5-2024

LEVERAGING BLOCKCHAIN TECHNOLOGY TO REVAMP THE VEHICLE ELECTRIFICATION JOURNEY: PERSPECTIVES OF ACCOUNTABILITY AND ECONOMIC CIRCULARITY

Eva Escobar Brown
California State University – San Bernardino

LEVERAGING BLOCKCHAIN TECHNOLOGY TO REVAMP THE VEHICLE ELECTRIFICATION JOURNEY: PERSPECTIVES OF ACCOUNTABILITY AND ECONOMIC CIRCULARITY

A Project

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Information Systems and Technology

---

by

Eva Escobar Brown

May 2024

LEVERAGING BLOCKCHAIN TECHNOLOGY TO REVAMP THE VEHICLE ELECTRIFICATION JOURNEY: PERSPECTIVES OF ACCOUNTABILITY AND ECONOMIC CIRCULARITY

A Project

Presented to the

Faculty of

California State University,

San Bernardino

---

by

Eva Escobar Brown

May 2024

Approved by:

Lewis A. Njualem, Ph.D, Committee Chair,

Conrad Shayo, Ph.D., Committee Member, Chair, Department of Information and Decision Sciences

ABSTRACT

The automotive industry is undergoing a significant transition accelerated by global emission regulations for a phase out of internal combustion engines (ICEs) and a transition toward the adoption of electric vehicles (EVs). While regulatory measures and incentivized adoption for EVs presents opportunities for reducing emissions and promoting sustainability, it also poses complex challenges. The EV industry faces potential production challenges, particularly in the sourcing, manufacturing, and lifecycle management of critical minerals and raw materials for electric vehicle batteries (EVBs). With a heavy reliance on a steady and diversified supply of critical minerals such as lithium, cobalt and rare earth elements, the finite nature of mineral resources poses long-term challenges for EV stakeholders.

The recent measures instituted by government regulations do recognize the need for EV stakeholder accountability, requiring substantiated evidentiary proof by way of data collection and analysis mandating resource recapture and reintroduction into circularity, environmental benefits, and real-time data availability. By implementing clear end-of-life requirements such as collection targets, material recovery goals, and extended producer responsibility, EV producers are held responsible for managing the entire lifecycle of electric vehicle batteries (EVBs). Government regulations are aimed at bolstering sustainability standards, and a high degree of accountability for all battery products, showing a clear shift towards circular economic standards.

This culminating experience project explores the role of collaborative initiatives and innovative technological frameworks, particularly, blockchain, smart contracts, and Nash equilibrium game theory, in addressing sustainability challenges within the EV ecosystem. The research questions are: (RQ1) *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?* (RQ2) *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?* (RQ3) *Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

The findings for each question are: (Q1) The partnership among RCS, IBM, Ford, exemplified how integrating blockchain into a circular economic framework can establish oversight, ensure accountability, and enable informed decision-making with traceable and transparent data circularity. Ford notably improved its cobalt due diligent management system, marked by a notable forty-six percentage point within one year, demonstrating its commitment to responsible sourcing and regulatory compliance. (Q2) Private-permissioned blockchain networks, especially with smart contracts, automate performance obligations, without an intermediary interaction, strengthening self-governance within a decentralized network. The consensus mechanism, integral to blockchain architecture, enhances accountability among EV stakeholders by validating and authenticating transactions. Opting for a consensus algorithm, emphasizing participant reputation over computational power, reduces reliance on resources while maintaining network integrity. (Q3) EV stakeholders and their tier-1 suppliers, in a consortium, are incentivized to uphold their reputation and branding through adherence to ethical and sustainable practices facilitated in a blockchain network. By doing so, they contribute to the overall stability of the industry and the circular economic framework, as mutual benefits are maximized, unilateral deviations are discouraged, and collaborative dynamics are fostered.

The conclusions are: (Q1) EV producers involved in circular economic initiatives can be perceived as collaborative partners that prioritize collective success over individual gain, fostering positive brand associations with teamwork and partnership. (Q2) By aligning incentives, fostering collaboration, and leveraging data-driven insights, EV producers and their suppliers can optimize resource use, minimize waste, and contribute to the transition towards a more sustainable economic model. (Q3) By adhering to ethical and sustainable practices the equilibrium ensures that EV stakeholders maintain trust and credibility, promoting a sustainable ecosystem for the EV industry within the circular economy.

Areas for further study should include prioritizing three fundamental areas: electric vehicle battery (EVB) end-of-life circularity, the development of recycling infrastructure, and the assessment of regulatory frameworks in promoting material circularity within a circular economy. It is urgent for collective action to address critical challenges such as supply chain disruptions and environmental impacts. These recommendations are timely in light of upcoming regulatory measures focused on holding all EV producers accountable for material reuse and recycling.

ACKNOWLEDGEMENTS

In sincere gratitude to the esteemed members of the California State University, San Bernardino Committee, Drs. Conrad Shayo and Lewis A. Njualem.

Your encouragement and support throughout my journey with this project have been nothing short of extraordinary. Your willingness to share not just your time, but also your vast wealth of expertise, has served as a guiding light, inspiring me every step of the way.

Dr. Shayo, having dedicated the past 25 years to the legal field, the prospect of transitioning into a new career path that merges legal expertise with information technology felt overwhelming. However, your consistent reassurance that such a transition is not only possible but also promising has been invaluable. Your profound statement, “Blockchain is the law,” resonates deeply with me and will continue to influence my endeavors. The impact of your mentorship during my time at CSUSB will undoubtedly endure for years to come.

With the deepest respect and gratitude.

DEDICATION

To my husband, Christopher. My rock, My protector. In our journey together, you are my unwavering compass, my "True North." From the moment we shared our first cup of coffee at the crossroads, you've given upon me a deep sense of contentment and fulfillment. With you, I have discovered the rare gift of remaining authentically true to myself even in the middle of life's challenges and complexities. Most importantly, your unwavering support has been a constant light of encouragement and understanding, providing me with the strength to navigate any challenge. In a lifetime filled with uncertainties, you stand as my singular, reliable pillar of support. Words cannot express the depth of gratitude I feel for your presence in my life. There will never be enough "Thank You's" to express my deepest love and appreciation I have for you. I Love You and thank you. *To My Christian*. I Love You and Thank you, to both you and the *Baby* Kumes, for being the brilliant ray of sunshine in my "Good Mernin'!" You are the morning's first light that brightens every single day. You are always playing a significant role in my journey towards success. Your continuous patience with your Madre is deeply appreciated, and I have no doubt your patience will lead to wonderful rewards in the future. *Chaise and Hannah*. Grammy is always considering the future and possibilities beyond the present moment. You have been a significant source of inspiration. Soon, Hannah will be boasting to your resourcefulness saying, "*My mommy can do anything*." I Love You. *For Grandma Mary*.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE:

INTRODUCTION

"Waste Equals Food" – Paul Hawken, 1994 "Toward a Restorative Economy"

Background and Context of Study

The impact of proposed regulatory compliance measures and subsidies, designed to influence the rate at which electric vehicles (EVs) are adopted, is a subject of considerable interest and debate, as emphasized by the (IEA, 2023). Such incentives are regularly evaluated for effectiveness, proposed revisions are made as global spending on EV and battery manufacturing trends and technical developments continues to increase (IEA, 2023). Subsidies reduce the financial burden on consumers, making EVs more affordable and appealing when compared to traditional internal combustion engines (ICEs) (Brown, 2024). Incentives for automotive original equipment manufacturers (OEMs) encourage investment in EV production and technology, stimulating innovation and expanding the availability of EV models in the market. Subsidies for consumers and incentives for automotive OEMs serve as synergy mechanism for a transition toward EVs adoption (Smartcar, 2024) (Darin Buelow, 2023).

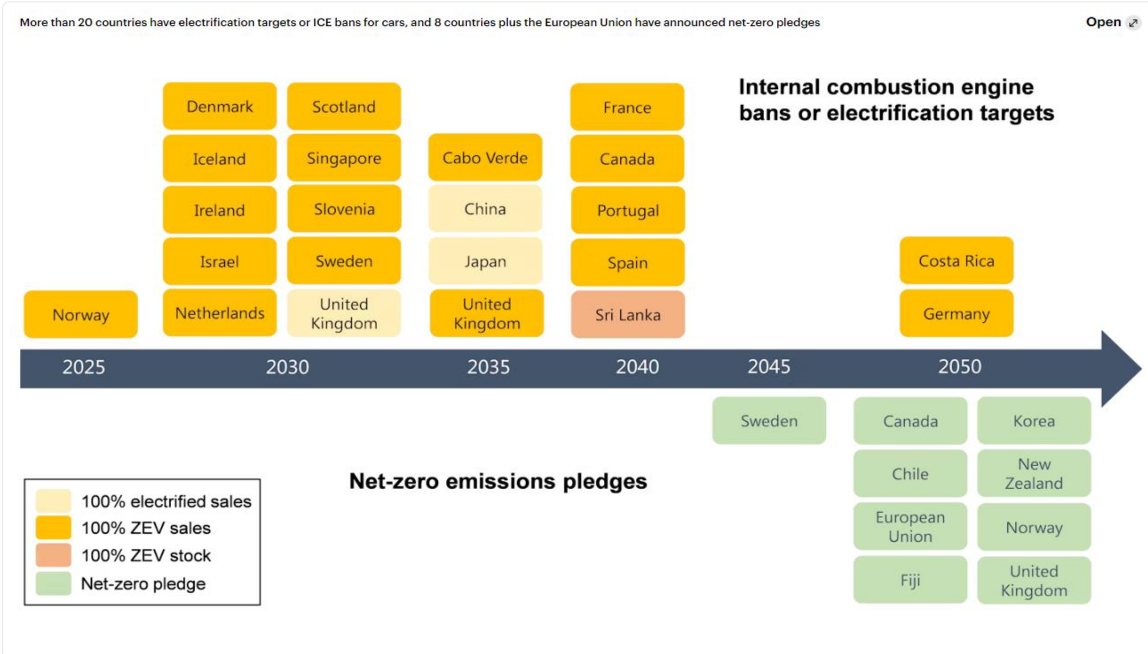
In early 2021, nine European Union (EU) countries urged the EU to accelerate an EU-wide phase-out of petrol and diesel cars (IEA, 2021). This initiative resulted in legislation to enforce national bans on ICEs, illustrated in

Figure 1 Internal Combustion Engine Bans or Electrification Targets (IEA, 2021) .

In addition to EU policies and directives, countries in Europe continue to offer EV subsidies and propose incentive measures. By the end of 2021, significant initiatives were instituted by key EV markets, which stimulated the major expansion of EV models, which included the EU CO2 emissions regulation for cars and China's New Energy Vehicles (NEV) mandate. Within the United States, California's 2020 Executive Order N-79-20 requires that by 2035 all new car and passenger light truck sales be Zero-Emission Vehicles (ZEVs)[1]. For other states across the nation, California is setting the pace for emission standards, which are far more stringent than federal standards (CARB, 2023). While regulatory measures and incentivized adoption for EVs presents opportunities for reducing emissions and promoting sustainability, it also poses complex challenges.

[1] CAP14-20200923101349

Figure 1. ICEs Bans or Electrification Targets (IEA, 2021)



The European Union Council has demonstrated pioneering efforts in the enactment of regulatory frameworks related to battery recycling specific to portable, industrial, automotive, electric vehicle (EV) and light means of transport (LMT) batteries (EU Regulations, 2023). Directives and regulations are targeted at promoting recycling and proper disposal of batteries to minimize environmental impact and encourage the reuse of valuable materials. By adopting new regulations to strengthen sustainability, this demonstrates the EU's primary incentive, "…*such measures are crucial for the transition to a* ***circular*** *and climate-neutral* ***economy.***" (EU Regulations, 2023)

The most recent legislation enacted on July 12, 2023, *Regulation (EU) 2023/1542* ("EU Regulation")[2], establishes battery regulations for every industrial or electric vehicle battery (EVB) on the EU market. Batteries with a capacity of over 2kWh will unequivocally require a battery passport. A battery passport is a digital system that stores relevant battery data along the entire battery lifecycle. Regardless of a battery's origin it will require a battery passport before it will be placed on the EU market. The placement of this digital system will be the responsibility of the producer (or economic operator) placing the battery on the market. This prerequisite is to ensure that all relevant data required for market placement or put into service is entered into a digital records system, ensuring all information is correct and up to date.

Due to the high number of battery components and the complexity of the manufacturing processes, a "*system boundary*" has been established by EU Regulations. The components and their processes must be identified throughout the battery life cycle stages, illustrated in *Table 1*. Battery passports will require producer-specific and secondary datasets from the following industry producers: (i) mining and refining, (ii) cell and battery manufacturers, (iii) automotive OEMs, (iv) battery servicing, refurbishing, and recycling.

[2] Regulation - 2023/1542 - EN - EUR-Lex (europa.eu)

Table 1. Life cycle stages and the processes involved included in the system boundary.

Life cycle stage	Processes involved
Raw material acquisition and pre-processing	Includes mining and other relevant sourcing, pre-processing and transport of active materials, up to the manufacturing of battery cells and battery components (active materials, separator, electrolyte, casings, active and passive battery components), and electric or electronic components.
Main product production	Assembly of battery cells and assembly of batteries with the battery cells and the electric or electronic components
Distribution	Transport to the point of sale.
End of life and recycling	Collection, dismantling and recycling.

EU Regulations advocate for a comprehensive and equitable distribution of responsibility and costs throughout the lifecycle of batteries, ensuring that all economic operators involved in their production, preparation, and disposal share the burden of environmental impact and waste management. EU Regulation, Section 102 explicitly states:

> “*Extended producer responsibility should apply also to economic operators placing on the market a battery that results from preparation for re-use, preparation for repurposing, repurposing or remanufacturing operations. Therefore, the economic operator that originally placed the battery on the market should not bear the*

> *additional costs that could result from the waste management arising from the subsequent life of that battery. It should be possible for the economic operators subject to extended producer responsibility to establish a cost-sharing.*"

By implementing clear end-of-life requirements such as collection targets, material recovery goals, and extended producer responsibility, EV producers are held responsible for managing the entire lifecycle of batteries. These provisions prevent producers from transferring risks onto each other, creating a state of balance or stability in the EV industry. Additionally, recycling efficiency and material recovery targets for specific elements are outline in *Table 2*, identifying proposed deadlines for recycling and treatment facilities for batteries. With the recent adoption of stringent regulations by the EU Council aimed at bolstering sustainability standards, and a high degree of accountability for all battery producers, this clearly represents that a firm shift towards *circular economic* standards is underway. A review of market trends will show why a transition towards a circular economic standard, supported by regulations, is relevant.

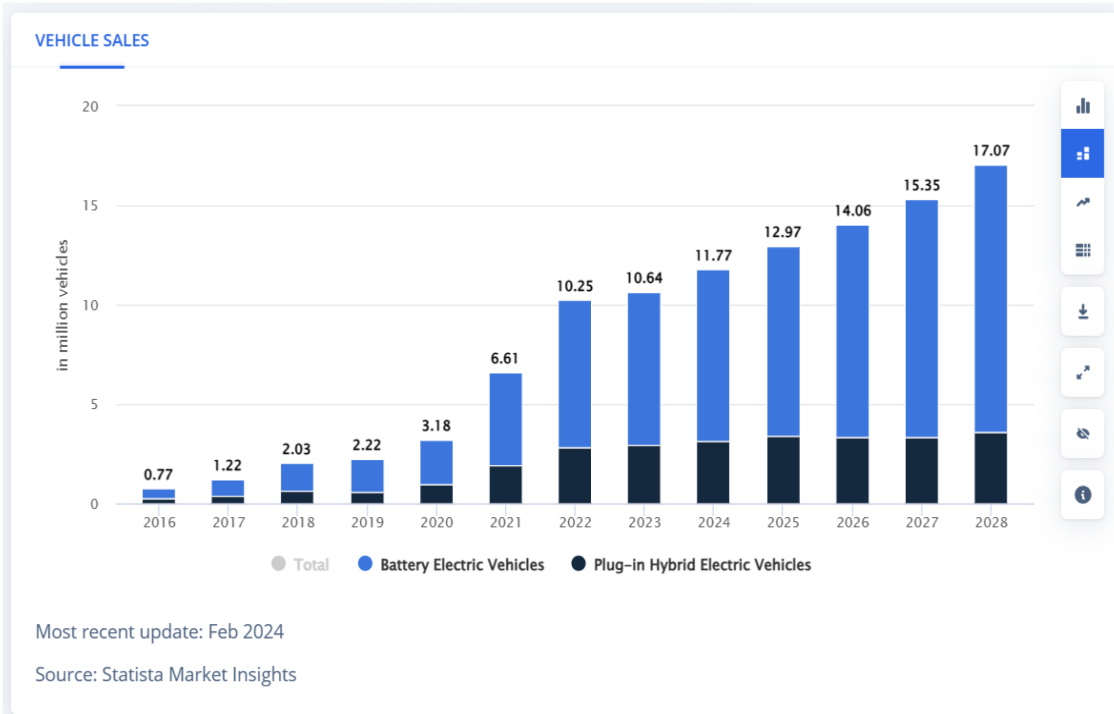
Table 2. EU's established targets for recycling efficiency and recovery of materials.

EU Regulations Targets for Recycling Efficiency			
Batteries	**Dec 2025**	**Dec 2030**	
Lead-acid	75%	80%	
Lithium-based	65%	70%	
Nickel-cadmium	80%		
Other Waste	50%		
EU Regulations Targets for Recovery of Materials			
Materials	**Dec 2027**	**Dec 2031**	
Cobalt	90%	95%	
Copper	90%	95%	
Lead	90%	95%	
Lithium	50%	80%	
Nickel	90%	95%	
EU Regulations Collection Targets for Waste Portable Batteries			
	Dec 2023	**Dec 2027**	**Dec 2030**
Portable Batteries	45%	63%	73%
EU Regulations Collection Targets for LMT Batteries			
	Dec 2028	**Dec 2031**	
Waste Batteries: Light Means of Transport Batteries	51%	61%	
EU Regulations Collection Targets for External Storage, Electric Vehicle & SLI batteries			
Materials	**Aug 2031**	**Aug 2036**	
Cobalt	16%	26%	
Lead	85%	85%	
Lithium	6%	12%	
Nickel	6%	15%	

Research conducted by Canalys indicates that 2024 should expect a potential decrease in EV subsidies for stakeholders, which could potentially diminish consumer appeal (Reuters, 2024). This shift comes on the heels of a significant growth surge in 2023, with sales surging by 29% reaching 13.7 million units sold (Canalys, 2024). Nonetheless, projections suggest a slight moderation in this growth rate to 27.1% in 2024. Faced with the prospect of declining demand for Battery Electric Vehicles (BEVs), a pivot towards Plug-in Hybrid Electric Vehicles (PHEVs) could alleviate market pressures, even amidst a vigorous global push for an ICE phase-out (Canalys, 2024).

If projected estimates hold true, EV stakeholders, including BEV and PHEV OEMs, charging infrastructure networks, and tier-1 supply chains, should prepare for either potential obstacles or increased production in the 2024 fiscal year (Smartcar, 2024). Consumer demand for greener and smarter cars surged between 2020 and 2023, as illustrated in *Figure 2* (Statista, 2024), driving innovation, and prompting pursuits of ambitious OEMs and numerous EV stakeholders to meet the demands of existing EV consumers, while attracting potential new buyers (Smartcar, 2024); (Dhondiyal, 2020). To ensure ongoing success in the EV market, stakeholders should prioritize factors favorable to consumers' economic welfare like warranty longevity, ease of maintenance, and resale value, while also integrating sustainability measures moving forward (Zhao, 2021). Despite possible challenges, the EV industry remains resilient, with a forecasted sale of 16.7 million BEVs and PHEVs in 2024 (Bloomberg, 2023).

Figure 2. Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) Sold Worldwide (Statista, 2024)



The evolving perception of EVs from being seen as a “green” alternative, is now transitioning towards one that is recognized as ethical, circular, and responsibly sourced (EU Regulations, 2023). Acknowledging that they contribute to sustainability issues, EV OEMs can pave the way for rectifying sustainability practices. Consumers increasingly value and expect EV OEMs to demonstrate active commitment to recycling and waste reduction. To encourage consumer awareness, EV OEMs must exemplify transparent responsible sourcing and promotion of material circularity. As projections hint of a potential decrease in demand, EV OEMs must capitalize on this moment to preserve a place in the EV market, such as readdressing current adaptive decision-making strategies. The strategies implemented must integrate sustainability considerations into operational internal controls throughout the battery manufacturing life cycle (Kshetri, 2022).

Considering the number of EVs currently on the road and potential increase in sales, there will be a pressing need for effective battery recycling and disposal solutions. The EV industry faces potential production challenges, particularly in the sourcing, manufacturing, and lifecycle management of critical minerals and raw materials (Cheng, 2022). The EV industry relies heavily on a steady and diversified supply of critical minerals such as lithium, cobalt and rare earth elements (R.C.S.Global, 2017). The *finite* nature of mineral resources poses long-term challenges. The supply chain for minerals is often concentrated in a few countries, posing geopolitical risks, disruptions, and price volatility. With rising demand, there may be concerns about the availability and accessibility of key materials, potentially leading to supply shortage and increased costs. Efforts to address these challenges may include diversifying mineral sources, developing recycling technologies, and promoting responsible mining practices[3]. Now, the focus shifts to accountability and sustainability within the EV industry sector.

To foster meaningful strides in sustainability and accountability, EV stakeholders must initiate comprehensive assessments of their current strategic

---

[3] 2023 Policy Brief Aligning CRMs-062823_0.pdf (un.org)

decision-making processes, specific to their current supply chain ecosystem (Gao, 2022). This system of operations offers a collaborative option to produce and deliver a product to a viable market. Supply chain disruptions present both challenges and opportunities for the global EV industry. Strategic decision-making must anticipate responses to disruptions, adherence to regulatory compliance, minimizing negative impacts and enhancing resilience in the face of uncertainty. Strategies should prioritize material provenance integrity throughout the supply chain lifecycle, from initial sourcing upstream production to end-of-life circularity (R.C.S.Global, 2017).

Proactive measures to address the environmental impact of EVB end-of-life (EoL) is poised to emerge as a pivotal issue in material circularization for the EV industry (Zhao, 2021). As established by *EU Regulation*, future requirements will mandate resource recapture and reintroduction into circularity, environmental benefits, and real-time data availability. Government regulations and consumers will want to know the intent of the EV stakeholders with evidentiary proof by way of data collection and analysis, without political posturing. Furthermore, EV stakeholders should forge alliances with like-minded competitors, engaging in communications with those aligned with responsible sourcing and circular practices (R.C.S.Global, 2017). This type of communication excels at promoting the exchange of best practices for resource and product reuse at the end of their useful life (da Silva, 2023).

The EV industry is currently presented with an exceptional opportunity to establish a collaborative and cohesive industrial ecosystem operating within a responsible sourcing economic framework. This opportunity allows for transition from a linear economy to a circular one, effectively closing the loop on waste. A move towards a collaborative circular economic ecosystem will also aid in determining which products must be prioritized as limited resources. In seizing this transformative opportunity, the EV industry should not only aim to minimize waste but also leverage technological innovations for this purpose (Kshetri, 2022). Innovative technology must enhance digital transparency and traceability within a circular economy, facilitating the creation of secure, immutable ledgers to track the life cycle of products, materials, and resources. (Calvão, 2021).

The circular economy (CE) concept was designed to manage products for continual resource use in a closed loop environment (Grati, 2023). A closed-loop supply chain, a specific aspect of CE, focuses on collecting, processing, and reintroducing products and materials back into the production lifecycle (Guo, 2024). Successful CE implementation and collaboration among stakeholders ensures shared profitability and waste reduction (Zhao, 2021). Incorporating technology to incentivize stakeholders can facilitate optimal data collection and analysis, acting as a catalyst towards a trusted and collaborative consensus (da Silva, 2023).

In the EV industry's current linear supply chain, different stakeholders play distinct roles, often driven by self-interest (Gao, 2022). Transitioning toward a circular economy through technological methods means the reliance on a decentralized digital ledger platform capable of tracking an EV's lifecycle from inception to end-of-life. This platform must facilitate participation from all stakeholders, ultimately improving accountability among them (Gao, 2022). This study aims to enhance equilibrium in a circular economic ecosystem, aligning with the EU Regulations that emphasize shared responsibility and equality. Ultimately, this concept requires a high degree of transparency from all stakeholders (Malinauskaite, 2021).

Transparency is crucial for accountability, enabling oversight and evaluation of the decision-makers' actions within the EV ecosystem. By promoting transparency, organizations strengthen accountability mechanisms, ensuring fair and ethical decision-making aligned with stakeholders' interests and regulatory compliance. A decentralized ledger technology (DLT) platform, within a circular economic framework, offers a distinct chance to bolster accountability especially when coupled with game theory concepts such as Nash Equilibrium (Gao, 2022). Incorporating game theory incentivizes stakeholders to act in ways that maximize efficiency and resource sustainability, potentially resulting in a stable CE ecosystem (Gao, 2022).

Studies show DLT platforms, specifically Blockchain, ensures the security and immutability of ledgers with applications already implemented in various industry sectors including E-commerce and supply chain management (Gao, 2022). However, DLTs full potential remains underutilized in both the EV ecosystem and CE framework. By integrating Nash Equilibrium into Blockchain architecture, EV stakeholders can identify, through predictive analytics, stable states where strategic choices foster cooperation, trust, and sustainability within a CE framework (Gao, 2022). The combination of blockchain technology's security and immutability, aligned with game theory concepts, plays a crucial role in improving accountability mechanisms, offering a groundbreaking solution.

Access to fundamental information is essential for optimal functionality and success of a CE ecosystem (Jäger-Roschko, 2022). Information accessibility in real-time is essential to overcome any barriers hindering a direct pathway to CE (Jaeger, 2020). Revamping EV industry strategies to include technical and technological documentation, sustainability practices, and CE principles is crucial to mitigating environmental impacts, adherence to regulatory compliance, and industry demand (Ovaitt, 2022). These efforts result in effective internal controls for data gathering and governance (Baars, 2021), contributing to long-term sustainability in the global supply chain consciousness and sustainable development goals (Ovaitt, 2022).

The increasing incentivized adoption of EVs presents accountability challenges relevant to a EVBs second life battery (SLB) use or its EoL disposition. This is particularly pertinent as EVB design, production, and technical compositions vary among competitors, lacking standardization (Garrido-Hidalgo, 2020). Stakeholders are encouraged to openly transmit and deploy data related to an EVB's lifecycle on a decentralized battery management tracking system

(Baars, 2021). By engaging in this type of tracking system, the outcome becomes an immutable chain of custody available in real-time for trusted competitors, tier-1 suppliers, and recyclers (Sheth RP, 2023). Chronicling a chain of custody for a EVB lifecycle can become an industry standard, driving focus on resource reduction and waste minimization (Sheth RP, 2023).

DLT capabilities offer the innovative potential to revolutionize industry standardization within a CE (Upadhyay, 2021). Leveraging a DLT platform tailored for monitoring the lifecycle of an EVB ensures the integrity of data collection and governance, ensuring it is verifiable, transparent, and traceable. Further emphasized by (Knieke, 2019), this enhances the accuracy and reliability of predictive analytics. A virtual genealogy of a single battery's lifecycle, founded on accountability and trust, improves predictive analytics and industry standard development (Sundarakani, 2021). The end goal is to sustain resources in a CE value chain for as long as they remain viable (EllenMacArthurFoundation, 2024). Without standardized guidelines for data collection benchmarks, sustainability and accountability within the CE value chain for the EV industry will not thrive, but will continue to persist as the *status quo* (Chamberlain K, 2021). Consequently, the absence of standardized guidelines, may hinder voluntary adoption of decentralized solutions in the EV industry (Harris, 2019).

In an EVB ecosystem, the adoption and integration of blockchain-based smart contracts is another key component by which traditionally privately owned sectors can be induced toward a verifiable, traceable, and transparent open forum of data distribution (Frizzo-Barker, 2020); (O'Shields, 2017). This open forum emphasizes the importance of this type of solution within a CE. Blockchain and smart contracts provide reliability and establish standardized methods for data collection (Deepa, 2022). Smart contracts offer automation, enforceability, immutability, and efficiency advantages over traditional legal agreements. However, legal agreements provide flexibility, familiarity, and interpretation advantages that may be preferred or required in certain contexts (De Filippi, 2018). Depending on the specific requirements and circumstances of a transaction or agreement, parties may choose to use smart contracts, legal agreements or a combination of both to achieve their desired outcome (De Filippi, 2018).

It is critical to note, that while smart contracts offer significant benefits in streamlining transactional activities and reducing the need for legal intervention, it is essential to know that they may not completely eliminate the need for legal advocates (such as attorneys) in all scenarios. Complex or high-stake transactions may still require legal expertise to ensure compliance with regulations, mitigate risks, and address unforeseen circumstances. Additionally, legal oversight and consultation may still be necessary to ensure that smart contracts accurately reflect the parties’ intentions and adequately protect their interests. This is further supported by (De Filippi, 2018) Pgs. 34-35, which indicates as follows:

> "*The distributed and transnational nature of blockchains, however, comes with tradeoffs, the larger and more distributed the blockchain-based network, the more complex and challenging it is to manage. Most blockchain-based protocols are open source software, developed by loosely connected team software developers, who often work on these systems on a vocational basis. These programmers may be skilled and technically proficient, but they often operate outside the formal organizational structures or legal entities, which are responsible for operations…*" (De Filippi, 2018), Pg. 52, further stating, "*As with other technologies, blockchains and smart contracts are capable of both circumventing and complementing law – depending on the developers' desired outcome.*"

The latter of the statements referenced by (De Filippi, 2018) must be judiciously highlighted, "…*depending on the developers' desired outcome*." Overall, the statements above point toward several key points: (i) there is no central authority controlling the network, (ii) open-source protocols are freely available for anyone to view, use, and modify, development and maintenance are made through decentralized consensus mechanisms rather than by a central authority, and (iii) they have the potential to impact legal systems that both circumvent and complement existing laws, all subject to a developers' desired outcome or intent. The proposition is that blockchain-based technology can be used to create systems that operate independently of traditional legal frameworks or that interact with them in new and innovative ways. Furthermore, as this study examines the multifaced implications of blockchain-based technology outlined above, it becomes evident that benchmarking against distributed ledger frameworks emerges as another crucial step toward leveraging its potential across the EV industry, within a CE.

One component of this project is to discuss development of a baseline or benchmark for the EV industry by leveraging blockchain-based solutions in a CE ecosystem (Kristoffersen, 2020) The EVB mineral and material provenance is the starting point from which a virtual fingerprint will enter the CE ecosystem (Schöggl, 2023). The output of the virtual fingerprint will be the quantifiable and qualifiable sole source of immutable transformative data distribution, by which predictable analytics can forecast future outcomes of EVB minerals and material composition (Pons, 2022). Data imported into a Blockchain network, governed by smart contract algorithmic terms, can be no more or no less than that, just data related to the composition of the EVB. Data would be comprised of *only* the raw mineral data, material composition, SLB use, and EoL disposition of materials placed back into an EV ecosystem's circularity (Júnior, 2022). Similar to the EU Regulation battery passport, which tracks a battery throughout its lifecycle for the *discretionary* purpose of *producers* to meet regulatory standards, the "virtual fingerprint" is a snapshot stored within a Blockchain network. It can be recognized as the *immutable* "Battery Fax" and provides information on battery composition for *all* EV stakeholders. Blockchain-based smart contracts are the fundamental underpinning to secure the confidence and security for data distribution among EV stakeholders (Arora, 2022). Data collection begins at the point of acquisition, raw mineral and material extraction, progressing through cell production, battery manufacturing, subsequent second life or third-life reuse, repurposing, or recycling (Júnior, 2022).

The proposed single point of entry baseline or benchmark will focus on the data collected related to raw material values (Thuraisingham, 2020). Data collected will not disclose the producer's proprietary information specific to EVB design and build. The data will remain relevant to battery critical mineral and material composition, only. (Li, 2018). This benchmark is based on creating a "virtual fingerprint" to enable data collection without disclosing respective EV industry stakeholder trade secrets. The immutability of blockchain and smart contracts, supported through partnerships among EV industry stakeholders, ensures that the data captured will never change its focus and purpose (Hu, 2018) This process enables the EVB to have an immutable lifespan, resulting in an unbiased, industry standard baseline or benchmark (Hua, 2018). This also aligns with the measures proposed by EU Regulations.

This study proposes a comprehensive perspective of accountability within an EVB ecosystem, advocating for the incorporation of DLT solutions such as blockchain and smart contracts. Leveraging DLT solutions for benchmark standardization enables collaborative data-driven approaches to measure environmental impacts and EVB content and usage variables (Picatoste, 2022). By focusing solely on data related to EVB raw mineral and material composition, while preserving stakeholder proprietary information, this solution incentivizes sustainability collaboration (Sanni, 2021). This holistic approach enhances accountability by establishing a digital chain of custody, fostering collaboration and transparency among EV stakeholders (Calvão, 2021); (R.C.S.Global, 2017). This decentralized system allows for data-driven oversight from extraction to consumption, raising transparency, accountability, and sustainability standards (Kshetri, 2022).

Furthermore, integrating CE principles with blockchain-based smart contracts, and game theory dynamics offers transformative potential for the EV ecosystem (Kumar, 2022). By incorporating Nash Equilibrium principles into smart contracts algorithm design, stakeholders can optimize resource allocations efficiently and sustainably, adapting to changing market conditions and preferences (Gao, 2022). This interdependent relationship redefines sustainability and accountability, driving progress in the EV ecosystem where ecological responsibility, technological innovations, and strategic decision-making converge.

Problem Statement

Blockchain technology and game theory principles have been widely explored across diverse sectors such as E-commerce, supply chain management, and logistics, leading to innovative solutions. However, a significant gap exists in applying this approach within the electric vehicle (EV) ecosystem, within a circular economy context. No comprehensive exploration has been done on establishing sustainable verifiable consortiums among supply chain collaborators in the EV industry, using blockchain technology and Nash Equilibrium game theory.

For the EV industry, there exists a pressing need for further analysis of the strategic integration of blockchain technology within a circular economic framework. This integration holds the potential to generate cooperation among EV stakeholders, thereby addressing challenges related to oversight, accountability, and adaptive decision-making. However, to effectively leverage blockchain technology, it is imperative to examine its application through private-permissioned networks and smart contracts, to ensure transparency, traceability, and sustainability throughout the lifecycle of electric vehicles. Understanding the incentives and potential outcomes of engaging in a blockchain-driven consortium, coupled with Nash Equilibrium game theory, is essential for EV industry stakeholders to make informed decisions and realize the full benefits of such collaborations. Therefore, this research goal is to provide a perspective for the strategic implications of blockchain technology within the EV ecosystem and provide a perspective into this transformative potential on stakeholder dynamics and industry sustainability

Research Questions

The gaps identified in research studies centers on sustainability objectives, decision-making processes, the integration of blockchain-based technology in supply chains, particularly in the context of mineral supply and electric vehicle battery (EVB) supply chains. These gaps include developing new key performance indicators (KPIs), data-driven decision-making techniques, exploring best practices, understanding mechanisms for effective decision-making, and advocating for the adoption of blockchain to promote transparency and traceability during the transition to circular economies. Additionally, deficiencies in traceability systems, incentive mechanisms, and governance structure are noted, along with the need for future research on second-life battery (SLB) market mechanisms and regulatory compliance challenges. Overall, the gaps emphasize the complexity and significance of integrating blockchain-based technology into supply chains to address sustainability challenges and facilitate circular economies effectively. Based on the examination of existing research, the following research questions will be addressed:

Research Question 1: *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?*

Research Question 2: *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?*

Research Question 3*: Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

Organization of Study

This project is organized as follows: Chapter One frames the relevant topics, provides background and context of study, and creates a setting for the problem statement and research questions. Chapter Two provides an expansive literature review of scholarly works related to the following technologies, principles and concepts: decentralized ledger technology (DLT) such as blockchain, smart contracts, game theory concepts, like Nash Equilibrium, altogether relevant to the electric vehicle (EV) industry sector, within a circular economy. Additionally, the literature review outlines the relevant methods to support case study analysis, findings and gaps in existing research. Chapter Three describes the research method supporting a multiple case study approach used to answer the research questions. Chapter Four provides a comprehensive analysis of three case studies encompassing multiple industries or domains currently supporting the EV ecosystem. Chapter Five provides a brief discussion, conclusion and offers recommendations of areas for future study.

CHAPTER TWO:

LITERATURE REVIEW

This section is a review of scholarly works that divides the research into four major concepts: blockchain technology, smart contracts, game theory concept (specific to Nash Equilibrium) and the circular economy. The review includes peer-to-peer literature reviews, exploratory research, case studies, analyses of blockchain consensus mechanisms, empirical research, and structured interviews with subject matter experts. Articles published between the years 2017 and 2023 were included to ensure relevance and up-to-date data, covering approximately six years of scholarly research. This timeframe aligns with the rapid evolution of blockchain-based technology, smart contracts, and game theory, reflecting their emergence and significant development. Focusing on recent publications is crucial to capture the novelty and evolution of these concepts. The period marks the transition of these technologies from obscurity to mainstream awareness, prompting a surge in research exploring their applications in both linear and circular economies. Restricting the literature review to articles from 2017 to 2023 capture a significant phase of growth, innovation, and maturity in blockchain, smart contracts, game theory, and their integration into the circular economy. This approach ensured a strong basis for analysis and discussion.

To support this project, due credit is accorded to the indispensable tool "Publish or Perish" developed by A.W, Harzing, serving as a vital resource for bibliometric analysis and facilitating comprehensive research impact assessment (A.W.Harzing, 1990-2023). The use of this software enhanced the precision and depth of scholarly evaluations, contributing to a more robust examination of academic contributions and citation metrics. Relevant journal databases include, but are not limited to: Google Scholar, Elsevier, IJEST, MDPI, Emerald Insight, Research Gate, Frontiers, ScientificReports, and a selection of published books. To gather further insight into the innovations that have been applied within the industry the following key players were considered, but not limited to, Volvo, Volkswagen, Ford, IBM, Circulor, RCS Global, Responsible Sourcing Blockchain Network (RSBN), and DRIVE Sustainability.

The Publish or Perish tool and Google Scholar expanded access to scholarly articles by aggregating content from various peer-reviewed sources. Initially, both tools produced approximately 150 results, refined to 30 peer-reviewed articles excluding citations and patents through keyword sorting. Further narrowing the scope, an analysis of an article's *Abstract*, resulting in 20 relevant articles supporting the project's focus. Keywords, and logical operators (AND/OR) refined the search, focusing on themes such as "battery electric vehicle," "electric vehicle," "traceability," "transparency," "sustainability," "blockchain," "smart contracts," "circular economy," "Nash Equilibrium," and “game theory.” This comprehensive literature review encompasses multiple disciplines to address the research questions effectively.

This literature review relied on diverse peer-reviewed articles, books, and credible sources to comprehensively explore the integration of blockchain-based smart contracts in a circular economy. This approach facilitates a nuanced understanding of the subject and identified gaps in the existing literature, resulting in a balanced and evidenced-based review. Incorporating various perspectives, methodologies, and findings was essential to reflect the diversity of research on the topic. The emphasis on factual accuracy, credibility, and reliability advances the robustness of the discussion and fosters informed discourse on the subject.

Blockchain for the Circular Economy

The concept of circular economy (CE) has evolved over time, drawing from diverse ideas and contributions from various individuals and organizations. Recently, the term “*circular economy*” has gained prominence as a framework for sustainable economic development. In this landscape, the Ellen MacArthur Foundation, founded in 2010, has played a pivotal role in advocating for a CE (Esmaeilian, 2020). Their model emphasizes minimizing waste, optimizing resource use, designing products with considerations for longevity and end-of-life considerations (EllenMacArthurFoundation, 2024). The CE value chain is represented by an integrated process comprised of upstream, midstream, downstream, and end-of-life circularity (Carreon, 2023). This value chain model is in line with the cradle-to-cradle strategy, which is gaining ground in contemporary manufacturing (McDonough, 2010). Cradle-to-cradle design and philosophy embodies the idea of recycling materials and products, encouraging designers to craft products that are capable of being reintegrated into new production cycles either through biological or technical means (McDonough, 2010).

The emergence of blockchain architecture for the CE is subject to ongoing research, experimentation, and implementation by multiple experts and organizations in the fields of blockchain technology and sustainable development (Kshetri, 2022). Evolving blockchain platforms are being integrated into responsible resourcing practices and supply chain management (Mugurusi, 2022). The resulting efforts shows a tamper-proof record of transactions providing a chain of custody based on *traceability, transparency*, and *trust*. (Gerasimova, 2023). For tracking product provenance, blockchain platforms offer a decentralized and secure way to collect and distribute data in real-time, making it an ideal tool where data circulation for product identification and monitoring is required (Júnior, 2022). The features of data immutability and reliability are present, but its transparency also fosters trust and collaboration among stakeholders, which in turn enhances the overall integrity of a supply chain within a CE (Kshetri, 2022).

Safeguarding the supply chain's integrity within a CE demands an accessible network or private-permissioned environment capable of real-time data storage. The high degree of privacy, security, and immutability it provides fosters confidence in its accuracy and authenticity of relevant data throughout a supply chain lifecycle (Kshetri, 2022). Proactively anticipating potential disruptions is imperative for preventing financial setbacks and production delays. Leveraging advanced technologies such as blockchain and smart contract features enables the prediction of delays, efficient supplier selection, and mitigating of sourcing inefficiencies (Gao, 2022). This pursuit of an integrity-driven supply chain is especially vital in industries facing challenges like counterfeiting, unethical practices, or environmental concerns (Kshetri, 2022). By integrating *immutable*, *transparent*, *traceable*, and *trustworthy* data into the supply chain, companies can build trust with consumers, enhance their reputation, and promote sustainability (Kumar, 2022).

By implementing a blockchain-based CE, this proves companies' commitment to embracing innovative technology coupled with advanced strategies to enhance resource circularity and secure the integrity of data distribution. Research shows the implementation of blockchain significantly benefits the CE ecosystem (da Silva, 2023). When industry aligns its strategies with the CE framework it can facilitate seamless collaboration, leading to improved efficiencies, reduction in waste, fosters an environment conducive to innovation, improved ethical and sustainable practices, and adherence to regulatory requirements (Chou, 2023).

To conclude, the evolution from a linear, resource-depleting model to a circular, sustainable one signifies progress for the EV industry. Research indicates that as industries adopt blockchain to close the loop on its supply chain, aiming to maximize the circulation of products, components, minerals and materials, they naturally prioritize reuse, remanufacturing, and refurbishment (Grati, 2023). This shift can result in the discovery of new revenue streams as industries innovate to capture previously overlooked value (Grati, 2023). Emphasizing resource efficiency and minimizing environmental impact, this model seeks to create a more resilient and sustainable system by closing the loop on material flows and promoting responsible consumption and production practices within the CE supply chain (Grati, 2023).

Blockchain Digital Consensus Mechanism in a Circular Economy

Blockchain technology is defined by its key features, which includes *immutability*, *distributed ledger technology (DLT), peer-to-peer network infrastructure*, *decentralization*, and *cryptographic* protection (Ahmed, 2022). A "**block**" in a blockchain is like a digital container holding a list of transactions, creating a ledger. A "**chain**" signifies the linkage of these blocks in a specific order, forming an unchangeable, chronological sequence of transaction records – the **"blockchain"** (Drescher, 2017). An underlying concept related to protection is the cryptographic hash value and is a function for identifying data, which can be viewed as the digital equivalent to a fingerprint (Bitcoin, 2008). The hash value is a digital fingerprint for a specified piece of data. Cryptographic hash functions create a compact and unique representation of data making it easy to check if anything has been altered (Drescher, 2017). This can be likened to a digital chain of pages in a ledger that keeps a secure and transparent record of transactions (Bitcoin, 2008). This concept is rooted in creating a trustworthy and unchangeable network for managing transactions through the application of cryptographic techniques (Grati, 2023). The cryptographic nature of the hash function ensures the security and integrity of the entire blockchain (Chadly, 2023).

To harness and use the benefits of blockchain technology, it is imperative to consider the role of independent participants (or nodes) and the part they play in a DLT environment. Nodes on a blockchain refer to the separate and distinct Internet of Things (IoTs), *the interconnection of computing devices via the internet enabling them to send and receive data*, which are authenticated and authorized to share data on a peer-to-peer network (Drescher, 2017). Node communication contributes to the overall state of balance and stability in the network (Grati, 2023). Deploying nodes, which adhere to validation rules, collaborate to achieve a collective agreement, ensuring that transactions (or blocks) undergo thorough verification and decentralized recording. These validation rules guarantee that only compliant blocks are appended to the blockchain-data-structure (Drescher, 2017). Nodes ascertain a collective agreement through consensus mechanisms like Proof of Authority (PoA) or Practical Byzantine Fault Tolerance Protocol (PBFT), alongside other mechanisms, including combinations thereof (Drescher, 2017). The validation process contributes to the overall transparency and trustworthiness of blockchain, aligning with its core features of immutability, security, and decentralization (Grati, 2023). Researchers at the Hyperledger Foundation emphasize the importance of selecting the latest consensus algorithms validated through rigorous academic research and peer-review, demonstrating of their safety and vitally essential properties (Hyperledger Foundation, 2020).

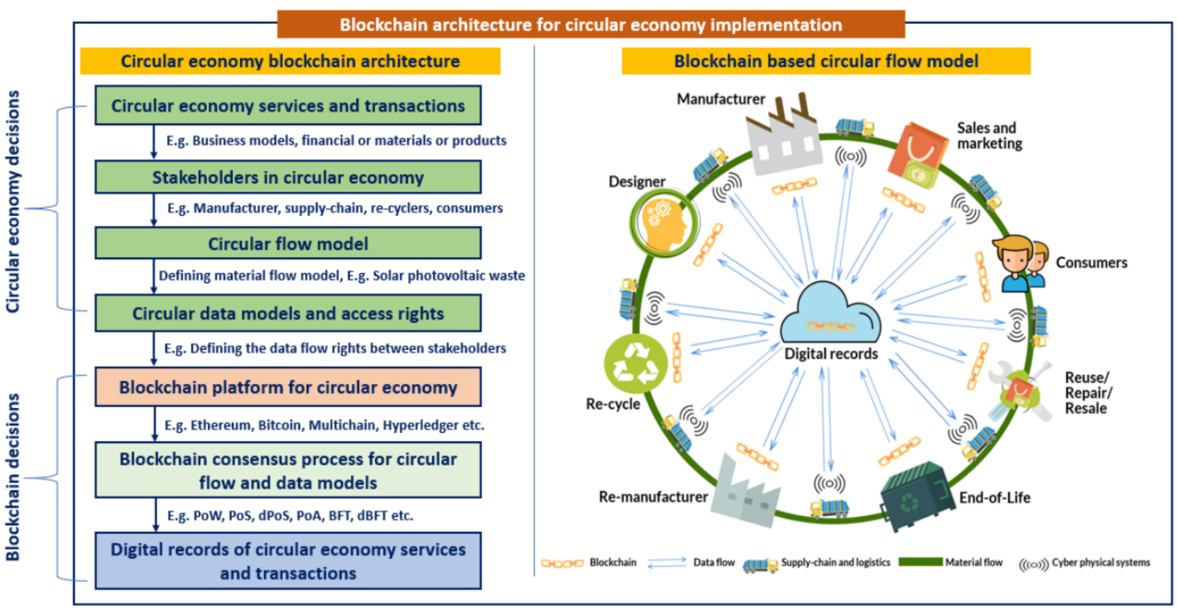
Validation rules on a blockchain are executed through a distributed consensus mechanism (De Filippi, 2018). A digital consensus requires a unanimous agreement among all nodes on the network, especially on the validity and chronological order of transactions appended or joined to the blockchain (Ahmed, 2022). Consensus mechanisms ensure a reliable balance in shared data distribution within a blockchain, even when nodes lack mutual trust or knowledge (De Filippi, 2018). Recognizing their significance is essential for achieving collective agreement among nodes and ensuring the integrity and security of the entire blockchain data structure (Chadly, 2023). Adopting blockchain consensus mechanisms in a CE, rather than a linear one, means leveraging the essential features to enhance transparency, trust, and coordination within a sustainable supply chain ecosystem (Kumar, 2022).

However, this transition presents challenges, notably the inability for unilateral decision-making among nodes.

Once a consensus mechanism is validated and joined to the blockchain data structure, it cannot be reversed. This emphasizes the importance of thorough research and testing before implementing a consensus mechanism in a blockchain network. Once it is in use, any changes or updates to the consensus mechanism would require careful consideration and potentially disrupt the stability and reliability of the blockchain network. Therefore, validation is an extremely important step in the long-term viability and integrity of the blockchain system. *Appendix A* presents a conceptual model wherein multiple nodes in a blockchain network receive and acknowledge a consensus request broadcast, initiating the consensus process among participating nodes. The blockchain's consensus mechanism primarily addresses the question of block construction and transaction packaging, serving as the cornerstone of its security, scalability, and decentralized characteristics (Mingxiao, 2017) (Deng, 2022).

(Kumar, 2022) presents a comprehensive framework comprised of seven steps for overcoming CE implementation challenges, referred to as the "*Circular Economy Blockchain (CEB),*" illustrated in *Figure 3*, the CEB architecture for implementing circular economy. This framework delineates the essential functionalities required for practicing CE principles and aids in classifying decision-making according to the roles of the stakeholders involved in CE endeavors. During the implementation of CEB, decision-making is expected to be influenced by two main categories: decisions pertaining to CE practices, and decisions relevant to the blockchain system. The first four steps of the framework are formulated around CE decisions, prioritizing the crucial functions of CE practices and the roles undertaken by stakeholders. The subsequent three steps focus on the decisions for the blockchain system in CE implementation. These latter steps are pivotal in defining the software architecture incorporating cryptographic functionalities.

Figure 3. Blockchain Architecture for Circular Economy Implementation (Kumar, 2022)



Blockchain has an ability to legitimize self-governance and enforce secure transactions among stakeholders by offering a decentralized and transparent framework for decision-making, a sustainable supply chain, and incentivized structures such as tokenization, thereby forging trust and accountability within the blockchain-based network (Gerasimova, 2023). A key advantage for the adoption of blockchain is its pivotal role in mitigating opportunistic behavior by emphasizing the importance of trust through consensus mechanisms (Chou, 2023). Furthermore, (Chou, 2023) argues that transaction data stored on a blockchain improves the reliability of data distribution among all stakeholders. (Kshetri, 2022) highlights key characteristics of blockchain technology and emphasizing its primary purpose for *recording*, *verifying*, and *validating* transactions. It is important to recognize blockchain's capabilities for fostering self-governance among network nodes. Its decentralized and transparent architecture encourages independent decision-making and incentivizes trustworthy data structures (Kshetri, 2022).

These findings, when considered together, underscore a potential benefit of leveraging blockchain technology in facilitating a trustworthy and collaborative system for sustainability within a CE (Gerasimova, 2023). In conclusion, the strategic application of blockchain consensus mechanism emerges as a powerful tool for promoting *transparency*, *trust*, and *accountability* (Kumar, 2022). These mechanisms significantly contribute to the success of CE initiatives. Furthermore, the following review, the integration of smart contracts will amplify the efficiency of blockchain technology by automating, enforcing predefined rules, conditions, and agreements, thereby streamlining a transactional chain of custody that enhances the overall efficiency and reliability of sustainable practices within a CE.

Smart Contracts and Traditional Contracts

Smart contracts are digital contracts stored on a blockchain and are automatically executed when predetermined terms and conditions are met, eliminating the need for intermediaries (Gao, 2022). Parties involved in a transaction or agreement interact directly with code, ensuring automatic enforcement of terms according to predefined rules (De Filippi, 2018). In a CE framework, smart contracts enforce compliance with predefined rules and impose penalties for rule violations (Gao, 2022). Smart contracts ensure adherence to preset rules and impose penalties for breaches. They function autonomously, deploying, executing, triggering actions, and overseeing validation (Gao, 2022). In contrast, traditional contracting relies on intermediaries for such tasks as legal enforcement of contracts, negotiations to mitigate breach of contract, and costly oversight (De Filippi, 2018).

Traditional contracting and blockchain-based smart contracts are designed to accommodate both unilateral (*one sided obligation*) and bilateral (*mutual promise*) agreements between parties for an exchange of transactional promises. The key feature is a focus on *performance obligations* (De Filippi, 2018). Performance obligations for traditional contracts are typically static and remain fixed once the agreement is executed. While on the other hand, performance obligations for smart contracts offers a more dynamic approach, where they can be programmed to self-execute and automatically adjust performance obligations based on specific conditions or events (Chadly, 2023). In traditional contracting, if the need arises for a modification on performance obligations, it always involves negotiation and mutual agreement between parties. This typically leads to contract amendments, often facilitated by a third party (Frizzo-Barker, 2020). Smart contract automation, powered by code, allows for real-time adaptation to changing circumstances without the need for third party intervention (Gerasimova, 2023). Consequently, a smart contract serves as a digital transaction protocol, facilitating the enforcement of negotiations and execution of the terms within an underlying legal contract (Gerasimova, 2023). This design aims to fulfill conditions such as payments, legal obligations, and autonomous enforcement, eliminating the need for third-party intermediaries (De Filippi, 2018). By removing the necessity for third-party intermediaries, smart contracts offer a novel approach to self-governance, or transactional oversight, through consensus mechanism validation.

When a smart contract is executed, the associated transactions need to be verified and joined to the blockchain, and consensus mechanisms play a crucial role in validating and confirming the execution of these contracts (Taherdoost, 2023). Consensus mechanisms, such as Proof of Authority (PoA) or Practical Byzantine Fault Tolerance Protocol (PBFT), are used to achieve agreement among network nodes on the validity of the transactions and the execution of the smart contract (Taherdoost, 2023). Smart contracts often include conditions that, when met, trigger the transfer of ownership (Taherdoost, 2023). Consensus mechanisms validate completed performance obligations according to the terms and conditions outlined in the validation rules encoded in the smart contracts. This guarantees accurate and secure transfer of ownership. Smart contracts function within a decentralized network where all nodes adhere to the rules defined in the code (Taherdoost, 2023). Consensus mechanisms maintain the integrity of rules across the network, preventing any single entity from tampering with or manipulating the smart contract logic. Differentiating blockchain networks may use various consensus mechanisms, and the choice depends on factors such as security, efficiency, and enterprise-specific goals.

The integration of smart contracts within a CE contractual environment, with a focus on performance obligations and transferring of ownership, emphasizes the potential of a DLT (De Filippi, 2018) (Júnior, 2022). The nature and functions of smart contracts which include *self-executing*, *immutability*, and *transparency*, combined with validation consensus mechanism makes it an innovative and efficient tool for automating, executing, and enforcing agreements in CE ecosystem. Smart contracts can be accessed and executed from anywhere, via an internet connection, providing global accessibility to contractual agreements. By eliminating intermediaries and automating processes, smart contracts can reduce transaction costs associated with traditional contractual agreements.

Given the nature of blockchain-based smart contracts, the relevance of game theory in a CE becomes increasingly relevant. Game theory offers insights into the strategic interactions among participants in DLT networks, influencing decision-making within an environment lacking inherent trust (Choi, 2020). Considering strategic factors, in a CE, coupled with the robustness of smart contracts and consensus mechanisms, this paves the way for a cooperative ecosystem that challenges traditional linear economy norms. By applying game theory principles, industry stakeholders can optimize strategies, incentives, and cooperation in a blockchain circular economy, ensuring a more resilient, equitable, and profitable future, fostering equilibrium in typically privatized and competitive industries.

Coordination Based on Game Theory

This section of the literature review examines earlier research, which integrated proof of concept built on advanced mathematical principles. Rather than delving into the sophisticated mathematical notions or formulas, it adopts a narrative approach to explore concepts like the Nash Equilibrium game theory. This study also considers the complex and intricate foundations of blockchain and smart contracts, which include cryptography, consensus mechanisms, and algorithms. To facilitate a clear understanding of concepts and principles, the focus will avoid unnecessary complexity.

Named after mathematician and economist John Nash, who introduced the concept in his doctoral dissertation in 1950 and later expanded upon it in his 1951 paper titled "*Non-Cooperative Games*" (Nash, 1951), Nash Equilibrium is a cornerstone of game theory. It signifies a scenario wherein each participant's strategy optimally responds to the strategies of all others, fostering a stable state where unilateral strategy changes yield no incentive, assuming other participants' strategies remain constant. This equilibrium underscores a balanced interplay where each participant's strategy represents the optimal response to the others' actions, a principle crucial in various disciplines, including computer science, technology and engineering (Gao, 2022). The "equilibrium" itself refers to a state of balance or stability, where the strategies of the participants are in equilibrium, and any deviation from this state would not benefit any individual participant.

Research conducted by (Gao, 2022) through a proof of concept, developed a blockchain-adaptive framework that incentivized participants to work together in a supply chain ecosystem to establish an equilibrium. (Gao, 2022) findings show that "*…blockchain possesses the necessary attributes needed in establishing a Nash Equilibrium and can be used to coordinate the supply chain in complex scenarios to ensure security, trust, and profitability*." Gao's proof of concept is based on transactions and bidding sessions between a set of suppliers and retailers. Gao's analysis highlighted blockchain's mathematical superiority in achieving an equilibrium, even among irrational parties. Furthermore, (Gao, 2022) proposed a self-enforceable contracting framework for establishing Nash Equilibrium, leveraging blockchain technology to calculate each participants expected payoff and profitability.

The integration of blockchain-based smart contracts not only ensures fairness but also enables equitable bargaining among multiple participants, providing valuable insights into the stability of decision-making (Gao, 2022). Under the research conducted by (Gao, 2022) the research implementation details incorporate sophisticated algorithms, exemplified by pseudocode, for *negotiation*, *bidding*, *expected retailer cost*, *expected supplier cost*, *total expected profit*, *supplier's optional order quantity*, *retailer's optimal order quantity* and *optimal order quantity*. An example of Gao's pseudocode is illustrated in *Figure 4*.

Figure 4. Gao Pseudocode for the 'Negotiate' Algorithm (Gao, 2022)

Algorithm 1: Pseudocode For Negotiate()

This is a mechanism that allows parties on the supply chain to decide whether to negotiate or not.

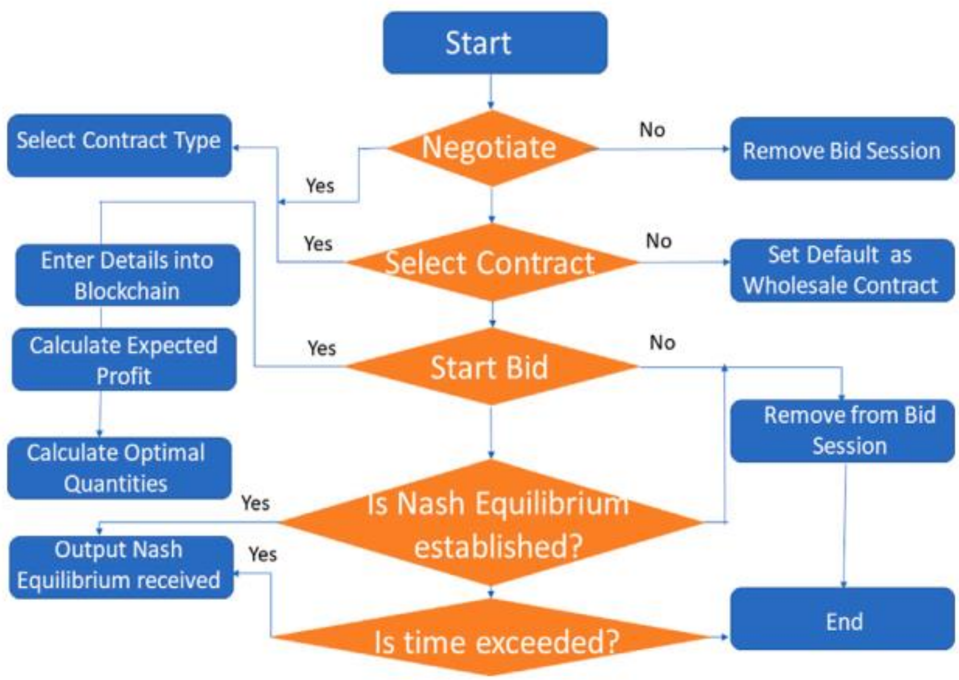
Require: INPUT Negotiation Id *NI*, Entity's Address *EA*, Entity's Name *EN*, Entity Role *ER*, Contract Type *CT*

Ensure: OUTPUT Agree to Negotiate *AN* to *true*

Enter into Negotiation Base *EA* , *PTP* , *PR*
Specify time as *time*
Specify counter as *counter*
For each Entity *EA* in Negotiation Base **do**
if Agree to Negotiate *AN* is *true* **then**
Specify Contract Type as *CT*
StartBid()
else
return *false*
endif
Do nothing
end

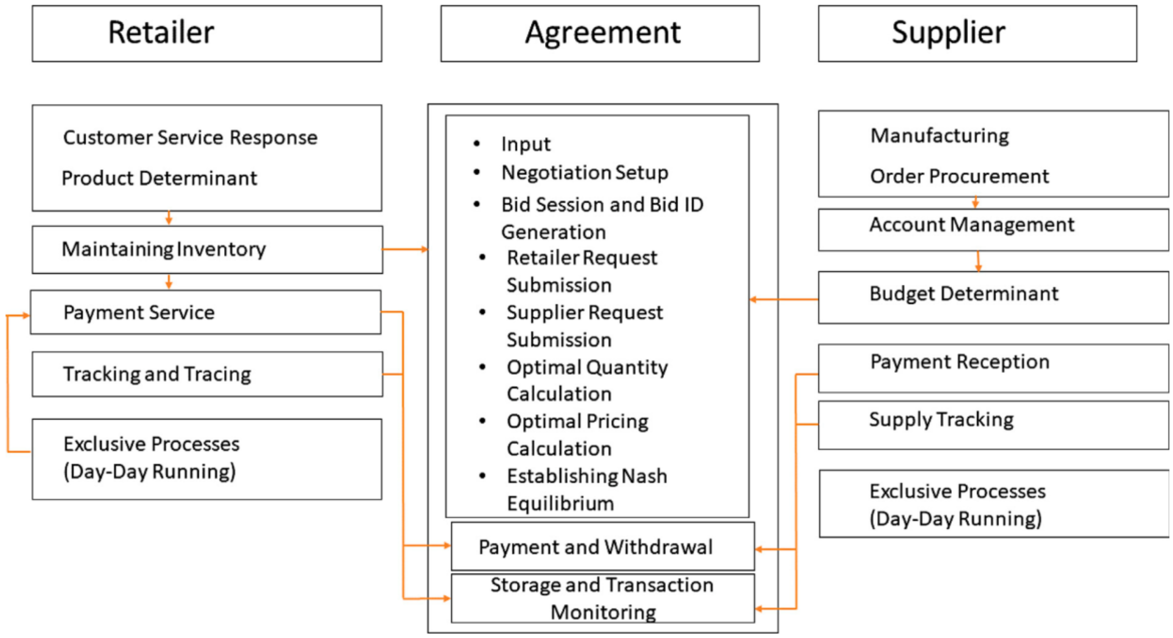
Leveraging smart contracts, (Gao, 2022), generated findings to estimate supply chain disruptions and measure the degree of supply uncertainty. By creating a bidding mechanism, illustrated in *Figure 5* (Gao, 2022) was able to explore the use of an iterative version of game theory, and findings showed blockchain can be used to provide a suitable outcome over a period of time.

Figure 5. Gao Flow Diagram showing interaction between retailer and supplier to establish Nash Equilibrium on the Blockchain (Gao, 2022)



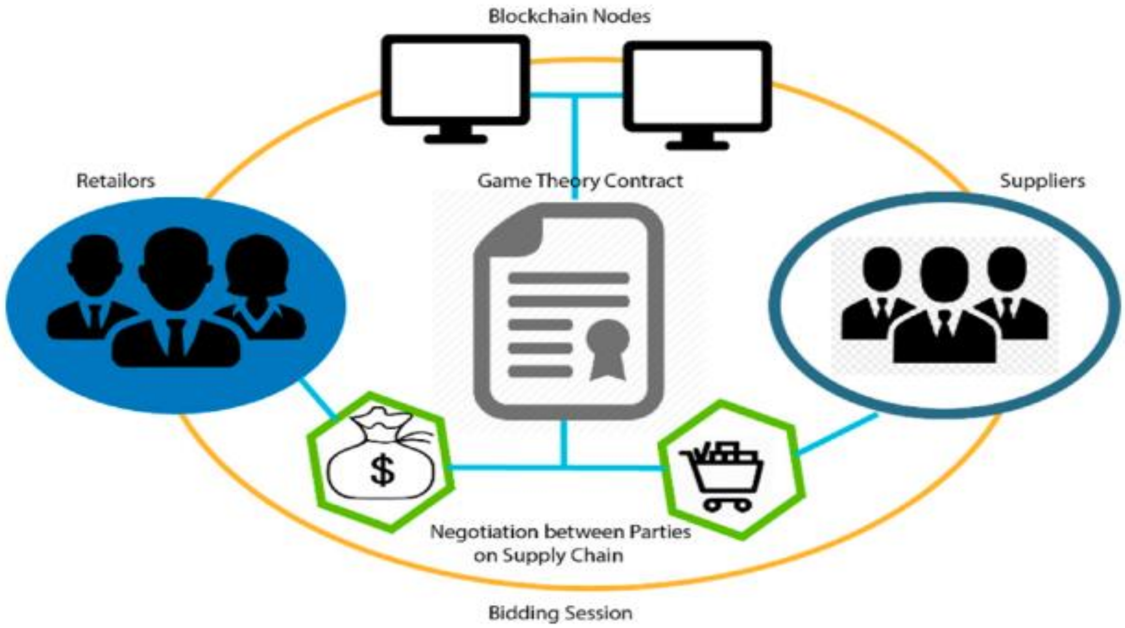
While Nash Equilibrium highlights stables states in strategic interactions, it can be extended to resource allocation dynamics and environmental sustainability within industry supply chains (Gao, 2022). Gao further illustrates how strategic interactions among stakeholders, through cooperation, competition, and negotiation, shape a supply chain equilibrium. Gao's *Figure 6* illustrates a proposed contracting mechanism for multiple entities on the supply chain network which ensures that coordination is achieved for all participants in a supply chain network. Studies conducted by researchers such as (Gao, 2022), (Wang, 2022) and (Guo, 2024), have extensively analyzed different models and algorithms to maximize profits and foster cooperation on decentralized ledger technology platforms, like blockchain. This equilibrium can also be applied in a CE for the purpose of optimizing resource allocations and environmental sustainability (Gao, 2022).

Figure 6. Gao Proposed Contracting Mechanism for Multiple Entities on the Supply Chain Network (Gao, 2022)



The (Gao, 2022) framework aims to leverage technological components to incentivize cohesive transactions among supply chain participants, ensuring optimal decision-making for meeting a stable equilibrium. By integrating blockchain features like transparency and trust are enhanced, laying a robust foundation for achieving equilibrium in a CE. Moreover, incorporating game theory principles considers both individual and collective equilibrium, fostering sustainable and mutually beneficial outcomes for all parties involved (Gao, 2022). From a perspective of profitability, (Gao, 2022) proof of concept bidding system illustrated in *Figure 7*, exemplifies the circular interaction between retailer and supplier nodes in an incentivized game-theory blockchain network.

Figure 7 Gao Bidding System Showing an Interaction Between Retailer and Supplier on a Game-theory Incentivized Blockchain Network (Gao, 2022)



Overall, the literature review suggests that the integration of game theory, blockchain technology and smart contracts offers promising solutions for enhancing collaboration, trust and sustainability within the EV industry's circular economic system. In the EV industry, trust among supply chain stakeholders is essential for profitability. More often than not, individual interests often lead to less-than-ideal outcomes, disrupting trust and equilibrium. To counteract this issue, coordination and collaboration are vital. Past approaches relied on centralized contracting mechanisms, which are prone to compromise and lack trust enforcement, especially if deployed on public-permissionless DLT platforms.

To overcome these challenges, this study proposes a blockchain-based framework based on a private-permissioned DLT platform which would incentivize collaboration in a CE. Although the game theory model exemplified by (Gao, 2022), validates blockchain's effectiveness in promoting fairness in what appears to be a linear economic context, applying this framework on a private-permissioned platform can offer the same opportunity within a CE.

Literature Review Summary

This literature review explores the intersection of blockchain technology, smart contracts, and Nash Equilibrium game theory, and the circular economy (CE), emphasizing their potential to enhance sustainability, trust and collaboration within supply chains, particularly in the context of the EV industry.

In summary, the literature review finds that the groundwork for building a successful circular economy must highlight the importance of minimizing waste, optimizing resource use, and designing products with longevity in mind. Implementing a blockchain-based circular economy is a promising tool for realizing these goals. Blockchain's fundamental characteristics such as providing tamper-proof records of transactions, immutability, enhanced traceability, and transparency, has proven its ability to foster trust among stakeholders. Smart contracts enable automated execution and enforcement of agreements with the need for intermediaries. Consensus mechanisms, such as Proof of Authority (PoA) or Practical Byzantine Fault Tolerance Protocol (PBFT), ensure the integrity and security of blockchain networks, through deployment of validation rules.

The review further explores the application of Nash Equilibrium game theory within a blockchain-based supply chain ecosystems, highlighting its role in incentivizing cooperation and fostering equilibrium among participants. Through a proof of concept, researchers demonstrate how blockchain can be used to establish Nash Equilibrium and coordinate supply chain activities, ultimately leading to more sustainable and profitable outcomes. The review suggests that the strategic application of blockchain technology, smart contracts, and game theory can facilitate a trustworthy, collaborative, and sustainable system within a circular economy (Júnior, 2022). It suggests that integrating these elements offers potential benefits such as transparency, efficiency, and coordination, thereby reshaping traditional paradigms and optimizing resource allocation for environmental sustainability.

Literature Review Research Identified Gaps

The literature review offers valuable insights and potential solutions that align directly with the challenges outlined in the problem statement. It identifies literature gaps, outlined in *Appendix B,* emphasizing the need for further exploration of how blockchain, smart contracts, and game theory can effectively promote accountability, sustainability, and circular economic practices within the EV industry. These gaps shed light on motivations for seeking blockchain solutions and their potential business value, aligning with the project's aim to revolutionize the EV industry through accountable and sustainable practices, within a circular economy. Additionally, these gaps highlight the integration of game theory principles to guide decision-making and foster cooperation among industry stakeholders, addressing key research questions related to optimizing resource use and promoting sustainability. Moreover, the exploration of blockchain-enabled self-governance mechanisms aligns with the project's focus on ensuring regulatory compliance within the EV industry, contributing to the overarching goal of enhancing accountability and sustainability within this sector. This study aims to address gaps in current research by exploring the integration of blockchain technology and game theory principles within a circular economy framework, in the EV industry. Through this interdisciplinary approach, the study seeks to contribute to advancements in information technology while promoting accountability, sustainability, and strategic collaboration within the EV ecosystem.

CHAPTER THREE:
RESEARCH METHODS

Multiple Case Study Approach

The goal of this research approach is to investigate the integration of blockchain-based smart contracts, and the Nash Equilibrium game theory principles within a circular economy framework, particularly within the EV ecosystem. A multiple-case study approach emerges as the most suitable methodological approach as it allows for a comprehensive exploration of diverse contexts and implementations enhancing the generalizability of the findings. As emphasized by (Yin, 2018), case studies are instrumental in investigating complex phenomena within their real-world contexts, especially when boundaries between the phenomenon and its context are ambiguous. To navigate this complexity, the research approach will draw upon pre-existing theoretical frameworks to guide its design, secondary sources, data collection, and analysis, ensuring a robust and organized approach.

The case study will encompass multiple industries or domains beyond the EV ecosystem that have implemented similar technologies and principles, such as Hyperledger Fabric, in their operations. By examining diverse industry cases, the goal is to gain valuable comparative analytical insights, identifying best practices, challenges, and transferable lessons for the EV industry. This approach aligns with the notion that innovation often arises from cross-pollination of ideas from different domains (Pourzarei, 2020), potentially revealing innovative applications or approaches that could inspire solutions within the EV context.

In selecting cases, the research will prioritize companies actively engaged in sustainability initiatives, reflecting a broader shift towards responsible sourcing and sustainable practices across all aspects of their operations. Each selected case will demonstrate how companies have made sustainability a key focus area and continues to invest in various projects and initiatives to reduce its environmental impact, leveraging blockchain-based smart contracts as a tool for transparency, traceability, and accountability.

To gain a comprehensive understanding of the intricacies of this study and explore its diverse aspects, the cases highlighted below will be thoroughly analyzed. These cases provide comprehensive insights into various industries that have effectively implemented blockchain pilot programs, smart contract applications, and consortiums within responsible sourcing networks. Furthermore, this study will explore a wide range of dimensions related to blockchain, enabling a comprehensive examination of the various deployments within these collaborative networks.

The literature review “Blockchain for the Circular Economy” addresses Research Questions 1, 2 and 3, focusing on blockchain’s diverse applications in supply chain management. It examines how blockchain ensures transparency, security, and traceability, and supports ethical sourcing and lifecycle management for electric vehicle (EVs) and their components. Overall, the review emphasizes blockchain's potential to enhance efficiency, flexibility, and competitiveness manufacturing and industrial sectors by creating interconnected, data-driven, adaptive systems for circular economic practices.

The literature reviews, "Blockchain Digital Consensus Mechanism in a Circular Economy" and "Smart Contracts and Traditional Contracts" both address Research Question 2. It examines how blockchain and smart contracts can address challenges in implementing circular economy practices, focusing on leveraging private-permissioned blockchain platforms to enhance transparency, traceability, and sustainability in the EV ecosystem. By examining real-world applications like "*Blockchain Architecture for Circular Economy*" implementation, it offers practical insights into the challenges and opportunities associated with implementing blockchain solutions for ethical sourcing. Additionally, this review provides a critical review of smart contracts in blockchain technology, enriching the literature review by examining the technical and legal implications of smart contract implementation.

The final literature review, "Coordination Based on Game Theory" focuses on Research Question 3, examines various consensus algorithms to design a reliable and efficient blockchain network for an EV consortium, crucial for gaining trust among EV stakeholders. By Understanding game theory applications, the review informs the design of incentive mechanisms for cooperation among EV stakeholder, essential for achieving equilibrium. It directly discusses how equilibrium can achieve balance and cooperation among EV stakeholders.

CHAPTER FOUR:

CASE STUDY ANALYSIS AND FINDINGS

In today's rapidly evolving industries, blockchain technology and game theory have transformed sectors like e-commerce, transportation, and supply chain management. However, there is a significant gap in understanding how blockchain can benefit the electric vehicle (EV) industry in a circular economy. Traditional literature predominantly navigates the linear economy terrain, leaving a noticeable void in understanding the potential impact of blockchain integration within the EV ecosystem. This gap presents a compelling opportunity to explore how blockchain technology, underpinned by game theory principles, can foster accountability, sustainability, and cooperation among EV stakeholders. By addressing this challenge, this can pave the way for a more transparent and responsible EV industry, meeting supply chain challenges, its potential disruptions, and environmental impacts head on, along the journey towards a more sustainable vehicle electrification future.

Case 1: Mining and Material Supply Chain

To support the research questions, as suggested in Chapter One, this case study examines leading technology-driven platforms dedicated to responsible sourcing in the mining and materials sector. It focuses on key materials used in EVB manufacturing, such as cobalt, lithium, and natural graphite. The analysis centers on exploring how innovative technology and methodologies for mapping battery mineral and metal supply chains is possible using blockchain-based technology. The case study will show how industry collaboration further enhances oversight, accountability, and decision-making for EV stakeholders, by aligning data collection and distribution with regulatory oversight. The transformative impact of adopting blockchain-based solutions, for promoting sustainability and collaboration, exemplifies a momentous advancement towards a circular economic framework by EV industry stakeholders.

The Responsible Sourcing Blockchain Network (RSBN) emerged as a pioneering industry collaboration, with the primary objective of strengthening human rights and environmental protection in mineral supply chains. RSBN is the result of research conducted in the Democratic Republic of the Congo (DRC), and rooted in the findings of Dr. Nicholas Garrett and Harrison Mitchell (IBM, 2024). In 2008, Garrett and Mitchell's work eventually led to the formation of the RCS Global Group (RCS). Garrett the RCS's CEO knew that tracing resources through the supply chain from mine to end-product was achievable. Garrett and Mitchell's findings revealed how warlords fund conflict by selling natural resources to Western companies (IBM, 2024). As a result, they recognized the feasibility of obtaining information and knew the issues of illegal resources needed to be prohibited from entering their supply chain. RCS is now a leader in collecting and verifying data and providing assurance over the responsibility of practices of supply chains.

RCS aligns relevant best practice frameworks and due diligence regulations to ensure the transparency and accountability of mineral and metal supply chains (RCS Global Group, 2024). In 2018, RCS Global joined forces with International Business Machines Corporation (IBM) to conceptualize and deployed the blockchain network, RSBN. The RSBN platform went live by mid-2020 and is currently operational, steadily expanding its participant base, and proving its efficacy through ongoing growth and use (IBM, 2024). To ensure its adherence to rigorous data collection and verification processes, RSBN's framework is aligned with standards set forth by the Organization for Economic Cooperation and Development Guidance Framework (OECD Guidance) and the Responsible Mineral Initiative (RMI) blockchain guidelines[4] (RCS Global Group, 2023), (Eurotrade International Limited (ETI), 2022). RCS has earned renowned recognition as an accredited auditing body and trusted advisor in responsible mining initiatives (Ghamrawi, 2023). While aligning with OECD Guidance and RMI blockchain guidelines, RCS advocates for resource-efficient and circular economies, and is continuously demonstrating an ability to apply digital product traceability across the mineral supply chain. Studies are finding sustainability or

[4] https://www.responsiblemineralsinitiative.org/media/docs/RMI%20Blockchain%20Guidelines%20-%20Second%20Edition%20-%20March%202020%20FINAL.pdf

environmentally responsible branding is just as significant to consumers as is it for automotive EV OEMs like Ford, Volvo, and Volkswagen.

Research Question 1: *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?*

In 2019, Ford Motor Company (Ford) joined forces with RSBN to initiate a pilot project for cobalt provenance, launched at Hauyou Cobalt's mine site in the DRC[5]. The project, relying on IBM Blockchain Platform, successfully traced critical minerals to a smelter, a cathode plant, a Li-ion battery plant and, finally, overseas to its final destination, a Ford factory in the United States (RCS Global Group, 2023). The pilot project demonstrated that blockchain for tracking the mineral from mine to the manufacturer, through the upstream, midstream, and downstream, enables a sustainable supply chain in the industry. This project also demonstrated RSBN's efficacy in meeting stringent sourcing standards, instilling confidence in stakeholders who rely on mineral and material provenance for EV production (de Sa, 2021) (OECD, 2024).

What can be drawn from this collaborative relationship between RCS, IBM and Ford, signifies the importance of industry-wide cooperation in addressing complex supply chain challenges. By pooling industry expertise and resources,

[5] 2019 Sustainability Report (ford.com)

these companies aim to establish best practices, standards, and frameworks not only for responsible mineral sourcing, but for a circular economy. The resultant efforts benefit not only their respective industries but also society on a global scale. By November 2019, IBM announced RBSN's plans were underway to expand from tracing cobalt to other key battery metals, tungsten, tantalum, tin, and gold (IBM, 2019). By November of 2019, with the popularity of its success, other automotive EV OEMs expressed their interest in joining the RSBN. RCS, after completing a rigorous responsible sourcing assessment of each participating company, announced that Volkswagen Group[6], and Volvo Group[7] were joining the RSBN platform. The number of RSBN participants, engaging in mineral sourcing transactions within the EV industry, continues to increase steadily.

The intent of the RSBN pilot project was to demonstrate, via blockchain technology, how the materials used in Ford's vehicles are responsibility produced, traded, and responsibly managed throughout their lifecycle, from initial production to eventual recycling or return to the earth. All participants were validated against responsible sourcing standards developed by the OECD. Review of the Ford Motor Company Conflicts Minerals Reports for The Year Ended December 31, 2020[8], shows after undergoing an assessment of its cobalt due diligence management system for conformance with the requirements of the

---

[6] Nonfinancial_Report_2019_en.pdf
[7] VOLVO GROUP ANNUAL AND SUSTAINABILITY REPORT
[8] https://www.sec.gov/Archives/edgar/data/37996/000003799621000040/conflictmineralsreport2020.htm

OECD Guidance. By 2020, Ford conducted a follow-up assessment and demonstrated significance performance improvements, increasing their audit score from 34.5% to 80% (out of 100%). Within a span of one year, the IBM-led pilot project exemplified how Ford made substantial progress in enhancing its cobalt due diligence management system, improving its score by nearly 46 percentage points. This increase highlighted above suggests a significant commitment to responsible sourcing practices and compliance with OECD guidance.

Research Question 2: *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?*

With the genesis of this collaboration powered by the Linux Foundation Hyperledger Fabric, a modular blockchain framework designed for enterprise blockchain platforms, will enable RCS to continue expanding RSBN beyond battery metals, allowing for widespread adoption across various industry sectors (RCS Global Group, 2021). Secondary sources are unavailable to confirm whether the integration of smart contracts into RSBN’s pilot project with Ford was employed. Although Hyperledger Fabric is not solely used for smart contract deployment, it is a significant component of the blockchain framework. It can be reasonably inferred that the pilot project incorporated predefined rules and executable code at each traceable provenance point at each tier of the supply chain, which leads the study to assert that smart contracts must have been deployed.

This study identifies a crucial prerequisite for business transactions built on Hyperledger Fabric: the creation of a shared framework of contracts encompassing standard terms, data, rules, regulations, conceptual definitions, and procedures (Hyperledger Fabric v3.0, 2023). Smart contracts on Hyperledger Fabric, or collective agreements, delineate the operational structure governing interactions among transactional entities. Leveraging a blockchain network, these contracts are transformed into functional programs, facilitating seamless execution of processes. A key factor about Hyperledger Fabric is its private-permissioned blockchain platform, which exemplifies the high-level of security applied in this type of blockchain platform.

Findings show the private-permissioned nature of Hyperledger Fabric makes it well-suited for businesses and consortia looking to leverage blockchain technology, while maintaining control over their networks and data. It also allows for the implementation of more complex governance models and finer-grained access control mechanisms, compared to public-permissionless blockchain platforms. Where Hyperledger Fabric breaks from some other blockchain systems is that it is ‘private’ and ‘permissioned’ (Hyperledger Fabric v3.0, 2023). Let’s further explore the meaning of “private-permissioned.” “Private” means allowing for the creation of private blockchain networks where only invited participants can join, and “permissioned” confirms that participants are known to each other, and they must be explicitly granted access to the network. A permissioned model enables better control over who can read and write transactions to the blockchain, making it suitable for enterprise use cases where privacy, confidentiality, and regulatory compliance are critical.

> Research Question 3*: Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

By fostering transparency, traceability, and accountability, RSBN incentivizes participants to adhere to responsible sourcing practices, enhancing their reputation and branding, mitigating risks, and contributing to sustainable goals. A consortium embodies a framework conducive to Nash Equilibrium, promoting mutual benefits, discouraging unilateral deviations, and fostering collaborative dynamics among participants. Additionally, the RSBN platform lays out the foundation for cooperative decision-making and promotes responsible sourcing practices within the CE framework (Barteková, 2022).

Over the long-term, RCS future findings will show that the participation in a consortium helps mitigate potential supply chain disruptions by improving transparency, responsiveness, and resilience. The overall equilibrium sought in a game theory-incentivized blockchain as established by (Gao, 2022), is achieved through the integration of environmental sustainability, economic viability, social responsibility, collaborative partnerships, and continuous improvements. By aligning incentives, fostering collaboration, and leveraging data-driven insights, suppliers can optimize resource use, minimize waste, and contribute to the transition towards a more sustainable economic model. Moving forward, automotive EV OEMs and their tier-1 suppliers now can negotiate costs more effectively within a private-permissioned platform, accessing information in real-time about market demand, competitor pricing, and available alternatives, enabling them to adjust their pricing strategies accordingly. Additionally, suppliers can offer incentives for buyers to choose more sustainable options, such as discounts for recycled materials or longer-term contracts that promote resource efficiency.

Case 2: Enhancing Supply Chain Management

This case study investigates the significant influence of blockchain-based smart contracts on supply chain management in the EV industry, within a CE framework. It will attempt to explore the potential for improvements to EVB lifecycle management. By assessing the capabilities of blockchain-based smart contracts, this study explores their role in transforming decision-making processes across the entire flow of critical mineral and raw materials in a CE.

In an era of the Internet and rapidly changing technological industry, traditional approaches to enterprise operations are constantly being transformed. Blockchain technology has emerged as a major force behind this innovation, disrupting traditional approaches to enterprise operations (Frizzo-Barker, 2020). The EV industry is gradually transitioning into an interconnected ecosystem, where regulations are enforcing practices for traceable and transparent responsible sourcing, holding producers accountable for providing evidentiary documentation of their EVB products on the market. Producers are pressured to find technological solutions to ensure data integrity in their supply chain.

Hyperledger Blockchain Technologies for Business, launched in December 2015, has emerged as a pivotal force for blockchain technology (Hyperledger Foundation Turns Five, 2020). Initially supported by 21 founding members, including industry giant IBM, it expanded capabilities to include blockchain shared service ledgers combined with smart contracts enabling the secure transfer of assets (IBM Annual Report, 2016). IBM's expansion has impacted various industries, including supply chain management, waste, renewable energy, carbon credits, and product lifecycle management. Functioning as an open-source collaboration initiative, Hyperledger continues to strive toward advancement and implementation of blockchain technologies across diverse industry sectors. Within the expansive framework of Hyperledger, various enterprise blockchain technology projects prosper, spanning distributed ledger frameworks and smart contract engines (Hyperledger Foundation Turns Five, 2020). Hyperledger's robust ecosystem fosters a fertile ground for Proof of Concept (PoC) experimentation and research and development in blockchain technology.

Propelled by collaborative input from IBM and Digital Asset Holdings (DAH), Hyperledger's "Fabric" emerged as the first project cultivated within the Hyperledger ecosystem. Under the support of the Hyperledger Fabric community, a diverse coalition of over 400 open-source developers representing various enterprises, both large and small, have come together to collectively devise and execute a distributed ledger technology (DLT) framework that addresses real-world requirements while fostering practicality.

Fabric stands as a testament to the initiative's commitment to pioneering cutting-edge blockchain solutions for enterprises and industries worldwide. Fabric, designed specifically for enterprise use, stands as a robust open-source enterprise-grade *permissioned* DLT (Hyperledger Foundation Docs Release Master, 2020). Operating on a permissioned basis, this requires that participants undergo an *authentication* and *authorization* process, and, unlike a public-permissionless network, the participants are known to each other, rather than anonymous and therefore fully untrusted (Hyperledger Foundation Docs Release Master, 2020). Notably, Fabric's architecture accommodates diverse trust models, even under circumstances where participants may harbor a varying degree of distrust or competitive industry dynamic toward one another. Such networks have an ability to function effectively under governance frameworks that leverage existing levels of trust whether through legal agreements or dispute resolution mechanisms (Hyperledger Foundation Docs Release Master, 2020). This finding implies that a network based on a high degree of trust can thrive when built upon foundations of pre-existing trust and supported by structured frameworks to address conflicts or regulate interactions. If participants already have an elevated level of trust established through legal agreements or other mechanisms, the network can choose a consensus algorithm that relies less on computational power and more on the reputation of the participants.

Distinguishing itself from other blockchain platforms, Fabric supports pluggable consensus protocols, offering unparalleled customization to suit specific use cases and trust models. This adaptability eliminates the necessity for native cryptocurrencies to be mined or to fuel smart contract execution, thereby reducing considerable risk and potential avenues for attack. Fabric prioritizes privacy and confidentiality by implementing safeguards for transactions and the execution of smart contracts, which Fabric refers to as “chaincode.” Chaincode represents trusted distributed applications, deriving their security and trust from the blockchain and the consensus among peers, serving as the foundational business logic of blockchain applications. This feature enhances the platform’s appeal where confidentiality is paramount, even among a backdrop of potential mistrust among participants. (Hyperledger Foundation Docs Release Master, 2020).

Fabric’s modular (or segmental) architecture stands as one if its foundational capabilities, facilitating the integration of plug-and-play components, such as consensus protocols and smart contract engines (Hyperledger_Circulor, Case Study, 2018). Among these components the support for pluggable consensus protocols emerges as particularly significant, enabling tailored customization to address specific use cases and trust models effectively. A crucial aspect of Fabric's functionality lies in its *unwavering* commitment to *data integrity* throughout the entire process, alongside ensuring that relevant participants only have access to pertinent information (Hyperledger_Circulor, Case Study, 2018). This emphasis on data integrity and selective visibility underscores Fabric's suitability for diverse enterprise and industry applications. IBM's substantial involvement in the development and adoption of Hyperledger Fabric, further accentuates its significance within the blockchain industry. As a key contributor, IBM has played a pivotal role in shaping Fabric's evolution, offering a range of enterprise solutions built atop the platform to facilitate seamless blockchain adoption for businesses (Hyperledger_Circulor, Case Study, 2018). This collaboration underscores the industry's recognition of Fabric's potential to revolutionize various sectors through its robust architecture and IBM's commitment to drive blockchain innovation.

Research Question 2: *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?*

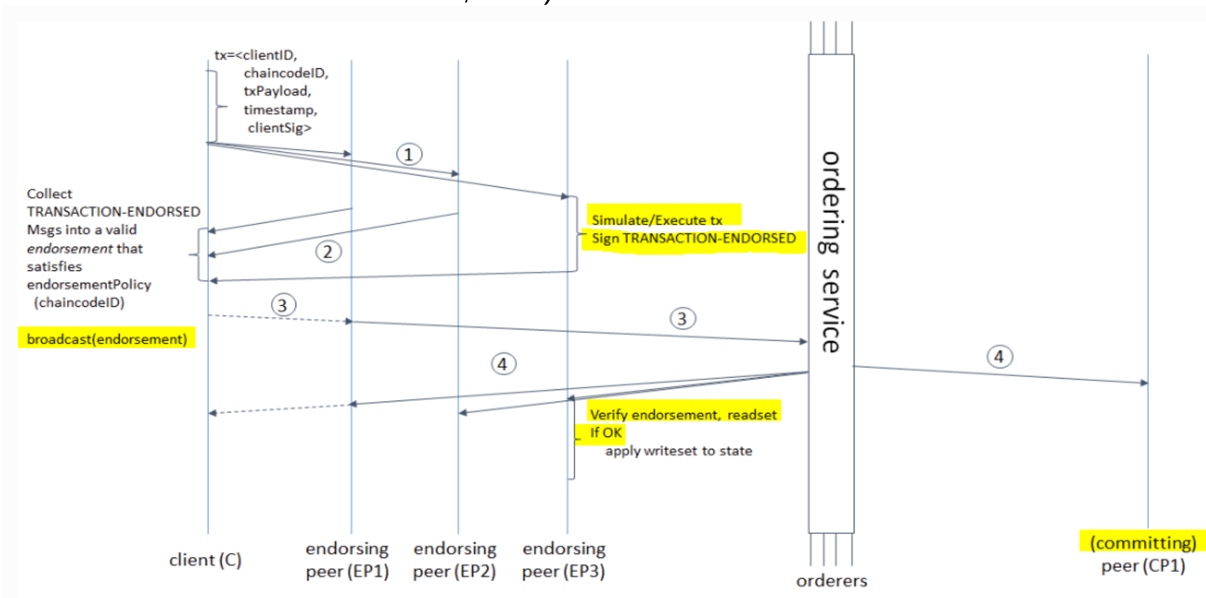
IBM has been instrumental in refining the capabilities of Hyperledger Fabric to support smart contracts authored in general-purpose programming languages, such as Java. This departure from a traditional domain-specific language (DSL) has widened the accessibility and usability of smart contracts making them more versatile and adaptable to a broader range of enterprise applications (Hyperledger Foundation Docs Release Master, 2020). For the EV industry, this means that smart contracts can be tailored more precisely to address specific needs and challenges with a CE framework. For example, smart contracts can be designed to facilitate transparent and automated processes for recycling, reusing and repurposing EV components and materials. The use of general-purpose programming languages allows for easier integration with existing enterprise systems and technologies. In the EV industry, where complex supply chains and diverse stakeholders are involved, seamless integration of blockchain-based solutions with existing infrastructure is critical.

Hyperledger Fabric highlights three fundamental points particularly pertinent when considering their application to a platform: (i) the concurrent execution of multiple smart contracts within the network, (ii) the dynamic deployment of these contracts, often by any participant, and (iii) the necessity to treat application code as potentially untrusted or even malicious. Traditional smart-contract capable blockchain platforms typically adhere to an *order-execute* architecture. In this architecture, the consensus protocol validates and orders transactions before broadcasting them to all peer nodes, with each peer sequentially executing the transactions. This architecture is prevalent across various blockchain systems, from public platforms like Ethereum (*with Proof of Work (PoW) based consensus*) to permissioned platforms.

Fabric introduces a new and revolutionary architecture for transactions which incorporates *validity*, called the *execute-order-validity* architecture, addressing resiliency, flexibility, scalability, performance and confidentiality, the new architecture separates transaction flow into three steps, as illustrated in Figure 8 (Hyperledger Foundation Docs Release Master, 2020):

a. ***execute***: a transaction and verifying its correctness, thereby endorsing it.
b. ***order:*** transaction via a (pluggable) consensus protocol, and
c. ***validate:*** transactions against an application-specific endorsement policy before committing them to the ledger.

Figure 8. Hyperledger Fabric “*execute-order-validity*” Architecture (Hyperledger Foundation Docs Release Master, 2020)



By executing transactions before finalizing their order, Fabric’s design allows for the specification of application-specific endorsement policies. These policies determine which subset of peer nodes, or how many of them, need to vouch for the accurate execution of a given smart contract (Hyperledger Foundation Docs Release Master, 2020). Consequently, each transaction only requires endorsement from the subset of peer nodes necessary to fulfill the endorsement policy, enabling parallel execution and enhancing overall system performance and scalability. In the EV industry, Fabric’s design adds a level of security through validation by determining which subset of peer nodes need to validate a transaction’s execution.

As we have seen in Case 1, Fabric’s innovative design and capabilities have already been employed, facilitating mineral traceability by establishing a transparent and immutable record of each transaction within the supply chain

(Hyperledger Blockchain Technologies for Business, 2018). Through this architecture design, participants to the network were able to track the journey of a mining supply chain from extraction to end-product. Fabric's design holds significant promise for the EV industry within a CE framework especially where contracting challenges may occur. The flexibility of Fabric enables the rapid deployment and updating of smart contracts tailored to specific use cases within the EV ecosystem. For example, EV stakeholders can deploy smart contracts to track the origin and authenticity of EV components, enforce sustainability standards, and facilitate transparent and traceable transactions related to EV manufacturing, distribution, and EoL management. Additionally, Fabric's capability for scalability, where complex supply chains and diverse stakeholders are involved, is essential for processing large volumes of transactions efficiently, such as tracking the lifecycle of EV components and materials.

Research Question 1: *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?*

In the area of supply chain management and sustainability, IBM is leveraging blockchain solutions through Hyperledger Fabric, to establish transparent and efficient systems for product monitoring and tracing throughout their lifecycle (Hyperledger Foundation Case Study, 2019). This initiative supports circular economy practices. IBM actively invests in blockchain solutions to enhance sustainability and transparency in supply chains through collaborations, such as Circulor. The synergy between Circulor's expertise in traceability and IBM's expertise in blockchain technologies holds promise for advancing sustainability and transparency objectives. Hyperledger Fabric, IBM, and Circulor contributes significantly to CE initiatives and responsible sourcing, albeit through different approaches and methodologies (IBM Case Study, 2024).

Circulor's CEO and co-founder Doug Johnson-Poensgen became involved in the tantalum industry at a time when Rwandan mines had already adopted what were considered advanced tracing methods. Tantalum is a rare mineral essential for making capacitors for devices like smartphones and laptops. The Rwandan mine methods for tracing were meeting the letter of the OECD Guidance but were being compiled through material tagging and paper documentation, but this did provide actual traceability (Circulor, 2019). Their traditional documentation approach was falling short in providing comprehensive traceability. Circulor intervened to assist these mines in developing a proof of concept for tantalum traceability.

Circulor's initial proof of concept was developed on Ethereum, due to its ease of development. However, challenges emerged, like Ethereum's sluggish transaction speed, its unpredictable and fluctuating costs driven by associated "gas" prices, necessitating corporate endorsement. Subsequently, Circulor transitioned to Hyperledger Fabric, its second proof of concept, selected for its enterprise-grade reputation. A tailored enterprise application was crafted, featuring mobile interfaces for on-the-go ID verification and document retrieval, alongside desktop versions for office-based supply chain management, all hosted on cloud databases supported by Oracle Cloud and Amazon Web Services (AWS) (Hyperledger Case Study , 2018). In 2018, Circulor provided the *"first-ever mine-to-manufacturer traceability of a conflict mineral*[9]" (Hyperledger_Circulor, Case Study, 2018). Powered by Fabric, Circulor created a system that ensures tantalum is mined, transported, and processed under approved conditions with an unbroken chain of custody. This system uses facial recognition and QR codes to deliver the world first mine-to-manufacturer traceability of a vital resource.

Hyperledger case study findings show the collaborative relationship between IBM and Circulor specifically targeted the EV industry, emphasizing the responsible sourcing of minerals crucial for EVB production, which posed environmental hazards if disposed of incorrectly. By integrating Circulor's platform with IBM's blockchain technology, transparent supply chain networks were forged. Similar to Case 1, aligning strategies and engaging in commitments to foster responsible sourcing within the EV sector, IBM and Circulor empowered industry to verify ethical and sustainable material procurement, meet regulatory compliance requirements, and achieved satisfactory consumer expectations for transparency. Furthermore, by monitoring the carbon footprint of materials and

[9] Hyperledger_CaseStudy_Tantalum_Print.pdf (hubspotusercontent-na1.net)

manufacturing processes, the EV industry can pinpoint areas for enhancement sustainable practices.

Research Question 3*: Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

The case study shows the importance of consortiums in fostering collaboration among stakeholders within the EV industry. By leveraging blockchain technology, smart contracts, and Nash Equilibrium game theory, stakeholders can establish transparent and trust-based ecosystems where all participants have a vested interest in maintaining equilibrium or a stable balance in their supply chain. Overall, the integration of blockchain-based smart contracts not only streamlines transactional processes but also empowers stakeholders to govern themselves, interacting directly with likeminded stakeholders within a CE. Engaging in such a consortium empowers stakeholders to govern themselves autonomously, eliminating the need for intermediaries and promoting a more decentralized approach to governance. Finally, EV producers involved in such initiatives can be perceived as collaborative partners that prioritize collective success over individual gain, fostering positive brand associations with teamwork and partnership.

Case 3: Automotive Industry Partnerships

This case study will explore why EV industry stakeholders should engage in a consortium driven by innovative technological frameworks, like blockchain. By examining potential impacts on sustainability, responsible sourcing, and supply chain resilience, the goal is to show the transformative potential of collaborative initiatives grounded in technological solutions. To answer the question of why a consortium built on blockchain and smart contract technology is essential to secure a CE ecosystem, it is important to first understand the present and future state of the critical mineral supply chain that sustains the EVB production industry.

Resources, such as critical minerals and raw materials used to supply EVB production are the very lifeblood of the industry, and their lifecycle of giving is *finite*. It is these vital resources that must be tracked to ensure the industry's sustainability. The ultimate challenge toward a traceable and transparent circular economic system is to engage a very privatized and competitive industry to collaborate on industry standards, use of blockchain, and smart contracts to trace data related to an EVBs mineral and material composition. The underlying goal is to go beyond all considerations for reduction in waste, reuse, and recycling, and develop a course of action towards a sustainable closed-loop system where recycled resources are prioritized for multiple production cycles, reducing the need for unexploited resources. Within a CE, strategic oversight of the supply chain holds paramount importance for the future of EV production.

Ensuring a CE supply chain is vital for sustainability, given the significant environmental impacts attributed to EVBs at every stage of their lifecycle. Ineffective management of supply chain inventory emphasizes the urgent need for efficient planning and management practices to prevent disruptions and ensure smooth operations. Strategic decision-making involves improvements to recycling infrastructure and transitioning towards a closed-loop system for battery materials. An intriguing opportunity arises at the intersection of blockchain technology, smart contracts, and Nash Equilibrium game theory, offering a compelling opportunity for industry stakeholders to collectively address critical supply chain challenges.

The automotive industry is experiencing a major transition that affects both electric and internal combustion engine vehicles. The demand for EVs has been significantly influenced by a combination of factors, including manufacturing incentives, regulatory compliance, environmental concerns, and technological advancements. As previously highlighted in Chapter One, the demand is a highly incentivized shift towards EVs and away from traditional ICEs. It is crucial to recognize that both types of vehicles share the same essential components, such as tires, suspension systems, brakes, chassis, drivetrain, windows, tires, and more. However, the key point of departure lies in the primary component, the propulsion system: the EVB, energized by the Lithium-ion Battery.

Lithium-ion batteries have emerged as the dominant rechargeable battery in EVs. The EV battery chemistries depend on five *critical minerals* whose global supply chain is potentially at risk for disruption: lithium, cobalt, manganese, nickel, and graphite (Congressional Research Service, 2022), with a substantial portion, more than 75 percent, of the world's lithium reserves, is situated beneath the salt flats of the "Lithium Triangle," in Chile, Argentina, and Bolivia (Harvard International Review (HIR), 2020). Despite this concentration, concerns loom regarding whether the global lithium supply can meet the burgeoning demand. Corinne Blanchard, Director of Lithium and Clean Tech Equity Research at Deutsche Bank, predicts by the end of 2025, a "modest deficit" of around 40,000 to 60,000 tons of lithium carbonate equivalent, potentially escalating to 768,000 tons by the end of 2030 (Shan, 2023). As we saw in Case 1, cobalt is predominantly found in the Democratic Republic of the Congo (DRC), which boasts over half of the world's reserves. However, this reliance on a single source raises questions about supply stability and sustainability. The DRC accounts for 70% of global cobalt production (Earth.Org, 2023), emphasizing its essential role in the EV industry. Projections from the World Bank paint a picture of exponential growth in the production of critical minerals essential for low-carbon technologies; by 2050 global production is estimated to rise by 965% for lithium, 585% for cobalt, 383% for graphite, 241% for indium, 173% for vanadium (Kirsten Lori Hund, 2019). In light of these challenges and projections, it becomes imperative to consider the longevity and sustainability of EVB production. This prompts fundamental questions about EVB lifespan and integration into a CE.

Automobile warranties serve as a significant provenance point for tracking battery performance metrics within an EVB lifecycle. If the warranty includes provisions or information about the potential second-life applications of the EVB, such as repurposing or recycling, it can serve as a crucial indicator of the battery's viability or suitability for such purposes and its overall sustainability. Comparing the extended battery warranties of three major electric vehicle manufacturers – Volvo Group, Volkswagen Group, and Ford Motor Company – reveals a commonality offering either an 8-year or 100,000-mile warranty, whichever comes first. Additionally, there is a stipulation that the battery must retain at least 70% of its original capacity (state-of-health) over the duration of the warranty period (Volvo, 2024) (Volkwagen, 2024) (Ford, 2024). This means that if the battery's capacity falls below 70% during the warranty period, the manufacturer would typically provide repair or replacement. Warranties allow for up to 30% degradation in battery capacity over the warranty period before triggering the warranty coverage. Building upon the understanding of warranties as crucial performance indicators of EVB performance and sustainability, the study now turns to second life and end-of-life disposal. Who bears the responsibility for these lifecycle phases, the consumer, or the OEM?

Beyond the warranty period, OEMs face a significant accountability challenge, given the EU Regulations advocacy for a comprehensive and equitable distribution of responsibility and costs throughout the lifecycle of batteries placed on the producers outlined in Chapter One. Typically, if an EVB's capacity falls below the stipulated threshold during the warranty period, the OEM provides repair or replacement, incentivizing them to reclaim degraded batteries for recycling or repurposing rather than outright disposal. Recycling, reuse, and repurposing EVBs can recover valuable materials and extend their useful life in other applications, contributing to sustainability efforts and waste reduction. However, a significant challenge arises with lithium battery recycling: it often costs more than mining new lithium. Consequently, only about 5% of lithium batteries are currently recycled globally, leaving the vast majority – 95% – to become pollutants, raising concerns about sustainability (Hirschlag, 2022).

The European Commission Raw Materials Information System (RMIS) recognizes when enhancing circularity along the battery value chain this has potential to decrease supply dependency, it is estimated by 2040, recycling could contribute to up to 51% and 42% of Cobalt and Nickel demand, respectively (European Commission , 2024). However, uncertainties loom over future supply levels beyond 2030, particularly concerning new projects at their early stage of development, lacking adequate documentation (European Commission , 2024). By the year 2020, around 550,000 EVBs had completed their lifecycle, with projections suggesting an additional 150 million EVBs will be produced by 2035 (FutureTracker , 2024). Addressing these challenges is important for sustainable EVB management as a worldwide industry concern.

As the EV industry continues its rapid production and advancement, fueled by a complex blend of technological innovation, environmental awareness, and economic incentives, the significance of resource management and supply chain sustainability cannot be overstated. The finite nature of resources essential to EVB production underlines the urgent need for a paradigm shift from a linear economy towards a circular one. This transition requires concerted efforts from industry stakeholders, regulatory agencies, and consumers. Embracing blockchain technology and smart contracts offers a promising avenue to enhance traceability, transparency, and accountability throughout the EVB lifecycle, as exemplified in Case 1 and Case 2. By fostering collaboration and standardization within a privatized and competitive industry, the EV stakeholders can begin to lay the groundwork for a sustainable closed-loop system prioritizing recycled resources, minimizing waste, and reducing the demand for newly extracted resources. Strategic oversight of the supply chain remains paramount to ensure the long-term viability of electric vehicles and mitigate environmental impacts for future generations (EV Battery Challenge, 2023).

In an era where sustainability is becoming increasingly paramount, the EV automotive industry stands at a critical juncture. This sector not only holds the potential to revolutionize transportation, but also to reshape global supply chains. However, achieving sustainability within the EV industry requires more than just individual efforts; it demands collective action and innovative solutions. Let’s further explore the rationale for way EV industry stakeholders’ participation in a consortium driven by blockchain, smart contracts, and Nash Equilibrium game theory is so paramount.

Imagine a scenario where the EV automotive industry transcends its traditional operational boundaries to prioritize sustainability throughout its supply chain. Envision the formation of a closed-loop circular economy within this sector, where resources are efficiently managed, reused, and recycled. This framework requires a collaborative approach, pooling individual organizational efforts and devising collective solutions to shared strategies and challenges. Such a vision necessitates wide-ranging collaboration among industry players, pooling their efforts to devise holistic solutions to shared strategies and challenges. It requires a unified commitment to sustainability and transparency across existing stakeholder and supplier partnerships.

Participation in a consortium driven by blockchain, smart contracts, and Nash Equilibrium game theory offers a promising pathway toward realizing a vision of CE. These technologies enable transparent, decentralized systems that can enhance traceability, accountability, and efficiency in supply chain operations. In a consortium, regulatory compliance serves as the baseline qualification required for participation, representing the minimum requirement. However, the consortia may impose additional restrictions or requirements beyond government regulations. By leveraging blockchain and smart contracts, stakeholders can establish immutable records of transactions and enforce agreements automatically fostering trust and reducing the risk of fraud or malpractice. Integrating Nash Equilibrium game theory into the consortium's framework introduces strategic decision-making mechanism that incentivizes sustainable practices. This equilibrium concept encourages participants to adopt cooperative strategies that maximize collective benefits, rather than pushing individual gains at the expense of participants. In the context of the EV industry, this could incentivize responsible sourcing practices, promote ethical standards, and mitigate supply chain disruptions caused by environmental or geopolitical factors. It is essential to consider the real-world implications of implementing such initiatives and the challenges that stakeholders may encounter in this endeavor.

Research Question 3*: Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

Since informal discussions began in 2007, DRIVE Sustainability (DS) partners formalized into a group in 2011. Operating within strict anti-trust regulations and compliance with competition laws, the group initially focused on aligning tools and fostering trust among members. This foundation facilitates cooperation among automotive industry leaders, leading to more ambitious collaborative efforts after the establishment of the European Automotive Working Group on Supply Chain Sustainability in 2013. A significant milestone was the introduction of the Global Automotive Sustainability Guiding Principles in collaboration with the Automotive Industry Action Group (AIAG), which has since supported subsequent activities. In 2017, the DRIVE Sustainability Partnership was publicly launched, signaling its status as a global leader in sustainability initiatives. This transition highlights DRIVE Sustainability's commitment to promoting standardization, cross-sector collaboration, and impactful solutions for supply chain sustainability (DRIVE Sustainability History, 2024).

DRIVE Sustainability (DS), a coalition comprised of sixteen prominent automotive companies, is actively advancing sustainability across the automotive sector by promoting collaboration and engaging supply chain partners, stakeholders, and related sectors in impactful initiatives (DS Progress Report, 2023). This initiative is crucial as the automobile industry faces an urgent need to minimize environmental impacts across the lifecycle of its products and transportation solutions, to protect its ecosystems. Compliance with environmental regulations, standards, and *voluntary* commitment to this partnership constitutes a fundamental aspect of strategic decision-making for businesses.

DRIVE Sustainability operates as a collective commitment among automotive companies to improve supply chain sustainability, operating within the constraints of competition law. The coalition aims to maximize the potential of the CE. Transparency regarding both achievements and challenges is central to DS partnerships, which stress the importance of commitment and collaboration throughout the supply chain. DS also emphasizes the integration of sustainability into company procurement processes within the EV industry.

In December 2023, DS released a progress report detailing efforts to address challenges such as regulatory changes, lack of consensus, and the complexity with protocols and certifications and other barriers. (DS Progress Report, 2023). Findings of the report shows the importance of incorporating stakeholder input to enhance decision-making and promote collaboration. The DS Strategy Action Plan outlines activities and milestones supporting OEMs steadfast commitment to long-term objectives amid the complexities of the supply chain network. The well-established activities and milestones extend into 2030 and encompass sustainable supply chains, sustainable raw materials, workforce well-being, carbon neutrality and circular value chains (DS Strategy Action Plan, 2019). A primary milestone highlighted in the DRIVE Sustainability Strategy Action Plan is the achievement of optimum transparency and traceability related to sustainable raw materials (DS Strategy Action Plan, 2019).

The importance of this partnership lies in its ability to bring together prominent automotive companies with a shared commitment to advancing sustainability across the industry. This collective effort carries far more weight and influence for otherwise privatized and competitive stakeholders, to work together towards a unified goal, with significantly more of an impact to initiatives than those undertaken by privatized companies. The combined power of a group of industry leaders working together can generate more influence at a profound level, rather than any single company acting on its own.

DRIVE Sustainability promotes collaboration not only among automotive companies but also with supply chain partners, stakeholders, and related sectors. This cross-sector collaboration is crucial for addressing complex sustainability challenges that span multiple industries and value chains. This partnership addresses the urgent need for the automotive industry to minimize its environmental footprint across the entire product lifecycle. This includes reducing emissions, optimizing resource use, and adopting sustainable practices from raw materials extraction to end-of-life disposal. DRIVE Sustainability emphasizes compliance with environmental regulations, standards, and voluntary commitments, highlighting the importance of responsible business practices. By adhering to these standards, partnered companies contributed to raising industry benchmarks for sustainability. The collaborative long-term commitment, as evidenced by strategic plans extending into the future, exemplifies its dedication to achieving sustainable outcomes (DS Strategy Action Plan, 2019). This commitment ensures that sustainability remains a priority despite the complexities of the supply chain network and evolving regulatory landscape.

Additional findings show, a new service was offered to automotive suppliers and supplier associations by DRIVE Sustainability, Drive+, was launched in 2020 (Drive+ FAQ , 2021). Drive+ offers automotive tier-1 suppliers and supplier associations the chance to participate in constructive discussions concerning shared sustainability issues and to work together to discover collective remedies. By connecting as partners in Drive+, suppliers gain direct insights and entry to the DRIVE Sustainability platform. The platform offers resources and are invited to contribute to discussions on subjects addressed by OEM partners and can engage in mutual learning on matters such as policies, due diligence, and strategies for tangible impact. Participation in Drive+ assists suppliers in meeting DRIVE Sustainability standards and disseminating them throughout their supply chains. Building on the transformative potential, highlighted by Drive+, in fostering collaborative efforts among automotive suppliers, the dynamics of the industry could significantly shift, particularly concerning the relationships between automotive OEMs and suppliers.

The cooperative synergy between DRIVE Sustainability and Drive+ serves as a strategic decision-making mechanism, incentivizing collaborative strategies among participants within the automotive industry. Participating OEMs and suppliers are encouraged to adopt cooperative behavior for the collective benefit of the industry. With a diverse range of suppliers available for automotive OEMs to choose from, competition among suppliers intensifies, prompting them to engage in cooperative behavior to secure long-term partnerships. Some suppliers may opt to form alliances or consortiums to bolster their negotiating power. By collaborating on sustainability initiatives like responsible sourcing and environmental impact reduction, supplier alliances can present a unified front to OEMs, leading to more favorable negotiation outcomes. This shift towards cooperative behavior could significantly influence the dynamics of the automotive supply chain. Furthermore, the potential for a Nash Equilibrium arises if selective suppliers collectively opt for cooperation to secure long-term contracts, fostering stable and mutually beneficial relationships between OEMs and suppliers. This cooperative framework, facilitated by blockchain and smart contracts within a CE ecosystem, supports the growth of the EV industry.

Research Question 1: *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?*

Research Question 2: *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?*

Given the long-term commitment established by DRIVE Sustainability partnerships, the milestone for transparency and traceability related to sustainable raw materials presents a significant opportunity for the implementation of blockchain technology and smart contracts within the automotive industry. This transparency ensures that suppliers and stakeholders have access to accurate information about the origins and sustainability credentials of raw materials used in automotive manufacturing. Smart contracts can circumvent the intermediaries, thereby streamlining the procurement process and incentivize suppliers to uphold sustainable practices. By integrating blockchain and smart contracts into the supply chain, automotive companies can enhance transparency, traceability, and accountability regarding the sourcing and use of raw materials. This not only aligns with the objectives of DRIVE Sustainability but also contributes to building consumer trust and meeting regulatory requirements for sustainability reporting. Additionally, blockchain and smart contracts can facilitate collaboration among supply chain partners by providing a shared platform for data exchange, distribution, and verification, ultimately driving collective efforts toward a more sustainable automotive industry.

Elements of Nash Equilibrium principles can be applied to DRIVE Sustainability, in the sense that it fosters cooperation among automotive companies and their suppliers toward common sustainability goals. Each participant in DRIVE Sustainability, including automotive manufacturers and tier 1 suppliers, has an incentive to contribute to sustainability efforts because doing so benefits the entire ecosystem. This aligns with the idea of Nash Equilibrium where players cooperate to achieve a mutually beneficial outcome. In the context of DRIVE Sustainability, the “game’ being played could be seen as the pursuit of sustainability improvements within the automotive industry. Each participant, driven by their own interests and motivations, cooperates within the initiative to achieve outcomes that are beneficial for all involved. DRIVE Sustainability does reflect certain aspects of cooperative behavior and alignment on incentives, which are the central principles of game theory.

In closing, the transformation of the EV industry towards sustainability hinges on strategic collaborations and technologically innovative solutions that address the challenges inherent in its complex supply chain ecosystem. The finite nature of critical resources essential for EVB production highlights the urgency for a paradigm shift towards a CE ecosystem. Through initiatives like DRIVE Sustainability, industry stakeholders are collectively driving towards sustainability by fostering transparency, traceability, and accountability within the supply chain. Leveraging blockchain technology, smart contracts, and Nash Equilibrium game theory offers a promising pathway to enhance collaboration and incentivize sustainable practices among automotive OEMs and suppliers. By embracing these technologies and principles, the EV industry can mitigate environmental impacts and ensure long-term viability and resilience in the face of future challenges. As DRIVE Sustainability continues to lead the charge, the automotive industry stands poised to pioneer a new era of sustainability-driven innovation and collaboration.

CHAPTER FIVE:

DISCUSSION, CONCLUSION AND AREAS FOR FUTURE RESEARCH

Discussion

The EV industry faces challenges related to battery production, supply chain sustainability, and end-of-life management of EV batteries. Most notably, the success of this implementation is primarily due to the decentralized and collaborative nature of blockchain. Platforms like the Responsible Sourcing Blockchain Network (RSBN) encourage participants to prioritize ethical and sustainable practices. This, in turn, enhances EV stakeholder reputation and branding, mitigates risks, and contributes to long-term sustainability. By recognizing the potential for mutually beneficial outcomes and establishing trust through transparency and aligned incentives, competitors, suppliers, and other EV stakeholders can work together towards common goals, ultimately putting down the sword of competition, in favor of cooperative and sustainable strategies.

. One focus of this project was on the IBM-led pilot project to digitally trace cobalt from a mine in the Democratic Republic of the Congo (DRC) to its destination at a U.S.-based Ford plant, completed through the use of blockchain technology. The collaborative partnership proved highly successful. The project was positioned to allow accessibility to material sourcing data, while aligned with

OECD Guidelines. By employing blockchain, this ensured transparent and immutable records of mineral provenance, and fostered accountability throughout the mineral supply chain. Blockchain's transparency capability enabled Ford and its Tier-1 suppliers to verify responsible sourcing practices, comply with regulatory standards, and mitigate risk associated with unethical sourcing.

Emphasizing the significance, the success of the pilot project stemmed primarily from the advantageous collaboration among the Linux Foundation, IBM, and Hyperledger Fabric in implementing the private-permissioned blockchain-based solution. This clearly illustrates the crucial role of industry-wide cooperation in addressing complex supply chain traceability challenges. The concept that innovation frequently arises from the cross-pollination of ideas from diverse domains, as emphasized by (Pourzarei, 2020) is evident. The Hyperledger automation framework is a secure, fault tolerant framework. The decentralization directly contributes to immutability because there's *no single point of failure* or control that could arbitrarily change the data stored on the blockchain.

IBM has significantly enhanced Hyperledger Fabric's capabilities to support smart contracts in general-purpose languages like Java, broadening their accessibility and versatility for enterprise applications. This advancement enables tailored smart contracts for the EV industry, facilitating transparent and automated processes for recycling EV components. Integration with existing enterprise systems is easier, critical for seamless adoption in the complex EV supply chains. Blockchain-based smart contracts automate contractual agreements and enforce predefined rules at each stage of the supply chain, enhancing efficiency and reducing the risk of fraudulent activities. The private-permissioned nature of the blockchain platform ensure data privacy, and confidentiality critical factors in the EV industry where sensitive information must be protected. Smart contracts autonomous nature reduces manual intervention and streamlining options. For example, processes like recycling, reusing, and repurposing EV components can be automated through smart contracts, leading to increased efficiency.

To support the project findings, research suggests the inclusion of Nash Equilibrium game theory into the Blockchain framework highlighted throughout this study. In the competitive EV industry, the underlying goal for different EV producers is profitability. In their pursuits for profitability, producers use vast amounts of resources and create waste. Within a circular economy, EV producers are encouraged to reuse and recycle as much as possible. This is a paradigm shift from a linear economy. In the context of the EV industry and the circular economy, finding a Nash Equilibrium would mean all EV stakeholders agree to produce EVs in a way that is good for sourcing and environmental sustainability and profitability. If each stakeholder engages in best practices or industry standards, where none exist, and none of them changes their trajectory, each are making the best choice, so all competitors win. As responsible sourcing practices evolve over time, the equilibrium transforms into the very essence of sustainability and sets new standards for the industry.

The case studies demonstrate pioneering efforts across various industries, ranging from mining to information technology products and services, as well as automotive partnerships. Although this study did not address the consumer perspective in detail, it does propose a noteworthy recommendation: the introduction of a “Battery Fax” for consumers’ general use.

Industries such as those mentioned above have made significant progress in establishing baseline or benchmarking Key Performance Indicators (KPIs) and metrics through blockchain technology. One key proposition put forward in this study is to standardize these benchmarks. In the future, it will be crucial to implement transparent methods for consumers. Much like how consumers rely on “Carfax” reports to access crucial information about the history and condition of a vehicle, a proposed “Battery Fax” would furnish transparent and essential data about the battery’s composition, usage history, and sustainability credentials. This empowerment would enable consumers to make informed decisions about their Electric Vehicle (EV) purchases, ensuring they grasp the environmental impact of their choice and have confidence in the sustainability of their investment.

The concept of a Battery Fax aligns perfectly with the broader trend towards transparency and accountability in the EV industry, further emphasizing the significance of responsible sourcing and lifecycle management of batteries.

Overall, integrating a “Battery Fax” system would not only benefit consumers but also contribute to fostering trust and driving positive change towards a more sustainable transportation ecosystem.

The intersection of the electric vehicle (EV) industry, circular economy (CE), blockchain technology, smart contracts, and Nash Equilibrium presents an intriguing interdisciplinary prospect for synergy in each of their respective areas of application. This study highlights how the convergence of these applications is successfully being implemented today, specifically for the purpose of tracing critical minerals from mine to the manufacturer. Each discussion summary below approaches the research questions from slightly different perspectives, they all converge on the importance of leveraging blockchain technology and smart contracts to foster accountability, sustainability, and economic circularity within the electric vehicle (EV) industry. A visual representation of the relationship between the summary case and the research questions is provided in **Table 3*Error! Reference source not found.***

Research Question 1: *How does the strategic application of blockchain technology within a circular economic framework facilitate cooperation among stakeholders in the EV industry, leading to improved oversight, enhanced accountability, and guided decision-making?*

The combined analysis from each case study presents compelling insights into the transformative role of blockchain technology and smart contracts in advancing circular economy principles within the electric vehicle (EV) industry. By leveraging platforms like Hyperledger Fabric and combined innovative approaches to smart contract deployment, stakeholders in the EV ecosystem are enhancing transparency, traceability and sustainability throughout the mining and mineral supply chain which supports EV batteries (EVBs). By establishing transparent and efficient supply chain blockchain-based networks, stakeholders are now able to verify ethical material procurement, meet regulatory compliance standards, and foster trust through enhance transparency. Furthermore, the collaborative nature of consortia driven by blockchain technology and smart contracts enables stakeholders to govern themselves autonomously, promoting decentralized decision-making and collective action toward circular economy goals. In the long-term, the integration of blockchain technology and smart contracts offers promising avenues for achieving a more sustainable and circular approach to EV production and EVB lifecycle management.

> Research Question 2: *How can the implementation of private-permissioned blockchain technology, particularly through smart contracts, be strategically employed to enhance transparency, traceability, and sustainability throughout the lifecycle of electric vehicles, within the broader context of the EV ecosystem?*

The combined analysis from each case study sheds light on the pivotal role of blockchain technology and collaboration in advancing the transition towards a circular economy, within the electric vehicle (EV) industry. Through the strategic application of blockchain technology, stakeholders can trace critical minerals like cobalt, lithium, and natural graphite from their mining source to end-product, ensuring responsible sourcing practices. This transparency not only enhances accountability but also facilitates informed decision-making, aligned with sustainably goals. Moreover, the collaborative efforts exemplified by initiatives such as the Responsible Sourcing Blockchain Network (RSBN) proved how industry-wide cooperation can drive systematic change towards a more sustainable and environmentally conscious future. By leveraging private-permissioned blockchain platforms and smart contracts capabilities, stakeholders can enhance transparency, traceability, and sustainability throughout the EV lifecycle, contributing to the circular economy by optimizing resource use and minimizing waste.

Research Question 3*: Why should EV industry stakeholders engage in a consortium, that is driven by blockchain technology, smart contracts, Nash Equilibrium game theory, and what are the potential effects?*

The combined analysis from each case study proves the indispensable role of blockchain technology, smart contracts and Nash Equilibrium game theory in revolutionizing sustainability practices within the electric vehicle (EV) industry. By leveraging these innovative frameworks, each case study shows stakeholders can enhance transparency, traceability, and accountability across the entire EV supply chain. The findings highlight the urgency for collective action in addressing critical challenges such as responsible sourcing, supply chain disruptions, and environment impacts. Through initiatives like DRIVE Sustainability, industry leaders are spearheading efforts to establish a circular economy ecosystem that prioritizes collaboration and sustainable practices. Embracing these technologies and principles not only drives operational efficiency but also fosters long-term resilience and innovation in the EV sector, paving the way for a more sustainable future.

Table 3. Visual Representation of the Relationship between the summary of cases and the research questions.

Case	Collaboration	Responsible Resourcing Efforts	RQ1:	RQ2:	RQ3:
1	**Responsible Sourcing Blockchain Network (RSBN), RCS Global Group, IBM, Hyperledger Fabric**	*Cobalt Provenance Tracing from Mine to Manufacturer*	Implementing transparent mapping and mineral supply chains promotes accountability & facilitates informed decision-making by aligning data collection with regulatory oversight and industry best practices. Case studies show improve oversight and accountability and progression towards sustainability goals in the EV industry, absent before 2018.	Private-permissioned blockchain-based smart contracts enhances transparency, traceability and sustainability through the execution of predefined rules and regulations at each stage of the mineral supply chain. Private-permissioned blockchain platforms ensures data security making it suitable for enterprise use cases.	A consortium framework promotes mutual benefits, discourages unilateral deviations, and facilities cooperative decision--making, ultimately optimizing resource use and contributions to a more sustainable circular economic model.
2	**Hyperledger Fabric, IBM, and Circulor**	*Tracing & Validation of Raw Mineral Sourcing Using Blockchain Platform*	Hyperledger Fabric capabilities, facilitates transparent and efficient system for product monitoring and tracing throughout their lifecycle. The synergy contributes significantly to circular economic initiatives and responsible sourcing. Transparency in supply chain networks allows stakeholders to verify ethical and sustainable activities to meet oversight requirements.	Hyperledger Fabric's design and capabilities, execute-order-validity architecture, enhance security and scalability, allowing for tailored deployed and updating of smart contracts in the EV ecosystem.	Blockchain technology, smart contracts, and game theory enable EV stakeholders to govern themselves autonomously, promoting decentralization in self-governance and eliminating the need for intermediaries.
3	**DRIVE Sustainability, EV OEMs, Tier-1 Suppliers**	*Automotive Partnership Sustainability throughout the Automotive Supply Chain*	Blockchain facilitates cooperation through Smart Contracts immutability and streamlined procurement processes, thereby incentivizing sustainable practices. Nash Equilibrium game theory encourages cooperative strategies among stakeholders for mutual benefit. Encourages oversight and decision-making, leading to more sustainable practices impacting accountability and transparency in sourcing practices.	Blockchain enhances transparency, traceability, and sustainability by creating shared, secure data platforms: Smart contracts automates agreements, ensuring compliance and reducing fraud. Nash Equilibrium fosters stable, mutually beneficial relationships among participants. The impact to sustainability is each of these aspects promotes responsible sourcing and waste reduction by through verifiable records.	Blockchain technology drives participation through accountable frameworks & consortium-based platforms. Smart contracts promote cooperative behavior by automating enforcement of agreement and incentivizing sustainable practices. Nash Equilibrium incentivizes stakeholders to collaborate towards common sustainability goals.

Conclusion

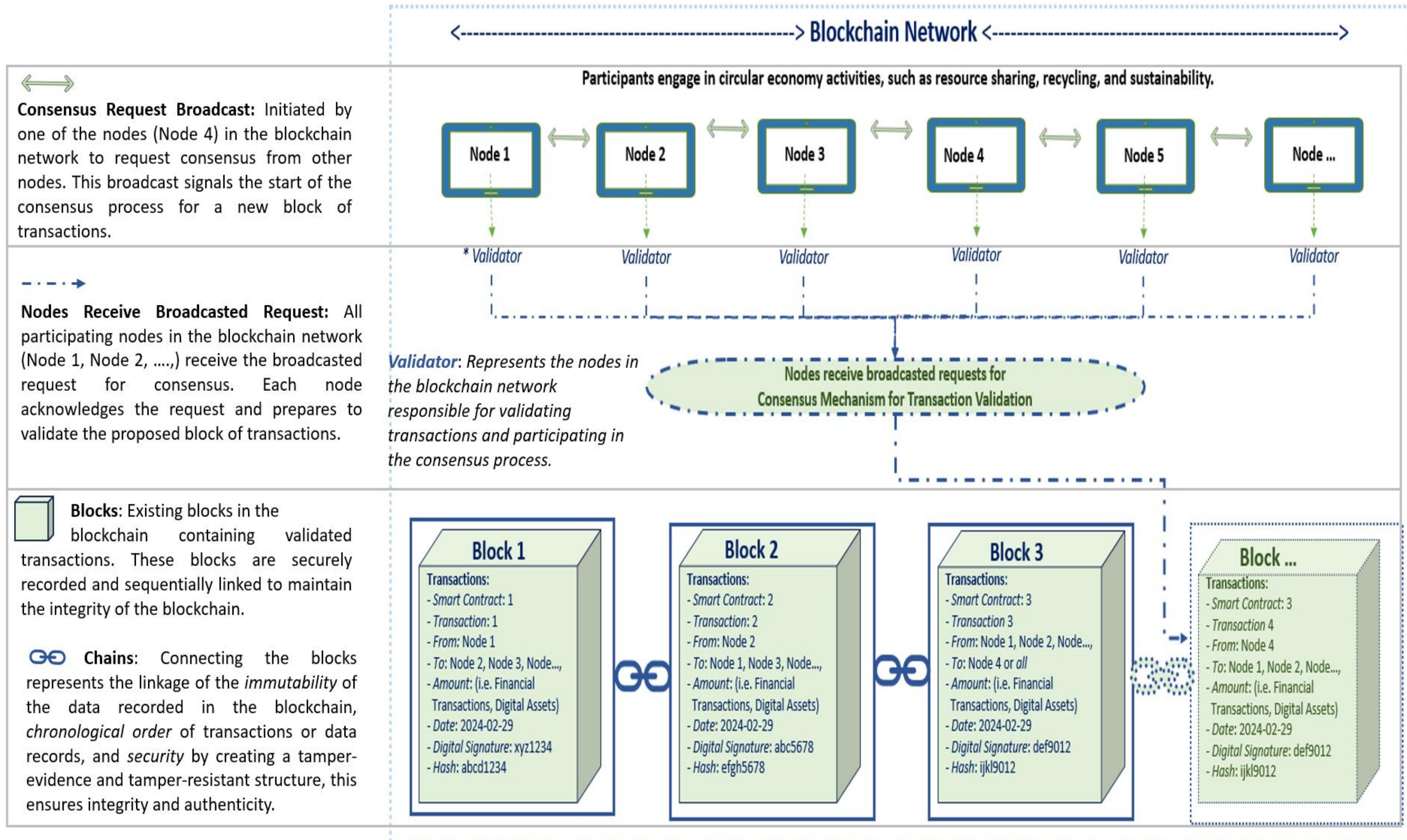
In conclusion, the case studies findings highlight the profound potential blockchain technology, smart contracts, and collaborative frameworks in reshaping sustainability paradigms within the electric vehicle (EV) industry. By strategically deploying these innovations, stakeholders can elevate transparency, traceability, and accountability across the EV lifecycle, fostering a more sustainable ecosystem. Through consortium-driven endeavors guided by Nash Equilibrium game theory, industry stakeholders are propelled towards collective action, addressing key challenges like responsible sourcing and environmental impact. These advancements not only optimize resource use and minimize waste but also bolster operational efficiency and long-term resilience, heralding a future marked by sustainable innovation and environmental care in the EV domain.

Future Research

It is important to reiterate that this project is based on limited literature of an innovative area of inquiry. Blockchain technology, particularly platforms like Hyperledger Fabric, holds immense promise for revolutionizing various industries, including the electric vehicle (EV) sector within the context of the circular economy (CE). The research highlighted a pilot project which addressed the upstream, midstream and downstream aspects of the circular economy, However, processes for end-of-life circularity remain at issue. Future research recommendations should be focused on end-of-life, development of recycling infrastructure and assessing the role of regulatory framework in driving circular economy. These recommendations come on the heels of regulatory measures poised to hold all EV battery producers accountable for material reuse and recycling.

APPENDIX A:

BLOCKCHAIN DIGITAL CONSENSUS MECHANISM



Blockchain Network
Participants engage in circular economy activities, such as resource sharing, recycling, and sustainability.
Consensus Request Broadcast: Initiated by one of the nodes (Node 4) in the blockchain network to request consensus from other nodes. This broadcast signals the start of the consensus process for a new block of transactions.
Node 1
Node 2
Node 3
Node 4
Node 5
Node ...
* Validator
Validator
Validator
Validator
Validator
Validator
Nodes Receive Broadcasted Request: All participating nodes in the blockchain network (Node 1, Node 2, ….,) receive the broadcasted request for consensus. Each node acknowledges the request and prepares to validate the proposed block of transactions.
Validator: Represents the nodes in the blockchain network responsible for validating transactions and participating in the consensus process.
Nodes receive broadcasted requests for Consensus Mechanism for Transaction Validation
Blocks: Existing blocks in the blockchain containing validated transactions. These blocks are securely recorded and sequentially linked to maintain the integrity of the blockchain.
Chains: Connecting the blocks represents the linkage of the immutability of the data recorded in the blockchain, chronological order of transactions or data records, and security by creating a tamper-evidence and tamper-resistant structure, this ensures integrity and authenticity.
Block 1
Transactions:
- Smart Contract: 1
- Transaction: 1
- From: Node 1
- To: Node 2, Node 3, Node...,
- Amount: (i.e. Financial Transactions, Digital Assets)
- Date: 2024-02-29
- Digital Signature: xyz1234
- Hash: abcd1234
Block 2
Transactions:
- Smart Contract: 2
- Transaction: 2
- From: Node 2
- To: Node 1, Node 3, Node...,
- Amount: (i.e. Financial Transactions, Digital Assets)
- Date: 2024-02-29
- Digital Signature: abc5678
- Hash: efgh5678
Block 3
Transactions:
- Smart Contract: 3
- Transaction 3
- From: Node 1, Node 2, Node...,
- To: Node 4 or all
- Amount: (i.e. Financial Transactions, Digital Assets)
- Date: 2024-02-29
- Digital Signature: def9012
- Hash: ijkl9012
Block ...
Transactions:
- Smart Contract: 3
- Transaction 4
- From: Node 4
- To: Node 1, Node 2, Node...,
- Amount: (i.e. Financial Transactions, Digital Assets)
- Date: 2024-02-29
- Digital Signature: def9012
- Hash: ijkl9012

APPENDIX B:

IDENTIFICATION OF THE RESEARCH GAPS

ID	Source / Year	Title	Research Method	Identified Research Gap
[1]	Global, R.C.S. (2017).	**Blockchain for traceability in minerals and metals supply chains: Opportunities and challenges.**	Qualitative Interviews	Any pilot project focus on a small *consortium* of companies.
[2]	Mingxiao, D., et al. (2017)	**A review on consensus algorithm of blockchain.**	Proof of Concept (PoC)	How to make blockchain performance better in different scenarios.
[3]	Esmaeilian, B. et al. (2020).	**Blockchain for the future of sustainable supply chain management in Industry 4.0.**	Literature Review	Sustainability objectives (1) Development of new performance indicators and life cycle assessment methods, (2) development of new data-driven decision-making techniques, (3) explore new case studies and best practices.
[4]	Frizzo-Barker, J., et al. (2020)	**Blockchain as a disruptive technology for business: A systematic review.**	Systematic Review	Conduct more studies on organizational practices and decision-making around the adoption of blockchain technologies.
[5]	Choi, T. M., et al. (2020)	**Game theory applications in production research in the sharing and circular economy era.**	Literature Review	Apply real-world case studies, with primary data collection. Big Data analytics. Emphasis on the whole supply chain system.
[6]	Kshetri, N., et al. (2022)	**Blockchain systems and ethical sourcing in the mineral and metal industry: a multiple case study.**	Multiple case study analysis. Literature Review.	More systematic comparison of blockchain and non-blockchain solutions in terms of costs and other indicators.
[7]	Gao, J., et al. (2022)	**Supply chain equilibrium on a game theory-incentivized blockchain network**	Proof of Concept (PoC)	Scope to understanding mechanisms that ensure effective decision-making across our proposed blockchain supply chain network in establishing equilibrium among parties.
[8]	Kumar, N. M., et al. (2022)	**Leveraging Blockchain and Smart Contract Technologies to Overcome Circular Economy Implementation Challenges**	Proof of Concept (PoC)	Build the literature around the digital circular economy and the proposed circular economy blockchain.
[9]	Mugurusi, G., et al. (2022)	**Blockchain technology needs for sustainable mineral supply chains: A framework for responsible sourcing of Cobalt**	Document Analysis/Systematic Procedure Document Review	End-to-end visibility. The strong focus of Blockchain today in the cobalt supply chain is on traceability and governance of the chain of custody but not necessarily on ESG considerations.

[10]	Ahmed, W. A., et al. (2022).	**Why, where and how are organizations using blockchain in their supply chains? Motivations, application areas and contingency factors**	Contingency theory.	Jointly consider the motivations for seeking a blockchain solution in the supply chain, identify and analyze in detail further important application areas in which blockchain can provide actual business value and further refine the contingency factors that influence blockchain deployment and application.
[11]	Júnior, C. A. R., , et al.(2022).	**Blockchain review for battery supply chain monitoring and battery trading.**	Systematic Review.	Literature results show that further studies are needed to identify and develop new unique identifiers for the different stages of the battery manufacturing process.
[12]	Deng, W.,et al. (2022)	**A Review of the Key Technology in a Blockchain Building Decentralized Trust Platform.**	Systematic Review.	Blockchain in combination with specific applications.
[13]	Wang, Y., et al. (2022)	**Green Supply Chain Coordination During the COVID-19 Pandemic Based on Consignment Contract.**	Literature Review	Investigate optimal decisions in the application of Nash Equilibrium in supply chain.
[14]	Chadly, et al (2023).	**A blockchain-based solution for the traceability of rare earth metals used in thin-film photovoltaics**	Smart Contract Testing and Validation.	Incorporating incentives and penalties by the certificate authority on the chain could be an interesting addition.
[15]	Gerasimova, V., et al. (2023).	**NFT-Enriched Smart Contracts for Smart Circular Economy Models**	Mixed methods: Expert interviews, desktop research, literature review, and case study.	The research advocates for the continued exploration and integration of such digital tools in various industries, contributing towards the transition of smart supply chains and circular economies.
[16]	da Silva, E. R., et al. (2023).	**Unleashing the circular economy in the electric vehicle battery supply chain: A case study on data sharing and blockchain potential.**	Empirical Research. Case Study	The specific design of incentives for actors in EVB SC's to share data is conceivable. Research on different roles of actors in blockchain-based systems, which may differ significantly from traditional structures in governance terms, is recommended.
[17]	Grati, R., et al. (2023).	**A Blockchain-based framework for circular end-of-life vehicle processing**	Feasibility Study - Prototype using the Ethereum blockchain.	Convince stakeholders in the automotive industry to adopt blockchain as a significant way to better transparency and traceability during the circular economy transition.

[18]	Chou, C. C., et al. (2023)	**Implementing a multichain framework using Hyperledger for supply chain transparency in a dynamic partnership: A feasibility study.**	Proof of Concept (PoC)	Development of new frameworks which include information sharing, party transactions, performance, evaluation, reporting and internal communications.
[19]	Taherdoost, H. (2023	**Smart Contracts in Blockchain Technology: A Critical Review.**	Literature Review	Future developments in domains such as data science, AI, and game theory into smart contracts in blockchain systems.
[20]	Guo, R., et al. (2024).	**New energy vehicle battery recycling strategy considering carbon emotion from a closed-loop supply chain perspective.**	Construction of evolutionary game model.	Construct an evolutionary game model based on other recycling models with the participation of multiple subjects, and to study the influence of heterogeneous emotions on the evolutionary behavior of multiple subjects.

REFERENCES

A.W.Harzing. (1990-2023). *Publish or Perish (Windows GUI Edition Version 8.9)*. Retrieved from Harzing.com: https://harzing.com/resources/publish-or-perish

Ahmed, W. A. (2022). Why, where and how are organizations using blockchain in their supply chains? Motivations, application areas and contingency factors. *International Journal of Operations & Production Management*, 42(12), 1995-2028.

Arora, A. K. (2022). Smart contracts and NFTs: non-fungible tokens as a core component of blockchain to be used as collectibles. *In Cyber Security and Digital Forensics: Proceedings of ICCSDF 2021*, 401-422.

Baars, J. D. (2021). Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. . *Nature Sustainability*, 4(1), 71-79.

Barteková, E. a. (2022). Digitalisation for the transition to a resource efficient and circular economy. *OECD Environment Working Papers*, No. 192, OECD Publishing, Paris.

Bitcoin, N. S. (2008). Bitcoin: A peer-to-peer electronic cash system. *www.bitcoin.org*.

Bloomberg. (2023, December 15). *GM, Ford and Tesla Contribute to Setback in EV Sales Growth*. Retrieved from www.bloomberg.com/news: https://www.bloomberg.com/news/newsletters/2023-12-15/electric-vehicle-sales-outlook-2024-less-bright-due-to-gm-ford-tesla

Brown, B. (2024, January 28). *The Manual* . Retrieved from www.themanuael.com: https://www.themanual.com/auto/government-ev-charger-subsidy/

Calvão, F. &. (2021). Digital extraction: Blockchain traceability in mineral supply chains. . *Political Geography*, 87.

Canalys. (2024, January 8). *Global EV market forecasted to reach 17.5 million units with solid growth of 27% in 2024*. Retrieved from www.canalys.com: https://www.canalys.com/newsroom/global-ev-market-2024

CARB. (2023, October). *Califonria Air Resources Board Advanced Clean Cars II*. Retrieved from ww2.arb.ca.gov: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii

Carreon, A. R. (2023, May 5). *RMI.rog*. Retrieved from The EV Battery Supply Chain Explained: https://rmi.org/the-ev-battery-supply-chain-explained/

Chadly, A. H. (2023). A blockchain-based solution for the traceability of rare earth metals used in thin-film photovoltaics. *Journal of Cleaner Production*, 428, 139399.

Chamberlain K, A.-M. S. (2021). Standardisation of UK Electric Vehicle Charging Protocol, Payment and Charge Point Connection. *World Electric Vehicle Journal* , 12.

Cheng, M. S. (2022). A sustainable framework for the second-life battery ecosystem based on blockchain. *eTransportation*, Volume 14, November 2022, 100206.

Choi, T. M. (2020). Game theory applications in production research in the sharing and circular economy era. . *International Journal of Production Research*, 58(1), 118-127.

Chou, C. C. (2023). Implementing a multichain framework using hyperledger for supply chain transparency in a dynamic partnership: A feasibility study. *Computers & Industrial Engineering*, 175, 108906.

Circulor. (2019, February 12). *Circulor.com*. Retrieved from Circulor achieves first-ever mine-to-manufacturer traceability on tantalum from Rwanda.: https://www.circulor.com/media-features

Congressional Research Service. (2022). *Critical Minerals in Electric Vehicle Batteries.* United States: https://crsreports.congress.gov.

da Silva, E. R. (2023). Unleashing the circular economy in the electric vehicle battery supply chain: A case study on data sharing and blockchain potential. *Resources, Conservation and Recycling*, 193, 106969.

Darin Buelow, S. C. (2023). *Deloitte Driving the Global EV Battery Supply Chain*. Retrieved from www2.deloitte.com: https://www2.deloitte.com/us/en/pages/operations/articles/ev-battery-supply-chain.html

De Filippi, P. a. (2018). Blockchain and the Law: The Rule of Code. In H. U. Press, *Blockchain and the Law: The Rule of Code* (p. 2). Cambridge, MA and London, England: Cambridge, MA and London, England: Harvard University Press.

de Sa, P. a. (2021). Resource efficiency, the circular economy, sustainable materials management and trade in metals and minerals. *OECD Trade Policy Papers*, No. 245, OECD Publishing, Paris.

Deepa, N. P. (2022). A survey on blockchain for big data: Approaches, opportunities, and future directions. *Future Generation Computer Systems*, 131, 209-226.

Deng, W. H. (2022). A Review of the Key Technology in a Blockchain Building Decentralized Trust Platform. *Mathematics*, 11(1), 101.

Dhondiyal, P. (2020). BLOCKCHAIN USE CASES EXPLORATIVE STUDY FOR INDIAN AUTOMOTIVE INDUSTRY. *International Journal of Engineering Applied Sciences and Technology*, Vol 5, Issue 7, ISSN No. 2455-2143, 83-101.

Drescher, D. (2017). *Blockchain Basics: A Non-Technical Introduction in 25 Steps.* Berkely: Apress.

DRIVE Sustainability History. (2024, March 23). *About Us - Our History*. Retrieved from https://www.drivesustainability.org: https://www.drivesustainability.org/our-history/

Drive+ FAQ . (2021). *Frequently Asked Questions Drive+.* DRIVE Sustainability .

DS Progress Report. (2023). *Drive Sustainability Progress Report 2023.* DRIVE Sustainability.

DS Strategy Action Plan. (2019). *Strategy Action Plan.* DRIVE Sustainability.

Earth.Org. (2023, March 28). *Earth.Org* . Retrieved from https://earth.org: https://earth.org/cobalt-mining-in-congo/

EllenMacArthurFoundation. (2024, February 2). *It's time for a circular economy* . Retrieved from Ellen MacArthur Foundation: https://www.ellenmacarthurfoundation.org/

Esmaeilian, B. S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. Resources. *Conservation and Recycling*, 163, 105064.

EU Regulations. (2023, July 12). Regulations (EU) 2023/152 of th European Parliament and of the Council. *Regulations (EU) 2023/152 of th European Parliament and of the Council*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542.

European Commission . (2024, March 22). *RMIS - Raw Materials Information System* . Retrieved from https://rmis.jrc.ec.europa.eu: https://rmis.jrc.ec.europa.eu/analysis-of-supply-chain-challenges-49b749

Eurotrade International Limited (ETI). (2022). *2021 Annual Due Diligence Report.* Rwandan mining Company: Eurotrade International Limited (ETI) .

EV Battery Challenge. (2023, July 3). *www.evbatterychallenge.com*. Retrieved from EV Battery Raw Material Inputs : https://evbatterychallenge.com/ev-battery-raw-material-inputs/

Ford. (2024, March 24). *What is my Electric Vehicle's Battery Warranty?* Retrieved from https://www.ford.com/: https://www.ford.com/support/howtos/warranty/warranties-and-coverage/what-is-my-electric-vehicles-battery-warranty/

Frizzo-Barker, J. C.-W. (2020). Blockchain as a disruptive technology for business: A systematic review. . *International Journal of Information Management*, 51, 102029.

FutureTracker . (2024, March 23). *Electric Vehicle Battery Recycling* . Retrieved from www.futuretracker.com: https://www.futuretracker.com/post/electric-vehicle-battery-recycling#:~:text=The%20global%20recycling%20rate%20of,or%20disposed%20of%20in%20landfill.

Gao, J. A.-A. (2022). Supply chain equilibrium on a game theory-incentivized blockchain network. *Journal of Industrial Information Integration*, 26, 100288.

Garrido-Hidalgo, C. R.-S. (2020). The adoption of internet of things in a circular supply chain framework for the recovery of WEEE: The case of lithium-ion electric vehicle battery packs. *Waste Management*, 103, 32.44.

Gerasimova, V. P. (2023). NFT-enriched smart contracts for smart circular economy models. *Entrepreneurship and Sustainability Issues*, 93-110.

Ghamrawi, N. G.-T. (2023). Teaching Licensure and Education Quality: Teachers' Perceptions. . *Sustainability*, 15(14), 10886.

Grati, R. L. (2023). A blockchain-based framework for circular end-of-life vehicle processing. . *Cluster Computing*, 1-14.

Guo, R. H. (2024). New energy vehicle battery recycling strategy considering carbon emotion from a closed-loop supply chain perspective. . *Scientific Reports*, 14(1), 688.

Harris, J. D. (2019). Decentralized and collaborative AI on blockchain. *IEEE international conference on blockchain*, 368-375.

Harvard International Review (HIR). (2020, January 15). *HIR Harvard International Review*. Retrieved from The Lithium Triangle: Where Chile, Argentina and Bolivia Meet : https://hir.harvard.edu/lithium-triangle/

Hirschlag, A. (2022, January 5). *Lithium batteries' big unaswered question.* . Retrieved from www.bbc.com: https://www.bbc.com/future/article/20220105-lithium-batteries-big-unanswered-question

Hu, Y. L. (2018). Blockchain-based smart contracts-applications and challenges. *arXiv preprint*, 26.

Hua, S. Z. (2018). Apply blockchain technology to electric vehicle battery refueling. *AIS eLibrary*.

Hyperledger Blockchain Technologies for Business. (2018). Case Study. *Case Study: Circulor achieves first-ever-mine-to-manufacturer traceability of a conflict mineral with Hyperledger Fabric*. Hyperledger Foundation.

Hyperledger Case Study . (2018). Case Study. *Case Study: Circulor achieves first-ever-mine-to-manufacturer traceability of conflint mineral with Hyperledger Fabric*. UK: Hyperledger Foundation.

Hyperledger Fabric v3.0. (2023). What's New in Hyperledger Fabric. *What's New in Hyperledger Fabric v3.0 Byzantine Fault Tolerant (BFT) ordering service*. hyperledger-fabric.readthedocs.io.

Hyperledger Foundation. (2020, March 31). *10 Practical Issues for Blockchain Implementations*. Retrieved from www.hyperledger.org: https://www.hyperledger.org/blog/2020/03/31/title-10-practical-issues-for-blockchain-implementations

Hyperledger Foundation Case Study. (2019). Case Study. *Materials Traceability Leader Circulor Expands Hyperledger Fabric-Based Solution to Underpin Digital Passports* . Hyperledger Foundation .

Hyperledger Foundation Docs Release Master. (2020, September 30). *hyperledger-fabric.readthedocs.io.* Retrieved from Hyperledger-fabricdocs Documentation Release Master: https://hyperledger-fabric.readthedocs.io/en/latest/whatis.html

Hyperledger Foundation Turns Five. (2020, December 17). *www.hyperledger.org*. Retrieved from Hyperledger Turns Five: https://www.hyperledger.org/announcements/2020/12/17/hyperledger-turns-five

Hyperledger_Circulor, Case Study. (2018). Materials Traceability Leader Circulor Expands Hyperledger Fabric-based Solution To Underpin Digital Battery Passports. *Materials Traceability Leader Circulor Expands Hyperledger*

Fabric-based Solution To Underpin Digital Battery Passports. Hyperledger Foundation.

IBM. (2019, November 6). *Volvo Cars Joins Responsible Sourcing Blockchain Network, Launched by IBM, Ford, and Volkswagen Group; Advancing Ethical Sourcing of Minerals Continues to Scale With This Network*. Retrieved from www.newsroom.ibm.com: https://newsroom.ibm.com/2019-11-06-Volvo-Cars-Joins-Responsible-Sourcing-Blockchain-Network-Launched-by-IBM-Ford-and-Volkswagen-Group-Advancing-Ethical-Sourcing-of-Minerals-Continues-to-Scale-With-This-Network

IBM. (2024, February 28). *Sourcing minerals responsibility with blockchain technology.* . Retrieved from IBM.com: https://www.ibm.com/case-studies/rcs-global-blockchain#:~:text=RCS Global Group-,Smarter supply chains for the future,practices in the ASM sector.

IBM Annual Report. (2016). *IBM Annual Report.* IBM.

IBM Case Study. (2024). The Future of Energy Business in Circular Economy. *The Future of Energy Business in Circular Economy*. IBM.

IEA. (2021, December). *Global EV Outlook 2021 Accelerating Ambitions Despite the Pandemic.* International Energy Agency.

IEA. (2023, April). *International Energy Agency Global EV Outlook 2023 Catching Up with Climate Ambitions.* Retrieved from www.iea.org: https://www.iea.org/reports/global-ev-outlook-2023/policy-developments

Jaeger, B. &. (2020). Understanding barriers to circular economy: cases from the manufacturing industry. *Journal of Enterprise Information Management*, 33(4), 729-745.

Jäger-Roschko, M. &. (2022). Advancing the circular economy through information sharing: A systematic literature review. *Jouirnal of Cleaner Production*, 133210.

Júnior, C. A. (2022). Blockchain review for battery supply chain monitoring and battery trading. . *Renewable and Sustainable Energy Reviews*, 157.

Kirsten Lori Hund, D. L. (2019, October 8). *Changing mining practices and greening value chains for a low carbon-world* . Retrieved from Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development : https://www.igfmining.org/changing-mining-practices-and-greening-value-chains-for-a-low-carbon-world/

Knieke, C. L. (2019). Predictive and flexible Circular Economy approaches for highly integrated products and their materials as given in E-Mobility and ICT. *Trans Tech Publications Ltd.*, In Materials Science Forum (Vol. 959, pp. 22-31).

Kristoffersen, E. B. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research*, 120, 241-261.

Kshetri, N. (2022). Blockchain systems and ethical sourcing in the mineral and metal industry: a multiple case study. *The International Journal of Logistics Management*, 33(1), 1-27.

Kumar, N. M. (2022). Leveraging blockchain and smart contract technologies to overcome circular economy implementation challenges. . *Sustainability*, 14(15), 9492.

Li, D. P. (2018). A blockchain-based authentication and security mechanism for IoT. *In 2018 27th International Conference on Computer Communication and Networks (ICCCN)*, 1-6.

Malinauskaite, J. A. (2021). Circular waste management of electric vehicle batteries: Legal and technical perspectives from the EU and the UK post Brexit. *International Journal of Thermofuilds* , 10.

McDonough, W. &. (2010). *Cradle to cradle: Remaking the way we make things.* New York : North point press.

Mingxiao, D. X. (2017). A review on consensus algorithm of blockchain. *In 2017 IEEE international conference on systems, man, and cybernetics (SMC)*, (pp. 2567-2572). IEEE.

Mugurusi, G. &. (2022). Blockchain technology needs for sustainable mineral supply chains: A framework for responsible sourcing of Cobalt. . *Procedia Computer Science*, 200, 638-647.

Nash, J. (1951). Non-cooperative games. *Annals of mathematics*, 286-295.

OECD. (2024, March 3). *OECD Better Policies for Better Lives*. Retrieved from Who We Are: https://www.oecd.org/about/

O'Shields, R. (2017). Smart Contracts: Legal Agreement for the Blockchain. *NC Banking Inst.*, 21.

Ovaitt, S. M. (2022). PV in the circular economy, a dynamic framework analyzing technology evolution and reliability impacts. *Iscience*, 25(1).

Picatoste, A. J. (2022). Circularity and life cycle environmental impact assessment of batteries for electric vehicles: Industrial challenges, best practices and research guidelines. *Renewable and Sustainable Energy Reviews*, 169.

Pons, J. R. (2022). Benchmark of Decentralised Identifier and Identity Terms for Harmonising Blockchain and Distributed Ledger Technology and Identification Standards. 15.

Pourzarei, H. R. (2020). Cross-pollination as a comparative analysis approach to comparing BIM and PLM: a literature review. *Product Lifecycle Management Enabling Smart X: 17th IFIP WG 5.1 International Conference, PLM 2020, Rapperswil, Switzerland, July 5–8, 2020*, Revised Selected Papers 17 (pp. 724-737).

R.C.S.Global. (2017). Blockchain for traceability in minerals and metals supply chains: Opportunities and challenges. *Self published*, 1(1), 1-21.

RCS Global Group. (2021, January 18). *NorNickel joining RCS Global – IBM Blockchain Collaboration (RSBN). Signals responsibility commitment.*

Retrieved from rcsglobal.com: https://www.rcsglobal.com/new-member-joins-rsbn/

RCS Global Group. (2023). *Better Mining Impact Report .* RCS Global Group.

RCS Global Group. (2023, October 24). *News RCS Global Group's Better Mining Upstream Mechanism Achieves Full Alignment Rating with OECD Guidance* . Retrieved from rcsglobal.com: https://www.rcsglobal.com/rcs-global-groups-better-mining-upstream-mechanism-achieves-full-alignment-rating-with-oecd-guidance/

RCS Global Group. (2024, February 29). *About RCS Global Group*. Retrieved from RCS Global Group: https://www.rcsglobal.com/about-rcs-global/

Reuters. (2024, January 8). *Global EV market growth to slow this year on lower subsidies - report*. Retrieved from www.Reuters.com: https://www.reuters.com/business/autos-transportation/global-ev-market-growth-slow-this-year-lower-subsidies-report-2024-01-08/

Sanni, M. I. (2021). Blockchain Technology Application: Authentication System in Digital Education. *Aptisi Transactions on Technopreneurship (ATT)*, 151-163.

Schöggl, J. P. (2023). Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector. *Sustainable Production and Consumption*, 35, 401-420.

Shan, L. Y. (2023, August 29). *www.cnbc.com*. Retrieved from A worldwide lithium shortage could come as soon as 2025:

https://www.cnbc.com/2023/08/29/a-worldwide-lithium-shortage-could-come-as-soon-as-2025.html#:~:text=The%20world%20could%20face%20a,lithium%20supply%20deficit%20by%202025.

Sheth RP, R. N. (2023). The Lithium-ion battery recycling process from a circular economy perspective - A review and future directions. *Energies*, 16.

Smartcar. (2024, January 26). *Unlocking growth: 5 key electric vehicle stats for 2024 · Smartcar blog. (n.d.).* . Retrieved from Smartcar.com.: https://smartcar.com/blog/2024-ev-statistic

Statista. (2024, March 31). *www.statista.com*. Retrieved from Electric Vehicles - Worldwide : https://www.statista.com/outlook/mmo/electric-vehicles/worldwide

Sundarakani, B. A. (2021). Big data driven supply chain design and applications for blockchain: An action research using case study approach. *Omega*, 102.

Taherdoost, H. (2023). Smart Contracts in Blockchain Technology: A Critical Review. *Information* , 14(2), 117.

Thuraisingham, B. (2020). Blockchain technologies and their applications in data science and cyber security. *In 2020 3rd international conference on smart blockchain (SmartBlock)*, 1-4.

Upadhyay, A. M. (2021). Blockchain technology and the circular economy: implications for sustainability and social responsiblity . *Journal of Cleaner Production* , 293, 126130.

Volkwagen. (2024, March 24). *High-Voltage Battery: Warranty and Maintenance*. Retrieved from www.volkwagen.co.uk: https://www.volkswagen.co.uk/en/electric-and-hybrid/should-you-go-electric/servicing/battery-maintenance-and-waranty.html

Volvo. (2024, March 24). *Volvo Electric Cars*. Retrieved from www.volvocars.com: https://www.volvocars.com/us/cars/electric-cars/

Wang, Y. R.-M. (2022). Green Supply Chain Coordination During the COVID-19 Pandemic Based on Consignment Contract. . *Frontiers in Environmental Science,* , 10, 899007.

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods, Sixth Edition.* Thousand Oaks, CA : SAGE Publications, Inc. .

Zhao, Y. P. (2021). A review on battery market trends, second-life reuse, and recycling. *Sustainable Chemistry*, Sustainable Chemistry.