EU Battery Regulation and the Role of Blockchain in Creating Digital Battery Passports

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***Abstract*—In response to concerns about climate change and environmental sustainability, there is a global emphasis on innovative solutions to reduce emissions and optimize resource use. A key initiative is the introduction of digital passports for batteries, with the primary goal of improving the circular economy. The European Commission has taken a pioneering role by publishing regulations, laying the groundwork for digital passports and standardization. This article has a twofold aim: first, with the aim of supporting the adoption of batteries passports, it provides an overview of current initiatives and regulations in the context of electric vehicle batteries; secondly, it examines the potential of blockchain technology in implementing digital passports, in order to demonstrate its compatibility with recent regulations, such as the one proposed by the European Commission.**

***Index Terms*—Digital battery passport, battery, traceability, blockchain, battery regulation, European Union**

I. Introduction

In recent years, the focus on environmental preservation has grown due to scientific and technological advancements. This is mainly driven by climate change concerns. Researchers, companies, and governments are seeking innovative solutions in production and energy consumption to reduce emissions, optimize resources, and promote sustainability. One initiative is digital passports (DPs) for products, aimed at advancing the circular economy by improving product durability, reliability, upgradability, repairability, recyclability, and efficiency. DPs store information on production, materials, and the product life cycle. They also open new business opportunities and provide data on repair, recycling, service, and remanufacturing, helping consumers make sustainable choices and enabling authorities to verify compliance with laws.

Notably, the European Commission (EC) published in 2022 a proposal to reduce the environmental impact of product life cycles and improve the internal market [1]. This was the first governmental document introducing the DP concept and its features, describing how DPs can address these issues. Additionally, the European Union (EU) in 2023 regulated the production, reuse, and disposal of electric vehicle batteries, requiring all batteries produced from 2027 to have a DP [3]. This regulation aims to ensure better tracking and management of batteries throughout their life cycle, promoting sustainability and compliance with environmental standards.

Batteries are composed of highly polluting materials that, if not properly disposed of or recycled, would harm the environment. The study described in [2] shows the high pollution level of fields near a battery disposal factory and also reports the health consequences for humans. Thus, the recently shift to the production of electrically powered vehicles makes the implementation of a digital battery passport (DBP) a necessity.

Although there are already some regulations and initiatives for the development of DBP, no official solution or standard for implementation has yet been defined. The purpose of this article is to demonstrate that blockchain technology is well-suited for the implementation of DPs due to its architecture and features aligning with the established European regulations.

The article is organized as follows: Section 2 provides an analysis of the initiatives, regulations, and literature related to DBPs. Section 3 describes the battery regulation part related to the passports and shows how the blockchain can fit into it. Section 4 presents and discusses the advantages of adopting the blockchain for the implementation of the passports. Conclusions and future works are reported in Section 5.

II. State of the art

DPs for products have long been discussed as a way to promote the circular economy and reduce environmental impact. Researchers and developers have proposed initiatives and prototypes, but no official standards exist yet. The EC has set a deadline for all batteries to have a DP. Manufacturers are now preparing for this change to avoid being caught off.

A. *World regulations and proposals*

In July 2023, the EU published its first regulation covering the entire battery life cycle, advancing the adoption of DBPs [3]. The regulation sets requirements for battery production, recycling, and disposal, and specifies the necessary information for DPs, including privacy, accessibility, and usage features. It also defines stakeholder roles and responsibilities for data updates, information validity, and usage.

The United States and China are also pursuing initiatives on the introduction of DBP and enacting new regulations, following in the footsteps of the EU. For instance, in the US, with the passage of the Inflation Reduction Act (The IRA) [4], the government has created incentives to reduce the carbon footprint in the US and switch to the use of electric vehicles, as long as they meet certain set criteria. As of 2018, China has issued regulations regarding battery production, recycling, and disposal, partially addressing some of the issues covered in the European regulation [5]. In the same year, a platform was introduced to store and track information on the maintenance, take-back, recycling, and reuse of batteries[1].

Other countries, such as Canada, India, and Japan, are collaborating with global organizations to develop a sustainable ecosystem based on DBPs. They are funding and incentivizing research and innovation related to this technology.

B. International initiatives

Several global initiatives aim to standardize DPs. One of the most significant is the Global Battery Alliance (GBA), a partnership of over 150 members from business, government, academia, industry, and international organizations. In 2022, the GBA proposed a proof-of-concept for a DP, defining technical parameters for batteries, tracking materials, and including indices for Child Labor and Human Rights [6]. This ensures all passports align with new regulations, though the technologies for practical implementation are still undecided. Additionally, Battery Pass, co-founded by the German Federal Ministry for Economic Affairs and Climate Action, has made significant strides. In 2022, the consortium published a comprehensive guide to help organizations implement DBPs based on EU regulations. This guide explains how to interpret regulatory requirements and provides a clear roadmap to compliance [7].

C. Scientific papers

Also researchers are contributing to the advancement of the fundamentals for promoting the introduction and adoption of DBPs. For instance, Naseri et al. [9], have explored potential use cases, key technologies (including blockchain), and requirements for creating Digital Twins (DTs) for batteries in terms of development/integration platforms, hardware/software requirements, and architectures. They identified significant challenges that need to be addressed for this topic, as well as circumstances that generate considerable value.

Berger et al. [11] conducted a study on the sensitivity of data included in DPs. They demonstrated that, in addition to common encryption techniques, stakeholders can use data science and machine learning to preserve the confidentiality of certain data and reduce reluctance to share them.

Several studies, including [12], [13], and [14], have analyzed the potential of blockchain technology for traceability and data sharing of batteries, from both a production system and life cycle perspective. These studies suggest that blockchain could remove existing barriers by promoting transparency and traceability for a circular economy. However, it is argued that this technology is still in its early stages and requires further research before full adoption.

The works [8], [10], and [15] have proposed practical implementations of DBPs. In particular, [10] introduced a DBP that uses Ultra-High-Frequency Radio Frequency Identification (RFID) technology to enable circularity in battery management. The system allows for reading and storing essential battery parameters and tracking battery history. Siska et al. [8] presented BatWoMan, a system that defines the concept of a DBP by including relevant regulations, standards, and initiatives. The work includes the necessary data that a passport must contain, describes the relevant stakeholders and their interactions, and introduces the system architecture based on the International Data Spaces and Gaia-X frameworks for data management. Nowacki et al. [15] identified a passport use case structure common to multiple application areas and proposed an architecture and a working prototype for passports based on IOTA and Smart Contracts.

Unlike works such as [12]–[14], which only analyze and highlight the potential of blockchains in the implementation of DPs in a broad sense, our work aims to analyze how blockchain aligns with and meets the requirements imposed by the EU Battery Regulation for the development of DBPs. This alignment not only demonstrates blockchain's compatibility with regulatory frameworks, but also serves as a catalyst for further research and deeper insights into its potential adoption for the stated purpose. It is worth remarking that we focus on the EU regulation because it currently stands out as the only regulatory framework that explicitly addresses DPs.

III. EU Regulation and Blockchain

The analysis of current state of the art showed that the use of blockchain and its benefits could be advantageous for the development and implementation of DPs. However, there are various strategies for leveraging blockchain, each with different impacts and applications. Therefore, it is necessary to carefully analyze the parts of the EU regulation [3] regarding DPs, specifically storage, format, data characteristics, passport access, sharing, creation, update, and disposal operations, in order to determine the best strategy for this specific use case.

A. Data Storage

The Battery Regulation states that "To ensure that the DBP is flexible, dynamic and market-driven and evolves in line with business models, markets and innovation, it should be based on a decentralized data system". In addition, "the DBP shall be such that a high level of security and privacy is ensured and fraud is avoided" and "data authentication, reliability and integrity shall be ensured". Based on these indications, blockchain turns out to be the best choice as a database for passports. In fact, it is a decentralized technology that offers:

- Data authentication – the information on the blockchain carries the address of the person who wrote it.
- Data reliability – since the information carries the blockchain address of the person who wrote it, it is possible to define whether it is reliable or not.
- Data integrity – information on the blockchain cannot be deleted or altered, so its integrity cannot be compromised.

Therefore, it provides a high level of security while minimizing the possibility of fraud. Regarding privacy, it depends on

[1]https://evmam-tbrat.com/

the type of blockchain and what data is stored directly on-chain, but even if it is publicly accessible, techniques such as Zero-Knowledge Proof and Self-Sovereign Identity would allow limiting access to certain data to authorized actors.

B. Data Type

According to the Battery Regulation, "all information contained in the DBP shall be based on open standards and be in an interoperable format, transferable over an open interoperable data exchange network without vendor lock-in, machine-readable, structured and searchable", so formats such as JavaScript Object Notation (JSON) or eXtensible Markup Language (XML) and the like must be used. In addition, the information in passports can be divided into two macro categories: static data and dynamic data, as follows:

- Static data – includes all data for which no updates are expected during the battery life cycle. For example, the battery identifier is created when the battery is registered in the registry and should not be changed or modified, as it is used to uniquely track the battery.
- Dynamic Data – includes any data that is updated periodically over the life of the battery and tracks changes in battery characteristics as the battery is used. For example, data from battery monitoring systems, or manually added information such as accidents or component upgrades.

Storing the above information directly on the blockchain may be inconvenient in the case of public or hybrid blockchains (private blockchains were not considered, as they have little or no decentralization) for two reasons: accessibility and cost. Some data might require some kind of restricted access (see III-C), and storing large amounts of data might be very expensive. Therefore, it is appropriate to use the blockchain by using techniques based on verifiable credentials and hashing functions that allow storing a small amount of data for each battery on the blockchain (e.g., battery identifier, verifiable credential identifier, and hash) without losing the reference or compromising the privacy of the data associated with it, as proposed in [16], [17]. The full version of the data could be stored in decentralized databases after being encrypted.

C. Data Access

The Battery Regulation states that "in order to ensure the availability of the information over time, that information should also be made available by means of QR codes printed or engraved on batteries [...]. The QR code should provide access to the DBP". The QR code (or a smart label) must be linked to a unique identifier, defined as "a unique string of characters for the identification of batteries that also allows a web link to the DBP", which in the case of a blockchain-based solution could correspond to a reference to the location of the data on decentralized storage.

The Battery Regulation also states that "actors shall have access to the DBP free of charge", a feature that would be guaranteed in the case of a blockchain implementation, since read operations can always be performed free of charge. Finally, the Battery Regulation adds that access to data by actors must be "based on their respective access rights" and defines certain access groups as follows:

- "General public" – have access to information on battery models and their sustainability requirements.
- "Notified Bodies, Market Surveillance Authorities and the Commission" – have access to test reports on battery models and information such as detailed composition.
- "Any natural or legal person with a legitimate interest in accessing and processing that information" – have access to information such as battery performance, durability and status.

With blockchain, basic code-level controls can be implemented directly in data access smart contracts to ensure access to information based on the different groups defined above, or more complex techniques such as decentralized identity protocols and verifiable credentials can be leveraged.

D. Data Responsibility

According to the Battery Regulation, "the data contained in the DBP shall be stored by the economic operator responsible for the fulfilment of the obligations or by operators authorized to act on their behalf". An economic operator is defined as any entity (the producer, importer, distributor or fulfillment service provider) that has obligations related to the production, reuse, placing on the market or putting into service. In particular, the economic operator is responsible for:

- Assigning a unique identifier linked to the QR code.
- "Ensure that the information in the DBP is accurate, complete and up-to-date".
- store the data contained in the DBP.

In addition, the Battery Regulation states that "the DBP shall remain available after the economic operator has ceased to exist or has ceased its activities in the Union" and that "a DBP shall cease to exist after the battery has been recycled". However, in case of the battery has been refurbished or prepared for reuse, the Battery Regulation provides for a transer of responsibility between economic operators.

In terms of responsibility management, a blockchain-based solution would also perfectly meet the requirements dictated by the regulation. In fact, one of the main features of blockchains is precisely to track the transfer of ownership (or in this case, liability), keeping the history over time. As for deletion, blockchains do not allow you to delete a piece of data within them, but one solution would be to invalidate it (as in the case of verifiable credentials).

IV. Discussion

In the previous section, it was shown that blockchain emerges as a potentially viable technology that can meet all of the requirements imposed by the EU Battery Regulation. In this section we will analyze what are the advantages and disadvantages of using blockchain, showing how it turns out to be more convenient for this type of task than centralized solution or a general distributed solution. In particular, the analysis focuses on transparency and traceability, efficiency and cost, and security and trust.

A. Transparency and Traceability

One of the main objectives of introducing DBPs is the traceability of batteries and their components, in order to promote the development of a circular economy. Blockchain would guarantee this feature, as it is one of its main advantages. Indeed, due to its distributed and immutable nature, any transaction or event involving a battery would be permanently recorded on the network. This would provide a complete and up-to-date view of the status and history of each battery, from production to recycling. In addition, all information stored on the blockchain would be transparent, meaning that anyone (based on the permission levels introduced in section III-C) could directly verify the history and attributes of the batteries.

B. Efficiency and Cost

Because of the blockchain structure and the decentralized consensus mechanisms used to store the information, the validity and integrity of the data is guaranteed without the need for an authoritative third party. This eliminates potential intermediaries that could be points of vulnerability or inefficiency. In addition, the distributed structure of the blockchain ensures the availability and resilience of the system by avoiding potential single points of failure.

In terms of cost, blockchain would reduce operational costs through the use of smart contracts that allow certain operations to be automated. However, operations such as the execution of smart contract functions and data storage have costs to achieve consensus, which can vary significantly depending on the blockchain used and the amount of data to be stored.

C. Security and Trust

Finally, a critical factor in the adoption of blockchain for DBPs is the security and trust that the technology can provide. In fact, blockchains are considered a highly secure technology because the mathematical and cryptographic principles on which they are based make it very difficult, if not impossible, to alter or compromise the recorded data. In addition, the multi-node distributed and decentralized structure forces a malicious user to simultaneously own/attack more than half of the nodes present, which becomes impossible for very large blockchains. This increases the level of trust among network participants, who can consider the information recorded in the network to be intact and trustworthy.

V. CONCLUSIONS

In this article, we conducted an analysis of the proposals, initiatives and regulations of the major actors in the global battery context. In addition, the state of the art in the scientific literature was analyzed to determine what implementation proposals have been made by researchers. The results of the analysis showed that currently no officially recognized standard for DBPs has been proposed. Therefore, the objective of this paper was to demonstrate that a blockchain-based solution is the most suitable for the implementation of DPss. In particular, we analyzed the textual parts of the EU Battery Regulation (at the present time, the only Regulation directly addressing DBPs) related to passports and showed how the requirements and details can be perfectly fulfilled by a blockchain-based solution. Finally, we discussed the reasons why blockchain is advantageous for this type of purpose.

In conclusion, our work was a preliminary step to show that it is worthwhile to focus efforts on the implementation of blockchain-based standards and solutions in anticipation of the deadline set by the EU. However, more work is needed on the practical part of the implementation. In the future, we plan to design a globally valid blockchain-based prototype solution that leverages the Decentralized Identity and Verifiable Credential protocols for passport tracking, and follow any future updates released for battery regulations.

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