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A PREDICTIVE TOOL FOR THE EMERGENCE OF TECHNOLOGY-CENTERED INNOVATION ECOSYSTEMS

GIANLORENZO MEGGIO, PETRA NYLUND, FERRAN GIONES, AGNIESZKA RADZIWON, ALEXANDER BREM

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FOREWORD

Innovation is increasingly a result of inter-firm processes e.g. open innovation, as well as of indirect, ecosystemic interaction between companies that happens by sharing common objectives, locations, or platforms. Innovation ecosystems allow for more agile, rapid innovation since they can draw on existing resources and activities of different firms. Ecosystem innovation also drives lasting systemic change. New technologies are embedded in more overarching technological solutions as well as in relationships between firms. Such layered and modular structures can incorporate further alterations and improvements and therefore make new solutions more resilient. Hence, our understanding of innovation emergence and diffusion is changing.

Still, little is yet known about the mechanisms that drive the emergence of different ecosystems. In this context, it has been suggested that certain technologies may enable the birth of ecosystems. Such enabling technologies form the basis for innovations in complementary sectors. Complex and complementary technologies that constitute dominant designs tend to be more enabling for subsequent innovation. Understanding and predicting the emergence of technology-centered innovation ecosystems allows for a purposeful orchestration of the emergence. Enabling technologies are usually underfunded, since the only future gains from the specific technology are considered, and not from the subsequential systemic change. Policy initiatives are therefore especially important for supporting these technologies, and the ecosystems that emerge in their wake.

However, these technologies need to overcome structural, societal, and cultural barriers. The unprecedented reach of digital technologies is therefore an enabling factor. Here, blockchain technology is such a digital enabling technology with a clear ecosystemic impact. On the one hand, blockchain enables the construction of new commercial relationships, thus increasing ecosystem reach. On the other hand, the technology increases trust and security in interactions, enabling relationships with more detailed information. Blockchain therefore generates richness in the ecosystem.

Hence, blockchain technology is ideal for understanding the drivers and barriers of technology-ecosystem emergence. This report therefore employs an inductive study of blockchain to generate a predictive tool for the emergence of technology-centered innovation ecosystems. This will have implications for managerial practice, but also for our understanding of how such innovation ecosystems emerge and evolve.

Alexander Brem and Petra Nylund

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1. INTRODUCTION

"What the internet did for communications, I think blockchain will do for trusted transactions."
IBM CEO (Rapier, 2017)

In the dynamic landscape of the business environment, pressure to innovate quickly, and the advent of digitalization has spurred a growing interest in the domains of ecosystems and platforms (Dąbrowska et al., 2022). Collaborations between organizations became easier and more frequent, making the proper management of interdependencies between companies, organizations, and institutions crucial, as predicted by Moore three decades ago (Moore, 1993). Despite many studies on ecosystems, we still know very little about the processes of ecosystem emergence (Hannah & Eisenhardt, 2018; Nylund et al., 2023; Pushpananthan & Elmquist, 2022) resulting from the innovative application of an enabling technology (Drori & Lavie, 2023; Nylund et al., 2022).

Navigating through the multilevel process of digital transformation requires a good orientation in the landscape of enabling technologies (Teece, 2018; Waßenhoven et al., 2023), as it could help accurately predicting the adoption barriers and enablers of any technology-centered innovation ecosystems. Against this background, the pervasiveness, technological improvement, and spawning capabilities of blockchain technologies (Ozcan & Unalan, 2022) make it a perfect candidate as the potential binder between technology-oriented innovation ecosystems.

Thus, this report delves into the emergence of three innovation ecosystems developing a blockchain-based solution to increase traceability in the EV battery supply chain. We will specifically focus on the launch phase of these ecosystems (Thomas et al., 2022) to develop a practice-oriented predictive tool for ecosystem emergence. The empirical input for the report comes from interviews with the CEOs of three established international organizations operating across Europe, Asia, and USA - Circulor, Everledger, and MOBI -, and secondary data about these organizations from press releases and online newspapers.

This report highlights three drivers that could foster the emergence of a blockchain-based innovation ecosystem and two adoption barriers. The drivers consist of societal, regulatory, and market trends, and the main barriers are knowledge gap and profitability. When appropriately managed the drivers could help in aligning the interests of the current ecosystem partners, while sparking interest from the potential clients. The two barriers – if not addressed early on may stand in the path of widespread adoption of the innovation and undermine the sustainability of blockchain-based endeavors.

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Beyond adoption, our findings show that interoperability and interorganizational issues represent the two most relevant implementation barriers. No technology and no organization is an island. Thus, the synergy between diverse entities within an ecosystem and the interoperability between the innovation process and legacy systems would be even more important now than with previous simpler systems. Finally, we argue that the launch of a technology-centered ecosystem is not a linear process but rather a dynamic journey encompassing experimentation, learning, and adaptation. Embracing this iterative cycle is crucial for ecosystem stakeholders as they navigate the uncharted waters of blockchain technology. This report, therefore, serves as a beacon for policymakers, industry leaders, and innovators, providing a roadmap to not only support the emergence but also harness the potential of blockchain-based ecosystems.

Managerial takeaways:

- No blockchain and distributed ledger is a particularly efficient and scalable way of storing much information. Conversely, distributed ledgers may be better suited to be used for the notarization and timestamping of transactions;
- Blockchain is not a stand-alone technology. Its potential can be realized just in combination with other technologies, e.g., Internet of Things;
- Blockchain-based platforms used for tracing supply chains are currently costly but can become viable business opportunities when the process they help track is expensive and regulations push for greater transparency.

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2. BACKGROUND

2.1 TECHNICAL BACKGROUND - BLOCKCHAIN TECHNOLOGIES

DEFINITION

The premises for the development of blockchain technologies can be dated back to the 70s when the first ideas regarding a distributed, safe, and immutable system were introduced (Chaum, 1979). In the following decades, other improvements related to consensus protocols and cryptographic hash functions have been developed (Jahankhani et al., 2022), leading to the famous Nakamoto's white paper (2008). The focus of that article was Bitcoin, i.e., a purely peer-to-peer version of electronic cash that would allow online payments to be sent without the intermediation of a financial institution (Nakamoto, 2008). This is why Nakamoto did not provide a general definition of blockchain, namely the underlying technology of Bitcoin. Blockchain was not even mentioned as such; rather, the author(s) has mainly described how the double-spending problem can be avoided through a block of chains. Since then, the term blockchain has gained momentum, leading to several different definitions.

We define blockchain as *a distributed ledger (DL) that chronologically records in digital blocks secured by cryptographic hashes a copy of the transactions that occurred*. To better understand the definition, we describe in Table 1 its core elements.

Concept	Description
Ledger	A ledger can be viewed as a file that continuously stores transactional data (assets that are assigned to users).
Distributed	A peer-to-peer network of nodes independent of each other, where each node is connected to a few others (not necessarily to all) and can have simultaneous access, validation, and registration powers.
Block	The elementary component of the chain holding batches of valid transactions. The blocks are linked together via cryptographic hashes.

Table 1. Core elements of the definition

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KEY TERMS

- **Distributed ledger**

A distributed ledger is a peer-to-peer network of nodes independent of each other, where each node is connected to a few others (not necessarily to all), as shown in Figure 1. Each node has a copy of the distributed ledger that stores the data, and an interface for users or other nodes to connect (Dhillon et al., 2021).

While in Blockchain technologies data is always encrypted, immutable, and stored in chained "blocks", in Distributed Ledgers data can be chained, but doesn't necessarily use "blocks". Therefore, blockchain is a subset of all the possible distributed ledgers, but not all distributed ledgers necessarily employ blockchains.

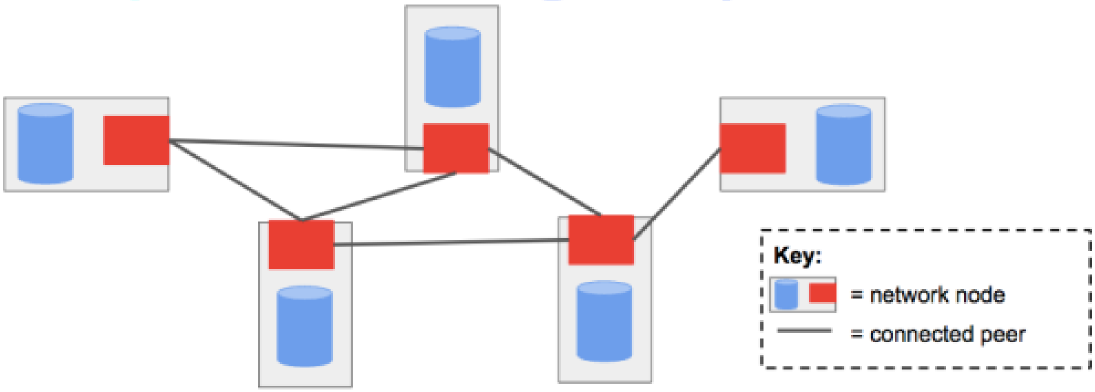

Figure 1 Structure of a Distributed Ledger taken from Dhillon et al. (2021)

Moreover, Figure 2 displays that blockchains are also usually (but not always) decentralized. This term means that the control over the system does not pertain to a single entity (Vergne, 2020). Instead, the decisions are taken collectively through a consensus process. Therefore, the adjective 'distributed' refers to the location of the network and the dispersion of organizational communications, while decentralized to the hierarchy structure (Jahankhani et al., 2022; Vergne, 2020).

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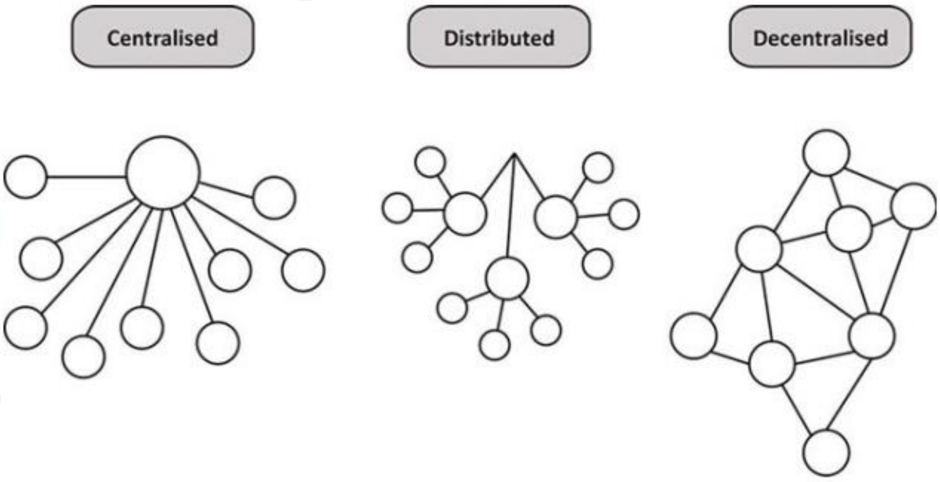

Figure 2 Description of different types of network architecture taken from Jahankhani et al. (2022)

- **Transaction**

A transaction occurs when a good or service is transferred across a technologically separable interface (Lumineau et al., 2021). Using a DL identity, a user can digitally sign a transaction to authorize actions on the network (e.g. casting a vote). All transactions must be from a sender account (e.g. voter) to a receiver account (e.g. a preferred candidate). A transaction may have a fee that is charged to the transaction sender and paid to the node of the network that adds this transaction to the distributed ledger (Dhillon et al., 2021).

- **Block**

The elementary component holds batches of valid transactions. Each block includes the cryptographic hash of the prior block in the blockchain, linking the two. The linked blocks form a chain. This iterative process confirms the integrity of the previous block, all the way back to the initial block, which is known as the genesis block (Block 0) (Dhillon et al., 2021).

- **Hash**

The operation of hashing (Figure 3) converts a digital object of arbitrary length, e.g., a document or an image, into a single character string, which is called the hash output. Hashing algorithms are deterministic (hashing the same digital object always gives the same hash output) and very hard to reverse-engineer as hashing similar digital objects results in very different hash outputs - thus they are considered a form of encryption (Dhillon et al., 2021).

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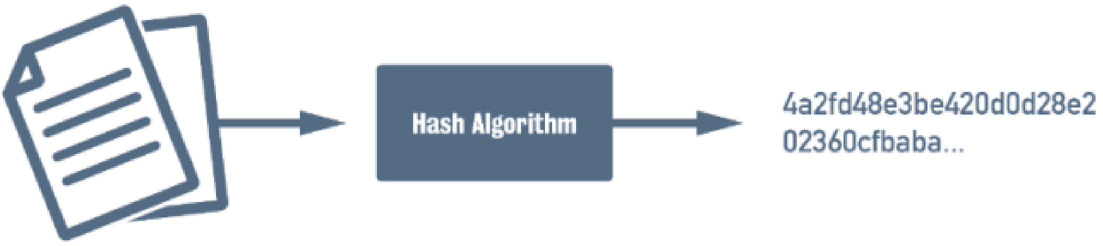

Figure 3 Hash graphical explanation taken from Dhillon et al. (2021)

- **Node**

Each node represents the device participating in the network and contains (Dhillon et al., 2021):

  - *Distributed Ledger*: the node's copy of the DL, the blocks (if this DL is a blockchain), and the confirmed transactions.
  - *Current network state*: the up-to-date voting data of the DL, e.g. What is each voter's most recent ballot?
  - *Wallet*: private keys for the voting accounts that this node controls and a mapping to the corresponding public key/address.
  - *Unconfirmed transaction pool*: the transactions (vote submissions) that this node receives (propagated from other nodes or sent from a user directly to this node) and are yet to be confirmed in the distributed ledger section of the node.
  - *Network routing aspects*: it describes how this node receives transactions and blocks and how it connects to the other nodes.
  - *Consensus protocols*: rules for when and how the node knows that transactions (and/or blocks if the DL is a blockchain) are verified and confirmed (discussed in more detail below)

Finally, two other elements not explicitly mentioned in the definition require to be explained to fully grasp the unique features of blockchain technologies: smart contract and consensus mechanism.

- **Smart contract**

Smart contracts are programs written in the blockchain that automatically verify and approve valid transactions that satisfy prescribed protocols (Lumineau et al., 2021). Although the notion of smart contracts appeared before the invention of blockchains, it did not gain prominence until blockchain technology made it possible to keep agreements immutable and to implement arrangements across networks for virtually any kind of asset or arrangement (Werbach, 2018).

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However, this deterministic execution frequently lacks the flexibility needed in legal contracts and highlights the difficulties of reducing contractual relationships and the complexities of the real world into computer code (Treiblmaier, 2020).

- **Consensus mechanism**

Consensus mechanisms are the way through which decentralized ledgers are governed (Wang et al., 2022). Different consensus mechanisms exist, ranging from proof-of-work (PoW), proof-of-stake (PoS), and practical Byzantine fault tolerant (PBFT) to proof-of-elapsed-time and proof-of-burn (Lumi). There are also many hybrid consensus mechanisms, including proof-of-activity (hybrid of PoW and PoS) and proof-of authority (hybrid of PoS and Byzantine fault-tolerant).

Consensus must provide the following core functionalities (Hyperledger, 2017):

- Confirms the correctness of all transactions in a proposed block, according to the policies;
- Agrees on order and hence on results of execution;
- Consists of interfaces and depends on the smart contract layer to verify the correctness of an ordered set of transactions in a block.

The overall process of transaction execution and validation is exemplified in Figure 4.

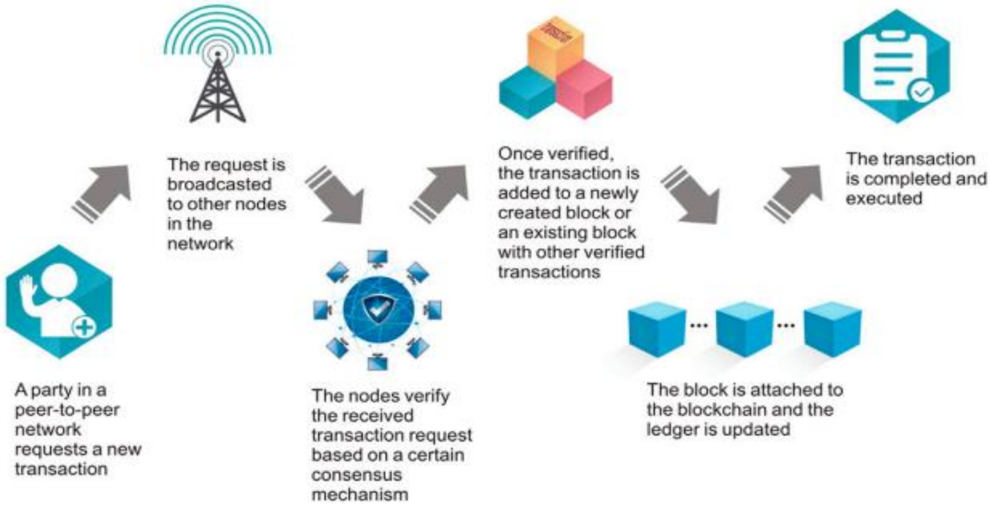

Figure 4 Transaction execution and validation process flow taken from Wang et al. (2022)

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BLOCKCHAIN TYPES:

Even though we offered a general definition and description of how a blockchain works, we cannot overlook that different types of blockchain exist. Figure 5 shows three macro-areas.

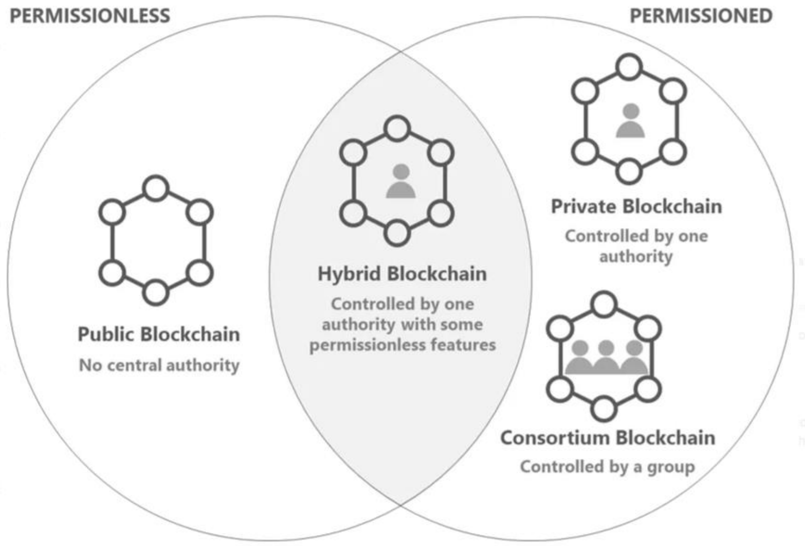

Figure 5 Venn diagram about the types of blockchain existing taken from Techskill Brew (2023)

- **Permissionless** blockchains are open networks that allow anyone to participate in the consensus and validate the data without revealing their identities, beyond a pseudonymous identifier (Sharma, 2024). Moreover, they can theoretically reach an unlimited set of participants or nodes (Cointelegraph, 2024).
  This type of protocol is usually adopted when trust between actors cannot be ensured, but the participants "trust the code". Thus, blockchain validators must choose to follow the consensus mechanism based on the incentives provided within the blockchain by its protocol (Bakos et al., 2021).
- **Permissioned** blockchains are closed networks with limited decentralization that have an access control layer (Sharma, 2024). This additional layer of security only allows participants to perform the actions that they are authorized to perform (Cointelegraph, 2024).
  If there is one just party, the blockchain should be called *private*, while, if there is more than one party, it should be called a *consortium* or *federated*. In permissioned blockchains, the number of validators is typically limited, and the advantage is that, given a certain level of trust among the actors that control the network, instead of depending on a single party, the operation of permissioned blockchains can be delegated to a

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community of permissioned validators (Bakos et al., 2021). These validators can be induced to behave according to the protocol based on enforcement mechanisms outside the blockchain, such as legal contracts or reputation.

Permissionless Blockchain	Permissioned Blockchain
Fully decentralized	Accountability
Pseudo-anonymity	Privacy
Incentivized	Scalability

Table 2 Features related to each type of blockchain taken from Cuomo (2022)

- **Hybrid** blockchain combines characteristics of both permissioned and permissionless blockchains (Figure 6).

In the hybrid blockchain, there are two different types of users/nodes based on the level of information that they access (Campbell, 2023): (i) The first type of users/nodes are those who are part of the permissioned (or private) blockchain and have all the control over the blockchain and can decide the level of security permissions for a particular user; (ii) the other type of users/nodes are those who are part of the permissionless (or public) blockchain and can just access the data released on the blockchain.

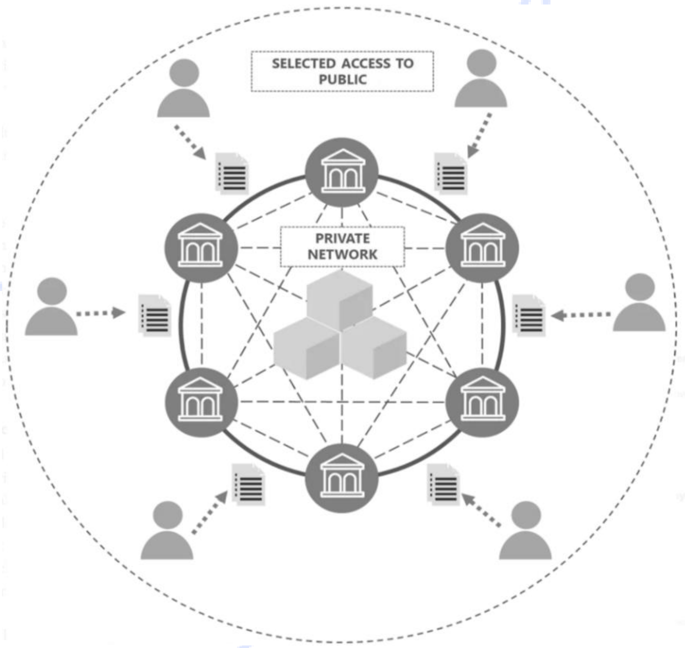

Figure 6 Graphic description of a hybrid blockchain taken from Techskill Brew (2022)

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Like a consortium blockchain, a hybrid blockchain has the privacy benefits of a permissioned blockchain. But, unlike a consortium blockchain with multiple participants collectively helping to maintain the network, a hybrid blockchain is usually partially decentralized having a single entity network administrator (Brew, 2022). Fusing different features from private and public blockchains ensures that an organization can work with its stakeholders in the best possible way.

2.2 BUSINESS BACKGROUND - PLATFORM-ECOSYSTEMS EMERGENCE

The pervasive digitalization of our society has led to a surge of research interest in platforms and ecosystems in recent decades (Dąbrowska et al., 2022). On one hand, while Gawer and Cusumano (2014) distinguished between internal platforms, supply-chain platforms, and industry platforms following categorizations differentiated platforms as a construct encompassing two extremes: innovation platforms—those that facilitate innovation on a foundation offered by a central actor —and transaction platforms—which connect buyers and sellers (Cusumano et al.; Gawer, 2021). On the other hand, scholars seem to concur that three defining elements set ecosystems apart from other forms of collective organization for value co-production (Adner, 2017; Jacobides et al., 2018; Thomas et al., 2022): their reliance upon non-hierarchical mechanisms, the generation of synergies among participants in terms of complementarities and interdependencies, and the presence of a coherent ecosystem-level value proposition.

To reconcile these two literature strands, this report builds on the comparative work of Jacobides et al. (2024), who defined a platform ecosystem as a construct focused on the non-generic complementarities and interdependences created by the technological platform that serves as a medium of coordination. In line with this framing, we revisit Thomas et al. (2022) work on platform ecosystems' emergence to understand the key features of this phenomenon. The authors state that, for a platform ecosystem to become established, four distinctive processes occur: value discovery, collective governance, platform resourcing, and contextual embedding. These processes unfold at different stages of the emergence process, which previous literature divided into three phases (Dedehayir et al., 2018; Moore, 1993; Pushpananthan & Elmquist, 2022). The 'launch' involves the orchestrator conceiving the entrepreneurial idea, crafting the initial prototype, and collaboratively exploring and articulating the joint value proposition. The 'expansion' phase marks the accelerated growth of the ecosystem, propelled by network effects identified during the initiation phase. During this stage, key competitive dynamics emerge both internally and externally. Finally, the third stage occurs when the ecosystem is 'established',

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having triumphed in the competitive contest of the previous stage, establishing legitimacy within their wider societal and competitive context.

Thomas et al. (2022) found that, while value discovery and platform resourcing tend to exhibit the highest frequency in the launch stage, as the orchestrators develop their value proposition and acquire the initial resources to launch the ecosystem, collective governance processes do not exhibit as high relative frequency at this stage. This means that, at least in these ecosystems, implementing a pre-established value blueprint was not a dominant activity. In our case, we will focus on blockchain as the main enabler of the launch of three innovative platform ecosystems[1] in the EV battery supply chain. Below, we will briefly present the state-of-the-art research on blockchain-based platforms in supply chains.

2.3 ADOPTION OF BLOCKCHAIN-BASED PLATFORMS IN THE SUPPLY CHAIN

Current studies have shown how supply chains may benefit from the digitalization and automation of processes that are currently manual and paper-based (Chang et al., 2020; Sund et al., 2020). To address these issues, and the lack of trust existing among supply chain actors, both practitioners and scholars proposed developing blockchain-based platform ecosystems (Jensen et al., 2019; Jovanovic et al., 2022). Its distributed architecture holds the potential to ensure automation, immutability, and transparency. Consequently, the attributes of blockchain promise to effectively tackle inefficiencies and trust-related concerns within the industry by shifting certain complexities from the organizational sphere to the technical realm (Beck et al., 2018; Catalini & Gans, 2020).

Nevertheless, the adoption of this technology is not straightforward. Saberi et al. (2019) identified four categories of adoption barriers for blockchain technology in the supply chain: inter-organizational, intra-organizational, technical, and external barriers. Kouhizadeh et al. (2021) developed an exploratory study that showed how inter-organizational and technological barriers are the most critical according to both academics and industry experts. Additionally, Kumar et al. (2022) study revealed that the lack of government regulation and low competency of workers are the most critical barriers restricting the utilization of blockchain and IoT systems in the Indian food supply chain. Finally, Jovanovic et al. (2022) identified a set of implementation barriers and drivers that a platform sponsor should consider, such as establishing a neutral

[1] From now onwards, we will use the terms ecosystem, platform ecosystem and platform interchangeably.

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position, deciding on the on-chain and off-chain governance about complementary and competing platforms, and identifying the type of blockchain to adopt.

Against this background, we present below the research context and the case studies that we analyzed to understand the drivers and barriers affecting the emergence of a blockchain-based platform.

3. EMPIRICAL CASE COMPANIES

3.1 THE CASE FOR BATTERY PASSPORTS

A *battery passport* is a document that stores relevant battery data throughout the entire battery lifecycle, containing detailed information about a battery's production, testing, and recycling (Stretton & Daphne, 2023). It aims to bring new levels of transparency to the global battery value chain by collecting, exchanging, and reporting trusted data among all lifecycle stakeholders (Globalbattery.org). This is especially important for batteries that are sold to consumers, as it provides them with the assurance that the battery they are purchasing is safe and compliant with the regulation (Stretton & Daphne, 2023).

While the definition is unique, different approaches exist regarding how to develop the technological infrastructure needed to collect, exchange, and report trusted data among all lifecycle stakeholders. For this reason, this report will be based on three different cases. These examples will allow us to understand the drivers and barriers that could predict the emergence of blockchain-based platform ecosystems in the EV battery supply chain.

3.2 CIRCULOR

Circulor is a platform founded in 2018 with the aim to improve the traceability and due diligence of raw materials and recycled content across supply chains.

Figure 7 Circulor platform impact on the supply chain. Source: (EINST4INE & Hyperledger, 2023)

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Circulor adopted the Hyperledger Fabric architecture to create a distributed permissioned ledger and smart contracts to verify the chain of custody, ownership, and provenance, with transparent data access controlled through the Oracle Blockchain Platform (Oracle, 2023). Circulor Protocol prevents data corruption using strict rules, including verifications at accredited facilities, and making use of GPS tracking, and facial recognition.

In 2018, Circulor provided the first-ever mine-to-manufacturer traceability of a conflict mineral to prove that tantalum ore from three mines in Rwanda was mined, transported, and processed under OECD-approved conditions, without child or enslaved labor (Hyperledger, 2023). More recently, Circulor has introduced a battery passport that collates, stores, and displays relevant information about a battery's entire life cycle in industries like electronics and automotive (Circulor). The platform ensures end-to-end transparency, validating transactions and establishing mineral provenance throughout the supply chain. Data is analyzed using AI to detect anomalies, ensure compliance, and initiate investigations and can be fed to the blockchain via system integration using RESTful Web Service APIs with security and authentication protocols (Circulor).

3.3 EVERLEDGER[2]

Founded in 2015, Everledger is an independent technology company helping businesses store and share asset information, using a combination of innovative technologies, including blockchain, AI, intelligent labeling, and the Internet of Things (Everledger). Everledger adopted the Oracle Blockchain Platform based on Hyperledger Fabric to let users capture blockchain transaction history and current state data for analytics (Oracle, 2019).

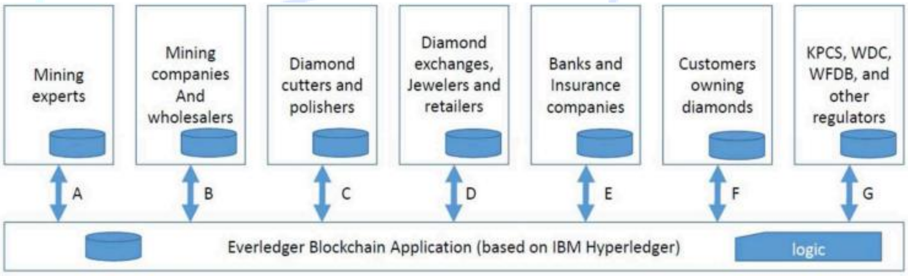

Figure 8 Overview of the Everledger blockchain application in the diamond industry. Source: (Smits & Hulstijn, 2020)

[2] In 2023, Everledger underwent extensive corporate restructuring. This included administration and subsequent liquidation processes for specific entities in the UK and Australia, not all entities of Everledger. Despite these circumstances, operations in Europe, China, India, and the USA remained uninterrupted.

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The first use case for Everledger concerned the tracking of rough-cut diamonds. Everledger created a digital twin for every diamond and gave a unique cryptographic ID to each piece based on more than 40 attributes (Berneis & Winkler, 2021). The analytics systems utilize AI to cross-check data related to regulations, relevant records, and IoT to ensure that the gems from conflict regions do not enter the supply chain. All permissioned parties have access to data (Kshetri, 2022).

The platform ecosystem built on blockchain technology facilitates thorough documentation of diamond transportation by utilizing tracking and tracing mechanisms, thereby ensuring transparency. Once the recipient confirms package delivery, a Smart Contract can seamlessly trigger a transaction. Crucially, the inherent nature of blockchain prevents any retrospective alterations to the recorded data (Berneis & Winkler, 2021). Nevertheless, given that Everledger is the main node, all new information must be verified by the company itself, which requires trust from all parties involved (Kshetri, 2022). Since then, Everledger has offered services in other six business domains: EV batteries, gemstones, minerals, wines, luxury goods, and art (Everledger).

3.4 MOBI

MOBI is a global nonprofit Web3 consortium creating standards for trusted decentralized identities (e.g. vehicles, people, businesses, things), verifiable credentials, and cross-industry interoperability. MOBI and its members are building the Web3 infrastructure for connected ecosystems and IoT commerce. The goal is to make the digital economy more efficient, equitable, decentralized, and sustainable while preserving data privacy for users and providers alike.

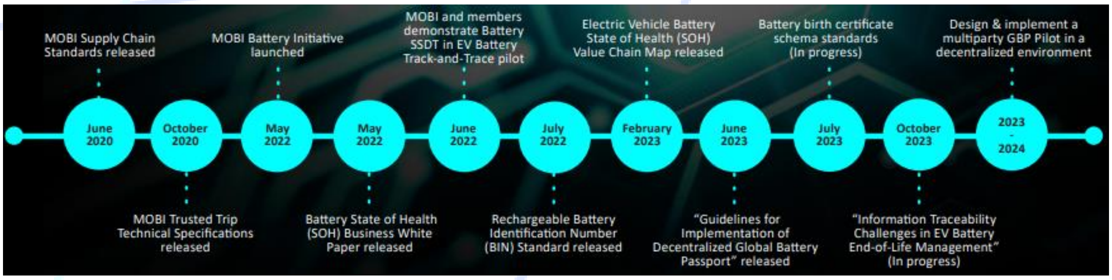

Figure 9 MOBI timeline for Global Battery Passport Pilot and implementation. Source: (MOBI, 2023)

Citopia is a member-owned and operated federated network of nodes creating a cross-industry, decentralized, interoperable Web3 marketplace, which leverages Self-Sovereign Digital Twin

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applications (Citopia Passports) and is based on World Wide Web Consortium (W3C) Verifiable Credentials (VCs) and Decentralized Identifiers (DIDs) standards (Citopia Global Battery Passport).

The GBPS is a standardized system that will allow the producers to issue battery passports. The system will include a registry of battery information sources with the ability to query battery data (public and confidential). The release of MOBI's Guideline for Implementation of a Decentralized Global Battery Passport System in June 2023 marked a critical milestone toward this goal (MOBI, 2023).

4. FINDINGS

Overall, Circulor and Everledger's value propositions are based on the transparency of origin and transactions. This can be considered an "application provider" business model, which is built on the new function of intermediaries among the partners of a supply chain (Tönnissen & Teuteberg, 2020). On the contrary, the last case represents an example of a Web3 infrastructure that would enable interoperability also among current Web2 supply chain applications.

After having introduced these three cases, we will now describe the key findings derived from the analysis of the data collected. We will start with a focus on the key drivers of adoption of their solutions, before moving on to discuss both the adoption and implementation barriers.

4.1 ADOPTION DRIVERS

The analysis of primary and secondary data revealed three main trends driving the adoption of a battery passport: societal, regulatory, and market trends.

- **Societal trends**:
  - According to Mancini et al. (2019), empowering countries where raw materials are extracted to reduce their environmental footprint and fight unethical working conditions is one of the steps necessary to achieve the 2030 SDGs.

    Accordingly, it is not surprising that the societal issue of making supply chains more sustainable is also mentioned by Leanne Kemp, CEO of Everledger, as one of the key trends pushing the adoption of innovative solutions. Additionally, in this quote, she shows how the link between societal and regulatory drivers is very tight:

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"It's clear that the work that we started in 2015 was not really on the minds of many, but now we're starting to see political leaders bringing policy to the forefront, whether it's the EU battery directive, or the G7, in the announcements of sanctions with Russian diamonds. So, the macro trend of sustainability, traceability, provenance […] is here to stay".

- **Regulatory trends**:
  - Indeed, regulatory bodies and voluntary agreements are pushing toward more sustainable practices. For this reason, from 1st February 2027, all EV and industrial batteries on the EU market will require a unique battery passport to be identified with a QR code. The European Union's Battery Regulation Amendment provides a comprehensive set of rules that are designed to protect the environment by reducing the amount of hazardous materials found in batteries and increasing the recycling rate of batteries (Stretton & Daphne, 2023).
  - Following the 2023 revision of the EU Battery Legislation, the Chinese government launched the development of a Chinese digital battery passport. The aim is to facilitate trade with the EU, by requiring similar data transparency requirements along the EV battery value chain in China, such as the carbon footprint, circularity, and ESG (WEF, 2023).
  - Multistakeholder initiatives, such as the Global Battery Alliance (GBA) or the Battery Pass consortium (Battery Pass), are also driving the development of a digital battery passport to increase transparency and enable sustainable and circular value chains.

The importance of the regulatory impulse is also highlighted by Circulor CEO, Douglas Johnson-Poensgen, exemplifying the relation between regulatory and market trends leading to the diffusion of digital battery passports:

"[We are going all in on battery Passport] because the economics work, you know, an EV battery is very expensive. There's a whole pile of regulations pushing behind it and people are prepared to pay."

- **Market trends**
  - Finally, also the surging global markets for products based on batteries, such as consumer electronics and electric vehicles are driving an escalating demand for crucial raw minerals like cobalt, tantalum, and tungsten (Andreoni, 2023).

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- Thus, the imperative for manufacturers to prioritize ethical supply chain practices and ensure transparency in raw material procurement has intensified, subjecting them to heightened scrutiny. Exhibiting ethical business conduct and diminished carbon footprints through passports can augment product value for buyers and investors, considerably mitigating compliance expenses and distinguishing certified companies' products from non-certified alternatives (Oracle, 2023).

4.2 ADOPTION BARRIERS

After having described the drivers of adoption, we now focus on the barriers faced by the companies in establishing their platform ecosystem. Two main aspects emerged from the interviews: the need to educate the partners about the blockchain field and the need to identify the best way to make this innovation economically sustainable.

KNOWLEDGE GAP

We report below one excerpt from an interview with Circulor illustrating the need to educate the clients about the basic concepts and features of blockchain.

> "We don't mention blockchain in the early sales conversation. We talk about business problems and a business solution. The participant is paying not to upload data but to get data insights from a platform. […] The core of it is telling me what the hell is going on in my supply chain. Or show me a battery passport for this battery in this electric vehicle. That's what they want. That's the business need."
>
> Douglas Johnson-Poensgen CEO, Circulor

Similarly, Everledger recognized that "*there is still a lot of confusion between what is the blockchain versus a blockchain, differentiating between public, private, permissioned networks or permissionless networks*", while MOBI highlighted that one of the main activities that they are conducting concerns education: *"The difficult thing, within what we're doing in web3, is education and bring everybody to the same understanding. And that's hard because different organizations come in at different times. And so, it's an ongoing communication, education."*

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PROFITABILITY

Here we move to the quotes concerning the other adoption barrier, that is, the risk of finding business cases that are not profitable. Circulor and Everledger have experimented with several sectors, before realizing that EV batteries represent the best option for the foreseeable future. In this regard, Leanne Kemp, Everledger CEO stated that: "*[Our approach was to] see where there is customer demand of labour sustainability, where regulations are going. And see if, of course, it's going to be profitable.*"

On the other hand, MOBI pointed out that another barrier concerns balancing the investments required in the short and long term: *"A lot of the time people keep buying new things or updating [the infrastructure on their own]. Those can be very costly. So, we think that accepting standards is important."*

These quotes highlight a shift toward a pragmatic approach to discussing blockchain in business settings. The focus has become over time finding profitable business problems, and educating clients about solutions that can be more efficient that previous ones.

4.3 IMPLEMENTATION BARRIERS

Additionally, two themes emerged as the main barriers hindering the implementation of blockchain-based platforms in the cases where it was adopted.

INTEROPERABILITY ISSUES

The first barrier concerns solving the interoperability issues between how different technologies work in different companies, as explained by Everledger.

Everledger

> The protocols and the technical environment was relatively embryonic, it certainly didn't have such a thing as a blockchain as a service in 2015. But now that's well matured. There's interoperability now between multiple blockchain networks and environments. Again, none of that happened or was occurring in 2015.
>
> Leanne Kemp – CEO, Everledger

Nevertheless, as pointed out by MOBI, interoperability may have different facets. Indeed, while

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MOBI's focus was on the interoperability between different companies' systems, Circulor focused more on the internal technical interoperability: *"Few technologies solve business problems entirely on their own. You have to put together a combination of technologies to solve a particular set of use cases."*

Overall, all of the interviewees confirmed that one of their main concerns was not just to facilitate seamless interconnection between multiple blockchains but also with other types of technological components and standards, e.g., sensors, KYB, KYC etc.

GOVERNANCE

On the other hand, another issue concerns aligning the roles, interests, and tasks of the multiple actors using the platform.

In this regard, Everledger and MOBI expressed similar reflections. The former talked about the need of aligning value creation activities among partners: *"There's still a lot of work to be done in the alignment of value and value creations within a supply chain. You have to align the value and the values of a blockchain network with the participants of that supply chain to enable them to be onboarded and then to incur or receive value from that network."* Instead, the latter focused on the sense of community as a key success factor for the consortium:

> "We are doing somewhat different than others in the sense that we think that this only works, if we have a community. If you do this as a company, and then go out and try to convince all the others to use it, that's much harder, because you have to get them all to use your own way of doing things, your own standard. So we started out with a community, […] and it's a much slower process. But I think this is a better way of doing things."
>
> Tram Vo – CEO, MOBI

On the other hand, Circulor posed the attention on the partners' willingness of sharing data and be committed to support a platform that would increase transparency on their activities: *"Willingness of participants to contribute data to a platform that will identify whether they are not sourcing from the suppliers they had previously declared or not is not so high. Visibility, transparency in the deeper tiers of supply chains, have never really existed. So, most car manufacturers have little more than a hazy view of what happens beyond tier2 or tier1 in some cases."*

These quotes highlight the critical role of governance in aligning interests, expectations and creating a sense of community within blockchain-based platforms in the supply chain. Finally,

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establishing a shared understanding of needs, pain points, and use cases through community-driven approaches is emphasized as a more effective strategy than imposing a company-centric model, especially in consortium-based platforms.

4.4 TECHNOLOGY-CENTERED INNOVATION ECOSYSTEM EMERGENCE

In the following paragraphs, we will describe the three steps followed by Circulor, MOBI and Everledger in the launch phase of their platform: experimentation, learning, and adaptation. Throughout these stages, we could identify a *fil rouge* related to two concerns: market and technology-related aspects.

4.4.1 EXPERIMENTATION

First, we noticed that Circulor, MOBI, and Everledger's activities started following the needs expressed by their first clients of partners. Consequently, all of the organizations had to first face what kind of (mix of technologies) could best address this demand.

MARKET

Market-driven demand:

In response to customer demand for transparency, Chow Tai Fook Jewellery Group and the leading independent diamond grading authority Gemological Institute of America (GIA) approached Everledger in 2015 to design a solution that would deliver secure, digital diamond grading reports on the blockchain. Customers of Chow Tai Fook T Mark luxury brand received a permanent and immutable blockchain record of their diamond's GIA grading information, giving them additional assurance and transparency of their diamond grading and traceability information (Everledger, 2023).

Similarly, Circulor CEO and co-founder Doug Johnson-Poensgen was first approached by a mining company in 2016. At the time, Rwandan mines were already using the best methods available to trace the extraction and transformation process of tantalum: tagging materials and filling in paper forms. However, this still generated a costly mountain of paper with room for errors or fraud. Thus, Circulor's team started by mapping every step of the supply chain (Hyperledger, 2023).

A few years later, MOBI announced its first pilot in 2018. The goal was to launch the automotive industry's first Vehicle Identity (VID) standard for use on blockchains. MOBI, whose consortium

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counted Renault, Ford, GM, Honda, and BMW amongst its members, aimed for VID to be the foundation upon which firms build to improve road safety, lower carbon emissions and alleviate traffic congestion. Renault and Ford led the working group for this first MOBI standard, which comprised more than 20 contributors including Accenture, BMW, Cognizant, ConsenSys, GM, Honda, Hyperledger, IBM, and IOTA (Insights Ledger, 2019).

TECHNOLOGY

Technology mix:

Consequently, all the companies started experiment with blockchain and other technologies to find the right solution. Circulor realized a blockchain could streamline those steps, but they faced the classic problem of "garbage in, garbage out". To ensure accurate data for the blockchain, the company tightly controlled raw materials using scanners, sensors, weigh scales, and smartphones throughout the global supply chain. Circulor implemented a tamper-proof blockchain as a secure repository for system data, ensuring user-friendliness via smartphones. Unique procedures, including the facial recognition system URU, were developed to address these challenges. Scan results were recorded on the blockchain, enabling Circulor to track ore from the mine to the refinery using smart contracts (Hyperledger, 2023). Similarly, Everledger used material science and scanning technologies like spectrography, HD photography, resonant ultrasound, and light refraction to create unique thumbprints of diamonds (Collins, 2018). On the other hand, MOBI started to test digital identities (the VID) in July of 2019 to track and give access to different events in the car's life, such as a change in ownership, any repairs, and also insurance claims.

Figure 10 MOBI pilots timeline. Source: MOBI Internal documentation

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TAKEAWAYS

This first step shows how the platform launch is primarily driven by business needs that blockchain may help to address. Nevertheless, blockchain is not a stand-alone technology. It is the combination of different technologies that allow blockchain to be effective. Something that will become even clearer in the next phases.

4.4.2 LEARNING

After the first phase of experimentation, Circulor, MOBI, and Everledger realized that not all their initial decisions worked out as expected. This learning phase concerns both their market and their technology decisions, as we will show below.

MARKET

Market niche:

Following the completion of the first pilot, Circulor started to explore other sectors to test the effectiveness of their solution. For example, in 2021, the company partnered with energy company TotalEnergies (formerly Total) and plastic chemical recycler Recycling Technologies to develop a solution for tracing Hard To Recycle Plastics (HTRP) (Insights Ledger, 2019). This is how Circulor CEO commented on that project in hindsight: *"When we did projects in recycling, the economics of plastic waste through chemical recycling didn't work at all. Plastic taxes are far too low. Who's going to pay for traceability? We aren't going to transform the business model of plastic waste."* In parallel, Everledger also started to rethink its market strategies: *"We just managed to understand that our strengths lie in the extractive space. And we did do a lot of traceability with wool, but we're best suited in the world where there's an extractive industry related to mining. That's where our expertise lies."* Differently from Circulor and Everledger, MOBI's learnings always concerned the same industry, i.e., mobility. Nevertheless, MOBI opted to form different working groups to test its technological solutions in different use cases.

We show below the lessons learnt technology-wise.

TECHNOLOGY

Technology maturity:

Technology-wise, the organizations understood the main limitations of blockchain. For example, Circulor understood that no blockchain and distributed ledger is a particularly efficient and scalable way of storing a lot of information: "*What we discovered in our prototypes is that the data that you need from a miner is completely different from the data that you need from a refinery or a battery cell manufacturer or even a car manufacturer. […] So, you end up storing, if you have a data*

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model, an awful lot of empty cells, which is not a particularly efficient thing to do on a distributed ledger." MOBI also reached a similar conclusion: "*Although blockchain can be used for many things, blockchain is not efficient enough, fast enough or cheap enough to do or store any kind of transaction with it."*

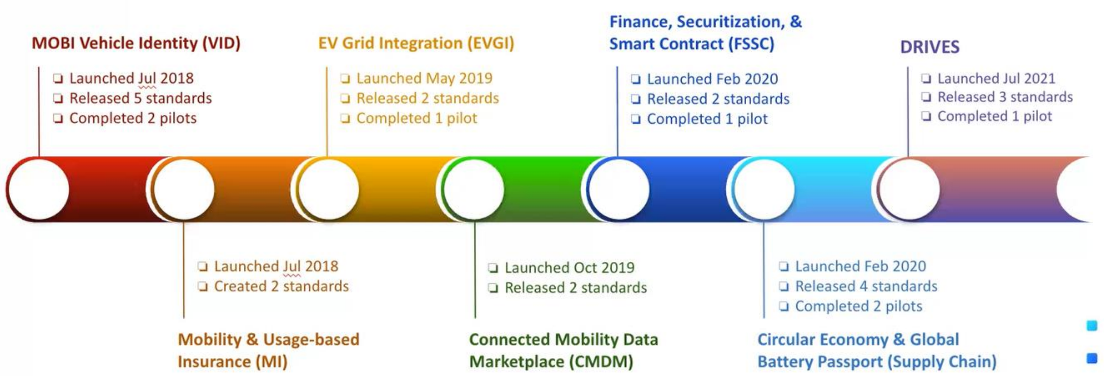

Figure 11 MOBI's Working Groups. Source: MOBI Internal documentation

TAKEAWAYS

The findings of this phase emphasize the need to explore and identify various sectors where blockchain technology can be profitable and effectively implemented. Moreover, the interviewees underscored the importance of tailoring the use of blockchain technology to match its unique features and the specific characteristics of the clients and their businesses.

4.4.3 ADAPTATION

The last phase of the process model concerns how the three organizations reacted to the lessons learnt in the previous stage. Circulor and Everledger started to heavily focus on EV battery business cases, while MOBI's working groups finetuned the technology infrastructure and developed the first reports about the infrastructure underlying a global battery passport.

MARKET

Market focus:

The improved understanding of the adoption barriers and drivers of their solutions pushed Circulor to narrow the focus of its offer: *"We deliberately focused on something that was bloody expensive with a whole pile of problems with a whole pile of regulation, because then it makes sense to pay for a solution."* Everledger followed a similar evolution process, increasingly focusing on EV batteries: *"Diamonds and EV batteries currently have equal importance and equal performance. But if you asked me that question five years ago, we would have had a large amount*

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of diamonds slowly followed by batteries and renewable energies. If you ask me this question in three to five years' time, it's probably going to be critical minerals and batteries that will outstrip. But arguably both industries that we focus on now have a policy which is a hard hammer that people have to consider digital product passwords, traceability, provenance, all the reasons why we exist."

TECHNOLOGY:

Technology finetuning:

At the same time, also the technology infrastructures was consistently finetuned. MOBI realized that they needed to build a new infrastructure to be able to register the Decentralized Identities for the VID and that blockchain should be used just for the registry. Similarly, Circulor mentioned that they store hashes of blobs of data on the distributed ledger, while the single transactions are stored thanks to a combination of Oracle and Graph databases. In this way, they have the benefit of a distributed ledger in terms of building trust in a distributed network, without the disadvantage of slow transactions and potentially high transaction costs. Finally, Everledger highlighted how the different characteristics of the sector of application may affect the business layer, while the technology stack should not be affected by it: *"From a technology stack perspective, we've had to account for sort of an agnostic approach to asset, as tracking a diamond is very different to even tracking an emerald even though they're both gemstones. And then of course, when you start to apply certain types of methodologies around traceability, the business logic layer and the way upon which you gain sort of consensus mechanisms, particularly around critical minerals, whether it be lithium cobalt, nickel, manganese is also fundamentally different again from diamonds."*

TAKEAWAYS

The last phase clearly shows that the priority for the ecosystem is to find the most profitable market niche and finetune the technology to make it more efficient and responsive to clients' requests. To do so, the ecosystem should show the viability of its offer identifying the sectors where regulations require more traceability and sustainability, and the sectors' characteristics reflect better the characteristics of the technology.

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5. CONCLUSION

In this report, we focused on the launching phase of a technology-enabled ecosystem. Despite different cases and different solutions, some common patterns emerged from the analysis of these three organizations. We present in the following figure the predictive tool for the emergence of a technology-enabled ecosystem, illustrating its evolution by looking at three elements: the adoption drivers, the adoption barriers, and the implementation barriers.

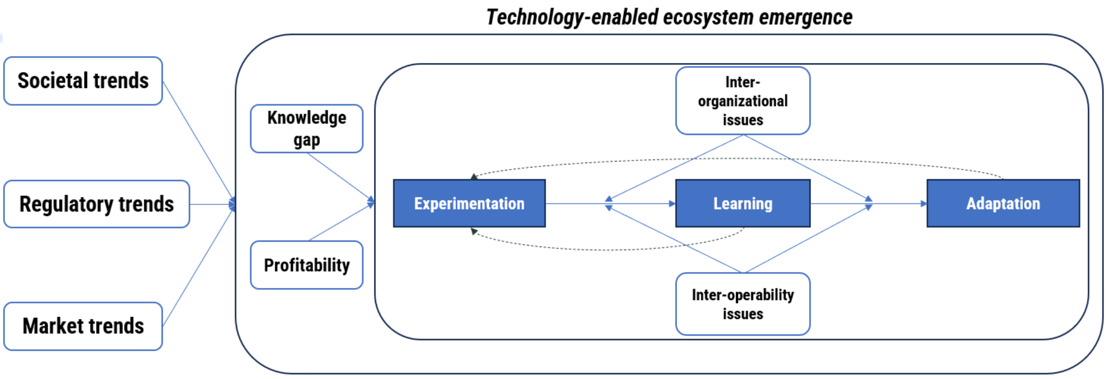

Figure 12 Predictive tool technology-enabled ecosystems emergence

The drivers for adoption - societal, regulatory, and market trends - represent the overarching forces compelling organizations to seek innovative solutions that could address existing issues. Despite these trends, certain barriers may impede the adoption of a new technology-enabled platform. Specifically, we have identified (a lack of) education and economic viability as critical aspects. If clients cannot comprehend the new terminology and, consequently, its added value, and if the market does not present profitable niches, the ecosystem may encounter difficulties in establishing itself. Finally, we identified two implementation barriers, which could affect the successful launch of an ecosystem: inter-organizational and interoperability issues. On one hand, inter-organizational challenges may arise when there is a misalignment of interests between ecosystem partners, or when partners move at different paces, as this could create tensions regarding who will be entitled to capture the value created. On the other hand, we found that "no technology is an island". Innovative ecosystems will not materialize solely thanks to the plug-in of a new technology; conversely, establishing interoperability between new technology and legacy systems is paramount for the successful emergence of an ecosystem.

Against this background, we predict that the emergence of a technology-centered innovation ecosystem will follow three steps. The experimentation phase, usually driven by market needs, concerns testing the interoperability between the new technology and legacy systems. Then, the ecosystem partners will learn what worked and what did not in the first phase from both a market

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and a technology perspective. Finally, the ecosystem will adapt its solution to find the most profitable market niche and finetune its technology to better serve its customers.

Companies can use the predictive tool to better understand the specific drivers and barriers to blockchain adoption and implementation. Particularly, analyzing each driver and barrier on the ecosystem level will help firms play a role in growing their ecosystem. Further, the predictive tool can be used also for other technologies. It is especially suitable for other technologies that are crucial to digital transformation e.g., artificial intelligence and its derivative ecosystems.

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BIOGRAPHIES

Gianlorenzo Meggio is an EINST4INE Early-Stage Researcher, doctoral student at the Department of Business Develpoment and Technology, Aarhus University and Affiliated Researcher at UC Berkeley, Haas. He is researching in the field of blockchain technologies, looking at their commercialization and acceptance in public and private contexts.

Petra A. Nylund is a research fellow of strategy and innovation at the Institute of Entrepreneurship and Innovation Science at University of Stuttgart. She holds a Ph.D. in Management from IESE, Barcelona and an M.Sc. in Engineering and Business Management from KTH, Stockholm. She has created strategies in the telecoms industry of Africa, Latin America, and Europe. Her recent work centers on ecosystem dynamics in the context of artificial intelligence and its standardization. She also studies the emergence of ecosystems based on other enabling technologies.

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Ferran Giones is the Deputy Head of the Institute of Entrepreneurship and Innovation Science (ENI) at the University of Stuttgart, Germany. He received a BBA & MBA from ESADE Business School and a Ph.D. from La Salle – Ramon Llull University in Barcelona, Spain. Before joining academia, he worked as a strategy consultant at Deloitte Spain and as an international project manager in China. His research areas are technology entrepreneurship, science commercialization, and industry emergence. He explores intriguing questions on how technological progress relates to entrepreneurial action and innovation in established organizations.

Agnieszka Radziwon is an Associate Professor of Innovation Management and works both at Aarhus University in Denmark and the University of California Berkeley in the USA. Her expertise is in innovation and technology management. Agnieszka is looking into a broader perspective of inter-organizational collaboration in various types of (eco)systems. She is interested in the ways knowledge is transferred across organizations, the role of networks in facilitating or hindering innovation, and how institutions codify ideas and practices. Together with Henry Chesbrough, Joel West, and Wim Vanhaverbeke, Agnieszka is an editor of the forthcoming *Oxford Handbook of Open Innovation*.

Alexander Brem is an Endowed Chaired Professor and Institute Head with the University of Stuttgart and an Honorary Professor with the University of Southern Denmark. He studied business administration with a major in entrepreneurship at Friedrich-Alexander-University Erlangen-Nürnberg (FAU), where he also received his PhD.

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PARTNERS

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LUISS

LUT University

RMIT UNIVERSITY

Sant'Anna School of Advanced Studies – Pisa

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