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Article

Battery Passports for Sustainable Battery Systems: A Review of Roles, Data Requirements, and Implementation Challenges Across Value Chain Stages

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Abstract: Battery passports are emerging as important digital governance tools for improving sustainability, transparency, and circularity in battery value chains. This review examines the role of battery passports in advancing traceability, transparency, compliance, and circularity across the battery lifecycle, while also identifying the main challenges associated with their implementation. A systematic review approach was used to synthesize academic, regulatory, and technical sources related to battery passports, lifecycle data systems, and circular battery management. The findings show that traceability is the most emphasized role of battery passports, as it enables battery identity, provenance, composition, and lifecycle history to be connected across multiple actors and stages. Transparency is also strongly emphasized because passport systems can make sustainability and technical information more visible, comparable, and useful for decision-making. Circularity is supported by preserving data needed for reuse, second-life applications, remanufacturing, and recycling, while compliance is increasingly driven by regulatory requirements, particularly under the European Union Batteries Regulation. The review further shows that implementation is constrained mainly by interoperability, data quality and availability, governance and access rights, standards harmonization, and confidentiality concerns. A lifecycle-stage mapping demonstrates that battery passports create different forms of value across raw material sourcing, manufacturing, use, second-life assessment, recycling, and cross-cutting governance. Overall, the study shows that battery passport effectiveness depends not only on data collection, but also on reliable data updating, verification, sharing, and governance across lifecycle stages. The review provides a structured basis for future research, policy development, and industry implementation.

Keywords: Battery passports; Traceability; Circularity; Battery lifecycle management; Systematic Review

1. Introduction

The rapid growth of electric vehicles (EVs), renewable energy storage systems, and portable electronics has made batteries a strategic component of the global low-carbon transition. Lithium-ion batteries have become central to decarbonization pathways because of their widespread application in transport electrification, stationary energy storage, and consumer electronics (Terkes et al. 2024; Plociennik et al. 2022; Wang et al. 2026). However, the accelerated expansion of battery production and use has also raised major concerns regarding raw material sourcing, environmental impacts, carbon emissions, safety, lifecycle monitoring, and end-of-life management (Berger et al. 2022; Langley et al.

2023; European Union 2023). These concerns are increasingly important because batteries are not only technological products, but also resource-intensive systems linked to mining, global supply chains, industrial processing, and waste governance. As a result, ensuring battery sustainability requires a lifecycle perspective that connects upstream production, use-phase monitoring, and downstream circularity strategies (Kamath 2024; Jensen et al. 2023).

In response to these concerns, the concept of the battery passport has emerged as an important digital tool for collecting, storing, and sharing key information on a battery's origin, composition, carbon footprint, performance, and circularity-related attributes throughout its lifecycle (Berger et al. 2022; Fangerow et al., 2025). A battery passport is increasingly understood not as a simple digital label, but as a traceability and data-governance mechanism that can support more transparent and accountable battery value chains. In this review, a battery passport is defined as a battery-specific form of a digital product passport that records, updates, and communicates lifecycle information for battery systems. While the broader digital product passport concept can apply to many product categories, including textiles, plastics, buildings, electronics, and other circular-economy products, the battery passport is specifically focused on battery identity, chemistry, material origin, carbon footprint, state of health, safety, performance history, reuse potential, and end-of-life treatment information. Therefore, although this review draws on selected digital product passport literature where it informs lifecycle data governance, interoperability, transparency, and circularity, the term "battery passport" is used consistently throughout the manuscript to refer to battery-focused passport systems. The idea is particularly relevant in the context of rising regulatory and market demands for evidence-based sustainability claims, due diligence, responsible sourcing, and circular resource management. In this sense, battery passports are positioned as enabling instruments for linking technical information, environmental performance, and regulatory compliance within one integrated framework (Battery Pass Consortium 2024; Global Battery Alliance 2024).

The policy relevance of battery passports has grown significantly in recent years, particularly with the adoption of the European Union Batteries Regulation, which places strong emphasis on sustainability, transparency, carbon footprint disclosure, recycled content, due diligence, and lifecycle responsibility in the battery sector (European Union 2023). Under this evolving policy landscape, battery passports are increasingly seen as practical tools that can support regulatory implementation by making relevant data accessible across the supply chain. At the same time, international initiatives and industry-led platforms have further accelerated the discussion by promoting common frameworks, pilot projects, and implementation roadmaps for battery passport systems (Global Battery Alliance 2024; Battery Pass Consortium 2024; Jansen et al. 2023; Stör et al. 2025). As a result, the battery passport has moved from being a largely conceptual proposal to becoming an emerging operational instrument in battery governance.

To understand the role of a battery passport a lifecycle perspective is particularly useful. The function and value of battery passport information vary across different stages of the battery lifecycle (Yuan 2025; da Cruz et al. 2025). During manufacturing, battery passports can support traceability by recording chemistry, material origin, and embedded carbon information, thereby helping manufacturers and regulators verify responsible sourcing and production practices (Kemmner et al. 2025). During the use and second-life stage, passports can support circularity by providing data on battery status, performance history, and state of health, which are critical for decisions on reuse, repurposing, or remanufacturing (Wagner 2025). During recycling and end-of-life management, passports can facilitate compliance and material recovery by making composition, dismantling information, and hazardous content more visible to recyclers and downstream operators. However, the data needed, the key barriers, and the main responsible actors differ at each stage. This lifecycle-stage mapping adds practical value because it shows that battery passports are not uniformly useful in one single way; rather, they serve different governance and operational purposes depending on whether the battery is being produced, used, repurposed, or recycled.

Despite their promise, battery passports also face several research and implementation challenges. One of the most frequently identified issues is data quality, since battery passports depend on accurate, complete, up-to-date, and verifiable information across the entire lifecycle. Another major challenge is interoperability, because battery-related data are generated in different formats and digital systems across multiple organizations. In addition, confidentiality remains a sensitive issue, as firms may hesitate to disclose commercially valuable or proprietary information. Governance is another major challenge, particularly with respect to data ownership, access rights, responsibilities for updating information, and verification mechanisms. These issues demonstrate that the successful deployment of battery passports requires not only technical readiness, but also institutional coordination, harmonized standards, and trusted data governance frameworks (Rizos and Urban 2024; Battery Pass Consortium 2024; Rufino Júnior 2024).

Existing literature has increasingly examined battery passports from conceptual, technical, regulatory, and implementation perspectives. Berger et al. (2022) provided one of the earliest conceptualizations of battery passports, emphasizing their role in enabling sustainable and circular battery value chains. Subsequent studies have expanded this foundation by addressing more specific dimensions of implementation. For example, Berger et al. (2023) analyzed data requirements and availabilities from the perspective of battery value chain actors, while Pohlmann et al. (2024) explored stakeholder requirements for battery passports for electric vehicle batteries, particularly in relation to sustainability and circularity. Gianvincenzi et al. (2024) further contributed by proposing a standardized data model for battery passports, and Ott et al. (2024) highlighted the importance of end-of-life-focused data structures for supporting recycling and downstream lifecycle management. In addition, Haupt et al. (2024) emphasized the integration of life cycle assessment-related information into battery passports, particularly for environmental performance assessment.

Beyond academic studies, policy and industry publications have focused on implementation guidance, technical architecture, data requirements, and reporting obligations under the evolving European regulatory framework (European Union 2023; Battery Pass Consortium 2024). At the same time, industry initiatives such as the Global Battery Alliance have highlighted pilot efforts, practical use cases, and collaboration models for real-world implementation (Global Battery Alliance 2024). Nevertheless, the literature remains fragmented across academic, policy, and technical sources, making it difficult to build a fully integrated understanding of the field.

This fragmentation reveals an important research gap. While battery passports are increasingly recognized as strategic tools for battery lifecycle sustainability, there is still limited systematic synthesis of their functional roles, lifecycle applications, and implementation barriers across both scholarly and policy-oriented sources. A focused review is therefore needed to examine how the literature discusses the contributions of battery passports to traceability, transparency, compliance, and circularity, while also identifying the main obstacles related to data quality, interoperability, confidentiality, and governance. More specifically, a review should responds the need to examine not only established passport functions, but also emerging factors that are gaining importance as implementation moves closer to practice, including dynamic data updating, auditability, actor-specific access rights, data ownership, and downstream availability of state-of-health information for second-life and recycling decisions.

Accordingly, this review paper has three main research objectives. First, it aims to analyze the role of battery passports in improving traceability, transparency, compliance, and circularity across the battery lifecycle. Second, it seeks to identify and critically assess the major implementation challenges associated with battery passports, with particular attention to data quality, interoperability, confidentiality, and governance. Third, it aims to examine how the role of the battery passport, key data requirements, major barriers, and responsible actors vary across different lifecycle stages, particularly manufacturing, second life, and recycling. By incorporating this lifecycle-stage mapping perspective, the review moves beyond a general discussion of battery passports and provides a more structured understanding of where and how these systems create value, where constraints are most pronounced, and which stakeholders are central at different points in the battery chain.

The novelty of this paper lies in moving beyond a descriptive synthesis of battery passport concepts toward an integrated, stage-specific assessment of how passport functions, data requirements, implementation barriers, and responsible actors interact across the battery lifecycle. Although previous studies have examined individual aspects such as conceptual design, actor-specific data requirements, stakeholder expectations, standardized data models, end-of-life data structures, and LCA-related information needs, these contributions remain relatively fragmented. Several issues are still insufficiently integrated in the literature, including dynamic lifecycle data updating, data ownership and access-right governance, verification and auditability of sustainability claims, confidentiality of commercially sensitive information, and the transfer of battery health data from first use to second life and recycling actors. These factors are becoming more important as battery passports shift from conceptual tools to regulatory and operational infrastructures under emerging policy frameworks such as the EU Batteries Regulation. Therefore, this review contributes by systematically linking functional roles, neglected and emerging implementation barriers, lifecycle-stage data needs, and actor responsibilities within one analytical framework. This approach clarifies not only what battery passports are expected to do, but also where their practical value may be constrained if data continuity, verification, interoperability, and governance are not adequately addressed.

2. Material and Methods

This study employed a systematic review to synthesize existing evidence on the roles and implementation challenges of battery passports. A systematic review was selected because the topic is relatively recent, interdisciplinary, and dispersed across academic publications, policy documents, and technical reports. The review process was guided by the PRISMA 2020 framework, which provides structured guidance for transparent identification, screening, eligibility assessment, and inclusion of sources in evidence synthesis (Page et al. 2021). Following PRISMA improved the clarity, reproducibility, and reporting quality of the review process.

The literature search was conducted using three major academic databases: Scopus, Web of Science, and Google Scholar. To capture policy and implementation-oriented evidence, additional targeted searches were also undertaken in institutional and organizational sources, including European Union policy repositories and battery passport initiative websites. The search strategy used combinations of keywords such as "battery passport," "battery passport," "battery passport AND traceability," "battery passport AND transparency," "battery passport AND compliance," "battery passport AND circularity," "battery passport AND interoperability," and "battery passport AND governance." These terms were selected to align directly with the study objectives and to capture both the functional and implementation dimensions of battery passports.

The initial search yielded 150 records. These records were exported and reviewed in stages consistent with the PRISMA flow process. In the first stage, duplicate records were identified and removed. After duplicate removal, the remaining records were screened based on title and abstract. A total of 100 studies were retained for full-text assessment because they addressed battery passports, closely related digital product passport and related battery lifecycle data systems with relevance to traceability, transparency, compliance, circularity, or implementation challenges. During the first full-text screening, 20 research articles were excluded because they focused broadly on batteries without discussing passport systems, were not sufficiently relevant to the objectives, or lacked accessible full text.

During the eligibility stage, full texts were examined in detail against predefined inclusion and exclusion criteria. To be included, documents had to be published in English and provide substantive discussion of battery passports from academic, regulatory, technical, or policy perspectives. For this review, "substantive discussion" was operationally defined as a document that met at least two of the following criteria: (i) discussed battery passports for batteries as a main or clearly identifiable topic; (ii) provided information on at least one functional role of battery passports, such as traceability, transparency, compliance, or circularity; (iii) discussed at least one implementation challenge, such as data quality, interoperability, confidentiality, governance, access rights, verification, or standardization; (iv) described data requirements, lifecycle-stage applications, or actor responsibilities; or (v) provided regulatory, technical, or policy guidance directly relevant to battery passport implementation. Both peer-reviewed and credible grey literature sources were considered appropriate because battery passport development is strongly shaped by policy and industry initiatives in addition to academic research. At this stage, an additional 15 records were excluded because they did not provide meaningful analysis of passport roles, implementation challenges and lacked sufficient relevance to the study objectives. After completion of the full-text review, 65 studies and documents were retained for final synthesis. The overview of research study selection process can be seen in Figure 1.

Data from the included studies were extracted using a structured review matrix. The matrix captured bibliographic information, document type, study focus, and key findings related to the functional roles of battery passports and their implementation barriers. Attention was given to four role-related themes: traceability, transparency, compliance, and circularity. Implementation challenges were coded into 12 sub-themes, including interoperability, data quality and availability, governance and access rights, standards harmonization, confidentiality and intellectual property protection, dynamic lifecycle data gaps, verification and auditability, second life and end-of-life data gaps, carbon-footprint and LCA complexity, cost and readiness burden, update responsibility and ownership, and cybersecurity.

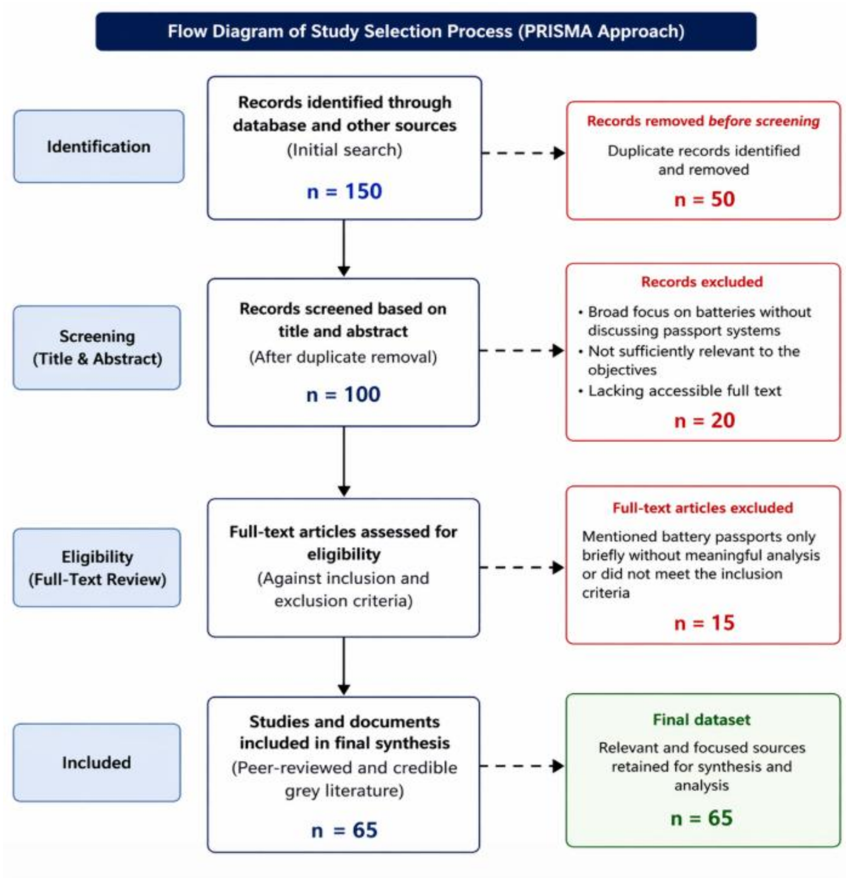

Figure 1. PRISMA Guidelines Based Research Approach

The extracted evidence was analyzed using thematic synthesis. This involved repeated reading of the selected documents, grouping findings under recurring themes, and comparing how different sources framed the roles and barriers of battery passports. Coding was conducted using a structured review matrix developed from the study objectives. The full coding of all 65 included sources document type, inclusion basis, and primary role and challenge codes are provided in Appendix Table A1. For the functional role analysis, each source was assigned to one primary role category based on its dominant emphasis: traceability, transparency, compliance, or circularity. For the implementation-challenge analysis, each source was assigned to one primary challenge category based on its dominant emphasis among the 12 identified challenge sub-themes. Coding was treated as a categorical classification rather than a weighted scoring system. The primary coder conducted the initial classification, and the coding decisions were reviewed by the co-authors for consistency with the inclusion criteria, extracted evidence, and study objectives. Any ambiguous classifications were discussed and resolved through consensus. Because the coding was not conducted independently by multiple coders, formal inter-coder reliability statistics were not calculated; this is acknowledged as a methodological limitation. The resulting frequency distributions were then ranked and converted into percentage shares and cumulative percentages for Pareto analysis.

3. Results and Discussion

3.1. Role of Battery Passports in Improving Traceability, Transparency, Compliance, and Circularity Across the Battery Lifecycle

Across the 65 documents retained in this review, battery passports were consistently framed as a lifecycle data system designed to improve how information travels with a battery from sourcing to end-of-life. The literature converged around four functional roles: traceability, transparency, compliance, and circularity. These roles are closely connected rather than independent. Traceability is usually presented as the operational backbone, transparency as the disclosure function, compliance as the regulatory application, and circularity as the sustainability outcome. This framing is also consistent with current policy momentum. In the EU, Regulation 2023/1542 has already established the legal basis for battery passports, and implementation guidance now treats them as a core mechanism for lifecycle data management rather than a voluntary information add-on (European Union 2023; Rizos and Urban 2024; Battery Pass Consortium 2024).

The first and most foundational role is traceability. The reviewed literature generally treats battery passports as tools for linking battery identity, provenance, composition, and status data across multiple actors and lifecycle stages. Berger et al. (2022) and King et al. (2023) argue that battery passports can support sustainable product management by making key battery information available throughout the value chain, while Pohlmann et al. (2024) show that lifecycle information availability and accessibility essential for a functioning passport system. This role is particularly important because battery value chains are fragmented across mining, refining, cell manufacturing, pack assembly, vehicle integration, use, second-life operations, and recycling. The practical relevance of traceability is evident in recent pilot activity: the Global Battery Alliance's 2024 Battery Passport pilots involved 10 consortia, and the participating cell makers accounted for more than 80% of global EV battery manufacturing capacity, demonstrating that traceability is now being tested at industrial scale rather than discussed only conceptually (Global Battery Alliance 2024a, 2024b; Patel et al. 2024). In analytical terms, traceability matters because it reduces information discontinuities between actors and creates the data continuity needed for all downstream functions of the passport.

A second major role is transparency. If traceability answers whether information can follow the battery, transparency addresses whether relevant information can be made visible and usable for decision-making. The literature repeatedly associates battery passports with improved access to standardized information on origin, carbon footprint, recycled content, technical characteristics, and sustainability performance (Berger et al. 2022; Global Battery Alliance 2024b; Popowicz et al. 2024). The Global Battery Alliance explicitly defines the Battery Passport as a transparency and accountability framework built around traceable and comparable performance information, and its 2024 pilot program tested real-life sustainability data gathering and verification across global supply chains (Global Battery Alliance 2024a, 2024b). This is important because transparency supports comparability across firms and enhances the credibility of sustainability claims. At the same time, literature does not treat transparency as unrestricted openness. Technical guidance from Battery Pass emphasizes interoperable but governed data access, suggesting that useful transparency depends on structured permissions and purpose-specific information sharing rather than full public disclosure (Battery Pass Consortium 2024). Thus, transparency is best understood as controlled visibility that improves accountability without ignoring commercial realities.

The third role is compliance, which has become more prominent as battery passport discussions have moved from conceptual design to policy implementation. The EU Batteries Regulation entered into force in August 2023, and Battery Pass guidance notes that the passport is mandated in the EU framework from February 2027 for relevant batteries (European Union 2023; Battery Pass Consortium 2024). As a result, literature increasingly presents battery passports as instruments for demonstrating conformity with regulatory requirements relating to sustainability, due diligence, labeling, and waste management. This shift is significant because it changes the passport from a desirable innovation into a compliance infrastructure. Several sources also imply that compliance is inseparable from data quality and auditability: a passport only supports regulatory conformity if its data is reliable, retrievable, and sufficiently standardized to be verified across organizations (European Union 2023; Battery Pass Consortium 2024). In this sense, compliance is not merely one more role of the passport; it is a major driver of why implementation is accelerating.

The fourth role is circularity, which the literature frames as the long-term sustainability promise of the battery passport. Battery passports are expected to support reuse, repair, repurpose, remanufacturing, and recycling by preserving information on battery composition, state, and history beyond the first-use phase (Berger et al. 2022; Walden et al. 2021). Recent studies on battery passports for EV batteries argue that sustainability and circularity depend on better access to lifecycle information by different actors, especially at later stages of the chain where information asymmetry is often the greatest (Adisorn et al. 2021; Hassini et al. 2024; Popowicz et al. 2025). This is why circularity is usually discussed as a downstream benefit that depends on the successful delivery of traceability, transparency, and compliance. Second-life or recycling decisions cannot be made unless the underlying data has been captured consistently across earlier stages, which a passport should facilitate. Overall, the literature suggests that circularity is the most ambitious role because it turns battery data into retained value across the full lifecycle rather than limiting information use to compliance alone.

Taken together, the evidence shows that battery passports are being positioned as a multi-function governance tool rather than a single-purpose digital record. Traceability provides the data continuity, transparency makes that information usable, compliance institutionalizes it within regulation, and circularity extends its value into second life and end-of-life pathways. For this reason, the four roles should be read as cumulative and mutually reinforcing. The literature therefore supports the view that battery passports can improve battery lifecycle management, but only when they are implemented as integrated systems that connect operational data, sustainability disclosure, regulatory evidence, and circular decision-making across the chain. The functional roles of battery passport are summarized in Table 1 below.

Table 1. Functional roles of battery passports across the battery lifecycle

Functional role	How literature frames it	Quantitative/policy evidence	Typical lifecycle relevance	Key sources
Traceability	Connects battery identity, provenance, composition, and history across actors	GBA's 2024 pilots involved 10 consortia; participating cell makers represented >80% of global EV battery manufacturing capacity	Sourcing, manufacturing, use, second life, recycling	Global Battery Alliance (2024b); TNO (2024); P3 Group (2024)
Transparency	Makes sustainability and technical information visible and comparable	Pilot-tested real-life sustainability data collection, ESG scoring, and verification	Reporting, accountability, stakeholder communication	Battery Pass Consortium (2024); Global Battery Alliance (2024b); Simboeck (2024); Capgemini (2025)
Compliance	Supports conformity with regulatory and reporting requirements	EU Batteries Regulation entered into force in 2023; battery passport implementation is mandated from February 2027	Regulatory reporting, due diligence, auditability	Rizos and Urban (2024); Battery Pass Consortium (2024); P3 Group (2024); Simboeck (2024)
Circularity	Enables reuse, repair, repurpose, remanufacturing, and recycling decisions	Literature links passport value to lifecycle data continuity for later-stage decisions	Use extension, second life, end-of-life recovery	Rizos and Urban (2024); Pohlmann et al. (2025); TNO (2024); Capgemini (2025)

From this review, we infer that the main value of battery passports does not lie simply in creating a digital record, but in preserving data continuity across organizational and lifecycle boundaries. The literature is relatively strong in explaining expected passport roles, particularly traceability and transparency, but weaker in demonstrating whether these roles consistently translate into measurable sustainability outcomes. Therefore, this review positions battery passports as conditional sustainability enablers rather than automatic circularity solutions.

3.2. Major Challenges Associated with Implementation of Battery Passports

Although battery passports are increasingly promoted as enabling tools for traceability, transparency, compliance, and circularity, the reviewed literature shows that their practical implementation remains constrained by a wide range of sustainability-related challenges. These challenges are not limited to technical system development; rather, they reflect broader difficulties in managing lifecycle data across complex, global, and multi-actor battery value chains (Wesselkämpfer et al. 2025; Magni et al. 2024; Kurniadi et al. 2026; Chigbu 2024).

Recent studies and policy-oriented reports indicate that effective battery passport deployment depends on the quality, reliability, accessibility, and governance of data throughout the battery lifecycle (Rizos and Urban 2024; Battery Pass Consortium 2024; van Capelleveen et al. 2023; Zhang and Seuring 2024). Recurring barriers such as poor data quality, lack of interoperability, fragmented standards, confidentiality concerns, weak governance arrangements, and uncertainty regarding data ownership have been widely identified as critical obstacles to implementation (TNO 2024; P3 Group 2024). These challenges are especially important in the sustainability domain because battery passports are expected not only to store product information, but also to support credible carbon footprint reporting, responsible sourcing, circular value retention, and end-of-life decision-making (Jaspers 2024).

Moreover, the multi-stakeholder nature of battery passport systems introduces additional concerns regarding access rights, updating responsibilities, verification mechanisms, and trust between supply chain actors (Capgemini 2025; United Nations Economic Commission for Europe [UNECE] and Global

Battery Alliance [GBA] 2024). Therefore, understanding these implementation barriers is essential for assessing whether battery passports can realistically deliver their promised sustainability benefits. Table 2 summarizes the major challenges identified in the reviewed literature and highlights their implications for effective battery passport implementation. To reduce overlap among closely related barriers, the implementation challenges are grouped into broader categories in Table 2, while retaining the more specific challenge labels used for thematic coding and Pareto ranking in Table 4.

Table 2. Overview of battery passport implementation challenges identified in the reviewed literature.

Challenge	Why it matters for sustainability	Key supporting sources
Data reliability and verification	Data quality; Data validity and verification; Unclear responsibility for updates	Rizos and Urban (2024); Battery Pass Consortium (2024); Pesaran et al. (2023); Weng et al. (2023); Chacana-Olivares et al. (2025)
Interoperability and standardization	Interoperability across systems; Lack of common standards; Data silos across the value chain	Global Battery Alliance (2024a); Battery Pass Consortium (2024); Global Battery Alliance (2024b)
Governance, ownership, and access	Unclear data ownership; Access-rights governance; End-of-life responsibility gaps	Rizos and Urban (2024); Battery Pass Consortium (2024); Cintra et al. (2025)
Confidentiality and security	Confidentiality of commercial data; Cybersecurity and data security	Rizos and Urban (2024); Gianvincenzi et al. (2024); El Khatib et al. (2025); Carvalho et al. (2025); Soavi et al. (2026)
Sustainability reporting and circularity	Difficulty measuring carbon footprint consistently; Tracking recycled content reliably; Due diligence data collection burden; Bias toward recycling over reuse/second life	Rizos and Urban (2024); Madani (2025); Chen et al. (2025); Haupt et al. (2024); Ma (2025)

Our synthesis indicates that these barriers are interconnected rather than independent. Data quality affects traceability, interoperability affects exchange, access-right rules affect transparency, and verification affects compliance credibility. The evidence is strongest in identifying these barriers, but weaker in showing how responsibilities for updating, verifying, and transferring battery data should be assigned across different actors. Therefore, the implementation problem should be interpreted as both a technical and governance challenge.

3.3. Thematic Emphasis on Roles and Challenges in Literature and Policy

To analyze the thematic emphasis, the Pareto ranking method was used. The results show that literature emphasizes traceability most strongly, followed by transparency and circularity. Whereas compliance remains important, it is slightly less dominant in conceptual and applied discussions (see Table 3; Figure 2). Based on this observation, it can be deduced that battery passports are still framed primarily as information infrastructures for lifecycle visibility and circular decision-making, with regulatory compliance acting as a strong implementation driver rather than the only value proposition.

The results are consistent with several research studies. Berger et al. (2022) and Berger et al. (2023) explained that the passport's core value lies in making battery-related data available across actors and stages, which directly supports traceability and information continuity. Similarly, Gianvincenzi et al. (2024) and Ott et al. (2024) highlight the importance of structured data models for capturing battery composition, lifecycle history, and end-of-life information, reinforcing the operational significance of traceability. The strong emphasis on transparency is also consistent with studies showing that battery passports improve the visibility of sustainability and technical attributes needed for stakeholder communication and lifecycle decision-making (Pohlmann et al. 2024; Jaspers 2024). Circularity ranked third, which aligns with the argument that passports are essential for enabling reuse, second-life applications, and recycling by preserving information value beyond first use (Pohlmann et al. 2024; Jaspers 2024). Although compliance ranked last among the four roles, recent regulatory studies indicate that it remains a major implementation driver, particularly under the EU Batteries Regulation, which is increasingly pushing firms to translate conceptual battery passport models into operational systems (European Union 2023; Battery Pass Consortium 2024). Overall, the ranking implies that the literature still frames battery passports more strongly as tools for lifecycle visibility and circular information flow than as purely compliance-oriented instruments.

Table 3. Pareto distribution of battery passport roles identified across the reviewed studies.

Role	Frequency (n=65)	Share (%)	Cumulative (%)
Traceability	18	27.7	27.7
Transparency	17	26.2	53.9
Circularity	16	24.6	78.5
Compliance	14	21.5	100.0

Note: Each of the 65 reviewed sources was assigned to one primary functional role based on its dominant emphasis. Coding was categorical rather than weighted; therefore, frequencies represent source counts, not intensity scores.

The ranking should not be interpreted as evidence that compliance is unimportant. Rather, it shows that the reviewed literature still frames battery passports mainly through lifecycle visibility and information continuity. In our interpretation, compliance acts as the regulatory driver, while traceability and transparency remain the operational basis for circularity and accountability.

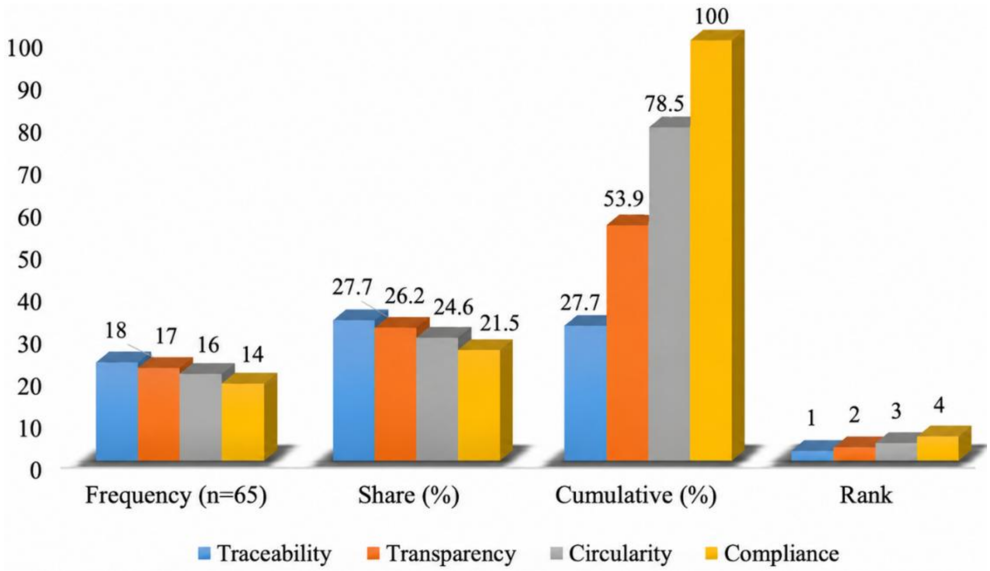

Figure 2. Final ranking of functional roles of battery passports

After ranking the functional roles, the next step was to rank the associated challenges. The result indicates that interoperability and data quality/availability are the most emphasized barriers, followed by governance/access rights, standards harmonization, and confidentiality/IP protection (see Table 4; Figure 3). This pattern implies that the main bottleneck is no longer whether battery passports are conceptually useful, but whether the ecosystem can deliver consistent, shareable, trusted, and verifiable lifecycle data across multiple actors and jurisdictions (TNO 2024; P3 Group 2024; Moawad et al. 2025; King 2026). The prominence of interoperability and data quality in the ranking is analytically significant because these barriers sit upstream of most other implementation problems. If firms cannot exchange lifecycle data across incompatible systems, then transparency, verification, regulatory reporting, and circular decision-making are all weakened at the outset. Likewise, if the available data are incomplete, outdated, or inconsistent, then even a technically functioning passport may fail to support credible sustainability claims or operational end-of-life decisions. In this sense, the ranking suggests that battery passport implementation is fundamentally a data-coordination challenge as much as a digitalization challenge.

Table 4. Pareto distribution of implementation challenges identified across the reviewed studies.

Challenge	Frequency (n=65)	Share (%)	Cumulative (%)
Interoperability	8	12.3	12.3
Data quality / availability	8	12.3	24.6
Governance / access rights	7	10.8	35.4
Standards harmonization	6	9.2	44.6
Confidentiality / IP protection	6	9.2	53.8
Dynamic lifecycle data gaps	5	7.7	61.5
Verification / auditability	5	7.7	69.2
Second-life / EoL data gaps	5	7.7	76.9
Carbon-footprint / LCA complexity	4	6.2	83.1
Cost / readiness burden	4	6.2	89.3
Update responsibility / ownership	4	6.2	95.4
Cybersecurity	3	4.6	100.0

Note: Each of the 65 reviewed sources was assigned to one primary implementation challenge based on its dominant emphasis. Coding was categorical rather than weighted; therefore, frequencies represent source counts, not intensity scores.

This ranking suggests that the most critical barriers occur upstream in the data system. Interoperability and data quality rank highest because most passport functions depend first on whether data can be generated, standardized, exchanged, and trusted. However, the evidence remains largely based on conceptual, policy, and pilot-stage studies, with limited empirical assessment of how these barriers affect real-world passport performance across complete battery lifecycles.

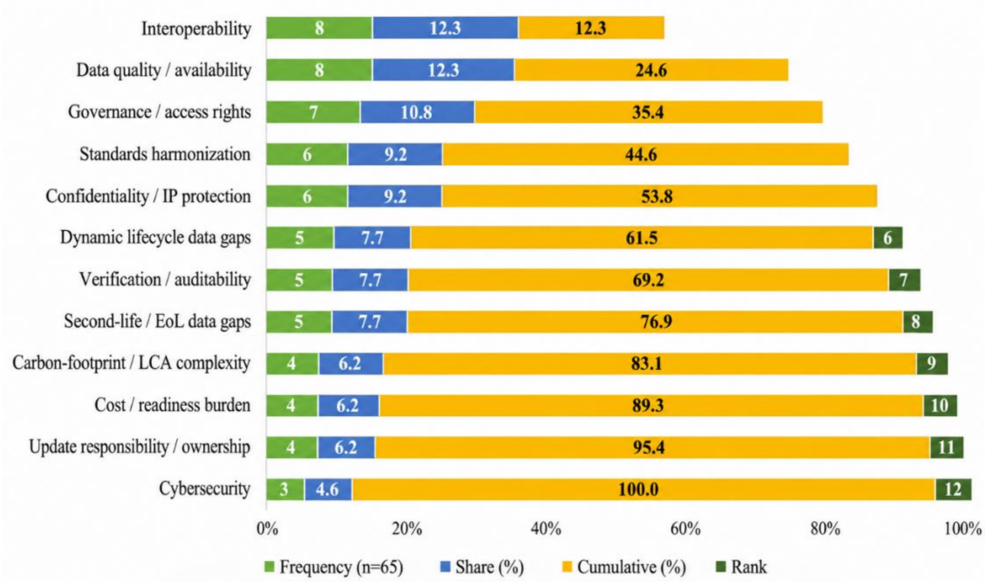

Figure 3. Final ranking of battery passport implementation challenges

These results are consistent with several research studies. Rizos and Urban (2024) argued that one of the major barriers to implementation is the lack of clear and interoperable governance structures capable of supporting trustworthy cross-chain data exchange. This is supported by the Battery Pass Consortium (2024), which stresses that technical implementation depends on common standards, access control mechanisms, and consistent data architecture. Likewise, TNO (2024) and P3 Group (2024) emphasize that future-proof battery passports require interoperable digital infrastructures rather than isolated firm-level solutions. The importance of data-sharing barriers is further reinforced by Jaspers et al. (2024), who show that production-level battery data must be tailored and shared across target groups to make passport systems functional in practice. At the same time, confidentiality and ownership concerns remain significant because firms may hesitate to disclose commercially sensitive lifecycle information, especially in multi-actor supply chains (Jaspers 2024; United Nations Economic Commission for Europe [UNECE] and Global Battery Alliance [GBA] 2024). Thus, the challenge ranking suggests that successful implementation of battery passports will depend less on conceptual design alone and more on solving the institutional and technical conditions required for trusted, standardized, and verifiable lifecycle data exchange. To integrate these two strands, Figure 4 maps all 65 sources simultaneously across document type, primary functional role, and primary implementation challenge. This combined view shows that the dominant roles of traceability and transparency are linked most strongly to the upstream barriers of interoperability and data quality, while compliance-oriented and grey-literature sources cluster around governance and standards challenges.

3.4. Comparative assessment of battery passport frameworks and implementation models

In addition to identifying thematic roles and challenges, existing battery passport frameworks and implementation models were compared to assessing their difference as shown in Table 5. The reviewed sources show that current approaches are not identical. Some are primarily regulatory, some are technical guidance frameworks, some are pilot-based transparency initiatives, and others are academic data models or lifecycle-specific information structures. This comparison helps clarify that battery passports are not a single fixed design, but a developing family of governance and data-infrastructure models with different strengths and limitations.

Table 5. Comparative assessment of selected battery passport frameworks and implementation models

Framework / model	Main orientation	Technical or implementation emphasis	Main strength	Main limitation / evidence gap
EU Batteries Regulation	Regulatory compliance	Legal requirements for sustainability, due diligence, carbon footprint, labeling, recycled content, and battery passport implementation	Provides the strongest regulatory driver and formal implementation timeline	Does not by itself resolve technical interoperability, data ownership, or actor-specific access issues
Battery Pass Consortium guidance	Technical implementation guidance	Data categories, technical architecture, access rights, interoperability, and implementation recommendations	Provides practical guidance for operationalizing battery passports	Still requires industry-wide adoption, verification mechanisms, and alignment across actors
Global Battery Alliance Battery Passport pilots	Pilot-based transparency and accountability	Real-world testing of sustainability data collection, ESG indicators, traceability, and verification	Demonstrates that battery passport concepts can be tested across industrial consortia and supply chains	Pilot evidence remains limited compared with full lifecycle deployment at scale
Academic standardized data models	Data-model development	Structured data fields for battery identity, composition, lifecycle history, and end-of-life information	Improves conceptual clarity and comparability of passport data requirements	Often remains model-based and requires validation in operational systems
End-of-life-focused passport models	Recycling and downstream circularity	Data needed for dismantling, material recovery, hazardous-content identification, and end-of-life decision-making	Addresses downstream information loss, which is critical for recycling and circularity	Less developed for dynamic transfer of use-phase and state-of-health data
LCA/carbon-footprint information models	Environmental performance assessment	Carbon-footprint reporting, LCA-related data requirements, environmental indicators, and sustainability disclosure	Links battery passports with measurable environmental performance	Harmonized calculation methods, verification, and data availability remain challenging
Second-life and lifecycle-management models	Reuse and repurposing	State of health, degradation history, remaining capacity, use history, and safety information	Supports second-life assessment and application matching	Depends heavily on accurate first-life data capture and access by downstream actors

Sources: (European Union 2023; Battery Pass Consortium 2024; Global Battery Alliance 2024; Cheng et al. 2022; Moawad et al. 2025; Yilmaz et al. 2025; Tabata et al., 2025)

This comparison shows that the strongest current progress is found in regulatory framing, technical guidance, and pilot-level transparency initiatives. However, evidence remains weaker for fully integrated implementation across the complete battery lifecycle. Regulatory frameworks define what information should be available, technical guidance explains how passport systems may be structured, and pilot projects demonstrate early feasibility. Yet the practical integration of dynamic use-phase data, second-life assessment data, recycling information, access-right governance, and third-party verification remains less mature. Therefore, the scientific contribution of this review is to show that battery passport implementation should be evaluated not only by the presence of a digital record, but by the degree to which different frameworks enable verified, interoperable, lifecycle-stage-specific data exchange.

3.5. Lifecycle-stage mapping of battery passport roles, data needs, barriers, and actors

To extend the thematic findings, a lifecycle-stage mapping was developed to clarify how the role of battery passports changes across the battery value chain. This mapping is important because battery passports do not create value in the same way at every stage. In the manufacturing stage, their primary role is to support traceability, transparency, carbon-footprint reporting, and regulatory compliance by recording material origin, chemistry, production location, embedded emissions, and recycled content (Berger et al. 2022; Chigbu 2024; European Union 2023; Battery Pass Consortium 2024). In the use phase, the value of the passport shifts toward performance monitoring, safety management, warranty support, and lifecycle transparency, particularly through data on state of health, operating conditions, cycle history, and maintenance records (Pohlmann et al. 2024; Global Battery Alliance 2024). During second-life assessment and repurpose, battery passports become especially important for circularity because reliable data on degradation history, remaining capacity, internal resistance, and safety status can reduce uncertainty and support reuse, remanufacturing, or application-matching decisions (Berger et al. 2023; Pohlmann et al. 2024; Cheng et al. 2022). At the recycling and end-of-life stage, passport information supports safe dismantling, material recovery, hazardous-content identification, and compliance with producer-responsibility requirements (Ott et al. 2024; Rizos and Urban 2024; Biswal et al. 2024). However, the barriers also vary across stages. Manufacturing is mainly constrained by interoperability, data standardization, and carbon-footprint calculation, whereas second life and recycling stages face stronger problems related to missing historical data, unclear data ownership, confidentiality, and limited access for downstream actors (Battery Pass Consortium 2024; Gianvincenzi et al. 2024; Rizos and Urban 2024; Shen et al. 2026). Therefore, a lifecycle-stage mapping helps show that the practical success of battery passports depends not only on collecting data, but also on ensuring that the right data are available, updated, verified, and shared with the relevant actors at each stage. Table 6 summarizes these stage-specific roles, data requirements, barriers, and responsible actors.

Table 6. Mapping of battery passport functions across the battery lifecycle stages.

Lifecycle stage	Role of battery passport	Key data required	Main barrier	Main actor
Raw material sourcing	Supports responsible sourcing, due diligence, and material traceability	Material origin, supplier information, recycled content, due diligence data, environmental and social risk indicators	Data reliability, supplier transparency, confidentiality, and verification	Mining companies, material suppliers, due diligence auditors, regulators
Cell and pack manufacturing	Enables product identity, traceability, compliance, and carbon-footprint reporting	Battery chemistry, cell design, material composition, carbon footprint, manufacturing location, safety data, product identification	Interoperability, common standards, carbon-footprint calculation, and data quality	Cell manufacturers, pack manufacturers, original equipment manufacturers, certification bodies
Vehicle or stationary-use phase	Supports performance monitoring, safety, warranty, and lifecycle transparency	State of health, state of charge, cycle history, operating temperature, maintenance records, safety incidents, warranty information	Dynamic data updating, access rights, cybersecurity, and data ownership	Vehicle manufacturers, fleet operators, energy-storage operators, service providers
Second-life assessment and repurposing	Supports reuse, grading, remanufacturing, and application matching	State of health, remaining capacity, degradation history, internal resistance, use history, safety status, dismantling information	Data gaps from first life, lack of standardized health assessment, and unclear responsibility for data transfer	Repurposes, refurbishers, remanufacturers, testing laboratories
Recycling and end-of-life management	Supports safe dismantling, material recovery, compliance, and circularity	Battery chemistry, material composition, hazardous content, dismantling instructions, recycled-content potential, ownership and collection records	Incomplete composition data, end-of-life responsibility gaps, and limited data access for recyclers	Recyclers, waste-management firms, producers, regulators
Cross-cutting governance	Enables trusted data sharing across the lifecycle	Data ownership rules, access permissions, verification records, update responsibilities, interoperability standards	Governance complexity, confidentiality, cybersecurity, and fragmented standards	Regulators, passport platform providers, industry consortia, value-chain actors

Sources: (Berger et al. 2022; Berger et al. 2023; European Union 2023; Battery Pass Consortium 2024; Global Battery Alliance 2024; Gianvincenzi et al. 2024; Ott et al. 2024; Pohlmann et al. 2024; Rizos and Urban 2024; Akram et al. 2024; Moawad et al. 2025; Kilavuz 2025; Mulhall et al. 2022)

Life cycle-stage mapping supports our view that battery passports should be designed as stage-specific governance instruments rather than uniform data containers. Manufacturing actors require verified material, chemistry, and carbon-footprint data; use-phase actors require dynamic performance and safety data; second-life actors require state-of-health and degradation-history data; and recyclers require composition, dismantling, and hazardous-content data. However, evidence remains limited on how data transfer, ownership, and access rights will operate when batteries move between actors, markets, and jurisdictions.

4. Conclusions

This study examined the role of battery passports in advancing traceability, transparency, compliance, and circularity across the battery lifecycle, identified the major implementation challenges associated with their deployment, and assessed which roles and barriers are most strongly emphasized in the existing literature and policy discourse. Based on a systematic review of selected academic, regulatory, and technical sources, the findings confirm that battery passports are increasingly recognized as important digital governance mechanisms for improving lifecycle information management in battery value chains.

The review shows that battery passports are primarily framed as tools for traceability, enabling battery identity, provenance, composition, and lifecycle history to be linked across multiple actors and stages. This role emerged as the most emphasized theme, indicating that reliable tracking of battery-related data is the foundation for other passport functions. Transparency was the second most emphasized role, reflecting the importance of making sustainability and technical information visible, comparable, and useful for decision-making. Circularity was also strongly supported, particularly because passport data can assist reuse, second-life applications, remanufacturing, and recycling. Although compliance ranked lower than these roles, it remains significant because battery passports are increasingly shaped by regulatory requirements, especially the European Union Batteries Regulation and related implementation frameworks.

The lifecycle-stage mapping further shows that battery passports do not create value in the same way at every stage. During raw material sourcing and manufacturing, their main value lies in responsible sourcing, traceability, carbon-footprint reporting, and regulatory compliance. During the use phase, they support performance monitoring, safety management, warranty support, and lifecycle transparency. In second-life assessment and repurposing, passport data help reduce uncertainty related to state of health, remaining capacity, degradation history, and application suitability. At the recycling and end-of-life stage, they support safe dismantling, material recovery, hazardous-content identification, and producer-responsibility compliance. This confirms that battery passport effectiveness depends not only on data availability, but also on whether the right data are collected, updated, verified, and shared with relevant actors at each lifecycle stage.

The study also demonstrates that implementation is constrained by several interconnected challenges. Interoperability and data quality or availability emerged as the most emphasized barriers, followed by governance and access rights, standards harmonization, and confidentiality or intellectual property protection. These findings suggest that the main challenge is no longer the conceptual value of battery passports, but the practical ability of stakeholders to create, exchange, verify, and update reliable lifecycle data across fragmented systems and institutional settings.

Overall, the findings imply that policymakers should prioritize harmonized standards, clear governance rules, access-right frameworks, and interoperable data infrastructures. For industry, the results highlight the need to invest in reliable lifecycle data systems, verification mechanisms, and stage-specific data management practices. For researchers, the study provides a basis for future work on passport design, data governance, second-life applications, recycling decision support, and measurable sustainability outcomes. Finally, the study is limited by its reliance on secondary literature and policy documents and using primary thematic coding without formal inter-coder reliability assessment. Therefore, the thematic ranking and lifecycle-stage mapping should be interpreted as structured synthesis results that require further empirical validation.

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No AI or AI assisted technologies were used for writing this paper.

Data Statement
The research data is available in the supplementary materials.

Ethical Approval
The current research is a review article, and the authors did not collect any type of primary data (surveys, interviews, experiments, personal data, confidential company data, or human/animal subjects). Hence the requirement of ethical approval does not apply.

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Author Contribution
Shabbir H. Gheewala (corresponding author) contributed to the conceptualization of the study, formulation of research objectives, guidance on data collection, and supervision of result visualization. Yossapong Laoonual[3] contributed to technical guidance, validation of the methodological framework, and review of the results. Zeshan Alam (first author) was responsible for data collection, conducting the analysis, visualization of results, and drafting of the manuscript.

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Table A1. Literature Classification & Coding Details

ID	Source (Author, Year)	Document type	Inclusion basis	Primary role code	Primary challenge code
S1	Adisorn et al. (2021)	Journal article	Battery Passport cross-sector relevance	Compliance	Standards harmonization
S2	Akram & Abdul-Kader (2024)	Review article	Second-life / recycling data	Circularity	Second-life / EoL data gaps
S3	Battery Pass Consortium (2024)	Industry/guidance report	Regulatory/policy guidance	Transparency	Interoperability
S4	Berger et al. (2023)	Journal article	Data requirements / lifecycle stage	Traceability	Data quality / availability
S5	Berger et al. (2022)	Journal article	Battery Passport roles + challenges	Traceability	Governance / access rights
S6	Biswal et al. (2024)	Review article	Second-life / recycling data	Circularity	Second-life / EoL data gaps
S7	Capgemini (2025)	Industry report	Regulatory/policy guidance	Transparency	Update responsibility / ownership
S8	Carvalho et al. (2025)	Review article	Digital Passport cross-sector relevance	Transparency	Confidentiality / IP protection
S9	Chacana-Olivares et al. (2025)	Journal article	Second-life / recycling data	Circularity	Cost / readiness burden
S10	Chen et al. (2025)	Journal article	Battery Passport	Traceability	Interoperability

			challenges		
S11	Cheng et al. (2022)	Journal article	Second-life / recycling data	Traceability	Interoperability
S12	Chigbu (2024)	Review article	Second-life / recycling data	Circularity	Cost / readiness burden
S13	Cintra et al. (2025)	Journal article	Battery Passport roles + challenges	Compliance	Governance / access rights
S14	da Cruz & Cruz (2025)	Conference paper	Data requirements / lifecycle stage	Traceability	Standards harmonization
S15	El Khatib et al. (2025)	Review article	Second-life / recycling data	Circularity	Confidentiality / IP protection
S16	European Union (2023)	Regulation / legal text	Regulatory/policy guidance	Compliance	Governance / access rights
S17	Fangerow et al. (2025)	Conference paper	Data requirements / lifecycle stage	Compliance	Carbon-footprint / LCA complexity
S18	Gianvincenzi et al. (2024)	Conference paper	Data requirements / lifecycle stage	Traceability	Confidentiality / IP protection
S19	Global Battery Alliance (2024a)	Industry report	Regulatory/policy guidance	Transparency	Interoperability
S20	Global Battery Alliance (2024b)	Industry report	Regulatory/policy guidance	Transparency	Verification / auditability
S21	Hassini et al. (2024)	Journal article	Second-life / recycling data	Circularity	Second-life / EoL data gaps
S22	Haupt et al. (2024)	Conference paper	Data requirements / lifecycle stage	Transparency	Carbon-footprint / LCA complexity
S23	Jansen et al. (2023)	Journal article	Battery Passport roles + challenges	Traceability	Data quality / availability
S24	Jaspers et al. (2025)	Conference paper	Battery Passport challenges	Transparency	Confidentiality / IP protection
S25	Jensen et al. (2023)	Journal article	Data requirements / lifecycle stage	Circularity	Data quality / availability
S26	Kamath et al. (2020)	Journal article	Second-life / recycling data	Circularity	Cost / readiness burden
S27	Kemmner et al. (2025)	Journal article	Battery Passport roles + challenges	Traceability	Governance / access rights
S28	Kilavuz (2025)	Review article	Second-life / recycling data	Circularity	Cost / readiness burden
S29	King et al. (2023)	Journal article	Battery Passport roles + challenges	Traceability	Interoperability
S30	King (2026)	Journal article	Regulatory/policy guidance	Compliance	Standards harmonization
S31	Kurniadi et al. (2026)	Journal article	Digital Transformation	Transparency	Cybersecurity
S32	Langley et al. (2023)	Journal article	Battery Passport roles + challenges	Circularity	Governance / access rights
S33	Ma et al. (2025)	Review article	Second-life / recycling data	Circularity	Second-life / EoL data gaps
S34	Madani et al. (2025)	Review article	Second-life / recycling data	Circularity	Dynamic lifecycle data gaps
S35	Magni et al. (2024)	Editorial	Second-life / recycling data	Circularity	Second-life / EoL data gaps
S36	Moawad et al. (2025)	Journal article	Battery Passport challenges	Traceability	Interoperability
S37	Mulhall et al. (2022)	Journal article	Battery Passport cross-sector relevance	Transparency	Standards harmonization

S38	Ott et al. (2024)	Conference paper	Data requirements / lifecycle stage	Traceability	Verification / auditability
S39	P3 Group (2024)	Industry report	Regulatory/policy guidance	Compliance	Interoperability
S40	Page et al. (2021) - PRISMA	Journal article (reporting guideline)	Review methodology (PRISMA)	Compliance	Verification / auditability
S41	Patel et al. (2024)	Review article	Second-life / recycling data	Circularity	Dynamic lifecycle data gaps
S42	Pesaran et al. (2023)	Technical report	Data requirements / lifecycle stage	Compliance	Update responsibility / ownership
S43	Plociennik et al. (2022) - Procedia CIRP	Conference paper	Digital Passport cross-sector relevance	Traceability	Data quality / availability
S44	Plociennik et al. (2022) - INFORMATIK	Conference paper	Digital Passport cross-sector relevance	Traceability	Standards harmonization
S45	Pohlmann et al. (2024)	Journal article	Battery Passport roles + challenges	Traceability	Data quality / availability
S46	Popowicz et al. (2025)	Journal article	Battery Passport roles	Transparency	Update responsibility / ownership
S47	Popowicz et al. (2024)	Conference paper	Battery Passport roles	Transparency	Dynamic lifecycle data gaps
S48	Rizos & Urban (2024)	Policy/industry report	Regulatory/policy guidance	Compliance	Governance / access rights
S49	Rufino Junior (2024)	Review article	Battery Passport roles + challenges	Compliance	Standards harmonization
S50	Shen et al. (2024)	Journal article	Battery Passport challenges	Traceability	Cybersecurity
S51	Simboeck (2024)	Presentation	Regulatory/policy guidance	Transparency	Verification / auditability
S52	Soavi et al. (2026)	Journal article	Battery Passport roles + challenges	Compliance	Confidentiality / IP protection
S53	Tabata & Tsai (2025)	Journal article	Data requirements / lifecycle stage	Transparency	Carbon-footprint / LCA complexity
S54	Terkes et al. (2024)	Review article	Battery Passport roles + challenges	Traceability	Verification / auditability
S55	TNO (2024)	Technical report	Regulatory/policy guidance	Compliance	Interoperability
S56	UNECE & GBA (2024)	Presentation	Regulatory/policy guidance	Compliance	Confidentiality / IP protection
S57	van Capelleveen et al. (2023)	Review article	Digital Passport cross-sector relevance	Traceability	Data quality / availability
S58	Wagner (2025)	Journal article	Battery Passport challenges	Transparency	Data quality / availability
S59	Walden et al. (2021)	Journal article	Digital Passport cross-sector relevance	Transparency	Dynamic lifecycle data gaps
S60	Wang et al. (2026)	Review article	Second-life / recycling data	Circularity	Dynamic lifecycle data gaps
S61	Weng et al. (2023)	Journal article (perspective)	Battery Passport roles	Compliance	Update responsibility /

					ownership
S62	Wesselkamper et al. (2025)	Journal article	Second-life / recycling data	Circularity	Carbon-footprint / LCA complexity
S63	Yilmaz & Koseov (2025)	Journal article	Battery Passport challenges	Traceability	Cybersecurity
S64	Yuan (2025)	Review article	Digital Passport cross-sector relevance	Transparency	Governance / access rights
S65	Zhang & Seuring (2024)	Review article	Digital Passport cross-sector relevance	Transparency	Data quality / availability
Color Scheme					
	Circularity	Traceability		Transparency	Compliance

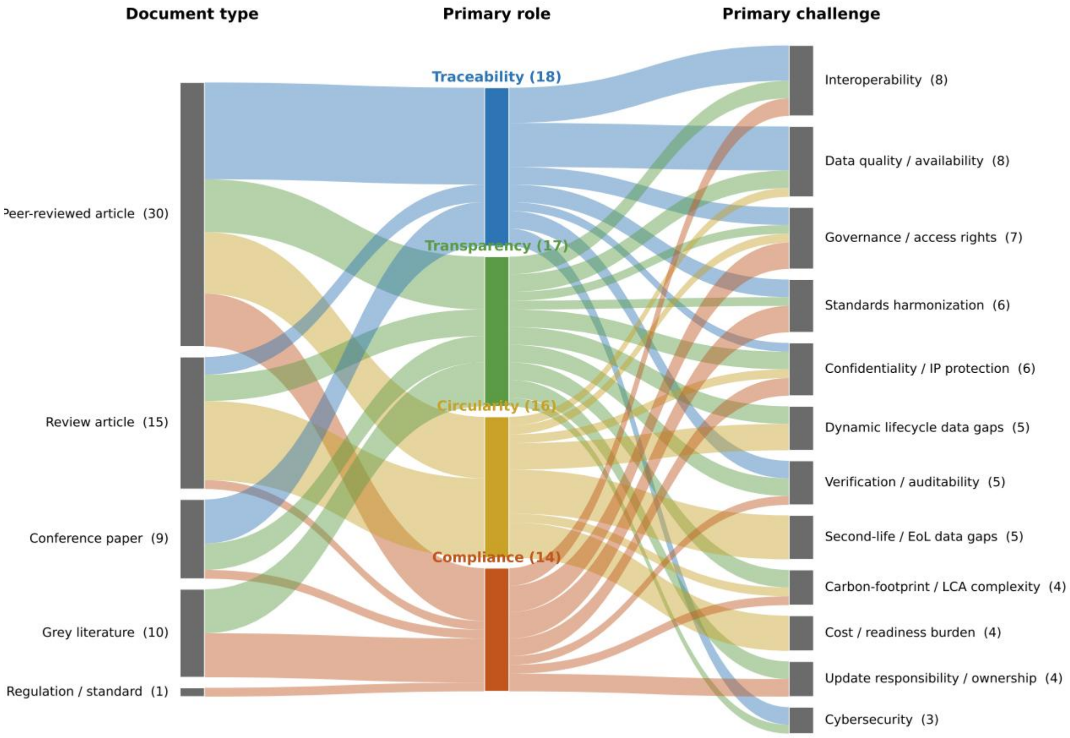

Figure A1. Coding of the 65 Included Literature Sources: Document Type, Primary Role, Primary Challenge