementação. Embora a validação empírica se limite a um único estudo de caso de um OEM, os resultados indicam que o DBP-MAF proporciona um diagnóstico organizacional diferenciado e orientações práticas para a implementação do DBP.

Palavras-chave: Passaporte Digital de Baterias; Preparação Organizacional; *Framework* de Avaliação da Maturidade; *Design Science Research*; Cadeia de Valor das Baterias.

Index

Acknowledgments i

Abstract iii

Resumo iv

Index of Tables viii

Index of Figures ix

1. Introduction 1

1.1. Motivation, Objectives and Research Question 3

1.2. Research Design and Work Plan 5

2. Literature review 7

2.1. Search Strategy and Selection Criteria 7

2.2. Overview of Selected Literature 9

2.2.1. Data Requirements and Data Models 10

2.2.2. Lifecycle Assessment Integration 11

2.2.3. Implementation Challenges, Adoption Factors and Readiness Approaches 11

2.2.4. Ecosystem Coordination and Data Sharing 13

2.3. Critical synthesis and research gap 14

3. Methodology 17

3.1. Research Design 17

3.2. Design and Evaluation Process 19

3.2.1. Problem Awareness and Design Requirements 19

3.2.2. Artefact Development and Operationalisation 21

3.2.3. Case Application, Practitioner Evaluation and Data Analysis 22

4. The DBP-MAF: Framework Design and Components 25

4.1. Mapping Responsibilities and Readiness: The Model Component 26

4.2. From Data to Diagnosis: The Assessment Method 31
4.3. Making the Framework Operational: The Instantiation 34
5. Evaluation 37
5.1. Application to the Case Study Company 37
5.2. Practitioner Evaluation of the Artefact 40
6. Discussion 45
7. Conclusions 49
8. Contribution to the United Nations Sustainable Development Goals 53
References 55
Appendix A: Keyword Co-occurrence Network of DBP-Related Literature (VOSviewer Output) 58
Appendix B: List of Co-cited Articles of the DBP Literature (VOSviewer Output) 59
Appendix C: Comparative Summary of Selected Articles on DBP Implementation 61
Appendix D: Responsibility Matrix 66
Appendix E: Organisational Readiness Assessment for the Implementation of the Digital Battery Passport in the Portuguese Battery Sector 69
Appendix F: Excel-based Scoring Tool 86
Appendix G: Validation Questionnaire of the DBP Maturity Assessment Framework – DBP-MAF 92

Index of Tables

Table 1 - Formulated Research Questions 4

Table 2 - Overview of database queries and filtered results for DBP-related literature (Scopus and WoS, March 2026) 8

Table 3 - Comparative synthesis of reviewed literature and positioning of the DBP-MAF. Contributions are classified as addressed (+), partially addressed (P), acknowledged as limitation (–), or not covered (blank). 16

Table 4 - DSR research process applied to the development and evaluation of the DBP-MAF 19

Table 5 - Design requirements of the DBP-MAF 20

Table 6 - DBP-MAF assessment criteria and scoring rubric (0-5 scale) 28

Table 7 - Receive and Integrate scoring rubric for Rx-designated attributes 29

Table 8 - DBP-MAF maturity levels: definitions and progression criteria 31

Table 9 - Validation Questionnaire (Q2) results: the company's assessment of the DBP-MAF's utility, quality, and efficacy. 41

Index of Figures

Figure 1 - Evolution of the published articles based on DBP in the Scopus and WoS databases between 2021 and 2026 (search conducted in April 2026) 3

Figure 2 - PRISMA diagram outlining the systematic search process conducted 8

Figure 3 - DSR Framework applied to this study (adapted from Hevner et al., 2004) 18

Figure 4 - DBP-MAF: integrated framework components 25

Figure 5 - DBP-MAF Assessment representation using BPMN 2.0.2. 32

Figure 6 - OEM readiness scores across the applicable DBP data categories. 38

1. Introduction

Resource extraction and processing in traditional linear economies, characterised by the "take, make, dispose" model, account for a significant share of global greenhouse gas emissions and environmental degradation (Abedi et al., 2024; Walden et al., 2021). In response, Circular Economy (CE) approaches have gained increasing relevance among policymakers, researchers and industry stakeholders, as they aim to extend product lifecycles, reduce waste, improve resource efficiency, and support reuse, recycling and remanufacturing strategies (Abedi et al., 2024; Walden et al., 2021).

Circular transformation is inherently linked to the digital transformation (Jensen et al., 2023). The digitalisation of CE requires reliable lifecycle information on products, components and materials, enabling traceability, informed decision-making and coordination across value chains (Jensen et al., 2023; Voulgaridis et al., 2024). Within the European Union, this "twin transition" has been reinforced through the European Green Deal (European Commission, 2019) and the Circular Economy Action Plan (CEAP) (European Commission, 2020). One key regulatory instrument emerging from this policy agenda is the Digital Product Passport (DPP), introduced under the Ecodesign for Sustainable Products Regulation (ESPR) (European Commission, 2024), as a mechanism to make product-related information available throughout the lifecycle (European Commission, 2024; Walden et al., 2021).

Among the different applications of the DPP, batteries represent a particularly relevant case. The increasing demand for batteries, driven by the electrification of mobility and energy systems, creates significant environmental, economic, and geopolitical challenges, including critical reliance on raw materials, complex global supply chains, and end-of-life management (Berger et al., 2023; Losa & Torjesen, 2025). In response, Regulation (EU) 2023/1542 (European Union, 2023) introduced the Digital Battery Passport (DBP), making batteries the first product category subject to a mandatory digital passport requirement. The DBP will become mandatory from February 2027 for Electric Vehicle Batteries (EVBs), industrial batteries above 2 kWh, including stationary Battery Energy Storage Systems (BESS), and Light Means of Transport (LMT) batteries (European Union, 2023).

The DBP is expected to provide structured lifecycle information on batteries, including identification, composition, performance, durability, carbon footprint and circularity-related data (DIN/DKE, 2025; European Union, 2023; Soufi et al., 2023). Its implementation is therefore central to increasing transparency, supporting circular strategies and improving coordination among value chain actors. However, the effectiveness of the DBP depends not

only on the existence of regulatory requirements, but also on the capacity of organisations to generate, manage, verify, digitalise, and share the required data across complex supply chain networks (Berger et al., 2023; Kemmner et al., 2025; Losa & Torjesen, 2025).

Existing literature highlights several challenges associated with DBP and DPP implementation. Data required for the DBP is often fragmented, inconsistently structured and distributed across different actors in the battery value chain (Berger et al., 2023; Ott et al., 2024). Dynamic lifecycle data, such as state of health, remaining capacity and usage history, is particularly difficult to collect and update, requiring technological infrastructure such as Battery Management Systems (BMS) and interoperable data-sharing mechanisms (Losa & Torjesen, 2025; Ott et al., 2024). In addition, organisations face barriers related to data governance, interoperability, data sovereignty, standardisation, supplier coordination and reluctance to share sensitive information (Abedi et al., 2024; Chaudhuri et al., 2025; Kemmner et al., 2025). These challenges are amplified by the multi-actor nature of the battery value chain. The data required to populate the DBP is not held by a single organisation; rather, it is generated by multiple upstream, midstream and downstream actors (Berger et al., 2023; Paeplow et al., 2026). Nevertheless, under Regulation (EU) 2023/1542 (European Union, 2023), the economic operator placing the battery on the market, the Original Equipment Manufacturer (OEM), remains accountable for ensuring that the DBP is complete and accessible. This creates a critical organisational-readiness problem: companies must understand not only whether they possess the required data internally, but also whether they can obtain, verify, and integrate data generated by other value chain actors.

Despite growing academic interest in DPPs and DBPs, the field remains relatively recent within the broader DPP and CE literature (Figure 1). Existing studies address important aspects such as data requirements (Berger et al., 2023; Stratmann et al., 2023), data models (Gianvincenzi et al., 2024; Ott et al., 2024), Lifecycle Assessment (LCA) integration (Haupt et al., 2024; Soufi et al., 2023), adoption barriers (Abedi et al., 2024; Chaudhuri et al., 2025), and ecosystem coordination (Jensen et al., 2024; Kemmner et al., 2025). However, fewer contributions provide structured approaches to assess how prepared organisations are to implement the DBP in practice. There is still limited guidance on how companies can evaluate their readiness at the level of specific DBP data attributes, while accounting for their own capabilities and their dependency on data flows from other value chain actors. This dissertation addresses this gap by developing the Digital Battery Passport Maturity Assessment Framework (DBP-MAF) for evaluating organisational readiness for DBP implementation in companies across the battery value chain.

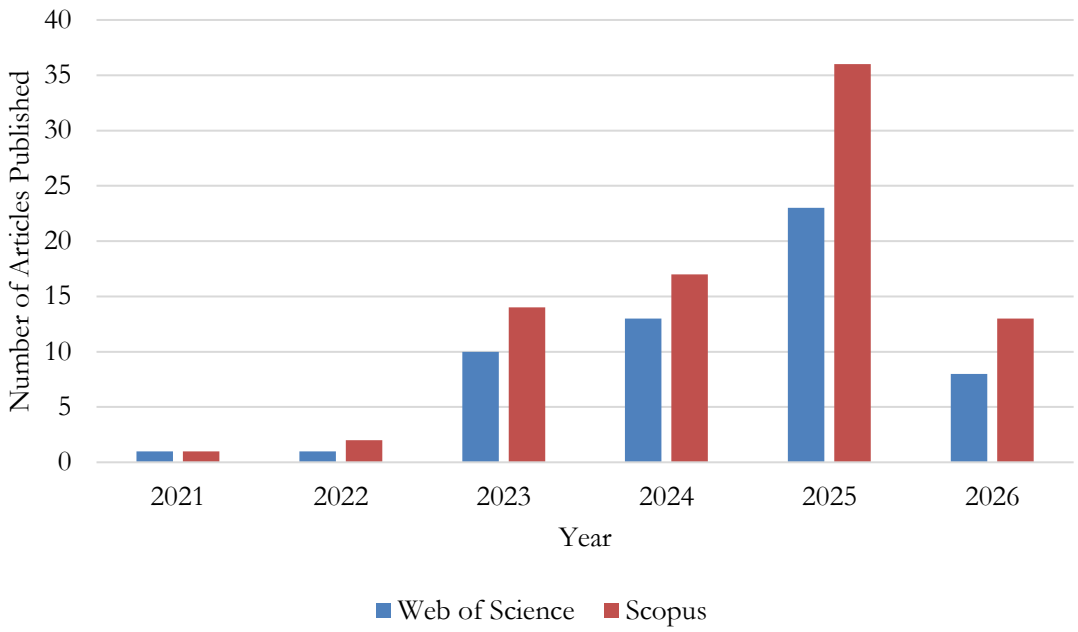


Figure 1 - Evolution of the published articles based on DBP in the Scopus and WoS databases between 2021 and 2026 (search conducted in April 2026)

1.1. Motivation, Objectives and Research Question

Building on the gap identified, this research is motivated by the need to translate DBP regulatory and data requirements into a structured readiness assessment approach that organisations can apply. While the DBP is often presented as a mechanism for transparency, traceability and circularity, its implementation depends on organisational capabilities that are not evenly distributed across the battery value chain. Some attributes may already exist in internal technical documentation, while others depend on supplier data, end-of-life data, carbon footprint calculations or dynamic information generated during the battery lifecycle. As a result, DBP implementation should not be understood only as a compliance exercise, but also as an organisational readiness challenge involving data management, digital infrastructure, internal processes and value chain coordination. This research is also motivated by the researcher's academic and professional involvement in DPP/DBP related research and sustainability-driven innovation, which has highlighted the gap between theoretical requirements and practical implementation challenges, reinforcing the need for tools that can bridge this.

The general objective of this dissertation is to develop a MAF for evaluating organisational readiness for DBP implementation in companies across the battery value chain. The

proposed artefact, the DBP-MAF, aims to support companies in identifying their current maturity level, detecting critical gaps, and prioritising improvement actions before the DBP becomes mandatory. To achieve this, the study pursues the following specific objectives:

- Identify the key DBP data requirements, implementation challenges and enabling factors associated with DBP implementation in the literature and regulatory context;
- Analyse the data requirements defined in Regulation (EU) 2023/1542 (European Union, 2023) and DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025), and translate them into an attribute-level assessment structure;
- Define the organisational and interorganisational dimensions that influence DBP readiness, including data availability, quality, digitalisation, internal processes and value chain data dependencies;
- Develop a MAF that structures these requirements and dimensions into an operational assessment method;
- Apply the proposed framework to an OEM case study and evaluate the artefact's utility, quality, and efficacy using practitioner feedback.

Based on these objectives, the research is guided by the following Research Question (RQ) and Sub-questions (SQs) (Table 1):

Table 1 - Formulated Research Questions

ID	Research Question
RQ	How can organisational readiness for DBP implementation be assessed in companies across the battery value chain?
SQ1	What are the key DBP data requirements, implementation challenges, and enabling factors identified in the literature and regulatory context?
SQ2	Which organisational and interorganisational dimensions influence DBP readiness, and how do data responsibilities and dependencies vary across battery value chain actors?
SQ3	How can these requirements and dimensions be structured into a MAF that is theoretically grounded, anchored in regulatory requirements, and practically applicable?

The DBP-MAF is conceptually structured to account for different battery value chain actors. However, the empirical application and evaluation conducted in this dissertation focus on the OEM profile, since this actor is legally accountable for DBP completeness under Regulation (EU) 2023/1542 (European Union, 2023).

1.2. Research Design and Work Plan

To address the research question, this study adopts a Design Science Research (DSR) approach. DSR is particularly suited to research that aims to develop and evaluate artefacts providing practical solutions to identified problems, while also contributing to theoretical knowledge (Hevner et al., 2004). In this dissertation, the artefact is the DBP-MAF, developed from three knowledge sources: the academic literature on DPP and DBP implementation, the regulatory requirements established by Regulation (EU) 2023/1542 (European Union, 2023), and the data attribute structure provided by DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025). These sources inform the framework's design and ensure that it is both theoretically grounded and anchored in regulatory requirements.

The research follows a build-and-evaluate logic. First, the problem and research gap are identified through a literature review and regulatory analysis. Second, the framework is designed by translating DBP requirements into assessment dimensions, maturity levels and value chain responsibility logic. Third, the artefact is instantiated through practical assessment instruments, including a diagnostic questionnaire and a scoring tool. Finally, the framework is applied to an OEM case study and evaluated through practitioner feedback on its utility, quality and efficacy. The empirical evaluation is exploratory and based on a single OEM case.

The dissertation is structured as follows. Chapter 2 presents the literature review, which establishes the theoretical and empirical foundation for the DBP-MAF. Chapter 3 describes the research methodology. Chapter 4 introduces the DBP-MAF in detail. Chapter 5 presents its evaluation. Chapter 6 discusses the main findings, and Chapter 7 concludes the study.

2. Literature review

Academic research requires a systematic methodological analysis of the existing literature to ensure awareness of the current body of knowledge and to position the study within it (Levy & Ellis, 2006). Within the scope of DSR, this chapter reviews the academic and regulatory literature relevant to DBP implementation and organisational readiness assessment, following a concept-centric and systematic approach (Levy & Ellis, 2006).

The review is structured into three sections: the search strategy and selection criteria (Section 2.1), a thematic overview of the selected literature (Section 2.2), and a critical synthesis that identifies the research gap addressed by this study (Section 2.3).

2.1. Search Strategy and Selection Criteria

A structured literature search was conducted to identify, analyse, and synthesise the main academic contributions related to the DPP and the DBP, with particular focus on data requirements, implementation challenges, and organisational readiness. As a result, an initial exploratory search was conducted in the Scopus database guided by the research question: *"What are the key requirements, challenges, and approaches associated with the implementation of the DBP, and how do they relate to organisational readiness?"*. For that, the Boolean string (TITLE-ABS-KEY (Digital Battery Passport)) was used, retrieved on 16 March 2026. The results were analysed using VOSviewer version 1.6.20 to visualise keyword co-occurrences and identify conceptual clusters. The bibliometric network (Appendix A) revealed four main thematic areas: (1) CE and digital product systems (green cluster); (2) LCA and sustainability (blue cluster); (3) Battery technologies and recycling systems (red cluster); and (4) Policy, regulation and digital enablers (yellow cluster). These clusters confirmed the multidisciplinary nature of the DPP/DBP and guided the refinement of the search scope. A co-citation analysis (Appendix B) further helped identify the most influential publications in the field. Since DBP research is still emerging, a refined search was subsequently performed in Scopus and WoS, applying a language filter (English only) (Table 2), intentionally combining DBP-specific terms with broader DPP implementation and adoption terms. This broader search logic was necessary to capture both battery-specific contributions and transferable insights from the wider DPP literature.

Table 2 - Overview of database queries and filtered results for DBP-related literature (Scopus and WoS, March 2026)

Database	Query	Goal	Docs. Returned	Results after filter applied	Date	Filename
Scopus	(KEY ((Digital OR Battery) AND Passport) AND TITLE-ABS-KEY (implementation OR adoption))	Identify relevant studies on DPP/DBP implementation	199	196	16 March 2026	*Scopus_DPP Search*
WoS	((Digital OR Battery) AND Passport (Author Keywords) and implementation OR adoption (Topic))	Complement Scopus results and ensure broader coverage	118	115	16 March 2026	*WoS_DPP Search*

To ensure methodological rigor and transparency, this study followed a systematic literature review process inspired by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021), as represented in Figure 2.

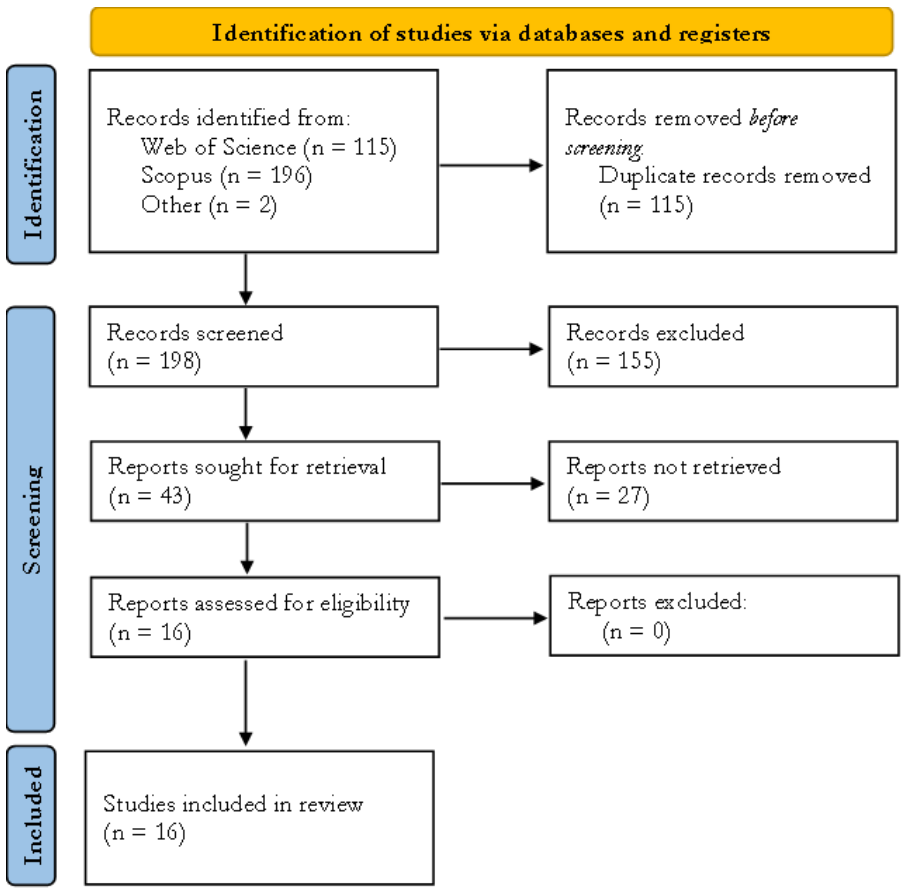


Figure 2 - PRISMA diagram outlining the systematic search process conducted

Two other articles were included outside the automated search, as their conceptual relevance and foundational importance justified their inclusion. After removing 115 duplicate records, 198 unique articles were retained for screening. Titles and abstracts were examined to exclude publications not directly related to the DPP. Full-text papers were then assessed against predefined exclusion criteria. Articles were excluded if they:

- Did not have an explicit focus on DPP or DBP within the context of CE initiatives and the European regulatory framework;
- Did not contribute to the understanding of DPP/DBP implementation from an organisational perspective (readiness, capabilities, data management, stakeholder coordination, or governance mechanisms);
- Focused exclusively on technical or engineering aspects (e.g., sensors, Radio-Frequency Identification - RFID systems, digital twins, or system-specific Information Technology - IT architectures) without providing insights into implementation or organisational challenges;
- Did not address barriers, enablers, challenges, drivers, or critical success factors associated with DPP/DBP implementation;
- Did not propose, apply, or critically discuss frameworks, models, or structured approaches relevant to DPP/DBP implementation, integration, or assessment;
- Were limited to highly specific use cases without offering transferable or generalizable insights;
- Presented redundant contributions already covered by more comprehensive studies.

No articles were excluded in the eligibility phase, resulting in 16 studies for review. These are examined in Section 2.2, and a comparative summary is provided in Appendix C.

2.2. Overview of Selected Literature

The selected literature covers a broad spectrum of DBP- and DPP-related contributions. This section organises the studies into four thematic areas: (1) data requirements and data models; (2) LCA and environmental data integration; (3) implementation challenges, adoption factors and readiness approaches; and (4) ecosystem coordination and data sharing. The thematic structure reflects the multidimensional nature of DBP implementation and supports comparison between studies addressing technical, organisational, regulatory and interorganisational dimensions.

2.2.1. Data Requirements and Data Models

Jensen et al. (2023), Berger et al. (2023), and Stratmann et al. (2023) converge on the need for structured product and lifecycle information, but differ in scope and analytical focus. Jensen et al. (2023) identify seven data clusters required to support circular product lifecycle (Usage and maintenance; Product identification; Products and materials; Guidelines and manuals; Supply chain and reverse logistics; Environmental data; and Compliance) and demonstrate that DPP data needs vary across supply chain positions and lifecycle stages. Stratmann et al. (2023) complement this perspective through a generic classification of 62 product data attributes covering product, utilisation, value chain and sustainability information. Both contributions provide broad classifications with cross-sector relevance. By contrast, Berger et al. (2023) provide a battery-specific and actor-oriented mapping 54 data points, showing that data needs and availability differ across beginning-of-life, middle-of-life, and end-of-life actors. The generic classifications offer greater transferability but limited DBP-specific regulatory detail, whereas Berger et al. (2023) provide stronger sectoral relevance without translating data availability into an operational organisational-readiness assessment.

Gianvincenzi et al. (2024) and Ott et al. (2024) address data fragmentation through structured battery data models, but focus on different lifecycle needs. Gianvincenzi et al. (2024) propose a Standardised Battery Passport Data Model (SBPDM) organised around the battery lifecycle and aligned with regulatory and LCA requirements, emphasising standardisation, interoperability and traceability. Ott et al. (2024) develop an end-of-life focused data model that highlights the importance of materials, state of health and usage-history data for recycling and other end-of-life decisions. Their study also reinforces the distinction between data established at the beginning-of-life and data generated during use or end-of-life stages, with dynamic data remaining particularly difficult to access and integrate.

Overall, the studies agree that DBP implementation requires more than defining which data should be reported. It also requires understanding where the data originates, which actor holds or generates it, whether it is available and reliable, and whether it can be exchanged in a structured and interoperable format. However, the contributions concentrate primarily on data classification, modelling and lifecycle use. They do not provide an operational method for assessing whether a specific organisation possesses the capabilities, processes and external relationships required to generate, manage, receive or integrate each applicable DBP data attribute.

2.2.2. Lifecycle Assessment Integration

Haupt et al. (2024) and Soufi et al. (2023) agree that the DBP can support the integration and communication of environmental information, but approach implementation from different perspectives. Haupt et al. (2024) focus on the methodological requirements of LCA integration, stakeholder needs and tensions between transparency, primary-data availability and confidentiality. Their analysis across LCA phases and stakeholder perspectives identifies requirements related to goal and scope definition, lifecycle inventory, impact assessment, interpretation and data exchange. The study highlights several tensions that are highly relevant to DBP implementation, particularly the conflict between transparency and data confidentiality, and the gap between the demand for primary data and companies' actual data generation capabilities. These challenges are especially relevant for Small and Medium-sized Enterprises (SMEs), which may lack the resources, expertise or digital infrastructure needed to generate and manage LCA-related information. Soufi et al. (2023) place greater emphasis on the technological infrastructure that may support lifecycle traceability and environmental-impact assessment, including Asset Administration Shell (AAS), ontology-based models and blockchain. They emphasise the need for standardised and accessible data repositories to enable carbon footprint calculations and lifecycle traceability.

These perspectives are complementary: Haupt et al. (2024) clarify the methodological and organisational conditions of environmental-data integration, while Soufi et al. (2023) examine possible technological enablers. However, neither study empirically evaluates whether organisations possess the primary data, expertise, internal processes and supplier relationships required to operationalise carbon-footprint reporting. The literature therefore identifies important methodological and technological conditions for environmental-data integration but does not translate them into an attribute-level organisational-readiness assessment.

2.2.3. Implementation Challenges, Adoption Factors and Readiness Approaches

The reviewed studies conceptualise implementation readiness at different levels and through different analytical perspectives. Abedi et al. (2024) and Chaudhuri et al. (2025) both examine the factors influencing DPP adoption, but differ in method and emphasis. Abedi et al. (2024) structure the implementation problem through the Technology-Organisation-Environment (TOE) framework and identify digital technologies, legislative pressure and collaboration as important enablers, while complex data management, lack of standardisation and reluctance to share information emerge as persistent barriers. Chaudhuri et al. (2025) provide an empirical supply-chain perspective and identify regulatory compliance, circular decision-making, transparency and

customer engagement as adoption drivers. Their findings also highlight the absence of a clear business case, increased data requirements, interoperability limitations and data-security concerns. While Abedi et al. (2024) provide a broader conceptual categorisation of adoption factors, Chaudhuri et al. (2025) offer greater empirical insight into how these barriers affect relationships among OEMs, suppliers, service providers and recycling partners.

Walden et al. (2021) offer an earlier and broader non-systematic review of the DPP as an enabler of the circular economy, drawing on precedents such as the International Material Data System (IMDS) and the Building Information Modelling (BIM)-supported Material Passport, and on the draft EU Battery Regulation. They identify challenges that remain relevant to DBP implementation, namely the absence of unified approaches across industries, uncertainty about how passport data will be kept up to date throughout the product lifecycle, and concerns regarding confidential business information and intellectual property. However, being a generic review based on the draft regulation, it does not provide attribute-level or actor-differentiated guidance on organisational readiness.

Losa and Torjesen (2025) and Paeplow et al. (2026) place stronger emphasis on the distribution of data and responsibilities across the value chain. Losa and Torjesen (2025) provide a battery-specific analysis that distinguishes between the information required for reuse and recycling and demonstrates an asymmetry between relatively accessible static data and more demanding dynamic data. Their findings show that data availability, intellectual property concerns and infrastructure limitations may favour recycling-oriented information flows over those required for reuse and second-life decisions. Paeplow et al. (2026), by contrast, adopt a broader stakeholder perspective and map 315 DPP requirements across multiple stakeholder groups. Their work demonstrates the complexity of aligning actors with different responsibilities, expectations and data needs.

Taken together, these studies demonstrate that DPP and DBP implementation depends on multiple technological, organisational and interorganisational conditions. However, the contributions primarily identify what facilitates or constrains implementation or map stakeholder requirements. They do not translate these factors into an operational method for measuring an organisation's readiness against individual DBP data attributes. Moreover, the studies differ in scope: generic DPP analyses offer broader transferability but limited battery-specific detail, whereas battery-focused studies provide stronger contextual relevance but remain predominantly exploratory and context-specific.

Petrik et al. (2025) move beyond barrier identification by operationalising DPP implementation through a maturity model. Their study develops a structured model comprising three dimensions,

nine maturation paths and five maturity levels, instantiated through a web-based self-assessment prototype and evaluated in several industry contexts. This contribution demonstrates the practical relevance of maturity-based assessment and is therefore the most directly comparable prior artefact. Nevertheless, the model remains generic to DPP implementation. It does not assess readiness against individual DBP data attributes, anchor the assessment in a battery-specific technical specification, or explicitly distinguish deficiencies originating within the assessed organisation from those associated with external data dependencies. These limitations are examined further in Section 2.3.

2.2.4. Ecosystem Coordination and Data Sharing

Jensen et al. (2024) and Kemmner et al. (2025) conceptualise DPP implementation primarily as an ecosystem coordination and data-sharing challenge, but focus on different aspects of ecosystem development. Based on a multiple-case study, Jensen et al. (2024) identify 16 practices and 5 orchestration mechanisms across four stages of ecosystem maturity: initiation, momentum, control, and self-renewal. Their contribution emphasises the active role of ecosystem orchestration, shared governance and stakeholder coordination throughout DPP development. Kemmner et al. (2025), by contrast, focus on the conditions under which industry-wide data sharing can generate systemic value. Their Ecosystem Adoption Model (EAM) identifies six central challenges: technology selection and scalability, data quality, data sovereignty, product-specific data requirements, standardisation and interoperability, and ecosystem momentum. Whereas Jensen et al. (2024) explain how ecosystem relationships can be orchestrated over time, Kemmner et al. (2025) clarify the technological, governance and participation conditions required for those relationships to support effective data exchange.

Voulgaridis et al. (2024) approach the same implementation problem from a more technology-oriented perspective. Their Digital Circular Economy framework structures DPP data processes into three tiers: data collection, curation and sharing, and leverage. The study identifies the Internet of Things (IoT), Artificial Intelligence (AI) and machine learning, blockchain and digital twins as potential enabling technologies and proposes a dual passport concept distinguishing business-oriented and user-oriented information. This perspective complements the ecosystem approaches of Jensen et al. (2024) and Kemmner et al. (2025) by illustrating how technological infrastructures may support data flows across the product lifecycle. However, it devotes less attention to the organisational capabilities, governance arrangements and actor-specific responsibilities required to implement those technologies in practice.

The three studies therefore converge on the view that DPP implementation extends beyond the boundaries of an individual organisation but operate at different analytical levels. Jensen et al. (2024) focus on ecosystem orchestration, Kemmner et al. (2025) on the conditions required for industry-wide data sharing, and Voulgaridis et al. (2024) on the technologies and data processes that may enable information exchange. These perspectives are complementary rather than contradictory. Nevertheless, they remain primarily ecosystem- or architecture-oriented and do not translate coordination, interoperability and data-sharing challenges into an attribute-level assessment of how a specific external dependency affects the readiness of an individual organisation.

2.3. Critical synthesis and research gap

The reviewed literature addresses DPP and DBP implementation through complementary but analytically distinct perspectives. Data-oriented studies clarify which information should be included and how it may be classified or modelled (Berger et al., 2023; Gianvincenzi et al., 2024; Jensen et al., 2023; Ott et al., 2024; Stratmann et al., 2023). Environmental-data studies examine the methodological and technological conditions required for LCA and carbon-footprint integration (Haupt et al., 2024; Soufi et al., 2023). Implementation studies identify technological, organisational and institutional barriers (Abedi et al., 2024; Chaudhuri et al., 2025; Losa & Torjesen, 2025), while ecosystem-oriented contributions emphasise stakeholder alignment, orchestration and interorganisational data sharing (Jensen et al., 2024; Kemmner et al., 2025; Paeplow et al., 2026).

These perspectives provide different but complementary forms of knowledge. Generic DPP data classifications provide cross-sector transferability but limited battery-specific regulatory detail. Battery-specific data models offer greater sectoral relevance but concentrate primarily on data structure and exchange. Adoption studies identify barriers and enabling conditions but do not operationalise them through a measurable readiness assessment. Ecosystem studies explain why coordination and participation are necessary but do not identify how a particular external dependency affects readiness at the level of an individual data attribute.

The literature also presents methodological limitations. Several contributions remain conceptual or requirement-driven and have not been empirically applied (Gianvincenzi et al., 2024; Haupt et al., 2024; Soufi et al., 2023; Voulgaridis et al., 2024). Other studies rely on qualitative and context-specific evidence, often involving a limited number of organisations or participants (Berger et al., 2023; Jensen et al., 2024; Kemmner et al., 2025; Ott et al., 2024). These approaches provide valuable exploratory insight but limit broader empirical generalisability and direct operational application.

The most directly comparable prior artefact is the DPP maturity model developed by Petrik et al. (2025). Unlike studies that primarily identify barriers or propose data structures, Petrik et al. (2025) operationalise implementation through a maturity-based assessment. However, the model remains generic to the DPP context. It does not assess readiness against individual DBP data attributes, anchor the assessment in a battery-specific technical specification, or explicitly distinguish deficiencies arising from internal organisational capabilities from those associated with external data dependencies.

Three interconnected research gaps therefore emerge from the review. First, the literature does not provide an integrated operational framework combining the organisational and interorganisational dimensions that influence DBP readiness, including data availability, quality, digitalisation, internal processes, technological infrastructure and ecosystem coordination. Second, existing approaches do not translate actor-specific data responsibilities and dependencies into an attribute-level readiness assessment method. Although several studies demonstrate that data needs and responsibilities vary across actors, they do not operationalise how these differences affect the readiness of a particular organisation. Third, existing maturity and readiness approaches are not anchored in the specific DBP data attributes defined in battery-related technical specifications and do not systematically account for their regulatory relevance or Static/Dynamic characteristics.

The DBP-MAF was developed in response to these gaps. It does not replace the contributions reviewed in this chapter; rather, it integrates and operationalises dimensions that previous studies generally address separately. It extends generic DPP maturity approaches through battery-specific regulatory anchoring, attribute-level assessment and explicit modelling of interorganisational data dependencies. This combination provides greater diagnostic granularity than approaches focused exclusively on organisational maturity, data-model design, implementation barriers or ecosystem coordination.

More specifically, the DBP-MAF combines: (1) the data requirements and lifecycle perspective identified in the DPP and DBP literature; (2) organisational readiness criteria covering data availability, quality, digitalisation and internal processes; (3) actor-specific responsibility and dependency modelling; and (4) maturity scoring and roadmap generation. A comparative synthesis of the reviewed contributions and the positioning of the DBP-MAF is presented in Table 3.

The framework's empirical applicability beyond the examined OEM context remains to be evaluated. Consequently, its contribution at this stage lies in the integration and operationalisation of the identified dimensions and in the initial demonstration of their use in an attribute-level DBP readiness assessment.

Table 3 - Comparative synthesis of reviewed literature and positioning of the DBP-MAF. Contributions are classified as addressed (+), partially addressed (P), acknowledged as limitation (–), or not covered (blank).

Article	Data requirements & models				Technological infrastructure		Organisational & ecosystem		DBP-MAF contributions		
	Data requirements /Data models	LCA /Carbon footprint integration	Static vs dynamic data distinction	Actor-differentiated data needs	Tech infrastructure & interoperability	Digital enablers (IoT, AAS, blockchain)	Implementation challenges & barriers	Ecosystem & stakeholder coordination	Maturity model/ readiness assessment	Regulatory anchor	Models' actor data dependencies
Abedi et al. (2024)				P	P	P	P	P			
Berger et al. (2023)	+		+	+			P		P	+	P
Chaudhuri et al. (2025)			P	P			+	P			
Gianvincenzi et al. (2024)	+	+			P				+		P
Haupt et al. (2024)	+	+		+			P		P		
Jensen et al. (2023)	+		P	+			+			P	P
Jensen et al. (2024)				+			P	+			
Kemmner et al. (2025)				P	+	P	P	+			
Losa and Torjesen (2025)	+		+	+			+		P	P	P
Ott et al. (2024)	+		+	P			P		P	P	P
Paeplow et al. (2026)				P			+	+	+	+	
Petrik et al. (2025)			P		+	+		+	+	-	-
Soufi et al. (2023)	P	+		P	+	+					
Stratmann et al. (2023)	+			P							P
Voulgaridis et al. (2024)				P	+	+		P			
Walden et al. (2021)	P			P		+		P			
DBP-MAF	+	+	+	+	+	P	+	+	+	+	+

3. Methodology

This chapter presents the research methodology adopted to address the study's central research question: *"How can organisational readiness for DBP implementation be assessed in companies across the battery value chain?"* It justifies the adoption of a DSR approach, characterises the DBP-MAF as the artefact developed through the research process, and describes how the artefact was designed, operationalised, applied and evaluated.

Section 3.1 presents the research design and explains how the study connects the practical DBP implementation environment with the relevant scientific, regulatory and technical knowledge base. Section 3.2 describes the design and evaluation process, including the derivation of the design requirements, the development of the artefact, its application to an OEM case study, the practitioner evaluation and the data analysis procedures.

3.1. Research Design

This study adopts a DSR approach, a research paradigm concerned with the development and evaluation of purposeful artefacts designed to address relevant real-world problems (Hevner et al., 2004; Vaishnavi et al., 2004). DSR seeks to produce prescriptive knowledge by constructing and evaluating solutions intended to improve a given problem context (Hevner et al., 2004).

DSR is appropriate for this study for three main reasons. First, DBP implementation constitutes a practical and time-sensitive organisational challenge arising from an evolving regulatory context. The approaching February 2027 implementation deadline underscores the need for an actionable readiness assessment rather than a purely descriptive analysis of implementation barriers. Second, the intended outcome is an artefact that supports organisations in assessing their current preparedness, identifying critical gaps and prioritising actions for DBP implementation. This objective aligns with the DSR's emphasis on artefacts that are both scientifically grounded and practically useful (Hevner et al., 2004). Third, although the DBP literature remains fragmented, the existing knowledge base provides sufficient evidence on data requirements, implementation challenges, organisational capabilities, technical specifications and interorganisational dependencies to inform the design of a grounded artefact. This knowledge base includes the academic literature reviewed in Chapter 2, the regulatory requirements established by Regulation (EU) 2023/1542 (European Union, 2023), and the battery passport data attributes specified in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025). Figure 3 represents the DSR framework applied to this study, adapted from Hevner et al. (2004).

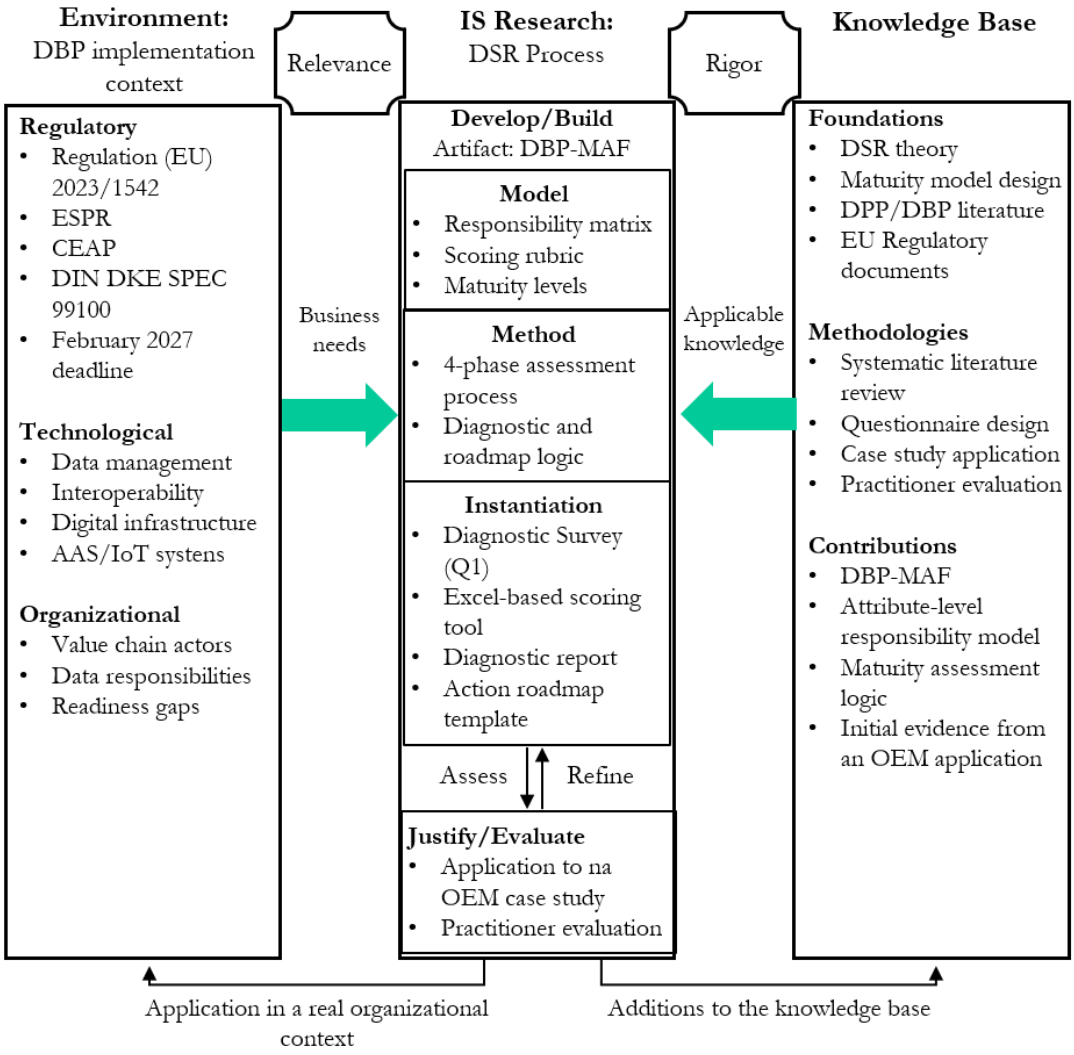


Figure 3 - DSR Framework applied to this study (adapted from Hevner et al., 2004)

The environment comprises the regulatory, technological and organisational conditions that establish the practical relevance of the research problem. The knowledge base includes DSR theory, maturity-model design principles, DPP and DBP literature, Regulation (EU) 2023/1542 (European Union, 2023) and DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025). The central IS Research domain represents the development and evaluation of the DBP-MAF as a model, method and instantiation. The Relevance Bridge translates practical and regulatory needs into artefact requirements, while the Rigour Bridge connects the design process with the existing scientific, regulatory and methodological knowledge base. The framework was subsequently applied to one OEM, providing an initial naturalistic demonstration and formative practitioner evaluation.

3.2. Design and Evaluation Process

The design and evaluation process followed the DSR phases described by Vaishnavi et al. (2004): Awareness of Problem, Suggestion, Development, Evaluation, and Conclusion. Table 4 summarises how the five DSR phases were operationalised in this study and identifies the main output associated with each phase.

Table 4 - DSR research process applied to the development and evaluation of the DBP-MAF

DSR phase (Vaishnavi et al., 2004)	**Activities conducted in this study**	**Main output**
Awareness of Problem	Literature review; regulatory analysis of Regulation (EU) 2023/1542 (European Union, 2023) and DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025); identification of organisational readiness challenges and research gaps.	Problem definition and research gaps
Suggestion	Derivation of design requirements for an attribute-level, actor-sensitive and regulatory-anchored maturity assessment framework.	Design requirements and conceptual architecture of the DBP-MAF
Development	Translation of the design requirements into the model, method and instantiation components; development of the Responsibility Matrix, assessment criteria, maturity scale, Q1, Excel-based Scoring Tool, Diagnostic Report structure and Implementation Roadmap.	Operational DBP-MAF
Evaluation	Naturalistic single-case application to an OEM through Q1 and the Excel-based Scoring Tool; production of the Diagnostic Report; subsequent practitioner evaluation through Q2.	Case-based diagnostic results and practitioner feedback
Conclusion	Interpretation of findings; reflection on theoretical and practical contributions and limitations; formulation of recommendations and future research directions.	Research conclusions and opportunities for future refinement

These phases were not treated as a strictly linear sequence. During the Suggestion and Development phases, design decisions were progressively refined through iteration between the existing knowledge base, the regulatory and technical context, and the emerging artefact.

The following sections consolidate these phases into three methodological blocks. Section 3.2.1 describes problem awareness and the derivation of the design requirements. Section 3.2.2 presents the development and operationalisation of the artefact. Section 3.2.3 describes the case application, practitioner evaluation and data analysis. The outcomes associated with the Conclusion phase are presented in Chapters 5, 6 and 7.

3.2.1. Problem Awareness and Design Requirements

Problem awareness was established through the literature review (Chapter 2) and the regulatory analysis of Regulation (EU) 2023/1542 (European Union, 2023) and DIN DKE SPEC

99100:2025-02 (DIN/DKE, 2025). The literature review revealed a fragmented knowledge base covering DBP data requirements, data models, LCA integration, implementation barriers, adoption factors, technological infrastructure and ecosystem coordination. Although these contributions provide important foundations, three interconnected research gaps were identified. First, prior literature does not provide an integrated operational approach that combines the organisational and interorganisational dimensions that influence DBP readiness. Second, existing approaches do not provide attribute-level modelling of the data responsibilities and dependencies connecting the economic operator with other battery value chain actors. Third, the maturity and readiness approaches identified in the literature are not anchored in the specific DBP data attributes defined in battery-related technical specifications and do not systematically account for differences between mandatory and recommended, or static and dynamic, data attributes.

The regulatory and technical analysis established the practical significance of these gaps. Regulation (EU) 2023/1542 (European Union, 2023) defines the DBP obligations, the affected battery categories and the responsibilities associated with placing batteries on the market. DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025) provides a detailed specification of the relevant DBP data attributes. Together, these sources demonstrated the need for an approach capable of translating regulatory and technical requirements into an organisational readiness assessment.

The Suggestion phase translated the identified gaps and practical needs into explicit design requirements. These requirements established traceability between the problem, the evidence base and the design choices incorporated into the DBP-MAF.

Table 5 presents the Design Requirements (DRs), their evidence base and the corresponding response incorporated into the DBP-MAF.

Table 5 - Design requirements of the DBP-MAF

ID	Design requirement	Evidence base	Response incorporated into the DBP-MAF
DR1	Assess readiness at the level of individual DBP data attributes.	Regulation (EU) 2023/1542 (European Union, 2023); DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025); research gap 3	Attribute-level assessment structure
DR2	Distinguish data responsibilities and dependencies across battery value chain actors.	Berger et al. (2023); Jensen et al. (2023); Paeplow et al. (2026); research gap 2	Actor profiles and Responsibility Matrix
DR3	Assess multiple readiness dimensions rather than data existence alone.	Abedi et al. (2024); Chaudhuri et al. (2025); Petrik et al. (2025); research gap 1	Organisational and external-data assessment criteria
DR4	Distinguish static and dynamic DBP data.	Losa and Torjesen (2025); Ott et al. (2024)	Static/Dynamic classification

DR5	Differentiate attributes according to regulatory relevance.	Regulation (EU) 2023/1542 (European Union, 2023); DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025)	Mandatory/Recommended classification
DR6	Translate assessment results into interpretable maturity outcomes.	Petrik et al. (2025); maturity assessment logic	Maturity scale and readiness results
DR7	Distinguish gaps associated with internal capabilities and external data flows.	Berger et al. (2023); Jensen et al. (2024); Kemmner et al. (2025)	Responsibility-based gap classification
DR8	Generate actionable guidance for DBP implementation.	Practical organisational need; DSR utility principle	Diagnostic Report and implementation roadmap
DR9	Operationalize the assessment through usable data-collection and processing instruments.	Practical implementation context	Q1 and Excel-based Scoring Tool

The design requirements were combined into an integrated conceptual architecture rather than treated as independent features. Attribute-level assessment provided regulatory granularity; the actor profiles and Responsibility Matrix (Appendix D) represented interorganisational data relationships; the assessment criteria captured organisational readiness; the maturity scale supported the interpretation of results; and the roadmap translated the diagnosis into actionable guidance. The requirements guided the internal design of the DBP-MAF. The subsequent practitioner evaluation examined the perceived utility, quality and efficacy of the resulting artefact rather than testing each design requirement as an independent hypothesis.

3.2.2. Artefact Development and Operationalisation

The Development phase translated the design requirements into three interconnected artefact components: a model, a method and an instantiation. The model component organised the data attributes specified in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025) into an assessment structure and represented their relationship with different battery value chain actors. It also established the assessment criteria, scoring structure and maturity interpretation required to evaluate organisational readiness. The method component was developed as a four-phase process covering configuration, attribute-level assessment, scoring and diagnosis, and roadmap generation. It was designed to produce both an aggregated maturity result and a differentiated diagnosis of the gaps affecting DBP implementation. The instantiation component comprised the Diagnostic Questionnaire (Q1), the Excel-based Scoring Tool, the Diagnostic Report and the Implementation

Roadmap. These instruments operationalised the framework by enabling the collection, processing and communication of assessment information.

Q1 was designed to collect the organisational information required to define assessment scope, including the company's actor profile, size and applicable battery categories. Two assessment structures were used according to the relationship between the assessed organisation and the relevant data attribute. Attributes generated, maintained or contributed to by the assessed organisation are evaluated through Availability, Quality, Digitalisation, and Internal Process and attributes dependent on data generated by another value chain actor are evaluated through Receive and Integrate. The two structures use a common scale from 0 to 5, allowing the results to be interpreted within the same readiness framework. Receive and Integrate were separated because external data readiness involves two distinct conditions. An organisation may possess the technical capability to integrate a data attribute while the source data remains unavailable. Conversely, an organisation may receive data in a format that cannot be effectively incorporated into the DBP.

Several data attributes specified in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025) were grouped into individual questionnaire items when they shared the same data source, organisational owner, evidence base and readiness logic. The corresponding score was subsequently applied to each related attributes in the scoring tool. This reduced respondent burden while maintaining attribute-level traceability. However, the approach assumes similar readiness conditions among grouped attributes and may reduce the ability to detect differences within the group. Q1 also collected qualitative observations concerning perceived barriers, ongoing initiatives and contextual factors relevant to score interpretation. The complete instrument is provided in Appendix E.

The Excel-based Scoring Tool (Appendix F) linked responses collected through Q1 to the applicable data attributes, calculated readiness results, identified critical gaps, and supported the preparation of the Diagnostic Report and the implementation roadmap. The detailed actor profiles, responsibility designations, score descriptors, weighting rules, maturity levels, and gap classifications are presented in Chapter 4.

3.2.3. Case Application, Practitioner Evaluation and Data Analysis

The Evaluation phase combined the application of the DBP-MAF in a real organisational context with a subsequent practitioner evaluation of the artefact.

The DBP-MAF was applied to an OEM affiliated with Battery Cluster Portugal. The organisation was selected because its position provided a relevant setting for examining both internal readiness

and dependency on data generated by other battery value chain actors. The organisation operates as an OEM and as the economic operator placing batteries on the market, and must therefore coordinate product, manufacturing, supplier, lifecycle, and end-of-life information relevant to DBP implementation. This made the case suitable for demonstrating the artefact in an organisational setting involving both internal capabilities and interorganisational data dependencies. The application was exploratory and served as a naturalistic demonstration of the DBP-MAF in one OEM context. Its purpose was to examine whether the framework could be configured, applied and used to generate an organisational readiness diagnosis and implementation roadmap. The case does not provide statistical generalisation or comprehensive empirical validation of the framework across the battery value chain, since only one organisation, one respondent and the P4 profile were included. The organisation participated voluntarily, and the information collected was used exclusively for academic purposes. Its identity and commercially sensitive information are not disclosed. The case is therefore described in terms of the relevant actor profile.

Data collection via Q1 took place on 10 June 2026 using Google Forms and was completed by an organisational representative from the Development Engineering Department. The assessment was conducted independently, and the responses were supported by documentary evidence, technical documentation and the participant's organisational knowledge. The Q1 responses were entered into the Excel-based Scoring Tool and used to determine the organisation's maturity, category-level readiness profile, gaps, and implementation priorities.

After receiving and reviewing the Diagnostic Report, the organisation evaluated the artefact through the Practitioner Evaluation Questionnaire (Q2), also administered using Google Forms. Conducting Q2 after the case application ensured that the evaluation was informed by direct experience with the assessment process and its outputs. Drawing on the DSR evaluation principles of usefulness and effective problem solving discussed by Hevner et al. (2004), Q2 addressed three dimensions: Utility, referring to the practical value of the artefact; Quality, referring to the perceived accuracy, clarity and internal consistency of the framework; and Efficacy, referring to whether the artefact functioned in the context for which it was designed. Q2 included closed items scored on a 0–5 agreement scale and open-ended questions regarding strengths, limitations, implementation barriers and improvement opportunities. The complete instrument is provided in Appendix G. Q2 was completed by the same organisational representative who completed Q1 and reviewed the resulting Diagnostic Report. This sequencing ensured that the evaluation was informed by direct experience with the assessment process and its outputs. However, the participant's prior involvement reduced the independence of the evaluation and introduced a potential risk of confirmation and common-method bias. The Q2 results should therefore be interpreted as

formative practitioner feedback rather than independent, statistical or sector-wide validation of the artefact.

The data analysis involved two distinct but related sources: the organisational readiness data collected through Q1 and the practitioner evaluation data collected through Q2. Q1 results were calculated at attribute, category and overall-readiness levels. Attributes assessed through Availability, Quality, Digitalisation, and Internal Process were calculated as the arithmetic mean of the four scores and attributes assessed through the Receive and Integrate dimensions were calculated as the arithmetic mean of the two scores. Both forms of assessment produced normalised results on a scale from 0 to 5. Attributes not applicable to the company profile, company size, or battery category were excluded from the calculations.

Mandatory and recommended attributes were differentiated during aggregation, and those below the readiness threshold defined in Chapter 4 were identified as critical gaps. Category results were calculated from the applicable attribute scores, and categories with no applicable attributes were excluded from the overall-readiness calculation. Qualitative observations were used to contextualise the numerical results and support the formulation of the implementation roadmap. The resulting scores represent indicators of organisational readiness for DBP implementation. They do not constitute evidence or certification of legal compliance, and the DBP-MAF does not replace a formal legal, regulatory or conformity assessment.

For Q2, closed-item responses were summarised by item and evaluation dimension. No inferential statistical analysis was conducted because of the limited number of respondents. Open-ended responses were reviewed and organised according to themes relating to practical value, design quality, feasibility implementation, adoption barriers and recommended improvements.

Q1 and Q2 provided complementary evidence. Q1 demonstrated the capacity of the artefact to produce a differentiated organisational readiness diagnosis, while Q2 captured the practitioner's assessment of whether the artefact and its outputs were useful, coherent and applicable in practice. The DSR Conclusion phase is completed through the interpretation of the findings, the assessment of contributions and limitations, and the identification of future research opportunities presented in Chapters 5, 6, and 7. Chapter 4 first presents the detailed structure and operation of the DBP-MAF.

4. The DBP-MAF: Framework Design and Components

This chapter presents the DBP-MAF, the artefact developed through this DSR study. The DBP-MAF translates DBP regulatory and technical requirements into an operational approach for assessing organisational readiness at the level of individual data attributes. The DBP-MAF integrates a model defining its assessment structure, a four-phase method for its application and an instantiation comprising Q1, the Excel-based Scoring Tool, the Diagnostic Report and the Implementation Roadmap. The framework is anchored in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025) and Regulation (EU) 2023/1542 (European Union, 2023). However, the DBP-MAF is a readiness assessment artefact rather than a legal assessment instrument. Figure 4 presents the integrated architecture of the DBP-MAF and the relationship between regulatory and technical foundations.

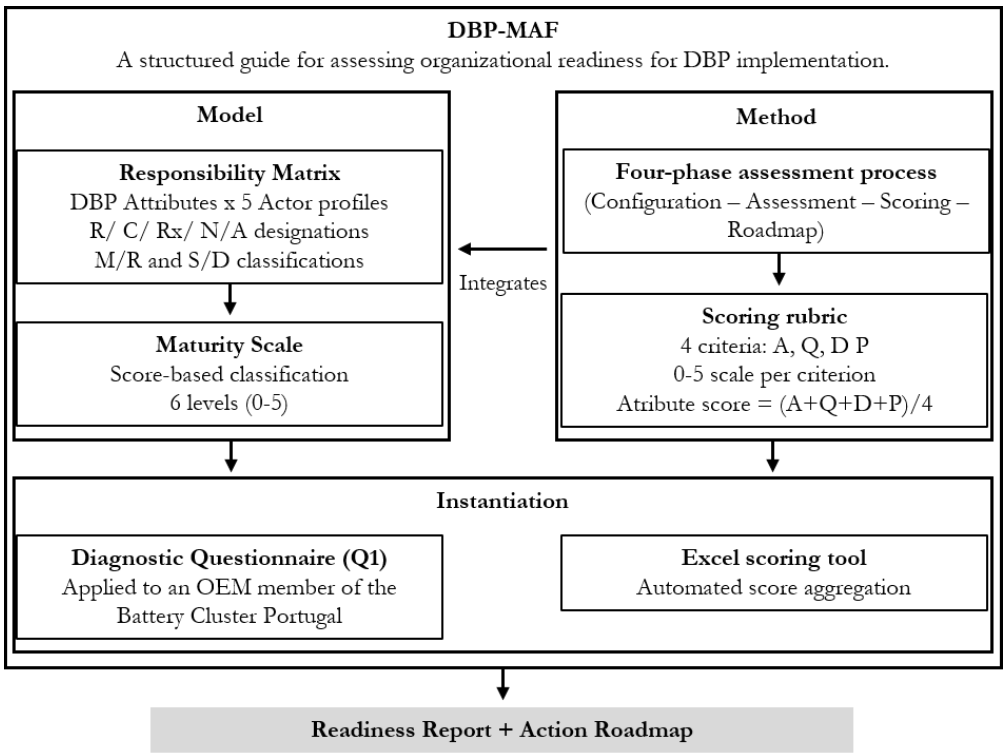


Figure 4 - DBP-MAF: integrated framework components

The following sections describe the components in detail. Section 4.1 presents the model through which data responsibilities and organisational readiness are represented and measured. Section 4.2 describes the four-phase assessment method. Section 4.3 presents the instruments through which the framework is operationalized.

4.1. Mapping Responsibilities and Readiness: The Model Component

The model component defines the concepts, classifications and scoring rules through which DBP readiness is represented. It comprises six interconnected elements: the DBP data attribute structure, battery value chain actor profiles, Responsibility Matrix, regulatory and temporal attribute classifications, assessment criteria, and maturity-level interpretation. The model assumes that DBP readiness cannot be adequately assessed through a general organisational checklist, as each mandatory or recommended attribute may involve different data sources, organisational owners, technological requirements and external dependencies. Therefore, the DBP-MAF assesses readiness at the individual attribute level before aggregating results into categories and an overall organisational readiness score.

The DBP data attributes were derived from DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025), categorized into seven categories: (1) Identifier and product data; (2) Symbols, labels and documentation of conformity; (3) Battery carbon footprint; (4) Supply chain due diligence; (5) Battery materials and composition; (6) Circularity and resource efficiency; and (7) Performance and durability. These categories structure the assessment and presentation of results. The complete attribute list and its category allocation are presented in the Responsibility Matrix in Appendix D.

To represent the distribution of DBP-relevant data across the battery value chain, the model defines five actor profiles: P1 - Raw material extractors and miners; P2 - Material refiners and processors; P3 - Cell and component manufacturers; P4 - Battery module or pack manufacturers and OEMs; and P5 - End-of-life operators, including recyclers, dismantlers and second-life operators. The profiles represent functional positions in the battery value chain rather than fixed legal categories. P1 generates raw-material origin, extraction and traceability data; P2 provides processing and pre-consumer recycled-content information; P3 generates cell chemistry, composition, technical and manufacturing-performance data; P4 integrates battery components and manages product-, pack- and market-level information; and P5 provides end-of-life, recycling, recovery and second-life data. Although the empirical application focuses on a P4 OEM, all five profiles are included to represent relevant data flows and enable future adaptation of the framework to other value chain positions.

The Responsibility Matrix maps each DBP data attribute against the five actor profiles and assigns one of four designations: Responsible (R), when the actor primarily generates, maintains or controls the data; Contributor (C), when the actor contributes information without solely generating or controlling the complete attribute; Recipient (Rx), when the actor depends on data generated externally and must receive and integrate it; and Not Applicable (N/A), when the attribute is

irrelevant to the actor's role or assessment scope. As designations are assigned from each actor's perspective, the same attribute may receive different designations across the matrix.

The Responsibility Matrix serves two functions. First, it defines the assessment scope: R, C or Rx attributes are included when applicable regulatory and product-specific conditions are met, whereas N/A attributes are excluded. Second, it supports gap interpretation: a low R score indicates an internal capability gap; a low C score indicates an insufficiently mature contribution to a shared data requirement; and a low Rx score indicates that external data is unavailable or cannot be effectively integrated. The matrix also serves as the reference structure for configuring Q1 and determining the assessment logic for each data attribute.

Each attribute is further classified according to regulatory relevance and temporal behaviour. The Mandatory/Recommended (M/R) classification distinguishes attributes required under the applicable regulatory and technical framework from recommended information in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025). Mandatory attributes receive a weight of 2 and Recommended attributes a weight of 1 during score aggregation, giving mandatory weaknesses greater influence on results. The weighting reflects implementation priority rather than demonstrating legal compliance.

The Static/Dynamic (S/D) classification distinguishes attributes by temporal behavior. Static attributes are established at a specific lifecycle point and generally remain unchanged unless the battery, product specification or legal status changes. Dynamic attributes require periodic or event-driven updates and may depend on BMS functionality, item-level data collection, and communication infrastructure. The framework treats BMS availability and communication capability as distinct conditions, since the existence of a BMS does not ensure that relevant data can be extracted, transmitted or integrated into the DBP.

The DBP-MAF applies two assessment structures according to the organisation's relationship with the data attribute. Attributes designated R or C for the assessed organisation are evaluated through four criteria (Table 6):

- Availability (A): whether the required data exists and the extent to which it is complete and maintained for the relevant batteries;
- Quality (Q): whether the data is reliable, traceable, verifiable and subject to suitable quality-assurance mechanisms;
- Digitalisation (D): whether the data is available in a structured and shareable digital format and can be exchanged through interoperable systems;

- Internal Process (P): whether responsibilities, procedures and update mechanisms for the data are defined, documented, monitored and improved.

Each criterion is scored on an ordinal scale from 0 to 5. Lower scores represent absent, informal or non-digitalized conditions, while higher scores represent complete, controlled, interoperable and formally managed conditions.

Table 6 - DBP-MAF assessment criteria and scoring rubric (0-5 scale).

	Criteria			
	A	**Q**	**D**	**P**
0	Data does not exist within the organisation	No quality assurance in place	Paper-based or unstructured spreadsheet	No defined process or process owner
1	Data generation planned but not yet implemented	Informal validation; no traceability or documentation	Digital but unstructured (e.g. PDF, email)	Ad hoc process; informal responsibility
2	Data exists partially or informally; no quality assurance	Internal validation process defined; partial traceability	Structured digital format (CSV / JSON / database)	Documented process with designated owner
3	Data exists systematically for all relevant cases	Internal quality assurance documented and monitored	Interoperable via API or standardised data exchange format	Documented process, KPI-monitored, with defined update cadence
4	Data complete and internally validated by a designated owner	Data externally reviewed; full traceability chain established	Asset Administration Shell (AAS/IDTA) connectivity established	Process integrated into quality management system (ISO-certified)
5	Data complete, verifiable and auditable by external third parties	Data externally certified; internationally recognised standard applied	Full AAS/IDTA integration with automated lifecycle updates	Process formally audited; continuous improvement cycle in place

For an R- or C-designated attribute, the attribute score is calculated as the arithmetic mean of the four scores. A high Availability score cannot fully compensate for the absence of a defined process or a digitally shareable format. Criterion-level results remain visible in the Diagnostic Report because the aggregate score may conceal different readiness deficiencies. Attributes designated Rx require a different assessment structure because the assessed organisation is not the original generator of the information. The readiness of an Rx attribute depends on two conditions: whether the required data is received from the relevant value chain actor in a reliable and systematic manner, and whether the received data can be incorporated into the organisation's systems, calculations, and DBP data structure. The two criteria are evaluated independently on the same 0–5 scale. This distinction prevents the absence of external data from being confused with an internal integration limitation. A company may have the technical infrastructure to integrate a data attribute but may

not receive the data from its supplier. Conversely, it may receive the information in a format that cannot be incorporated into the DBP.

Table 7 - Receive and Integrate scoring rubric for Rx-designated attributes

Score	Receive	Integrate
0	Required data is not received	Data cannot be integrated
1	Receipt is planned or requested but not implemented	Integration requirements are identified but no solution exists
2	Data is received occasionally, partially or through informal channels	Manual or partial integration is possible
3	Data is received systematically in a defined digital format	Data can be integrated through a defined and repeatable process
4	Data is received through a controlled and traceable exchange process	Integration is interoperable and subject to validation
5	Data is received automatically through an established data-sharing mechanism	Data is integrated automatically and updated through connected systems

For an Rx-designated attribute, the score is calculated as the arithmetic mean of the two scores. It does not reduce their regulatory relevance. Mandatory Rx attributes retain the same regulatory weight as other mandatory attributes during score aggregation.

The scoring scale, critical-gap threshold and regulatory weighting constitute pragmatic design choices developed to support an interpretable assessment. A 0–5 ordinal scale was selected to balance diagnostic differentiation and ease of use: a scale with fewer response categories could be insufficient to represent intermediate readiness conditions, whereas a scale with a larger number of response categories could increase complexity and imply a level of precision that the available evidence could not support. Within this scale, 0 represents the absence of the required data, process or capability and 5 represents the most developed condition defined in the rubric. The critical-gap threshold was set at 2.5, the mathematical midpoint of the scale, to prioritise Mandatory attributes whose attribute scores remain closer to the absent, informal or partially implemented conditions represented by scores 0–2. Mandatory attributes were assigned a weight of 2 and Recommended attributes a weight of 1 to give greater influence to required information while retaining recommended information in the readiness profile. These rules are neither prescribed by the applicable regulation nor by the technical specification, and they have not been statistically calibrated. They should therefore be interpreted as initial heuristic design choices developed within the DSR process and subject to sensitivity testing and empirical calibration through future multi-case applications and expert elicitation (e.g. the Delphi method).

The DBP-MAF calculates results at three levels: attribute, category and overall organisational readiness. Attributes classified as N/A because of the organisation's profile, company size, battery

category or other regulatory condition are excluded. For that reason, a category containing no applicable attributes is reported as N/A instead of zero. The overall-readiness score is calculated as the weighted average of all applicable attribute scores across the assessment. This approach means that the overall score reflects both the number of applicable attributes and their regulatory relevance. Category scores are retained to support diagnosis and visual comparison, while the overall score provides a compact reference point for maturity interpretation. The category- and criterion-level results remain essential because an overall average may conceal critical weaknesses in specific mandatory attributes. A Mandatory attribute scoring below 2.5 is classified as a critical gap. As explained above, this is a diagnostic prioritisation rule rather than a legal compliance threshold. Scores at or above 2.5 must still be confirmed through appropriate legal, technical or conformity assessment. Critical gaps are classified according to the responsibility designation of the assessed organisation:

- Capability gap: an R-designated attribute scores below the threshold because the organisation's own data, infrastructure or processes are insufficient;
- Contribution gap: a C-designated attribute scores below the threshold because the organisation's contribution to a shared data requirement is incomplete or insufficiently mature;
- Integration gap: an Rx-designated attribute scores below the threshold because the required external data is not received or cannot be integrated

The classification links diagnosis to action. Capability gaps primarily require internal improvement. Contribution gaps generally require internal action combined with coordination over a shared requirement. Integration gaps require supplier or partner engagement, data-sharing arrangements, interoperability improvements or a combination of these actions.

The overall-readiness score is interpreted through six maturity levels. The DBP-MAF uses the maturity scale as a diagnostic reference for implementation readiness. Level 0 is a qualitative entry condition applied when the organisation has no structured awareness of DBP requirements and no meaningful assessment evidence. Once an organisation begins the structured assessment, its quantitative results are interpreted through Levels 1 to 5. The score bands provide an overall maturity indication. Nevertheless, mandatory attribute-level gaps remain visible regardless of the overall result. An organisation with a relatively high overall score may still have implementation-critical weaknesses if one or more mandatory attributes remain below the critical-gap threshold. Table 8 defines each maturity level, its score range, associated regulatory risk, typical organisation profile, and progression criteria.

Table 8 - DBP-MAF maturity levels: definitions and progression criteria

Level	Designation	Score range	Regulatory risk	Typical organisational profile	Typical priorities for progression
0	Unaware	-	Non-compliance	No structured data; no awareness of DBP requirements	Identify applicable attributes; map existing data assets; raise internal awareness
1	Initial	0.1-0.9	Very high	Scattered data in silos; no digital format; no defined process	Achieve score ≥1.0 on all Mandatory attributes in at least 3 of 7 categories
2	Developing	1.0-1.9	High	Data partially available; informal processes; limited digitalisation	Achieve score ≥2.0 on all Mandatory static attributes; document internal processes
3	Defined	2.0-3.4	Moderate	Structured data; defined processes; partial supply chain integration	Achieve score ≥3.0 on all Mandatory dynamic attributes; integrate tier-1 suppliers
4	Managed	3.5-4.4	Low	Full DBP compliance; interoperable data; integrated supply chain	Sustain full compliance; expand to Recommended attributes; leverage DBP for value creation
5	Optimized	4.5-5.0	Minimal	DBP as competitive advantage; continuous improvement; beyond-compliance value	Contribute to sector benchmarks; share data proactively; support upstream actors

The maturity level is assigned from the overall-readiness score, while critical mandatory gaps are reported as a separate diagnostic safeguard. Consequently, a maturity level should always be interpreted in conjunction with the critical-gap register, the category profile, and the criterion-level results. Level 3 indicates a defined implementation condition, but remaining mandatory gaps may still prevent legal or operational fulfilment of DBP obligations. This distinction prevents an aggregate score from creating a false sense of readiness.

4.2. From Data to Diagnosis: The Assessment Method

The method component operationalises the model through four interrelated phases: Configuration, Attribute-level Assessment, Scoring and Diagnosis, and Implementation Roadmap. Although the phases are presented sequentially, the method allows iteration. Evidence obtained during assessment may necessitate revising the applicable scope, while data inconsistencies identified during diagnosis may require reconsideration of individual scores. Figure 5 represents the DBP-MAF assessment process using Business Process Model and Notation (BPMN) 2.0.2 (Object Management Group, 2013).

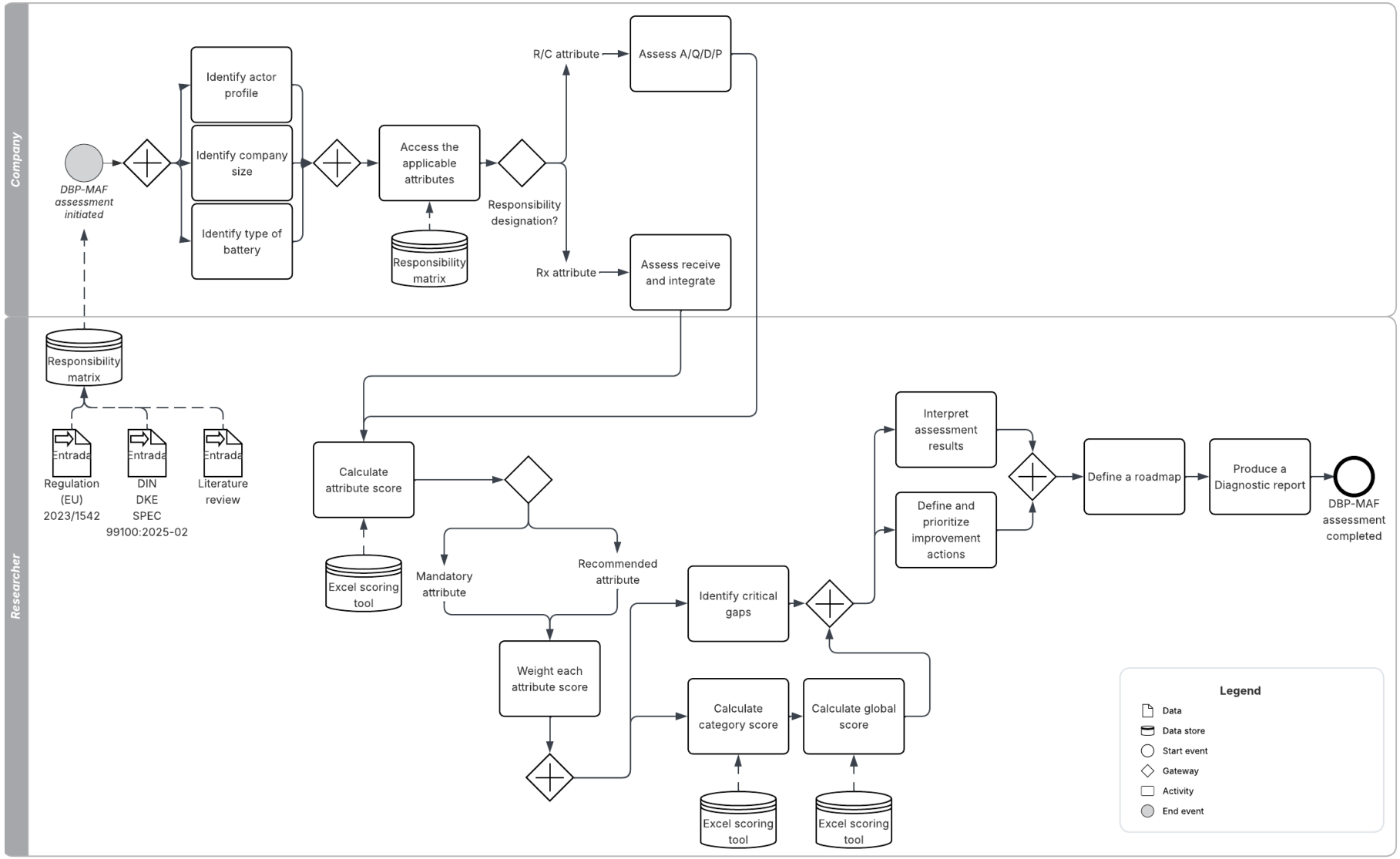


Figure 5 - DBP-MAF Assessment representation using BPMN 2.0.2.

The Configuration phase establishes the assessment scope. The organisation's actor profile or combination of profiles is identified, together with its size and the battery categories covered by the assessment. These characteristics influence which attributes and regulatory provisions apply. The Responsibility Matrix is then used to identify attributes assigned R, C or Rx for the assessed profile. Attributes designated N/A are excluded. Additional applicability conditions are subsequently considered, including battery category, battery configuration, company-size exemptions and the presence of a BMS. In the configuration phase, dynamic attributes distinguish BMS functionality from the communication infrastructure. The BMS may calculate or record the required information without providing a mechanism for external transmission or DBP integration. The assessment must therefore determine whether the data can be generated and communicated. The main output of the Configuration phase is the organisation-specific list of applicable DBP data attributes and the assessment structure assigned to each attribute.

During the Attribute-level Assessment phase, the applicable attributes are evaluated through Q1. R- and C-designated attributes are assessed using the Availability, Quality, Digitalisation, and Internal Process criteria. Rx-designated attributes are assessed using Receive and Integrate. The assessment records quantitative scores and qualitative observations. Supporting evidence may include documentary evidence, technical documentation and the participant's organisational knowledge. The assessment captures the organisation's current condition rather than planned future capabilities. Attributes grouped into a shared Q1 item receive the same criterion scores when they share an equivalent data source, owner, evidence base and readiness logic. Their traceability is nevertheless retained individually in the scoring tool. The output of this phase is an attribute-level dataset containing the applicable scores, responsibility designations, regulatory and temporal classifications, supporting observations and evidence references.

The Scoring and Diagnosis phase converts the assessment data into organisational readiness results. The Excel-based Scoring Tool calculates attribute scores using the relevant formula, applies the Mandatory/Recommended weighting and generates category and overall-readiness results. Attributes and categories classified as N/A are excluded from the calculations. The tool then identifies Mandatory attributes below the critical-gap threshold of 2.5 and links each critical gap to the corresponding responsibility designation. The diagnosis distinguishes between capability, contribution, and integration gaps and retains criterion-level results that explain the nature of the deficiency. For example, two attributes may have the same aggregate score while requiring different interventions: one may lack data entirely, while another may contain reliable information that is not digitally shareable. The resulting Diagnostic Report includes the overall maturity level, applicable

category scores, the register of critical gaps and the qualitative interpretation of the results. A radar chart or equivalent category-level visualisation may be used to communicate the readiness profile, provided that non-applicable categories are clearly represented as N/A.

The Implementation Roadmap phase translates the diagnosis into an actionable improvement plan. Each critical gap is considered according to its regulatory relevance; the applicable implementation deadline; its responsibility or dependency designation; the criterion-level cause of the gap; the estimated implementation effort; and its dependency on external actors or technological infrastructure. The recommended actions are prioritised based on regulatory criticality and implementation effort. Actions concerning missing mandatory data or long-lead technological and interorganisational capabilities receive greater urgency than improvements affecting recommended data or documentation that is already substantially available. Each roadmap action should include an intended outcome, a responsible organisational owner, relevant external stakeholders, an indicative target date and any dependencies on other actions. Where appropriate, actions are aligned with the applicable milestones of Regulation (EU) 2023/1542 (European Union, 2023). The method's final output is a Diagnostic Report accompanied by an Implementation Roadmap. The report explains the organisation's current readiness, while the roadmap outlines the sequence of interventions required to improve it.

4.3. Making the Framework Operational: The Instantiation

The instantiation component consists of the instruments through which the DBP-MAF model and method are used in practice: the Q1, the Excel-based Scoring Tool, the Diagnostic Report and the Implementation Roadmap.

Q1 is the primary data-collection instrument. It filters company characterisation and scope configuration, to the questions applicable to the relevant actor profile, battery category and organisational conditions. The questionnaire translates the attribute-level assessment logic into questions that can be answered by company representatives with knowledge of data management, engineering, quality, compliance, information systems or supply-chain processes. The Q1 items are linked to one or more DBP data attributes. R- and C-designated attributes use the A/Q/D/P structure, while Rx-designated attributes use the Receive/Integrate structure. Open-ended fields allow recording evidence, barriers, ongoing initiatives, and relevant contextual information. The complete version of Q1 used in the OEM case application is provided in Appendix E.

The Excel-based Scoring Tool connects the Q1 responses to the applicable data attributes and performs the calculations described in Section 4.1. For each attribute, the tool records the DBP category, regulatory relevance, temporal classification, responsibility designation, criterion scores, attribute score and critical-gap status. It subsequently calculates category and overall-readiness results and supports the identification of prioritised gaps.

The Diagnostic Report communicates the assessment results to the organisation. It includes the assessment scope, overall-readiness score, maturity-level interpretation, category-level profile, critical-gap register and explanatory observations. The report should retain sufficient attribute-level detail to support corrective action while presenting the main findings in a format understandable to decision-makers.

The Implementation Roadmap converts the critical-gap register into a plan. It records the recommended intervention, responsibility for implementation, relevant external partners, priority, target date and anticipated dependencies. The roadmap is generated from the assessment results and subsequently refined through organisational judgment, as resource availability and implementation feasibility cannot be determined solely from the numerical scores.

The Q2 is not considered a core component of the operational DBP-MAF. It was developed specifically to evaluate the artefact in the context of this DSR study after the company had completed Q1 and reviewed its Diagnostic Report. Its design and application are described in Chapter 3, and the practitioner evaluation results are presented in Chapter 5.

Together, Q1, the Excel-based Scoring Tool, the Diagnostic Report and the Implementation Roadmap operationalise the transition from regulatory data requirements to organisational diagnosis and implementation planning. Chapter 5 presents the application of these components to the OEM case study and the subsequent practitioner evaluation of the artefact.

5. Evaluation

This chapter presents the evaluation of the DBP-MAF through its application to the OEM case study and the subsequent practitioner assessment of the artefact. The evaluation provides two complementary forms of evidence. The case application demonstrates whether the DBP-MAF can produce an attribute-level organisational readiness diagnosis in a real setting, while the practitioner evaluation examines whether the artefact and its outputs were perceived as useful, coherent and applicable.

Section 5.1 presents the organisational readiness results generated through the Q1 and the Excel-based Scoring Tool. Section 5.2 presents the feedback collected through Q2, covering the perceived utility, quality and efficacy of the DBP-MAF.

5.1. Application to the Case Study Company

The DBP-MAF was applied to an OEM affiliated with Battery Cluster Portugal in Q1. The application, therefore, examined both the organisation's internal DBP-related capabilities and its dependency on data generated by upstream and downstream battery value chain actors.

The company qualifies as an SME under Article 47 of Regulation (EU) 2023/1542 (European Union, 2023). Consequently, the attributes associated with Supply Chain Due Diligence (Category 4) were excluded from the assessment scope because the corresponding due diligence obligations were not applicable to the company. Category 4 was therefore treated as Not Applicable (N/A).

The final assessment scope comprised 72 applicable data attributes distributed across the remaining six DBP data categories defined in DIN DKE SPEC 99100:2025-02 (DIN/DKE, 2025). The assessment produced an overall-readiness score of 1.76 out of 5.00. According to the maturity scale presented in Table 8, this result places the company at Level 2 - Developing. This indicates that relevant DBP data and capabilities are partially available, but that implementation remains constrained by incomplete data coverage, informal or insufficiently developed processes, limited digital integration and unresolved external data dependencies. The result suggests that the company has already developed some of the technical and organisational foundations required for DBP implementation, but these foundations are uneven across data categories and are not yet sufficiently mature to support consistent implementation. The overall score should not be interpreted in isolation. First, it is an aggregate measure and may conceal substantial differences among data categories and individual attributes. Second, the maturity level does not demonstrate legal compliance. Mandatory attributes below the critical-gap threshold remain relevant regardless of the

overall result. Consequently, the organisational diagnosis combines the overall-readiness score with category-level results, criterion-level scores and the critical-gap register.

The category-level results show a markedly uneven readiness profile. Category 5, related to Battery Materials and Composition, achieved the highest score, at 4.80. This result indicates a high level of readiness for the applicable composition-related information assessed in the case. According to the respondent, this performance is supported by an established data-exchange relationship with the cell supplier, through which chemistry, material and composition, and hazardous-substance information are received and integrated. On the other hand, Category 3, related to Battery Carbon Footprint, obtained the lowest score, 0.00. The company had not implemented a battery carbon-footprint calculation process, and the required lifecycle-stage contributions were not being received from the relevant upstream and downstream actors at the time of the assessment. This result indicates that the required information was not available to, received by or integrated within the assessed organisation and that the company had not yet established the internal process needed to consolidate the complete carbon-footprint declaration. The results of all categories are shown in Figure 6.

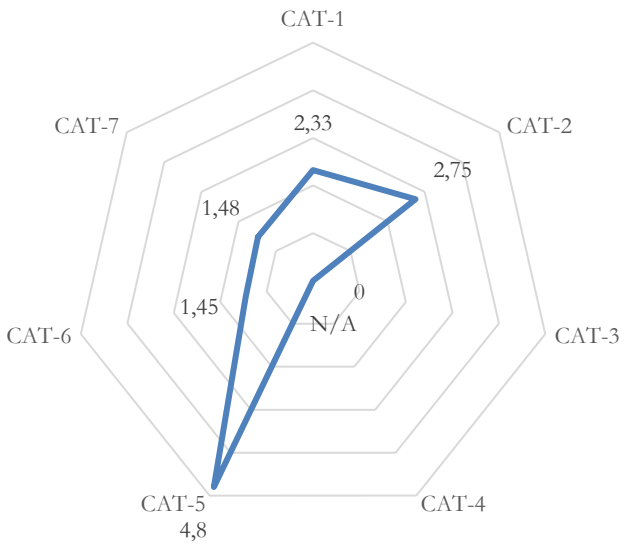


Figure 6 - OEM readiness scores across the applicable DBP data categories.

These results indicate partial readiness rather than a complete absence of relevant capabilities. In several cases, the underlying technical or product information existed, but was not maintained through sufficiently formalized internal processes or made available in a structured and interoperable format suitable for DBP integration.

The assessment identified 47 critical gaps, defined as Mandatory attributes with an attribute score below 2.5. Of these, 41 were classified as capability gaps and 6 as integration gaps. No contribution

gaps were identified in the case application. Capability gaps were particularly pronounced in the Battery Carbon Footprint and Performance and Durability Categories. Within the Carbon Footprint Category, the company has not yet implemented the internal calculation, documentation, and update processes required to produce the complete battery carbon footprint declaration. Within the Performance and Durability Category, capability gaps were associated with a combination of incomplete dynamic data, insufficient BMS configuration, limited communication infrastructure and the absence of defined processes for transmitting and updating lifecycle information in the DBP. These results demonstrate that the presence of a BMS does not, by itself, establish readiness for dynamic DBP data. The system must also generate the required information in the appropriate form, maintain item-level traceability and support external communication or integration. The six integration gaps were concentrated in the carbon-footprint lifecycle-stage contributions expected from upstream and downstream partners, including raw material extraction and pre-processing, cell manufacturing, and end-of-life and recycling activities. The case results indicate that the main limitation was the absence of systematic data flows to the company at the time of the assessment. This finding does not demonstrate that the information was absent from every relevant value chain organisation; rather, it shows that the assessed company did not receive the required information through an established and usable data-sharing process. The gap classification, therefore, provided additional diagnostic value beyond the numerical scores. Capability gaps pointed primarily to the need for internal organisational or technological action, while integration gaps highlighted the need for supplier engagement, data-sharing arrangements and interoperable information flows.

The identified gaps provided the basis for an implementation roadmap organised into four intervention areas. The first intervention area focuses on carbon footprint readiness. This includes establishing the internal capability required to calculate and maintain the battery carbon footprint, defining the relevant methodology and evidence requirements, and engaging the upstream and downstream actors responsible for providing lifecycle-stage contributions. These actions have a relatively high implementation effort and require coordination across the value chain. The second intervention area concerns the digitalisation and formalisation of information that already exists within the company. Examples include test reports, technical documentation, dismantling information, and other product-related records that were available but not maintained in structured, shareable formats or through formally defined update processes. These actions may represent comparatively achievable improvements because they build on existing information. The third intervention area addresses dynamic and BMS-dependent attributes. The required actions include assessing whether the BMS generates the necessary data, verifying item-level traceability,

establishing appropriate update rules and developing the communication infrastructure required to transmit the data to the DBP. This intervention area must distinguish between data-generation capability and external communication capability. The fourth intervention area focuses on extending effective supplier data-exchange practices. The high readiness result obtained for Category 5 demonstrates that structured external data flows are feasible in the company's context. The existing practices, supporting materials, and composition data may therefore provide a reference for developing data-sharing mechanisms in less mature areas, particularly carbon footprint, recycled content and lifecycle performance. The roadmap is therefore based on the specific cause of the identified gap rather than on the category score alone.

The case application demonstrates that the DBP-MAF can transform regulatory and technical data requirements into a differentiated organisational diagnosis. The combination of attribute-level scoring, category aggregation and responsibility-based gap classification identified both areas of relatively high readiness and areas requiring substantial intervention. The results constitute a naturalistic demonstration of the artefact in one OEM context. They do not establish the DBP-MAF's effectiveness across all OEMs or battery value chain profiles.

5.2. Practitioner Evaluation of the Artefact

Following completion of the DBP-MAF assessment and delivery of the Diagnostic Report, the same organisational representative who completed Q1 evaluated the artefact through Q2, focusing on Utility, Quality, and Efficacy (Hevner et al., 2004). The sequencing of Q1 and Q2 ensured that the practitioner's evaluation was based on direct experience with the assessment process, the resulting maturity classification, the critical-gap analysis and the implementation roadmap.

Utility concerned the practical value of the diagnosis, gap classification and roadmap. Quality was concerned with the perceived clarity, accuracy, and internal consistency of the framework's components. Efficacy concerned whether the DBP-MAF functioned in the organisational context in which it was applied and whether its outputs could support implementation activities. Each dimension was evaluated through five closed items scored from 0 to 5 (Table 9). Open-ended questions collected additional feedback regarding the artefact's strengths, limitations, implementation barriers and improvement opportunities. The practitioner also provided separate overall ratings for Utility, Quality and Efficacy. These overall ratings are direct global assessments and should not be interpreted as arithmetic means of the five item-level scores.

Table 9 - Validation Questionnaire (Q2) results: the company's assessment of the DBP-MAF's utility, quality, and efficacy.

Dimension	Item	Score (0–5)
Utility	Diagnostic Report gives a clear, accurate picture of readiness	5.0
	Maturity level classification is a meaningful reference point	5.0
	Gap classification (capability/integration) aids understanding of intervention type	5.0
	Implementation roadmap is actionable	5.0
	Overall, DBP-MAF generates useful insights for planning	5.0
Quality	Scoring rubric reflects meaningful readiness levels	5.0
	Maturity level definitions correctly characterize organisational profiles	5.0
	Level 3 threshold is appropriate and realistic for February 2027	4.0
	Responsibility Matrix correctly reflects the company's data obligations	4.0
	Q1 questions accurately captured the information needed	5.0
Efficacy	DBP-MAF is applicable to companies of this size and profile	5.0
	Data required for Q1 was, in principle, available internally	5.0
	Roadmap is realistic and achievable within the available timeframe	3.0
	Company would use the DBP-MAF as a self-assessment tool in future	4.0
	Company would recommend the DBP-MAF to other value chain companies	5.0
Overall (perceived by the company)	Utility	5.0
	Quality	5.0
	Efficacy	4.0

All five Utility items received the maximum score of 5.0. The practitioner, therefore, considered the Diagnostic Report to provide a clear representation of the company's readiness and regarded the maturity classification as a meaningful reference point. The capability and integration gap classifications were considered useful for understanding the nature of the required intervention. The implementation roadmap was also evaluated as actionable, and the practitioner assigned the maximum score to the DBP-MAF's overall usefulness for implementation planning. In the open-ended feedback, the practitioner identified *"the implementation roadmap and justifications therein"* as the most useful output of the assessment. This response reinforces the quantitative results and indicates that the practical value of the artefact lies not only in assigning a maturity score, but also in explaining the reasons for the score and translating those findings into improvement priorities. The practitioner identified two additions that could improve the Diagnostic Report. First, the report could include a proposed organisational responsibility diagram that distinguishes the roles of the company, its clients, and its suppliers in roadmap implementation. Second, it could provide a glossary explaining the seven DBP category codes before presenting the detailed results. These suggestions primarily concern the communication and usability of the Diagnostic Report rather than the model's or method's fundamental structure. Nevertheless, the proposed responsibility diagram could strengthen the translation of the Responsibility Matrix into organisational action.

The Quality items received scores between 4.0 and 5.0. The scoring rubric, the maturity-level definitions and the Q1 question set each received a score of 5.0. These results indicate that the practitioner considered the assessment criteria and questions clear and sufficiently representative of the organisation's DBP-readiness conditions. Two items received a score of 4.0: the readiness interpretation associated with the February 2027 deadline and the extent to which the Responsibility Matrix reflected the company's actual data responsibilities and dependencies. The practitioner identified one substantive limitation concerning dynamic attributes: *"Some batteries with BMS do not have a communication infrastructure, and therefore some dynamic values with responsibility assigned to the manufacturer do not seem to reflect real-world use cases."* This feedback reveals that the presence of a BMS and the ability to communicate DBP data are distinct readiness conditions. A battery may contain a BMS capable of generating or storing relevant data, but lacking the hardware, connectivity, or system interfaces required to transmit that information to the DBP. The current DBP-MAF partly captures this distinction through the Availability and Digitalisation criteria. However, the feedback indicates that the configuration of the assessment should explicitly distinguish among the absence of the required data-generation capability, the availability of the data within the BMS, the ability to extract the data from the BMS, the availability of the communication infrastructure, and the ability to transmit or integrate the data into the DBP. This represents an opportunity to refine the Responsibility Matrix, the configuration questions and the interpretation of dynamic-attribute gaps. No Q1 questions were identified as unclear or ambiguous.

Efficacy received more varied scores than Utility and Quality. The applicability of the DBP-MAF to the company's size and actor profile received a score of 5.0. The practitioner also assigned a score of 5.0 to the accessibility, in principle, of the information required for Q1 and to the willingness to recommend the DBP-MAF to other battery value chain companies. The company's willingness to use the DBP-MAF again as a self-assessment instrument received a score of 4.0. This indicates a favourable intention toward future use, while also suggesting that improvements to the tool or assessment process could facilitate repeated application. The realism and achievability of the implementation roadmap within the available timeframe received a score of 3.0, the lowest item-level result. This finding does not necessarily indicate that the roadmap was considered conceptually inadequate. Rather, the open-ended feedback indicates that implementation feasibility was constrained by organisational and ecosystem conditions. The practitioner identified three main barriers: limited human and financial resources; hardware and communication limitations affecting dynamic data; and inconsistency among cell suppliers in the range and format of data made available for different cell types. These barriers correspond closely to the readiness conditions examined by the DBP-MAF. Resource limitations affect the organisation's capacity to implement

internal improvements. Hardware and communication limitations affect the readiness of dynamic data. Supplier inconsistency affects the receipt and integration of information generated outside the company. When asked what would support wider adoption of the framework, the practitioner recommended implementing the scoring logic in an easily updateable tool, preferably in an online format. This suggests that the current Excel-based instantiation is suitable for demonstration and initial application, but that a more automated and user-oriented digital implementation could support recurring organisational use.

The DBP-MAF was considered a useful and distinctive contribution relative to other regulatory-readiness or compliance-support tools encountered by the respondent. It was also perceived as providing value beyond a generic readiness checklist or a maturity model that does not differentiate among value chain actors. The modelling of external dependencies through Rx-designated attributes received the maximum score. This supports the importance of evaluating not only whether the company has the necessary internal capabilities, but also whether it receives and integrates information generated by other actors. The practitioner provided overall ratings of 5.0 for Utility, 5.0 for Quality and 4.0 for Efficacy. These are global ratings provided directly by the respondent and are consistent with the item-level pattern. Utility and Quality were evaluated very positively, while Efficacy was moderated by concerns about resources, implementation time, technological infrastructure, and supplier data availability. The practitioner's recommended priority improvement was to include an updated timeline of regulatory milestones and entry-into-force dates within the tool. This addition could improve the roadmap's continued relevance as regulatory and technical requirements evolve.

Overall, the practitioner evaluation provides positive formative evidence regarding the DBP-MAF's perceived utility, quality and efficacy in the case study context. The results support the practical relevance of the attribute-level diagnosis, the responsibility-based gap classification, and the implementation roadmap. At the same time, the evaluation identified concrete opportunities for improvement, particularly regarding dynamic data communication, organisational responsibility assignment, explanation of category terminology, regulatory timeline maintenance, and the development of a more updatable digital tool. The evaluation provides formative evidence of the DBP-MAF's perceived utility, quality and efficacy in the examined OEM context, rather than comprehensive empirical validation across the battery value chain. Only the P4 profile was applied, and the findings reflect one organisation and one practitioner. As the same representative completed Q1, reviewed the Diagnostic Report and subsequently completed Q2, the evaluation benefited from direct knowledge of the assessment but was subject to limited independence and potential confirmation and common-method bias.

6. Discussion

The development and case-based evaluation of the DBP-MAF indicate that organisational readiness for DBP implementation cannot be represented solely by data availability or an aggregate maturity score. It depends on the organisation's ability to generate or obtain each applicable attribute, ensure its quality, maintain it in a suitable digital format, govern it through defined processes and coordinate the corresponding data flows with other battery value chain actors.

The OEM case revealed a markedly uneven readiness profile. Some areas benefited from established data ownership and supplier exchanges, while others remained constrained by internal capability limitations and absent external data flows. This variation supports attribute-level assessment before aggregation into category and overall results, since a general checklist could conceal significant differences in organisational preparedness. The contrast between the high readiness of Battery Materials and Composition and the zero-readiness result for Battery Carbon Footprint demonstrates that interorganisational dependency is not inherently a weakness. Where data ownership was understood and structured supplier exchanges existed, externally generated information could be received and integrated effectively. By contrast, carbon-footprint readiness was constrained by the absence of both an internal calculation and governance process and systematic lifecycle-stage data flows from upstream and downstream partners. Unlike information already maintained in technical documentation, carbon-footprint reporting requires methodological expertise, consistent calculation rules, primary supplier data, verification and coordination across several lifecycle stages. The zero score therefore reflects the absence of an integrated organisational and interorganisational capability rather than a single data field. This interpretation is consistent with Haupt et al. (2024) and Soufi et al. (2023), who emphasise methodological consistency and integrated lifecycle data, and with the data asymmetries identified by Berger et al. (2023) and Losa and Torjesen (2025). Although the finding cannot be generalised to the Portuguese battery sector or to SMEs more broadly, it illustrates conditions that may be particularly challenging for smaller organisations. SMEs may have fewer sustainability and data-management resources, limited access to specialised LCA expertise and digital infrastructure, and reduced influence over international suppliers. Carbon-footprint readiness may consequently depend on sectoral guidance, standardised supplier-data templates, shared calculation resources and collaborative infrastructure. Similar gaps may occur in other OEMs that purchase cells or critical components externally, although their magnitude will depend on organisational size, LCA capabilities, supply-chain integration and supplier-data maturity. Nevertheless, the high readiness

achieved in Materials and Composition shows that SME status does not necessarily imply uniformly low readiness where stable supplier relationships and structured data exchanges exist.

The distinction between internal and external gaps is therefore relevant to implementation planning. Capability gaps require improvements to the organisation's data, processes or technological infrastructure, whereas integration gaps may require supplier engagement, data-sharing arrangements and interoperability mechanisms. Supplier dependency and interoperability are related but distinct: information may not be provided by the relevant actor, or it may be available but unusable because it is incomplete, inconsistent or delivered in a non-standardised format. The separation of Receive and Integrate captures this distinction by differentiating absent external data flows from insufficient internal integration capability. These findings confirm that DBP implementation is both an organisational and ecosystem challenge. This is consistent with Jensen et al. (2024), who emphasise ecosystem orchestration and shared governance, and Kemmner et al. (2025), who identify interoperability, data sovereignty and ecosystem participation as conditions for effective data sharing. The Responsibility Matrix operationalises this perspective by identifying where information originates and how the assessed organisation relates to it, thereby locating specific dependencies and their effect on readiness.

The case also confirms the distinction between static and dynamic data highlighted by Losa and Torjesen (2025) and Ott et al. (2024). Static attributes were more likely to exist in documentation, technical records or information systems, although further digitalisation and process formalisation were often required. Dynamic attributes presented greater difficulties because they depend on item-level monitoring, BMS functionality, traceability, update rules and communication infrastructure. Practitioner feedback further demonstrated that the existence of a BMS does not necessarily imply dynamic data readiness, since a BMS may generate or store a value without enabling its extraction, communication or DBP integration. Future refinements should distinguish between these technological conditions more explicity.

The findings also support the separate assessment of Availability, Quality, Digitalisation, and Internal Process. Several attributes existed but remained insufficiently mature because they were not maintained in structured, interoperable formats or supported by formally defined, monitored processes. Data existence alone is therefore insufficient to demonstrate readiness, while criterion-level assessment indicates whether intervention is required in data coverage, assurance, digital infrastructure or organisational governance.

The attribute-level and actor-sensitive structure differentiates the DBP-MAF from the maturity model developed by Petrik et al. (2025). Both apply maturity-based thinking to DPP

implementation, but the DBP-MAF is anchored in battery specific attributes and differentiates regulatory relevance, temporal behaviour, and actor-level responsibility. The approaches are complementary: a generic maturity model supports broad organisational reflection, whereas the DBP-MAF provides a more granular diagnosis of the data and coordination capabilities required for DBP implementation.

The case also illustrates the limitations on aggregate maturity results. An overall score provides a useful reference but may conceal differences between categories and attributes. It must therefore be interpreted together with category results, criterion-level scores, and the critical-gap register, and as an indicator of implementation readiness rather than evidence of legal compliance.

The scientific contribution of this dissertation is fourfold. First, it develops an attribute-oriented readiness model that assesses individual DBP data requirements rather than readiness exclusively at the overall organisational level. Second, it integrates interorganisational dependencies by distinguishing attributes that the organisation generates, contributes to, receives or integrates. Third, it operationalises maturity-based assessment for the DBP context through explicit criteria, scoring rules, maturity levels and responsibility-based gap classification. Fourth, it conceptualises DBP readiness as the alignment of regulatory data requirements, organisational capabilities and interorganisational data relationships. From a practical perspective, the DBP-MAF translates regulatory and technical requirements into an organisational diagnosis and implementation roadmap. It supports organisations in identifying applicable attributes, locating the origin of readiness deficiencies and prioritising improvement actions. Its practical contribution therefore lies in connecting regulatory requirements with attribute-level assessment, gap identification and actionable implementation planning.

The lower evaluation of roadmap achievability is also significant. A coherent diagnosis does not ensure that an organisation has the resources, infrastructure, time or partner cooperation required to implement every action. The practitioner identified limited organisational resources, communication and hardware constraints, and inconsistent supplier data availability. These findings are consistent with the implementation barriers identified by Abedi et al. (2024) Kemmner et al. (2025) and demonstrate the distinction between the usefulness of the diagnostic artefact and the feasibility of the transformation it recommends. Practitioner feedback also suggested improvements to responsibility allocation, category explanations, regulatory-timeline maintenance, and digital tool automation. These refinements could facilitate recurring use, evidence management and progress monitoring without fundamentally changing the conceptual model.

The case should be interpreted as a naturalistic demonstration and formative evaluation rather than comprehensive empirical validation of the DBP-MAF. It involved one SME OEM, one organisational representative and only the P4 profile. The findings show that the framework can generate a differentiated diagnosis in the examined context, but do not establish that the Responsibility Matrix, questionnaire or scoring rules are equally applicable to other OEMs or actor profiles. The use of one respondent limited organisational triangulation across the engineering, sustainability, quality, information systems, compliance and supply-chain functions. Moreover, the same representative completed Q1, reviewed the Diagnostic Report and subsequently completed Q2, reducing evaluation independence and introducing potential confirmation and common-method bias. The case therefore supports process feasibility and identifies opportunities for refinement, but not the general validity of the DBP-MAF across the battery value chain.

The scoring design also requires further evaluation. The Mandatory/Recommended weighting, critical-gap threshold and maturity intervals are initial design choices that have not been calibrated across a larger sample. Categories containing more attributes exert greater influence on the overall result, while grouping attributes into questionnaire items may conceal differences among attributes assumed to share equivalent readiness conditions. Refinement of the critical-gap threshold, maturity intervals and scoring scales could be supported by structured expert judgement, namely through a Delphi study or other expert elicitation methods involving practitioners from different value chain actor profiles.

The DBP-MAF will also require periodic revision as the regulatory and technical context evolves. Future research should apply it to multiple organisations and actor profiles, involve respondents from different organisational functions and include practitioners who did not complete Q1. Perception-based feedback should also be combined with independent evidence review. Multi-case and longitudinal applications could support scoring calibration, reduce reliance on single-respondent perceptions and assess readiness progression.

Despite these limitations, the study provides initial case-based and practitioner-informed evidence that the DBP-MAF is applicable, useful and internally coherent in the examined OEM context. The findings support the central argument that DBP readiness should be evaluated at the level of applicable data attributes while accounting for organisational capabilities, technological infrastructure and value chain dependencies.

7. Conclusions

This dissertation addressed the following research question: *How can organisational readiness for the implementation of the Digital Battery Passport be assessed across companies in the battery value chain?* To answer this question, the study adopted a DSR approach and developed the DBP-MAF, an artefact that translates regulatory and technical DBP requirements into a structured organisational readiness assessment.

The findings indicate that DBP readiness should be assessed through the combined evaluation of applicable data requirements, organisational capabilities and interorganisational data relationships. The DBP-MAF evaluates attributes generated, maintained or contributed to by the assessed organisation through Availability, Quality, Digitalisation, and Internal Process. Attributes dependent on external actors are assessed separately through the Receive and Integrate steps. The Responsibility Matrix connects these assessments to the corresponding value chain actors, enabling identified deficiencies to be interpreted by their internal or interorganisational origin.

The framework operationalises the assessment through Configuration, Attribute-level Assessment, Scoring and Diagnosis, and Implementation Roadmap. The Q1, Excel-based Scoring Tool, Diagnostic Report and Implementation Roadmap enable an organisation to determine which DBP attributes apply, evaluate its readiness, identify critical gaps and prioritise implementation actions.

The application to an SME OEM provided initial evidence of the framework's applicability in a real organisational context. The company obtained an overall-readiness score of 1.76 out of 5.00, corresponding to Level 2 — Developing. The results revealed an uneven readiness profile, with established supplier-data exchanges supporting high readiness in Battery Materials and Composition. The zero-readiness result for Battery Carbon Footprint highlighted the combined effect of limited internal LCA capabilities and absent lifecycle-stage data flows, illustrating the importance of both organisational preparation and value chain coordination. The assessment identified 47 critical gaps, demonstrating that aggregate maturity results must be interpreted together with attribute- and category-level evidence.

The practitioner evaluation provided positive formative evidence concerning the artefact's Utility, Quality and Efficacy. The roadmap, the responsibility-based gap classification, and the modelling of external dependencies were considered particularly useful. However, implementation remained constrained by organisational resources, technological infrastructure, and the availability of supplier data. A useful readiness diagnosis, therefore, does not remove the practical barriers affecting organisational transformation.

The principal scientific contributions are the development of an attribute-oriented readiness model, the integration of interorganisational data dependencies and the operationalisation of maturity assessment for the DBP context. From a practical perspective, the DBP-MAF translates regulatory and technical requirements into a differentiated diagnosis, responsibility-based gap classification and actionable implementation roadmap.

The empirical evidence is limited to one SME OEM, one organisational representative and the P4 actor profile. The application should therefore be interpreted as a case-based demonstration and formative evaluation rather than empirical validation of the DBP-MAF across the battery value chain. Part of the evidence was self-reported, and the scoring weights, critical-gap threshold and maturity intervals have not been calibrated across a larger sample. The DBP-MAF should consequently be interpreted as an implementation-readiness instrument rather than evidence or certification of legal compliance.

Future research should apply the framework to multiple organisations and actor profiles, involve respondents from different organisational functions and compare self-assessment results with independently reviewed evidence. As an initial step towards this broader evaluation, a workshop is planned for September 2026 to explain the questionnaire and support the application of the DBP-MAF to organisations representing other battery value chain profiles. The resulting applications may provide additional evidence on the Responsibility Matrix, questionnaire logic and actor-specific applicability of the framework. Multi-case and longitudinal studies, combined with a Delphi study or expert elicitation to refine the critical-gap threshold, maturity intervals and scoring scales, could subsequently support calibration of the scoring logic and examination of readiness progression. Further development could also implement the DBP-MAF as an online tool to support recurring assessment, evidence management and regulatory updates, drawing inspiration from online self-assessment tools such as HEInnovate (European Commission & OECD, n.d.).

In conclusion, DBP implementation should not be understood solely as a data-management or regulatory-compliance challenge. It represents an organisational transformation process requiring the alignment of governance, digitalisation, internal processes, technological infrastructure and interorganisational coordination. Organisations must not only possess the applicable data, but also ensure its quality, maintain it in interoperable formats and establish reliable information flows with other value chain actors. By connecting these conditions to individual DBP data attributes, the DBP-MAF provides a structured basis for distinguishing internal capability gaps from external integration gaps and translating them into implementation priorities. Although demonstrated in

one OEM context, the framework shows the value of approaching DBP preparation as an organisational and ecosystem challenge rather than as a generic compliance checklist.

8. Contribution to the United Nations Sustainable Development Goals

The United Nations 2030 Agenda establishes 17 integrated Sustainable Development Goals (SDGs) as a shared framework for balancing economic, social and environmental development. Although this dissertation does not directly measure progress against SDG indicators, its focus on organisational readiness for DBP implementation is particularly aligned with SDG 9 - Industry, Innovation and Infrastructure, SDG 12 - Responsible Consumption and Production, SDG 13 - Climate Action, and SDG 17 - Partnerships for the Goals.

The principal relationship is with SDG 12, which promotes sustainable consumption and production patterns. The DBP is intended to improve the availability of information on battery composition, carbon footprint, performance, durability, recycled content, dismantling and end-of-life management. This information may support more informed decisions concerning maintenance, reuse, repurposing and recycling. The DBP-MAF contributes to this objective by helping organisations determine whether they possess the data, processes and external information flows required to support these circular practices. In particular, its assessment of Battery Materials and Composition, Circularity and Resource Efficiency, and Performance and Durability is consistent with the responsible management of natural resources and waste reduction addressed by SDG 12.

The dissertation also contributes to SDG 9 by addressing the organisational and digital capabilities required to participate in an emerging battery information infrastructure. DBP implementation requires structured data, interoperable systems, defined internal processes and mechanisms for exchanging information across the battery value chain. The DBP-MAF supports organisations in identifying weaknesses in these areas and translating them into implementation priorities. Its attribute-level structure, Responsibility Matrix and distinction between Receive and Integrate also represent a methodological innovation for assessing readiness in a complex industrial and interorganisational context.

The relationship with SDG 13 is primarily associated with battery carbon-footprint information. The case study's zero-readiness result in this category demonstrated that credible carbon-footprint reporting depends on internal LCA capabilities, consistent calculation methods, primary lifecycle data and coordination with upstream and downstream actors. By identifying the organisational and integration gaps affecting this information, the DBP-MAF can support the development of the data and governance foundations needed for more transparent climate-related reporting. However, the framework does not calculate emissions or demonstrate actual greenhouse-gas reductions. Its contribution to SDG 13 is therefore indirect and enabling.

Finally, the work relates to SDG 17 because DBP implementation depends on cooperation among raw-material suppliers, processors, cell manufacturers, OEMs and end-of-life operators. No individual organisation controls all the data required throughout the battery lifecycle. The Responsibility Matrix represents these relationships, while the distinction between capability and integration gaps identifies when progress depends on internal action or external collaboration. The framework can therefore support supplier engagement, data-sharing arrangements, common standards and interoperable infrastructure across the battery ecosystem.

Overall, the contribution of this dissertation to the SDGs should be understood as an enabling contribution rather than a directly measured sustainability outcome. The DBP-MAF does not itself guarantee regulatory compliance, circularity or emissions reduction. Instead, it supports organisations in identifying whether they possess the data, governance, digital infrastructure and value chain relationships required to implement a mechanism intended to improve transparency and circularity in the battery sector. By translating these requirements into a differentiated diagnosis and implementation priorities, the framework provides an organisational foundation that may contribute to the advancement of SDGs 9, 12, 13 and 17.

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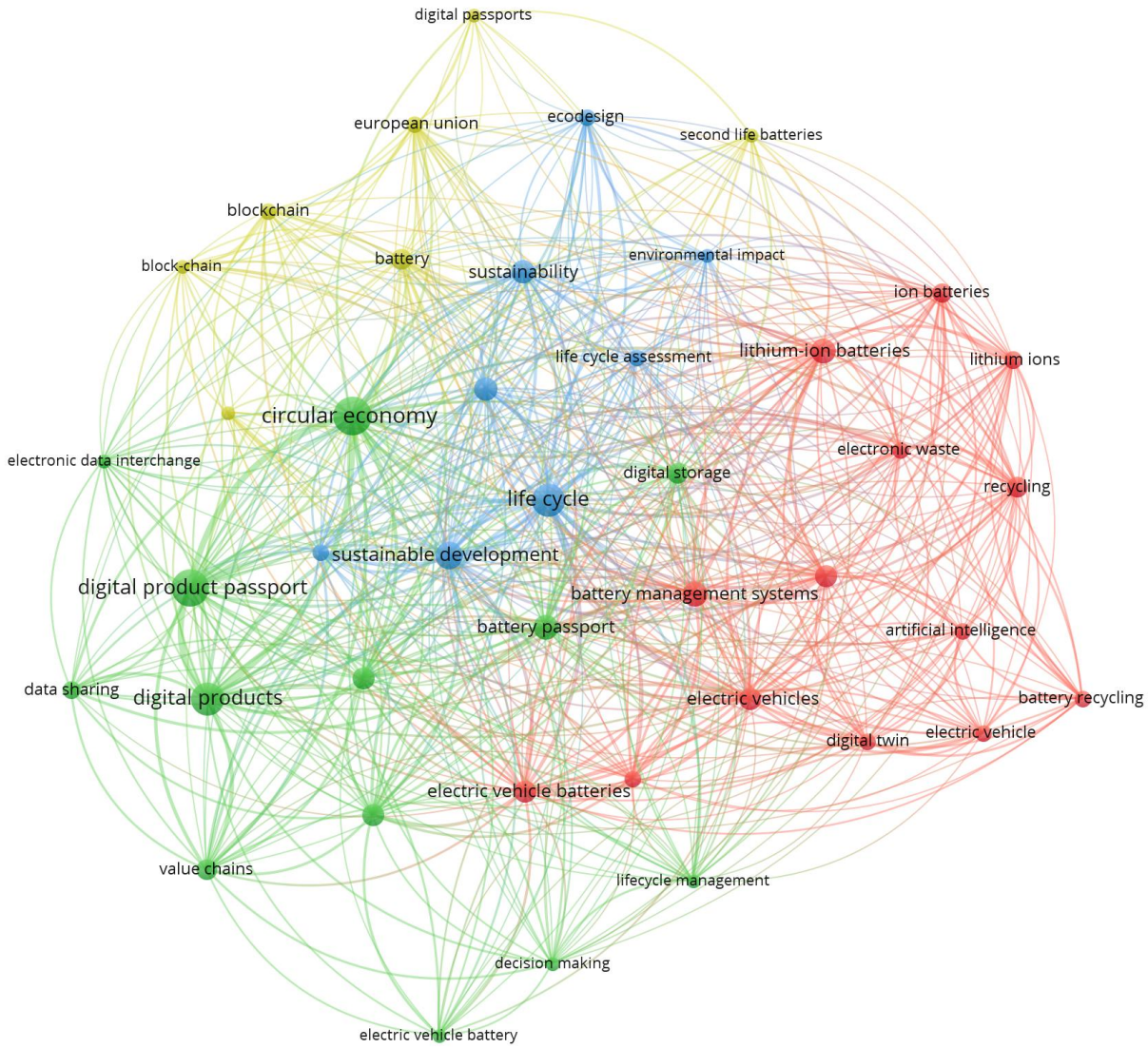
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Appendix A: Keyword Co-occurrence Network of DBP-Related Literature (VOSviewer Output)



Appendix B: List of Co-cited Articles of the DBP Literature (VOSviewer Output)

battery passport content guidance, (2023)
baumgartner r.j., digital battery passports to enable circular and sustainable value chains: conceptualization and use cases, j clean prod, 353, (2022)
baumgartner r.j., end of life focused data model for a digital battery passport, procedia cirp, 122, pp. 277-281, (2024)
baumgartner r.j., the narrative of sustainability and circular economy - a longitudinal review of two decades of research, resour. conserv. recycl., 163, (2020)
belharouak i., energy and environmental aspects in recycling lithium-ion batteries: concept of battery identity global passport, mater. today, 41, pp. 304-315, (2020)
canal c., second life batteries lifespan : rest of useful life and environmental analysis, j. environ. manag., 232, pp. 354-363, (2019)
faessler b., circular business models for lithium-ion batteries - stakeholders, barriers, and drivers, j. clean. prod., 317, (2021)
fontana a., a digital product passport for critical raw materials reuse and recycling, sustainability, 15, (2023)
gotz t., towards a digital product passport fit for contributing to a circular economy, energies, 14, (2021)
hultink e.j., the circular economy–a new sustainability paradigm, j. clean. prod., 143, pp. 757-768, (2017)
lee j., review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (ev) safety and mobility, j. power sources, 256, pp. 110-124, (2014)
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marinkovic m., digital product passports as enabler of the circular economy, chem. ing. tech., 93, pp. 1717-1727, (2021)
miehe r., untersuchung : kreislaufstrategien fur batteriesysteme in baden-wurttemberg, (2020)
mountney s., a proposed universal definition of a digital product passport ecosystem (dppe):worldviews, discrete capabilities, stakeholder requirements and concerns, journal of cleaner production, 384, (2023)
pawlowski s.d., the delphi method as a research tool: an example, design considerations and applications, inf. manag., 42, pp. 15-29, (2004)
pecht m.g., circular economy of li batteries: technologies and trends, j. energy storage, 40, (2021)
pfrang a., life cycle assessment of repurposed electric vehicle batteries: an adapted method based on modelling energy flows, j. energy storage, 19, pp. 213-225, (2018)
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roda-sanchez l., the adoption of internet of things in a circular supply chain framework for the recovery of weee: the case of lithium-ion electric vehicle battery packs, waste manag., 103, pp. 32-44, (2020)
roman l., the 'battery passport' and the future of the auto industry - everledger, (2021)
schoggl j.-p., factors of digital product passport adoption to enable circular information flows along the battery value chain, procedia cirp, 116, pp. 528-533, (2023)

waehrens b.v., digital product passports for a circular economy: data needs for product life cycle decision-making, sustain. prod. consum., 37, pp. 242-255, (2023)

Appendix C: Comparative Summary of Selected Articles on DBP Implementation

Reference	Methodology	Concepts Covered / Main Contributions	Future Research / Limitations
(Abedi et al., 2024)	Systematic Literature Review (SLR) of 53 articles, using qualitative thematic analysis (ATLAS.ti) and structured according to the Technology–Organization–Environment (TOE) framework	Provides a structured analysis of DPP implementation and adoption factors across industries; identifies key enablers (digital technologies such as IoT, Blockchain, Digital Twins; legislative frameworks; collaboration) and major barriers (data management complexity, lack of standardization, reluctance to share data); organizes findings into TOE dimensions (technological, organisational, environmental); highlights importance of data sharing, interoperability, and lifecycle transparency; offers practical recommendations for companies and policymakers to support DPP adoption	Limited to Scopus database and specific search terms (PP, MP), excluding sector-specific passports (e.g., DBP); does not fully address authentication, cost-benefit analysis, or implementation in specific industries; findings may not capture recent developments (post-2023/early 2024); future research should expand databases, include other passport types (e.g., DBP), and deepen analysis of data reliability, standards, and practical implementation
(Berger et al., 2023)	Qualitative empirical study based on focus groups (n=20), semi-structured interviews (n=6), and follow-up expert consultations; qualitative content analysis (abductive coding)	Provides first empirical mapping of data requirements for a DBP from a value chain actor perspective; identifies 54 data points across 4 categories (product, sustainability & circularity, diagnostics/performance, value chain actors); shows that data needs vary across life cycle stages (BoL, MoL, EoL); highlights data gaps, lack of interoperability, and fragmented information flows; demonstrates that DBPs can improve transparency, traceability, and support CE decisions (e.g., second life, recycling); reveals mismatch between data criticality and availability, especially for sustainability and in-use data	Limited to qualitative and exploratory analysis; focused on EV battery value chain (limited generalizability); relies on perceived (not measured) data availability; lacks quantitative validation; future research needed on standardization, data sharing mechanisms, business models, and scalable DBP implementation across industries
(Chaudhuri et al., 2025)	Qualitative empirical study based on 39 semi-structured interviews with OEMs and supply chain stakeholders; qualitative content analysis	Identifies key drivers and barriers of DPP adoption in supply chains; drivers include regulatory compliance, improved decision-making for CE, supply chain transparency, and customer engagement; barriers include lack of business case, high data requirements, lack of standards and interoperability, implementation effort, and data security concerns; proposes four research pathways (policy, circularity, data capabilities,	Limited to electronics supply chains and specific geographic context; qualitative and exploratory nature; lack of quantitative validation; need for research on business models, performance measurement, data capabilities, and large-scale implementation across industries

Reference	Methodology	Concepts Covered / Main Contributions	Future Research / Limitations
		performance outcomes) to guide future research	
(Gianvincenzi et al., 2024)	Conceptual research supported by literature review and analysis of Regulation (EU) 2023/1542; development of a structured data model	Proposes a Standardized Battery Passport Data Model (SBPDM) with a hierarchical structure covering the full battery lifecycle (materials, manufacturing, use, transport, end-of-life); aligns DBP data with EU regulatory requirements and LCA needs; enhances data standardization, interoperability, and traceability across the value chain; supports integration with digital systems and lifecycle data exchange	Conceptual model without empirical validation; implementation complexity due to data granularity and stakeholder coordination; challenges for SMEs; need for further validation, platform development, and real-world application
(Haupt et al., 2024)	Literature-based analysis combining scientific literature, legal regulations (Regulation (EU) 2023/1542, ESPR), and LCA standards (ISO 14040/44); development of a requirements catalogue structured by LCA phases and stakeholder perspectives	Derives a comprehensive set of requirements for integrating Life Cycle Assessment (LCA) into DBP; structures requirements across LCA phases (goal & scope, inventory, impact assessment, interpretation) and data exchange; highlights need for integration with existing systems (ERP, LCA tools), real-time data, and data quality transparency; identifies stakeholder-specific requirements and conflicts (e.g., transparency vs data confidentiality, primary vs secondary data); emphasizes importance of carbon footprint reporting and environmental indicators under EU regulation; contributes a structured framework linking DBP and environmental performance assessment	Strongly conceptual and requirement-driven (no empirical validation); focus on battery use case limits generalization; complexity of LCA integration and data requirements may hinder practical implementation; challenges related to data availability, company capabilities (especially SMEs), and confidentiality; need for further research on operationalization, platform development, and real-world application of DBP-LCA integration
(Jensen et al., 2023)	Multiple case study (3 circular supply chains); semi-structured interviews and survey.	Identifies seven DPP data categories and shows that data needs differ across value chain actors. Assesses data importance, availability and sensitivity, highlighting low data-sharing maturity and the need for phased DPP implementation.	Limited to the mechatronics sector. Recommends validating findings in other industries and exploring DPP implementation across different contexts.
(Jensen et al., 2024)	Exploratory multiple case study combined with grounded theory analysis	Development of an ecosystem orchestration framework for DPP design, identifying 16 practices and 5 orchestration mechanisms across four stages (initiation, momentum, control, self-renewal); highlights the role of interorganisational collaboration, data-sharing, and supply chain coordination in enabling DPP implementation	Limited empirical scope (three cases); early-stage field with limited industrial maturity; need for further research on operationalization, data governance, and large-scale implementation across industries

Reference	Methodology	Concepts Covered / Main Contributions	Future Research / Limitations
(Kemmner et al., 2025)	Mixed-methods approach combining literature review and 12 semi-structured expert interviews; grounded theory coding (open, axial, selective)	Develops the Ecosystem Adoption Model (EAM) for DPP adoption; highlights the critical role of industry-wide data sharing in enabling CE; identifies key data-sharing challenges (technology scalability, data sovereignty, standardisation/interoperability, data quality, product-specific requirements, ecosystem momentum); emphasises network effects and complementarity as central to ecosystem success	Field still nascent and evolving; reliance on emerging and partly non-academic sources; findings partially exploratory and subject to change; need for quantitative validation of the EAM and further research on large-scale implementation and ecosystem dynamics
(Losa & Torjesen, 2025)	Qualitative study combining 35 semi-structured interviews with industry stakeholders and literature + policy document analysis; abductive coding approach to analyse DBP implementation and CE implications	Examines the role of the DBP in enabling circular battery value chains, distinguishing between re-use and recycling practices; shows that DBP supports circularity by providing static (for recycling) and dynamic (for re-use) data; identifies key implementation challenges: data availability and asymmetry, reluctance to share data (IP concerns), digital infrastructure limitations, and policy gaps; highlights a systemic bias towards recycling over re-use, driven by data complexity and regulatory incentives; provides practical recommendations (e.g., data governance, standards, incentives, blockchain) to improve DBP effectiveness	Based on qualitative evidence (limited generalizability); focus on EU battery sector limits transferability to other industries; grouping of circular practices into re-use vs recycling reduces analytical granularity; calls for quantitative validation, deeper analysis of economic/environmental impacts, and studies in other sectors and contexts; need for further research on standards, data governance, and implementation mechanisms
(Ott et al., 2024)	Qualitative exploratory study combining literature review, policy analysis, workshop with stakeholders, and semi-structured interviews (n=8 EoL actors); development of a conceptual data model	Proposes an EoL-focused data model for a DBP; identifies key data needs for recycling use cases (e.g., material composition, state of health, usage history); maps data provision across life cycle actors (producer, user, recycler, government); highlights information asymmetries between BoL and EoL; demonstrates importance of dynamic data (SoH) and material data for decision-making; develops a data flow model linking stakeholders and lifecycle phases; contributes with a prototype-oriented approach to DBP implementation	Focuses primarily on EoL phase (limited lifecycle perspective); based on small sample of experts (n=8); qualitative and exploratory (limited generalizability); lacks quantitative validation and real-world deployment evidence; future research should test the prototype in practice, refine the model, and explore scalability, standardization, and integration with evolving regulation
(Paeplow et al., 2026)	Qualitative research combining literature	Identification and mapping of 315 DPP requirements across 14 stakeholder groups; development of a stakeholder-oriented requirement	Subjectivity in qualitative coding; focus on EU regulations limits generalizability; need for

Reference	Methodology	Concepts Covered / Main Contributions	Future Research / Limitations
	review, regulatory analysis (ESPR, EBR), and expert evaluation.	catalogue; highlights complexity of multi-stakeholder coordination and data sharing for DPP implementation.	further validation, expansion of stakeholder coverage, and clearer specification of requirements.
(Petrik et al., 2025)	Design Science Research (DSR); multivocal literature review, expert interviews, prototype development and validation workshops.	Proposes a DPP maturity model with 3 dimensions (Data Supply, Data Management and Supply Chain Integration) and 9 maturation paths to support organisations in implementing and operating DPPs.	Validated with a limited number of experts and workshops. Future work should further validate and refine the model across different industries and DPP application domains.
(Soufi et al., 2023)	Literature review on EV battery supply chains, environmental impact assessment methods, and DBP technologies	Explores the role of DBPs as enablers of environmental impact assessment (e.g., carbon footprint) in EV batteries; highlights DBP as a tool for lifecycle traceability and standardized data sharing; analyses DBP components and implementation technologies (AAS, ontology-based models, blockchain); emphasizes need for integrated data across the battery value chain	Conceptual and exploratory nature; limited empirical validation; challenges in data acquisition, consistency, and comparability; need for further research on implementation, standardization, and integration across stakeholders
(Stratmann et al., 2023)	Systematic literature review combined with case study and qualitative data analysis of industrial information systems	Development of a structured classification of DPP product data, including 62 data attributes across four categories (product, utilization, value chain, sustainability); provides a guideline for defining DPP content and highlights data availability gaps in organisations	Lack of validation with industry experts; high-level abstraction requires further operationalization; need to define data models, interfaces, and stakeholder data-sharing mechanisms
(Voulgaridis et al., 2024)	Systematic literature review combined with conceptual framework development and validation through a theoretical use-case scenario	Proposes a Digital CE framework integrating DPPs from a technological perspective; structures DPP implementation into three data tiers (data collection, curation, and leverage); identifies key enabling technologies (IoT, AI/ML, blockchain, digital twins); introduces a two-layer architecture (passport generation + digital passport) and dual passport concept (business vs user); emphasizes data flows, interoperability, and stakeholder interaction across the value chain	Strong technological focus with limited consideration of organisational and behavioral factors; lacks empirical validation; challenges related to standardization, data requirements definition, infrastructure readiness, and post-use data collection; need for testing across industries and real-world implementation

Reference	Methodology	Concepts Covered / Main Contributions	Future Research / Limitations
(Walden et al., 2021)	Narrative literature review (non-systematic), combining peer-reviewed and grey literature	Examines the DPP as an enabler of the circular economy and of a "digital circular economy"; reviews policy, industry and economic drivers of circularity; draws on IMDS and the BIM-supported Material Passport as precedents for industry-wide product-information systems; discusses benefits (traceability, due diligence, recycling, circular services, market surveillance) and the differentiated read/write access of actors; analyses the draft EU Battery Regulation and the battery passport as the first legally required DPP	Not a systematic review and based on the draft Battery Regulation; no unified DPP approach across industries; unclear how the passport is kept up to date throughout the lifecycle; confidential business information and IP issues; need to standardise formats and metrics, define the required data and ensure data accessibility; calls for multi-stakeholder collaboration and further research on the DPP as a usable information system

Appendix D: Responsibility Matrix

Data attribute	M/R	S/D	P1	P2	P3	P4	P5
Battery passport identifier	R	S	N/A	N/A	N/A	R	N/A
Battery identifier	M	S	N/A	N/A	N/A	R	N/A
Operator identifier and information	R	S	N/A	N/A	N/A	R	N/A
Manufacturer identifier and information	M	S	N/A	N/A	C	R	N/A
Manufacturing place	M	S	N/A	N/A	C	R	N/A
Manufacturing data	M	S	N/A	N/A	C	R	N/A
Date of putting battery into service	M	S	N/A	N/A	N/A	R	Rx
Warranty period of the battery	M	S	N/A	N/A	N/A	R	N/A
Battery category	M	S	N/A	N/A	N/A	R	N/A
Battery mass	M	S	N/A	N/A	C	R	N/A
Battery status	M	D	N/A	N/A	N/A	R	Rx
Separate collection symbol	M	S	N/A	N/A	N/A	R	N/A
Symbols for cadmium and lead	M	S	N/A	N/A	N/A	R	N/A
Carbon footprint label	M	S	N/A	N/A	N/A	R	N/A
Extinguishing agent category	M	S	N/A	N/A	N/A	R	N/A
Meaning of labels and symbols	M	S	N/A	N/A	N/A	R	N/A
EU declaration of conformity	M	S	N/A	N/A	N/A	R	N/A
Results of test reports providing compliance	M	S	N/A	N/A	C	R	N/A
Battery carbon footprint per functional unit ($kgCO_2e/kWh$)	M	S	C	C	C	R	N/A
Contribution: raw material acquisition & pre-processing stage	M	S	R	Rx	N/A	Rx	N/A
Contribution: main product production/manufacturing stage	M	S	N/A	C	R	Rx	N/A
Contribution: distribution lifecycle stage	M	S	N/A	N/A	N/A	R	N/A
Contribution: end of life and recycling stage	M	S	N/A	N/A	N/A	Rx	R
Carbon footprint performance class	M	S	N/A	N/A	N/A	R	N/A
Web link to public carbon footprint study	M	S	N/A	N/A	N/A	R	N/A
General battery and manufacturer information (for CFP study)	M	S	N/A	N/A	C	R	N/A
Absolute battery carbon footprint ($kgCO_2e$)	R	S	C	C	C	R	N/A
Information of due diligence report in the Battery Passport	M	S	C	C	C	R	N/A
Third-party assurances of recognized schemes	R	S	R	C	Rx	Rx	N/A
Supply chain indices (Co, Li, Ni, natural graphite)	R	S	R	C	Rx	Rx	N/A
Battery chemistry	M	S	N/A	C	R	Rx	N/A
Critical raw materials (>0.1% weight by weight)	M	S	R	C	C	Rx	N/A
Materials used in cathode, anode and electrolyte	M	S	N/A	C	R	Rx	N/A
Hazardous substances (Hg, Cd, Pb, SVHC)	M	S	N/A	C	R	Rx	N/A
Impact of substances on environment, human health, safety, persons	M	S	N/A	C	R	Rx	N/A
Dismantling information: manuals for removal and disassembly	M	S	N/A	N/A	N/A	R	Rx
Part numbers for components	M	S	N/A	N/A	C	R	Rx
Postal/email/web address of sources for spare parts	M	S	N/A	N/A	N/A	R	N/A
Safety measures	M	S	N/A	N/A	C	R	Rx

Data attribute	M/R	S/D	P1	P2	P3	P4	P5
Pre-consumer recycled content share of Ni/Co/Li/Pb (%)	M	S	C	R	N/A	Rx	N/A
Post-consumer recycled content share of Ni/Co/Li/Pb (%)	M	S	N/A	N/A	N/A	Rx	R
Renewable content share	M	S	N/A	C	R	Rx	N/A
Information on the role of end-users in contributing to waste prevention	M	S	N/A	N/A	N/A	R	N/A
Information on the role of end-users in contributing to separate collection of waste batteries	M	S	N/A	N/A	N/A	R	N/A
Information on the separate collection, the take back, collection points and preparation for re-use, for repurposing and treatment available for waste batteries	M	S	N/A	N/A	N/A	R	C
Rated capacity	M	S	N/A	N/A	C	R	N/A
Capacity fade	M	S	N/A	N/A	N/A	R	Rx
Certified usable battery energy	R[1]	S	N/A	N/A	N/A	R	N/A
Minimal, nominal and maximum voltage	M	S	N/A	N/A	C	R	N/A
Remaining capacity	M/R[2]	D	N/A	N/A	N/A	R	Rx
Remaining usable battery energy	R[1]	D	N/A	N/A	N/A	R	Rx
State of certified energy	M[3]	D	N/A	N/A	N/A	R	Rx
State of charge	M	D	N/A	N/A	N/A	R	Rx
Original power capacity	M	S	N/A	N/A	C	R	N/A
Remaining power capability	M/R[2]	D	N/A	N/A	N/A	R	Rx
Power fade	M	S	N/A	N/A	N/A	R	Rx
Maximum permitted battery power	M	S	N/A	N/A	C	R	N/A
Ratio between nominal battery power and battery energy	R	S	N/A	N/A	N/A	R	N/A
Initial round trip energy efficiency	M	S	N/A	N/A	C	R	N/A
Round trip energy efficiency at 50% of cycle life	M	S	N/A	N/A	C	R	N/A
Energy round trip efficiency fade	M	S	N/A	N/A	N/A	R	Rx
Initial self-discharge rate	R[4]	S	N/A	N/A	C	R	N/A
Remaining round trip energy efficiency	M[5]	D	N/A	N/A	N/A	R	Rx
Current self-discharge rate	R[4]	D	N/A	N/A	N/A	R	Rx
Evolution of self-discharge rate	M[4]	D	N/A	N/A	N/A	R	Rx
Initial internal resistance of battery cell and pack	M/R[6]	S	N/A	N/A	C	R	N/A
Internal resistance increase of pack	M/R[7]	S	N/A	N/A	N/A	R	Rx
Expected lifetime in calendar years	M	S	N/A	N/A	C	R	N/A
Expected lifetime: Number of charge-discharge cycles	M	S	N/A	N/A	C	R	N/A
Cycle-life reference test	M	S	N/A	N/A	C	R	N/A
C-rate of relevant cycle-life test	M	S	N/A	N/A	C	R	N/A
Capacity threshold for exhaustion	M[1]	S	N/A	N/A	N/A	R	N/A

[1] For EV batteries.
[2] Mandatory for stationary BESS and LMT batteries using a BMS; Recommended for all batteries.
[3] Only for EV using a BMS
[4] For stationary BEES using a BMS and LMT
[5] For stationary BESS and LMT batteries using a BMS
[6] Mandaroty for cell and pack level; Recommended for module level
[7] Mandatory for pack level; Recommended for cell/module level

Data attribute	M/R	S/D	P1	P2	P3	P4	P5
Number of full charging and discharging cycles	M	D	N/A	N/A	N/A	R	Rx
Energy throughput	M[5]	D	N/A	N/A	N/A	R	Rx
Capacity throughput	M[5]	D	N/A	N/A	N/A	R	Rx
Temperature range idle state (lower and upper boundary)	M	S	N/A	N/A	C	R	N/A
Temperature information	M	D	N/A	N/A	N/A	R	Rx
Time spent in extreme temperatures	M/R[5]	D	N/A	N/A	N/A	R	Rx
Time spent charging during extreme temperatures	M/R[5]	D	N/A	N/A	N/A	R	Rx
Number of deep discharge events	M/R[2]	D	N/A	N/A	N/A	R	Rx
Number of overcharge events	R	D	N/A	N/A	N/A	R	Rx
Information on accidents	M	D	N/A	N/A	N/A	R	Rx

Appendix E: Organisational Readiness Assessment for the Implementation of the Digital Battery Passport in the Portuguese Battery Sector

Section 1

This survey is conducted within the framework of a Master's dissertation in Innovation and Technology Entrepreneurship (MIET) at the University of Porto, focused on the implementation of the Digital Battery Passport (DBP) in the battery sector in Portugal, as required by Regulation (EU) 2023/1542 available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R1542

The objective is to carry out an organisational diagnosis among companies belonging to the Battery Cluster Portugal, in order to assess their current preparedness for DBP implementation, identify critical gaps, and understand the perceived challenges and opportunities associated with the adoption of the DBP.

Participation is voluntary, and all responses will be treated confidentially and used exclusively for academic purposes. Results will be analysed in aggregate form.

Your collaboration is essential to contribute to a better understanding of the readiness for the DBP implementation.

For any additional information, please contact:

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Section 2 - How to Answer the Questionnaire

This questionnaire assesses your organization's current level of readiness for the implementation of the Digital Battery Passport (DBP).

For each data attribute, you will be asked to evaluate your organization across four criteria:

A — Availability: Does the data exist within your organization?

Q — Quality: Is the data reliable, traceable, and verifiable?

D — Digitalisation: In what format is the data, and can it be shared?

P — Process: Is there a defined and monitored organisational process?

Each criterion should be scored from 0 to 5, according to the level that best reflects your organization's current situation (not future plans), as explain in the table below.

	Criteria			
	A	Q	D	P
0	Data does not exist	No quality assurance in place	Paper-based or unstructured spreadsheet	No defined process or process owner

1	Data planned but not yet implemented	Informal validation; no traceability	Digital but unstructured (e.g. PDF, email)	Ad hoc process; informal responsibility
2	Data partially available	Internal validation; partial traceability	Structured digital format (CSV / JSON / database)	Documented process with designated owner
3	Data systematically available	QA documented and monitored	Interoperable via API or standardised format	Documented process, KPI-monitored, with defined update cadence
4	Data complete and internally validated	Externally reviewed; full traceability	AAS/IDTA connectivity established	Process integrated into quality management system (ISO-certified)
5	Full auditable by third parties	Externally certified	Full automated AAS/IDTA integration	Process formally audited; continuous improvement cycle in place

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Section 3 - Company Characterization

1 - Which category best describes your company?

(Select the option that best applies)

P1 – Raw material extraction (e.g. Li, Co, Ni, natural graphite)

P2 – Material refining/processing

P3 – Cell and components manufacturing

P4 – Battery model and pack manufacturing/OEM

P5 – End-of-life operator (recycling, second-life, dismantling)

Section 4 – P4 – Battery model and pack manufacturing/OEM

2 - Battery passport identifier

Battery identifier

Operator identifier and information

Manufacturer identifier and information

Likert scale (0 – 5)

- A - To what extent does your organisation have unique identifiers assigned for the DBP, the battery itself, the manufacturer, and the operator — each compliant with internationally recognised standards (e.g. GS1 GTIN, ISO/IEC 15459, GLN per GS1) — and maintain these for use in the DBP and physical label?
- Q - To what extent do these identifiers guarantee global uniqueness, ensuring unambiguous identification across different systems, partners and markets?

- D - To what extent are these identifiers included on the physical battery label (e.g. via QR code per ISO/IEC 18004) and available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined and monitored process to create, assign and maintain these identifiers throughout the battery lifecycle, including after status changes?

3 - Manufacturing place

Manufacturing data

Likert scale (0 – 5)

- A - To what extent does your organisation document and maintain all mandatory manufacturer and production information — including manufacturer name, registered trademark, postal address, website and email, manufacturing place and manufacturing date (YYYY-MM) — ready for inclusion in the DBP and physical label?
- Q - To what extent is this information accurate, up to date, traceable to each battery model and available in the language(s) of all target markets?
- D - To what extent is this information included on the physical battery label and available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined and monitored process to update this information in the DBP whenever there is a change (e.g. new address, new facility, change of operator)?

4 - Warranty period of the battery

Battery category

Likert scale (0 – 5)

- A - To what extent does your organisation document the commercial warranty period (in years and months from date of purchase) and the correct regulatory battery category under Regulation (EU) 2023/1542 (EV, industrial incl. BESS, LMT, or portable) for each battery model?
- Q - To what extent are the warranty period and battery category traceable to the battery model, with documented justification for the category classification?
- D - To what extent are the warranty period and battery category available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined process to update warranty period and battery category in the passport when policies change or when the battery's application changes (e.g. after second-life repurposing)?

5 - Battery mass

Likert scale (0 – 5)

- A - To what extent does your organisation document the mass of the battery pack (in kg) for each model?
- Q - To what extent is the mass value traceable to the battery model through official technical documentation and verifiable upon request?

- D - To what extent is the battery mass included on the physical battery label and available as a public data attribute in the DBP?
- P - To what extent does your organisation have a defined process to update and validate the mass value when design or configuration changes affect the pack mass?

6 - Battery status

Likert scale (0 – 5)

- A - To what extent does your organisation's system record and maintain the current status of each individual battery among the mandatory states defined in Regulation (EU) 2023/1542: 'original', 'repurposed', 're-used', 'remanufactured', 'waste' (and 'repaired' where applicable)?
- Q - To what extent is the history of battery status transitions traceable at item level, with documentation of each status change available?
- D - To what extent is the current battery status updated dynamically in the DBP and accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process to issue a new or updated DBP when a battery undergoes remanufacturing, repurposing or re-use and is placed back on the market?

7 - Separate collection symbol | Meaning of labels and symbols

Likert scale (0 – 5)

- A - To what extent does your organisation apply the mandatory separate collection symbol (wheeled bin with a cross) on the physical label of all batteries at the required minimum size (3% of the largest face, max 5×5 cm), and document its meaning in the language(s) of all target markets?
- Q - To what extent is the symbol compliant with the model defined in Annex VI Part B of Regulation (EU) 2023/1542 and its explanation verifiable and traceable to the specific battery model?
- D - To what extent is the separate collection symbol included in the DBP as a graphic element and machine-readable text, with its explanation publicly accessible?
- P - To what extent does your organisation have a defined process to verify dimensional and visual compliance of the symbol and keep its explanation updated when regulatory requirements change?

8 - Symbols for cadmium and lead | Meaning of labels and symbols

Likert scale (0 – 5)

- A - To what extent does your organisation identify batteries containing cadmium >0.002% or lead >0.004% by weight, apply the corresponding chemical symbol (Cd or Pb) on the label at the required size, and document the meaning of these symbols in the language(s) of all target markets?
- Q - To what extent is the presence or absence of Cd and Pb symbols justified by verifiable composition data, traceable to the battery model, and is the explanation of the symbols verifiable?
- D - To what extent are the Cd and Pb symbols included in the DBP as graphic elements and machine-readable text, with their explanation publicly accessible?
- P - To what extent does your organisation have a defined process to detect when Cd or Pb thresholds are exceeded, apply the correct symbol, and keep its explanation updated?

9 - Carbon footprint label | Meaning of labels and symbols

Likert scale (0 – 5)

- A - To what extent does your organisation have a carbon footprint label (including the carbon footprint value in $kgCO_2e/kWh$ and the carbon footprint performance class) ready for inclusion on the physical label of EV, industrial and LMT batteries, within the applicable regulatory deadlines?
- Q - To what extent is the carbon footprint label based on a declaration compliant with the delegated acts under Article 7 of Regulation (EU) 2023/1542?
- D - To what extent is the carbon footprint label available in the DBP as a graphic element and with the numerical values in machine-readable structured format?
- P - To what extent does your organisation have a defined and monitored process to update the carbon footprint label when the calculation methodology or applicable regulatory requirements change?

10 - Extinguishing agent category | Meaning of labels and symbols

Likert scale (0 – 5)

- A - To what extent does your organisation document the appropriate extinguishing agent category for each battery model and the explanation of this information in the language(s) of all target markets?
- Q - To what extent is the extinguishing agent information based on verifiable technical documentation (e.g. safety data sheets), traceable to the battery model, and is the explanation verifiable?
- D - To what extent is the extinguishing agent category included on the physical battery label and available as a public data attribute in the DBP, with its explanation publicly accessible?
- P - To what extent does your organisation have a defined process to review and update the extinguishing agent information and its explanation when battery chemistry or configuration changes?

11 - EU declaration of conformity

Likert scale (0 – 5)

- A - To what extent does your organisation have an EU Declaration of Conformity for each battery model, compliant with the template in Annex IX of Regulation (EU) 2023/1542, including the identification number and CE marking?
- Q - To what extent is the EU Declaration of Conformity up to date, available in electronic format and translated into the languages of all Member States where the battery is placed on the market?
- D - To what extent is the EU Declaration of Conformity uploaded to the DBP and publicly accessible, with its ID available as an individual structured data attribute?
- P - To what extent does your organisation have a defined and monitored process to keep the EU Declaration of Conformity updated and to issue a new declaration when changes are made to the battery model?

12 - Results of test reports providing compliance

Likert scale (0 – 5)

- A - To what extent does your organisation possess test reports proving compliance of each battery model with the applicable requirements of Regulation (EU) 2023/1542 and the applicable delegated and implementing acts?
- Q - To what extent were the test reports conducted by notified bodies or accredited laboratories, and are they traceable to the specific battery model?
- D - To what extent are the test reports available in the DBP, accessible to notified bodies, market surveillance authorities and the Commission (restricted access)?
- P - To what extent does your organisation have a defined process to update test reports when changes are made to the battery model or new regulatory requirements apply?

13 - Battery carbon footprint per functional unit ($kgCO_2e$/kWh)

Contribution: distribution lifecycle stage

Web link to public carbon footprint study

General battery and manufacturer information (for CFP study)

Absolute battery carbon footprint ($kgCO_2e$)

Likert scale (0 – 5)

- A - To what extent has your organisation calculated and documented the total battery carbon footprint per functional unit ($kgCO_2e$/kWh), including the distribution lifecycle stage contribution, the absolute carbon footprint (tCO_2e) and all general battery and manufacturer information required for the public carbon footprint study, with a web link to the publicly accessible study?
- Q - To what extent is the carbon footprint declaration compliant with the EU PEFCR for batteries or the GBA GHG Rulebook, subject to third-party verification as required by Article 17 of Regulation (EU) 2023/1542, and consistent across all its components?
- D - To what extent is the carbon footprint value available in the DBP and on the physical label ($kgCO_2e$/kWh), with the absolute value and web link to the public study available as structured data attributes?
- P - To what extent does your organisation have a defined and monitored annual process to recalculate and update the carbon footprint declaration when input data changes (e.g. energy mix, material suppliers, distribution routes)?

14 - Carbon footprint performance class

Likert scale (0 – 5)

- A - To what extent has your organisation determined the carbon footprint performance class for each battery model per manufacturing plant?
- Q - To what extent is the performance class determination based on the declared carbon footprint value and traceable to the battery model per manufacturing plant?
- D - To what extent is the carbon footprint performance class included in the DBP and on the physical label as a public data attribute?
- P - To what extent does your organisation have a defined process to review and update the performance class when the Commission publishes or revises the applicable methodology?

15 - Contribution: raw material acquisition & pre-processing stage

- Does your organisation receive GHG emissions data for the raw material extraction and pre-processing phase from your upstream suppliers (P1)?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into your carbon footprint declaration?
  Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

16 - Contribution: main product production/manufacturing stage

- Does your organisation receive GHG emissions data for the cell manufacturing phase from your cell suppliers (P3)?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into your carbon footprint declaration?
  Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

17 - Contribution: end of life and recycling stage

- Does your organisation receive GHG emissions data for the end-of-life and recycling phase from your end-of-life partners (P5)?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into your carbon footprint declaration?
  Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

18 - Battery chemistry

Critical raw materials (>0.1% weight by weight)

Materials used in cathode, anode and electrolyte

- Does your organisation receive full chemical composition data for the cells it uses — including battery chemistry (e.g. NMC, LFP), critical raw materials present above 0.1% by weight (per EU RMIS list) and the detailed composition of cathode, anode and electrolyte materials — from your cell suppliers (P3)?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into the DBP?
  Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

19 - Hazardous substances (Hg, Cd, Pb, SVHC)

Impact of substances on environment, human health, safety, persons

- Does your organisation receive hazardous substance and impact data for the cells it uses — including all hazardous substances (Hg, Cd, Pb, SVHC per REACH) with their concentrations and location, and their impact on the environment, human health and safety — from your cell suppliers (P3)?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into the DBP?

Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

20 - Dismantling information: manuals for removal and disassembly

Safety measures

Likert scale (0 – 5)

- A - To what extent does your organisation document and maintain dismantling and safety documentation for the battery pack — including dismantling and disassembly manuals (with required tools, sequence of operations and safety points) and safety measures for handling, dismantling and storage (e.g. electrical shock risks, thermal risks, required PPE)?
- Q - To what extent is this documentation traceable to the battery model, kept up to date and validated by dismantling professionals where applicable?
- D - To what extent is this documentation available in the DBP in publicly accessible format (e.g. PDF or equivalent)?
- P - To what extent does your organisation have a defined and monitored process to update dismantling and safety documentation when changes are made to the battery pack design or when new risk assessments are conducted?

21 - Part numbers for components

Postal/email/web address of sources for spare parts

Likert scale (0 – 5)

- A - To what extent does your organisation document and maintain operational support information for the battery pack — including reference numbers for all components (e.g. cells, modules, connector, BMS) and the sources of spare parts (postal address, email and website of authorised suppliers or distributors)?
- Q - To what extent is this operational support information accurate, up to date and traceable to the battery model?
- D - To what extent is this information available in the DBP as URLs or structured data, publicly accessible?
- P - To what extent does your organisation have a defined process to keep component reference numbers and spare parts source information updated when there are supplier or design changes?

22 - Pre-consumer recycled content share of Ni/Co/Li/Pb (%)

Post-consumer recycled content share of Ni/Co/Li/Pb (%)

Renewable content share

- Does your organisation receive recycled and renewable content data — including pre-consumer recycled content share of Ni/Co/Li/Pb (from P2), post-consumer recycled content share of Ni/Co/Li/Pb (from P5) and renewable content share (from P3) — from your upstream suppliers?
  Likert scale (0 — Do not receive | 5 — Receive automatically)
- When you receive this data, are you able to integrate it into the DBP?
  Likert scale (0 — Cannot integrate | 5 — Integrate fully automatically)

23 - Information on the role of end-users in contributing to waste prevention

Information on the role of end-users in contributing to separate collection of waste batteries

Likert scale (0 – 5)

- A - To what extent does your organisation document and maintain information on the role of end-users in battery waste prevention and in the separate collection of waste batteries (e.g. best practices for use, instructions on how and where to return batteries at end of life)?
- Q - To what extent is this information clear, verifiable and appropriate for the type of end-user of the battery?
- D - To what extent is this information available in the DBP (PDF or URL), publicly accessible?
- P - To what extent does your organisation have a defined process to update this information when regulatory requirements or waste prevention and collection practices change?

24 - Information on the separate collection, the take back, collection points and preparation for re-use, for repurposing and treatment available for waste batteries

Likert scale (0 – 5)

- A - To what extent does your organisation document and provide information on available battery collection points, take-back schemes and preparation options for re-use, repurposing and treatment of waste batteries?
- Q - To what extent is the collection point and take-back information up to date and verifiable (active collection points, functional contacts)?
- D - To what extent is this information available in the DBP (PDF or URL), publicly accessible?
- P - To what extent does your organisation have a defined process to keep collection point and take-back information updated when the collection network or available treatment options change?

25 - Rated capacity

Likert scale (0 – 5)

- A - To what extent does your organisation document the rated capacity of the battery pack (in Ah) for each model, based on normalised reference test conditions?
- Q - To what extent is the rated capacity value traceable to test reports with methodology documented per the CEN/CENELEC M/579 standardisation process?
- D - To what extent is the rated capacity included on the physical battery label and available as a public data attribute in the DBP?
- P - To what extent does your organisation have a defined process to verify and update the rated capacity value when changes are made to the battery pack design or cell configuration?

26 - Minimal, nominal and maximum voltage

Likert scale (0 – 5)

- A - To what extent does your organisation document the minimum, nominal and maximum operating voltage of the battery pack (in V) for each model, including temperature ranges where relevant?
- Q - To what extent are the three voltage values traceable to technical specifications and test reports, with methodology documented?
- D - To what extent are the three voltage values available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined process to update and validate voltage values when changes are made to the battery pack configuration?

27 - Original power capacity

Maximum permitted battery power

Ratio between nominal battery power and battery energy

Likert scale (0 – 5)

- A - To what extent does your organisation document the power parameters of the battery pack — including original power capability (W, at 80% and 20% SoC), maximum permitted battery power (W) and ratio between nominal battery power and battery energy (W/Wh) — for each model, based on normalised reference conditions?
- Q - To what extent are these power parameter values traceable to test reports and technical specifications, with temperature ranges and SoC conditions documented where relevant?
- D - To what extent are these power parameters available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined process to verify and update power parameters when changes are made to the battery pack design or safety specifications?

28 - Initial round trip energy efficiency

Round trip energy efficiency at 50% of cycle life

Likert scale (0 – 5)

- A - To what extent does your organisation document both the initial round trip energy efficiency (%) and the round trip energy efficiency at 50% of cycle life (%) for each battery model, based on normalised reference conditions or validated ageing models?
- Q - To what extent are both efficiency values traceable to test reports or validated ageing models with documented reference conditions specifying what '50% of cycle life' means for the battery model?
- D - To what extent are both efficiency values available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined process to obtain, document and update these efficiency values for each new battery model or variant?

29 - Initial internal resistance of battery cell and pack

Likert scale (0 – 5)

- A - To what extent does your organisation document the initial internal resistance of both the battery cell and battery pack (in Ω) for each model at begin of life under normalised reference conditions?
- Q - To what extent are the internal resistance values for cell and pack traceable to test reports conducted under normalised reference conditions per CEN/CENELEC M/579?
- D - To what extent is the initial internal resistance available as a public data attribute in the DBP?
- P - To what extent does your organisation have a defined process to verify and document cell and pack internal resistance for each new battery model or variant?

30 - Temperature range idle state (lower and upper boundary)

Likert scale (0 – 5)

- A - To what extent does your organisation document the lower and upper temperature boundaries (in °C) of the idle state temperature range for each battery model, based on reference qualification tests?
- Q - To what extent are the temperature boundary values traceable to environmental qualification test reports?
- D - To what extent are the idle state temperature boundaries available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined process to verify and update temperature boundary values for each new battery model or variant?

31 - Capacity fade

Power fade

Energy round trip efficiency fade

Internal resistance increase of pack

Likert scale (0 – 5)

- A - To what extent does your organisation calculate and document all battery degradation parameters — including capacity fade (%), power fade (%), energy round trip efficiency fade (%) and internal resistance increase of the pack (%) — upon each placement on the market or change of battery status?
- Q - To what extent are all degradation values calculated using documented and verifiable methodology consistent with the respective initial reference values (per ISO 12405-4:2018 or equivalent)?
- D - To what extent are all degradation parameters available in the DBP as structured data attributes accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined process to update all degradation parameters upon each change of battery status (i.e. each new placement on the market)?

32 - State of charge

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS calculate and record the State of Charge (SoC in %) — available energy or charge as a percentage of rated capacity — for each individual battery dynamically?
- Q - To what extent is the SoC calculated by validated BMS algorithms with documented methodology, including histogram reporting of time spent in SoC intervals where applicable?
- D - To what extent is the SoC transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of SoC in the DBP?

33 - Expected lifetime in calendar years

Likert scale (0 – 5)

- A - To what extent does your organisation document the expected lifetime in calendar years of the battery pack for each model under the reference operating conditions for which it was designed?
- Q - To what extent is the expected calendar lifetime traceable to ageing tests or validated degradation models with documented reference conditions (temperature, SoC, storage conditions)?
- D - To what extent is the expected calendar lifetime available in the DBP as a structured data attribute accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined process to update the expected calendar lifetime when changes are made to the battery design or specified operating conditions?

34 - Expected lifetime: Number of charge-discharge cycles

Cycle-life reference test

C-rate of relevant cycle-life test

Likert scale (0 – 5)

- A - To what extent does your organisation document the expected number of full charge-discharge cycles for each battery model, together with the cycle-life reference test used (applicable standard, temperature, depth of discharge) and the C-rate of charge and discharge (in A/Ah)?
- Q - To what extent are the cycle life value and test parameters traceable to cycle life test reports conducted under normalised reference conditions, with C-rate expressed separately for charge and discharge where applicable?
- D - To what extent are the cycle life value and reference test parameters available as public data attributes in the DBP?
- P - To what extent does your organisation have a defined and monitored process to document and update cycle life data when changes are made to the battery pack design or specified operating conditions?

35 - Number of full charging and discharging cycles

Temperature information

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS record and maintain cumulative usage data for each individual battery — including cumulative number of full charge-discharge cycles and operating temperature information (in °C, including time spent above and below idle state temperature limits)?
- Q - To what extent is all usage data recorded based on validated BMS sensors and algorithms, with documented aggregation methodology (e.g. histograms of temperature by intervals) and traceability at item level?
- D - To what extent is all usage data transmitted dynamically to the DBP, accessible to persons with a legitimate interest, with appropriate data protection considerations?
- P - To what extent does your organisation have a defined and monitored process for the update interval of usage data in the DBP?

36 - Number of overcharge events

Information on accidents

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS record and maintain adverse event data for each individual battery — including cumulative number of overcharge events and information on accidents (e.g. abrupt impacts above a defined acceleration threshold)?
- Q - To what extent is all adverse event data recorded based on documented threshold criteria, with traceability at item level and appropriate data protection considerations?
- D - To what extent is all adverse event data transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of adverse event data in the DBP, including data protection and privacy compliance?

37 - What type(s) of application are the battery packs/modules that your organization manufactures or commercializes intended for?

*(You may select more than one option)**

- Electric vehicle (EV) batteries
- Batteries for Light Means of Transport (LMT) with BMS
- Batteries for Light Means of Transport (LMT) without BMS
- Industrial batteries > 2 kWh, including stationary energy storage systems (BESS) with BMS
- Industrial batteries > 2 kWh, including stationary energy storage systems (BESS) without BMS
- Other

Section 5

38 - Date of putting battery into service

Likert scale (0 – 5)

- A - To what extent does your organisation record the date on which each individual BESS or LMT battery is put into service (format YYYY-MM) and update the DBP accordingly?
- Q - To what extent is the commissioning date traceable at item level, with documentation available to verify when the battery entered service?
- D - To what extent is the commissioning date updated dynamically in the DBP and accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process to capture and transmit the commissioning date to the DBP at the moment the battery is put into service?

39 - Remaining capacity

Likert scale (0 – 5)

- A - To what extent does your organisation measure and record the current remaining capacity (in Ah) of each individual battery dynamically, updating periodically throughout the lifecycle?
- Q - To what extent is the remaining capacity calculated by validated algorithms or measurement methods, with traceability to the estimation method used?
- D - To what extent is the remaining capacity transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of remaining capacity in the DBP?

40 - Remaining power capability

Likert scale (0 – 5)

- A - To what extent does your organisation measure and record the remaining power capability (in W) of each individual battery dynamically, where possible, as part of the state of health assessment?
- Q - To what extent is the remaining power capability calculated by validated algorithms or measurement methods at reference conditions (80% and 20% SoC), with documented methodology?
- D - To what extent is the remaining power capability transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of remaining power capability in the DBP?

41 - Initial self-discharge rate

Likert scale (0 – 5)

- A - To what extent does your organisation document the initial self-discharge rate (in %/month) of the battery pack for each BESS or LMT model, measured at begin of life under reference conditions?
- Q - To what extent is the value traceable to test reports with reference conditions documented (temperature, SoC at start)?
- D - To what extent is the initial self-discharge rate available in the DBP as a structured data attribute accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined process to verify and update the initial self-discharge rate for each new battery model or variant?

42 - Remaining round trip energy efficiency

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS calculate and record the remaining round trip energy efficiency (in %) for each individual BESS or LMT battery dynamically, where possible, as part of the state of health assessment?
- Q - To what extent is the remaining efficiency calculated by validated BMS algorithms with methodology consistent with the initial round trip efficiency measurement?
- D - To what extent is the remaining round trip energy efficiency transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of remaining round trip energy efficiency in the DBP?

43 - Current self-discharge rate

Evolution of self-discharge rate

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS calculate and record the current self-discharge rate (in %/month) and the evolution of self-discharge rates (% change from initial to current) for each individual BESS or LMT battery dynamically?
- Q - To what extent are both values calculated by validated BMS algorithms with methodology consistent with the initial self-discharge rate, and traceable to the battery model?
- D - To what extent are the current self-discharge rate and its evolution transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of both self-discharge rate values in the DBP?

44 - Energy throughput

Capacity throughput

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS record the cumulative energy throughput (in kWh or MWh) and cumulative capacity throughput (in Ah) of each individual BESS or LMT battery throughout its lifetime?
- Q - To what extent are both throughput measurements based on validated BMS sensors and algorithms, with methodology documented?
- D - To what extent are cumulative energy and capacity throughput transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of both throughput values in the DBP?

45 - Time spent in extreme temperatures

Time spent charging during extreme temperatures

Likert scale (0 – 5)

- A - To what extent does your organisation's BMS record the cumulative time each individual BESS or LMT battery spends in extreme temperatures (above and below the idle state temperature limits) and the cumulative time spent charging during extreme temperatures throughout its lifetime?
- Q - To what extent are both time measurements recorded based on documented threshold criteria linked to the idle state temperature boundaries, with traceability at item level?
- D - To what extent are both time measurements transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of both time measurements in the DBP?

46 - Number of deep discharge events

Likert scale (0 – 5)

- A - To what extent does your organisation record the cumulative number of deep discharge events (voltage below the minimum operating voltage threshold for each individual battery throughout its lifetime?
- Q - To what extent is the deep discharge event count based on documented threshold criteria, with traceability at item level?
- D - To what extent is the number of deep discharge events transmitted dynamically to the DBP, accessible to persons with a legitimate interest?
- P - To what extent does your organisation have a defined and monitored process for the update interval of deep discharge events in the DBP?

Section 6

47 - What is the size of your company?

(Select the option that best applies)

- Micro enterprise
- Small enterprise
- Medium-sized enterprise
- Large enterprise

Section 7

48 - In which market does your company mainly operate?

(Select the option that best applies)

- National
- European Union
- Global

49 - In your company, who do you believe should be primarily responsible for the implementation and management of the Digital DBP?

(Select the option that best applies)

- Sustainability / ESG
- Quality / Compliance
- IT / Information Systems
- Engineering / Product
- Operations / Supply Chain
- Not yet defined
- Other:

50 - Additional comments or main concerns regarding the DBP:

(Open-ended response)

Section 8 - If you would like to receive the diagnostic report, please provide your contact details below (optional).

51 – Company name

(Open-ended response)

52 – Contact person name

(Open-ended response)

53 – Email address

(Open-ended response)

Appendix F: Excel-based Scoring Tool

Category	Data attribute	M/R	S/D	A	Q	D	P	If receive Rx	If integrate Rx	Attribute Score	Max Attribute score	M/R Weighting	Max M/R Weighting	Category Score	Critical Gaps M score < 2,5
1	Battery passport identifier	R	S	3	3	3	1			2,5	5	2,5	5		
1	Battery identifier	M	S	3	3	3	1			2,5	5	5	10		
1	Operator identifier and information	R	S	3	3	3	1			2,5	5	2,5	5		
1	Manufacturer identifier and information	M	S	3	3	3	1			2,5	5	5	10		
1	Manufacturing place	M	S	5	2	5	0			3	5	6	10		
1	Manufacturing data	M	S	5	2	5	0			3	5	6	10		
1	Date of putting battery into service	M	S	0	0	0	0			0	5	0	10		CG
1	Warranty period of the battery	M	S	4	4	3	1			3	5	6	10		
1	Battery category	M	S	4	4	3	1			3	5	6	10		
1	Battery mass	M	S	5	3	5	2			3,75	5	7,5	10		
1	Battery status	M	D	0	0	0	0			0	5	0	10		CG
												46,5	100	47%	
														2,33	
2	Separate collection symbol	M	S	5	5	3	3			4	5	8	10		
2	Symbols for cadmium and lead	M	S	5	5	5	1			4	5	8	10		
2	Carbon footprint label	M	S	0	0	0	0			0	5	0	10		CG
2	Extinguishing agent category	M	S	5	5	4	1			3,75	5	7,5	10		
2	Meaning of labels and symbols	M	S	N/A	N/A	N/A	N/A			N/A			0		
2	EU declaration of conformity	M	S	5	3	1	1			2,5	5	5	10		
2	Results of test reports providing compliance	M	S	4	5	0	0			2,25	5	4,5	10		CG
												33	60	55%	

															2,75	
3	Battery carbon footprint per functional unit ($kgCO_2e/kWh$)	M	S	0	0	0	0			0	5	0	10			**CG**
3	Contribution: raw material acquisition & pre-processing stage	M	S					0	0	0	5	0	0			**CG**
3	Contribution: main product production/manufacturing stage	M	S					0	0	0	5	0	10			**CG**
3	Contribution: distribution lifecycle stage	M	S	0	0	0	0			0	5	0	10			**CG**
3	Contribution: end of life and recycling stage	M	S					0	0	0						**CG**
3	Carbon footprint performance class	M	S	0	0	0	0			0	5	0	10			**CG**
3	Web link to public carbon footprint study	M	S	0	0	0	0			0	5	0	10			**CG**
3	General battery and manufacturer information (for CFP study)	M	S	0	0	0	0			0	5	0	10			**CG**
3	Absolute battery carbon footprint ($kgCO_2e$)	R	S	0	0	0	0			0	5	0	5			**CG**
												0	65		**0%**	
															0	
4	Information of due diligence report in the Battery Passport	M	S	N/A	N/A	N/A	N/A			N/A						
4	Third-party assurances of recognized schemes	R	S	N/A	N/A	N/A	N/A			N/A						
4	Supply chain indices (Co, Li, Ni, natural graphite)	R	S	N/A	N/A	N/A	N/A			N/A						
															N/A	
															N/A	
5	Battery chemistry	M	S					5	5	5	5	10	10			

5	Critical raw materials (>0.1% weight by weight)	M	S					5	5	5	5	10	10		
5	Materials used in cathode, anode and electrolyte	M	S					5	5	5	5	10	10		
5	Hazardous substances (Hg, Cd, Pb, SVHC)	M	S					4	5	4,5	5	9	10		
5	Impact of substances on environment, human health, safety, persons	M	S					4	5	4,5	5	9	10		
												48	50	**96%** **4,8**	
6	Dismantling information: manuals for removal and disassembly	M	S	5	3	1	1			2,5	5	5	10		
6	Part numbers for components	M	S	2	3	1	1			1,75	5	3,5	10		**CG**
6	Postal/email/web address of sources for spare parts	M	S	2	3	1	1			1,75	5	3,5	10		**CG**
6	Safety measures	M	S	5	3	1	1			2,5	5	5	10		
6	Pre-consumer recycled content share of Ni/Co/Li/Pb (%)	M	S					0	0	0	5	0	10		**CG**
6	Post-consumer recycled content share of Ni/Co/Li/Pb (%)	M	S					0	0	0	5	0	10		**CG**
6	Renewable content share	M	S					0	0	0	5	0	10		**CG**
6	Information on the role of end-users in contributing to waste prevention	M	S	5	5	1	0			2,75	5	5,5	10		
6	Information on the role of end-users in contributing to separate collection of waste batteries	M	S	5	5	1	0			2,75	5	5,5	10		

6	Information on the separate collection, the take back, collection points and preparation for re-use, for repurposing and treatment available for waste batteries	M	S	2	0	0	0	0,5	5	1	10		CG
										29	100	**29%** **1,45**	
7	Rated capacity	M	S	5	3	1	0	2,25	5	4,5	10		CG
7	Capacity fade	M	S	3	2	2	0	1,75	5	3,5	10		CG
7	Certified usable battery energy	R[1]	S	N/A	N/A	N/A	N/A						
7	Minimal, nominal and maximum voltage	M	S	5	4	1	0	2,5	5	5	10		
7	Remaining capacity	M/R[2]	D	5	2	0	0	1,75	5	3,5	10		CG
7	Remaining usable battery energy	R[1]	D	N/A	N/A	N/A	N/A						
7	State of certified energy	M[3]	D	N/A	N/A	N/A	N/A						
7	State of charge	M	D	5	1	0	0	1,5	5	3	10		CG
7	Original power capacity	M	S	2	2	1	0	1,25	5	2,5	10		CG
7	Remaining power capability	M/R[2]	D	2	1	0	0	0,75	5	1,5	10		CG
7	Power fade	M	S	3	2	2	0	1,75	5	3,5	10		CG
7	Maximum permitted battery power	M	S	2	2	1	0	1,25	5	2,5	10		CG
7	Ratio between nominal battery power and battery energy	R	S	2	2	1	0	1,25	5	1,25	5		CG
7	Initial round trip energy efficiency	M	S	3	1	0	0	1	5	2	10		CG
7	Round trip energy efficiency at 50% of cycle life	M	S	3	1	0	0	1	5	2	10		CG
7	Energy round trip efficiency fade	M	S	3	2	2	0	1,75	5	3,5	10		CG
7	Initial self-discharge rate	R[4]	S	2	1	0	0	0,75	5	0,75	5		CG
7	Remaining round trip energy efficiency	M[5]	D	0	0	0	0	0	5	0	10		CG

7	Current self-discharge rate	R[4]	D	0	0	0	0	0	5	0	5	CG
7	Evolution of self-discharge rate	M[4]	D	0	0	0	0	0	5	0	10	CG
7	Initial internal resistance of battery cell and pack	M/R[6]	S	3	3	2	0	2	5	4	10	CG
7	Internal resistance increase of pack	M/R[7]	S	3	2	2	0	1,75	5	3,5	10	CG
7	Expected lifetime in calendar years	M	S	5	2	1	0	2	5	4	10	CG
7	Expected lifetime: Number of charge-discharge cycles	M	S	5	2	1	0	2	5	4	10	CG
7	Cycle-life reference test	M	S	N/A	N/A	N/A	N/A					
7	C-rate of relevant cycle-life test	M	S	N/A	N/A	N/A	N/A					
7	Capacity threshold for exhaustion	M[1]	S	N/A	N/A	N/A	N/A					
7	Number of full charging and discharging cycles	M	D	4	2	1	0	1,75	5	3,5	10	CG
7	Energy throughput	M[5]	D	0	0	0	0	0	5	0	10	CG
7	Capacity throughput	M[5]	D	0	0	0	0	0	5	0	10	CG
7	Temperature range idle state (lower and upper boundary)	M	S	5	2	1	0	2	5	4	10	CG
7	Temperature information	M	D	4	2	1	0	1,75	5	3,5	10	CG
7	Time spent in extreme temperatures	M/R[5]	D	4	4	0	0	2	5	4	10	CG
7	Time spent charging during extreme temperatures	M/R[5]	D	4	4	0	0	2	5	4	10	CG
7	Number of deep discharge events	M/R[2]	D	4	4	0	0	2	5	4	10	CG
7	Number of overcharge events	R	D	5	5	1	0	2,75	5	2,75	5	
7	Information on accidents	M	D	5	5	1	0	2,75	5	5,5	10	
										85,75	290	**30%**
												1,48

Category	Score	R/C Attributes	Rx Attributes	Number of Attributes	Global Score
CAT-1	2,33	11	0	11	
CAT-2	2,75	6	0	6	
CAT-3	0	6	3	9	
CAT-4	N/A	0	0	0	**1,76**
CAT-5	4,8	0	5	5	
CAT-6	1,45	7	3	10	
CAT-7	1,48	31	0	31	
		61	**11**	**72**	**35%**

Appendix G: Validation Questionnaire of the DBP Maturity Assessment Framework – DBP-MAF

Section 1

This questionnaire evaluates the DBP Maturity Assessment Framework (DBP-MAF), which has just been applied to your organisation through the Diagnostic Questionnaire (Q1) and the accompanying Diagnostic Report. The Q2 is the evaluation instrument of the DBP-MAF as a Design Science Research (DSR) artefact, following the evaluation criteria of Hevner et al. (2004).

The Q2 evaluates the DBP-MAF along three dimensions:

1. Utility — Does the framework provide practical value and actionable insight for your organisation?

2. Quality — Is the framework well designed, internally consistent, and robust — in its scoring rubric, maturity levels, Responsibility Matrix, and the clarity of the Q1 questions?

3. Efficacy — Does the framework work in practice, in the real organisational setting for which it was designed?

Please respond based on your direct experience of the Q1 assessment and the Diagnostic Report you received. Participation is voluntary and responses are confidential. Results will be analysed in aggregate and anonymised form in the dissertation.

For any additional information, please contact:

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Section 2: Dimension 1 – Utility

1 - Please rate your agreement with the following statements about the utility of the DBP-MAF for your organisation.

Likert scale (0 – 5)

1. The Diagnostic Report produced by the DBP-MAF provides a clear and accurate picture of my organisation's current level of readiness for DBP implementation.
2. The maturity level classification (0–5) gives my organisation a meaningful reference point for understanding its compliance position.
3. The gap classification (capability / integration) helped my organisation understand the nature of each identified gap and the type of intervention required.
4. The implementation roadmap provides actionable guidance that my organisation can use to prioritise improvement efforts.
5. Overall, the DBP-MAF generates insights that are useful for my organisation's DBP implementation planning.

2 - What was the most useful output of the DBP-MAF assessment for your organisation?

(Open-ended response)

3 - What output or insight was missing from the Diagnostic Report that would have been useful?

(Open-ended response)

Section 3: Dimension 2 - Quality

4 - Please rate your agreement with the following statements about the quality of the DBP-MAF's design.

Likert scale (0 – 5)

1. The scoring rubric (0–5 scale with descriptors for Availability, Quality, Digitalisation, and Process) accurately reflects levels of data readiness that are meaningful in the context of DBP implementation.
2. The maturity level definitions (0 = Unaware to 5 = Optimised) correctly characterise the organisational profiles at each level.
3. The threshold of Level 3 (Defined) as the minimum compliance target for the February 2027 deadline is appropriate and realistic.
4. The Responsibility Matrix correctly reflects my organisation's actual data obligations and dependencies under Regulation (EU) 2023/1542.
5. The questions in the Diagnostic Questionnaire (Q1) accurately captured the information needed to assess readiness for each data attribute.

5 - Are there any components of the framework (scoring rubric, maturity levels, Responsibility Matrix, gap classification) that you believe are inaccurate or inconsistent? Please specify.

(Open-ended response)

6 - Which questions or sections of the Q1 were unclear, ambiguous, or difficult to answer, and why?

(Open-ended response)

Section 4: Dimension 3 - Efficacy

7 - Please rate your agreement with the following statements about the efficacy of the DBP-MAF.

Likert scale (0 – 5)

1. The DBP-MAF is applicable to organisations of my size and profile in the battery sector.
2. The data required to complete the Q1 assessment was, in principle, available within my organisation (even if not yet fully documented or digitalised).
3. The implementation roadmap generated by the DBP-MAF is realistic and achievable for my organisation within the available timeframe.
4. My organisation would consider using the DBP-MAF as a self-assessment tool in the future to monitor progress towards DBP compliance.

5. I would recommend the DBP-MAF to other organisations in the battery value chain as a useful readiness assessment tool.

8 - What are the main barriers that would prevent your organisation from fully implementing the recommendations generated by the DBP-MAF?

(Open-ended response)

9 - In your view, what conditions or support mechanisms would be necessary for the DBP-MAF to be adopted more widely across the battery sector?

(Open-ended response)

Section 5: Overall Assessment

10 – Overall Rating

Likert scale (0 – 5)

- Utility
- Quality
- Efficacy

11 – Comparative Assessment

Likert scale (0 – 5)

1. Compared to other regulatory compliance tools or frameworks I have encountered, the DBP-MAF represents a useful and distinctive contribution.
2. The DBP-MAF adds value beyond what could be achieved through a generic readiness checklist or a non-actor-differentiated maturity model.
3. Modelling my organisation's dependency on data from other value chain actors (Rx attributes) is a feature that significantly increases the relevance of the assessment.

12 - What is the single most important improvement you would recommend to enhance the DBP-MAF?

(Open-ended response)

13 - Any additional comments, observations or suggestions regarding the DBP-MAF or the assessment process:

(Open-ended response)