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NFT-BASED LIFE CYCLE MANAGEMENT FOR BATTERIES OF E-CARS

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The classical pathway of mass production followed a linear model with trashed products and wasted remaining materials at the final stage of their life cycle. Smart approaches of manufacturing and product life cycle management aim for Circular Economy (CE) models to implement sustainable business models to overcome imbalances between resource supply and demand of goods. Non-Fungible Token (NFT) solutions together with smart contracts seem to have the potential to realise such new sustainable business models in the context of CE. The study demonstrates how NFT technology can become an integral part of smart product life cycle management for batteries of e-cars. The research highlights how circular business models can be developed and implemented in the e-car sector around the life cycle management of batteries as well as how NFT technology can contribute to sustainable conceptualisation for battery recycling.

Keywords: Non-Fungible Token, product life cycle management, batteries, e-cars, circular economy, Interreg South Baltic

1. Introduction

With the shift towards electric mobility, the purchase behaviour towards used cars is changing. In case of electric cars, the focus is primarily on the battery as a central component, i.e. the state of the battery (SoH: State of Health) becomes important for trading e-cars on markets. The reason for this is that the battery accounts for 50 percent or even more of the vehicle’s value (AB, 2023). However, it is complicated to look inside the battery so that several technology start-ups are tinkering with testing methods to evaluate the current value of battery of used e-cars. Unfavourable conditions, such as an inefficient driving style, high driving speed, heat or cold, as well as mileage, charging cycles, and many other factors can reduce significantly the battery capacity and its related value. Thus, a test is required that provides a clear indication of the remaining capacity and health status of the traction battery, allowing buyers and sellers to better assess the value, its functionality and the performance of used electric cars, and thus to reduce information asymmetries (Butera *et al*., 2023; Brousmiche *et al*., 2018; Chen *et al*., 2023; Naik *et al*., 2024).

Hence, fundamental approaches for testing the battery condition of electric cars represent an important pillar within the evaluation of used cars so that big companies, like the German Automobile Trust (DAT) supporting the development of testing technologies. From 2026 onwards, a rating system will become mandatory for e-car trade and even EU demands a battery passport for every electric car inside Europe (European Commission, 2020; European Parliament, 2022; Melin *et al*., 2021; Umicore, 2022). Paradoxically, while other sectors have already introduced digital coding or software solutions for tracing product life cycle or for the purpose to increase traceability of information, like agriculture, pharmaceutics, no technology or solutions existed by 2020 to trace battery quality by means of any traceability mechanisms (CEID, 2020; Torjesen & Isaksen, 2023). This bears a clear research gap. Next to that, a managerial gap can be also formulated here, since the European Commission stipulated the need for research and innovation proposals on the battery passport in Horizon Europe Programme starting from 2023 onwards (ibid., p. 8). By today, policies related to e-car battery treatment are to a high extent lacking (Lee *et al*., 2004). Consequently, a couple of projects on this topic are already underway, and in Germany, the Austrian start-up Aviloo will be among the first to meet the EU requirements (Aviloo, 2023; Lopez-Pimentel *et al*., 2023). Indeed, also a scholarly community calls for a need to increase research on the role of digital technologies in relation to e-car battery ecosystem collaboration, orchestration and dynamics, thus improving transparency of battery health data (Stefan & Chirumalla, 2025).

The evaluation of battery condition is not an easy task because the state of health of a used battery depends less on the age than on the usage and the operational profile of the battery, i.e. frequent fast recharging leads to quick aging battery as well as heat and high acceleration on the road. Meanwhile, there are already electric cars with a battery management system that display the SoH of a car, but the indicated status of the battery is often not reliable, i.e. displayed battery status often deviates significantly from the real status.

Therefore, Aviloo focusses on the measurement of tens of thousands of utilisation data that are captured in different operation situations and test trips of an e-car to be able to decide whether a specific battery is healthy or weak. Aviloo developed a test device that a client can order for 100€ and that is connected to the Onboard-Diagnosis-System of the car. After installation of the test unit, the client must drive his car one week with the installed test box until the state of charge of the battery, i.e. the remaining available capacity of the battery, drops below 10%. After this test week the box is sent back to Aviloo in Austria and the company issues and transfers, based on the individual test results, an individual certificate stating the status of health of the tested battery. This certificate is recognised by automotive experts and car evaluation consultants. In case of detected weakness of the battery health status, not the whole battery has to be trashed, often it is enough to replace some battery module to reach a satisfying health level (AB, 2023).

By doing so, the approach for keeping batteries of e-cars working differs from the classical pathway of mass production that has been known as a linear model, where products that reach the final stage of their life cycle are trashed so that the remaining resources are wasted, creating an imbalance between resource supply and goods demand (Gerasimova *et al*., 2023; Koopelaar *et al*., 2023; Prause, 2015). Thus, the linear model in production together with the current consumption rate make it impossible for future generations to use available limited resources. Therefore, a new sustaining development path is necessary. Overcoming the contradiction between the need for economic growth and the necessity for accomplishing environmental sustainability is thus one of the most compelling issues of our time (Ellen MacArthur Foundation, 2019; Götz *et al*., 2022; Hobson & Lynch, 2016; Koppelaar *et al*., 2023). The need for an alternative model of sustainable development with closed material loops spurred the emerge of Circular Economy (CE) within the scientific and political agenda causing a growing number of academic studies in different business sector (Leal Filho *et al*., 2021; Rizos & Urban, 2024, Uusitalo *et al*., 2024).

The paper investigates the research questions how smart contracting, blockchain technology and NFT solutions can facilitate the implementation of circular business models for batteries of e-cars. The authors participated in several research projects related to smart supply chains and Circular Economy. The research is based on expert interviews, and case studies from the EU projects as well as critical assessment of recent solutions stemming from industry. Expert interviews provide insights from professionals with extensive experience and knowledge in the field of investigation, whereas literature review offers a broad and systematic overview of existing scholarly perceptions and data sources. The research is complemented by a case study providing a detailed and contextualised understanding of the research topic. The gained empirical imprint represents a classic case of utilising a multi-method approach, which is underpinned by data from different sources that were analysed and interpreted using a methodological triangulation approach. Finally, the empirical results of the research are critically discussed in the context of the current literature and industrial achievements.

2. Theoretical background

Even though many scholars already made efforts to specify Circular Economy (CE), there is yet no comprehensive definition of the CE. The main objective of CE is to maintain the value of materials by keeping them in circulation and, consequently, to reduce our reliance on material extraction (Baars *et al*., 2021; da Silva *et al*., 2023; Kirchherr *et al*., 2023; Kirchherr *et al*., 2017; Sopha *et al*., 2022). According to Hislop and Hill (2011), the CE represents a development strategy that maximises resource efficiency and minimises waste production, within the context of sustainable economic and social development" (p. 2).

However, after decades of discussion and research around CE, the linear model is still deeply rooted, and political, economic, technological, and legal obstacles slowdown the transition to a CE (Alivojvodic & Kokalj, 2024; Hart *et al*., 2019; Kirchherr *et al*., 2018). In addition, potential bottlenecks hindering CE to become a common thread within supply chain management practices, relate to social aspects, such as relations between consumers, businesses and governments, or collaboration level (Bardhi & Eckhardt, 2012; Hartley *et al*., 2024; Sopjani *et al*., 2020). However, new initiatives to overcome these deficits have their source mainly in innovative production paradigms labelled smart supply chain management or Industry X.0 (Gallab & Nardo, 2023; Lamrani Alaoui *et al*., 2024; Prause 2015, 2014). Already the Industry X.0 concept highlights tenets, like energy and resource efficiency and embraces the idea of renewable materials and energy sources. These targets are sought to be reached by fusing the virtual and the physical world based on smart internet technologies and networked production processes. Consequently, the experts predict increased productivity, shorter innovation and time-to-market cycles together with a horizontal and vertical integration through value networks and an end-to-end digital integration of engineering across the entire value chain. Thus, the internet linked production facilities and networked manufacturing systems open up a new machine-to-machine interaction, which allows to name, identify and trace single products during their whole creation process, and later on during their lifetime. This concept generates new perspectives for the entire product life cycle, including product design and development, operations management and logistics. New technologies, like blockchain and Non-Fungible Token (NFT) unlock new perspectives for the implementation of those ideas.

In Circular Economy, the possibility to identify, trace and track products during their whole life cycle is of special interest because it opens the opportunity to attach special conditions, services and rights to events during different phases of their lifetime (Eshghie *et al*., 2022; Neramballi *et al*., 2024; Singh *et al*., 2024). Product Life Cycle Management (PLM) controls the entire life cycle of a product from initial product conception phase through its engineering, design and manufacture, via product-related services until disposal of manufactured products, i.e. PLM integrates humans, data, processes, and business systems and facilitates a product information backbone for enterprises and their supply chain members (Ameri & Dutta, 2005; ElMaragphy *et al*., 2013; Saaksvuori, 2008) Under this viewpoint, an effective PLM depends strongly on the performance and the sophistication level of the company's ICT (Information and Communication Technologies) structure, since all companies have to cope with the communications and information needs of their customers, their supply chain partners, their internal resource planning and their product development (Carvalho *et al*., 2013; Chandrasegaran *et al*., 2013; Gotsch *et al*., 2019).

Among ICT or digital technologies, the potential of blockchain technologies together with smart contracts to facilitate event-triggered and automatised transactions within supply chains shall be highlighted (Pang *et al*., 2019; Philipp *et al*, 2019; Schweitzer *et al*., 2019). In the traditional perception, a smart contract realises the digital execution of legal agreements and linked transactions between distributed units within a network or supply chain with reduced transaction costs, being trackable and irreversible (Chen *et al*., 2019; Kumar *et al*., 2022; Prause, 2019). However, the potential of smart contracts goes far beyond cost reductions by facilitating the entrepreneurial collaboration of cross-organisational business processes. In the Circular Economy context, smart contracts can realise the digital execution of transactions related to special events in the product life cycle based on predefined rules or legal agreements. In combination with Non-Fungible Token (NFT), i.e. links to fixed data set identifying and attributing special features to a product, smart contracts can be parametrised to execute triggered services related to the product or to implement and specify smart business models.

Gerasimova *et al*. (2023) investigated the case study of the Alfa Romeo's Tonale hybrid SUV representing a ground-breaking application of blockchain technology and NFTs in the automotive industry. This case study provided the understanding how smart contracts and NFTs can revolutionise the automotive industry, transforming customer experiences and influencing business models in the Circular Economy context. The Tonale car was launched in 2023 incorporating blockchain technology and each car is equipped with a complimentary NFT digital certificate linked to the vehicle that continuously updates the essential vehicle data ensuring a consistent and reliable record of the vehicle's history (Alfa Romeo, 2023). Hence, the NFT records and updates information about maintenance and milestones, such as reaching 100.000 miles. It provides a well-documented vehicle history offering added value to the owner in case the vehicle should be sold. This utilisation of NFTs offers an innovative solution to a longstanding issue of the product life cycle with an additional added value for the used car market mitigating information asymmetry and difficulty verifying a vehicle's history (Leng *et al*., 2020; Schmidt *et al*., 2019; Teslya, 2019).

The Alpha Romeo Tonale is still a hybrid car so that the next level of car evolution are the e-cars that require a healthy battery as their core element, as already explained earlier. Hence, batteries can be considered as one key technology for successful sustainable transition of global economy and an important pillar for renewable energy systems. In Europe, Germany and the UK are leading countries in storage deployment in the e-sector (Estebanez,2023; Potau *et al*., 2018). However, administrative barriers and missing infrastructure hinder battery deployment. Hence, many EU countries are trying to incentivise R&D activities and installation of battery systems by offering low-interest loans, subsidising electricity tariffs and enhancing smart grid systems.

The success of e-car sector in Europe is related to a couple of general key questions that must be solved by regulatory and technical frameworks. First question is linked to the creation of a fair and transparent used e-car market, since e-cars are still more expensive in purchasing than fossil cars, so that later selling of a used e-car should bring a high price that can be reinvested into a new e-car. Second question is, like already mentioned, to find a fair and reliable evaluation for the used e-car and here especially for the battery quality representing a high value component of the e-car. Finally, the umbrella question is linked to the recycling of batteries, since one important motivation for pushing the e-car sector are Circular Economy reasons, which should apply consistently to all parts of the e-car sector.

3. Circular Economy Models for Batteries

The mentioned main questions above pertaining to the e-car sector resulted into intensive research activities of scholars in the field of battery recycling. Like in all other recycling processes, in battery recycling as well, as much material as possible should be returned into Circular Economy. Within lithium-ion battery recycling and circularity, design, packing and modularisation can simplify battery dismantling and making recycling more efficient (Chirumalla *et al.*, 2024; Dun *et al*., 2021; Thompson *et al*, 2020; Zeng *et al*., 2022). While recycling of lithium-ion batteries obviates pollution, saves resources and boosts sustainability, thus increasing research interest, there is not commonly accepted economic or sustainable automotive battery recycling (Li *et al*., 2024; & Leker, 2024; Mao *et al*., 2022; Lilian *et al*., 2023; Yu *et al*., 2023). Thus, the importance of an initiative recycling-oriented product design of the cells configuration to improve a closed-loop design of new batteries is critical (ElJalbout & Keivanpour, 2024; Gianvincenzi *et al*., 2024; Thompson *et al*., 2020). We might it call also an eco-design. Next to that, different recycling techniques of lithium-ion batteries play a crucial role for their circularity from technical, economic and environmental perspectives. For instance, more than two-thirds of the current recycling capacity is in China and by summing approximately 90% of recycling capacity is concentrated in Europe and East Asia. While currently only partially recycling technology of lithium-ion batteries is established, additional technical research is necessary to improve the existing recycling processes (Baum *et al*., 2022; Lai *et al*., 2022; Roy *et al*., 2022, Wang *et al*., 2022). Recycling potential, however, for lithium and nickel is more than half the raw material demand for lithium-ion batteries in 2024, thus making a huge untapped horizon appearing on the sky, when it comes a better recycling of battery materials (Maisel *et al*, 2023).

Another important aspect of batteries that must be highlighted is linked to the fact that old batteries must be handled as dangerous goods. Therefore, the European Parliament and the European Council approved the Regulation (EU) 2023/1542 on 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC. The new regulation aims at promoting a Circular Economy for batteries throughout their life cycle. The circularity should be achieved by formulating sustainability rules for end-of-life requirements, including collection targets and obligations for recycling and recovery of materials and extended producer responsibility. Consequently, this EU regulation also affects all aspects of battery logistics including transport, storage and handling, which have to be considered in in the legal and organisational frameworks. Therefore, in this light, risk management concepts for green logistics of dangerous goods that are compliant with sustainability regulations plays a crucial role, when recycling and recovery battery metals (Schröder & Prause, 2016; 2015).

The application of blockchain and NFT-technology can contribute to safer handling of dangerous goods as well as to create sustainable business models for Circular Economy in high tech sector (Gerasimova *et al*., 2023). The involved NFT represents in such a case a unique digital identifier certifying ownership and authenticity. Such an NFT represents a proof of ownership of a blockchain record and can be therefore transferred from one owner to another in a purchase or in another commercial transaction, without the possibility to be copied, substituted, or subdivided. A technical implementation of such an NFT can be considered as a link to digital files that are stored on blockchains. An NFT acts as an artifact, which is uniquely identifiable, easy to create, and can be associated with a particular digital or physical asset, e.g. an image, a painting, a music song, or a good conferring licensing rights to use the asset for a specified purpose (Barclay *et al*., 2021; Heines *et al*., 2021; Osterland & Rose, 2020; Wang *et al*., 2021). In this sense NFTs are able to realise the naming, identification and tracking of single products during their whole life cycle.

In particular business sectors, especially in the Cultural and Creative Industries (CCIs), NFTs enjoy already high economic importance because they are linked to digital files pertaining to songs, videos or other artwork and thus represent the market value of an NFT (Altrichter *et al*., 2022). Hence, NFTs represent a public certificate of authenticity or proof of ownership defined by the blockchain. However, NFTs do not grant a copyright of a represented object, i.e. the author or a licensed user is able to create a generally unlimited number of further NFTs representing the same object. Thus, NFTs are not granting any other legal rights over their associated digital file, they can be considered rather as a "digital label" comparable to a price tag (Das *et al*., 2022; Davidova *et al*., 2022; Nadini *et al*., 2021; Marin *et al*., 2023; Pinto-Gutierrez *et al*., 2022; Wang *et al*., 2021).

In the context of Circular Economy, NFTs are considered as uniquely identifiable tokens that refer to a digital file that stores rights and conditions for certain trigger points in the product life cycle. Underlying smart contracts can use these NFTs for executing scripts with parameters stored in the digital files. By doing so, smart contracts can be parametrised through NFTs with actual parameters along the life cycle of a product so that blockchain implementation in the context with smart contracts and NFTs enhance supply chain and life cycle transparency, traceability, and accountability, thus leading to increased efficiency, reduced waste and improved environmental and social sustainability (Ayan *et al*., 2022). The application of NFTs is multifaceted in different business sectors. Current literature highlights especially the potential of improving operational efficiency and trust among supply chain participants, which is underpinned by several case studies from the food, fashion, and energy industries that showcase the potential of blockchain technology in promoting sustainability.

Indeed, recent approaches to traceability in the textile and clothing value chain showcases, which technologies are necessary for promoting a Circular Economy in this industry (Alves *et al*., 2022). Furthermore, some methods for efficient and unrestricted publicity of third-party certification of plant agricultural products by using smart contracts and blockchain tokens might provide economic incentives to actors in the supply chain (Ali *et al*., 2023; Dos Santos *et al*., 2021; Vasan *et al*., 2022). As Gerasimova *et al*. (2023) pointed out in their study about the Alfa Romeo's Tonale hybrid SUV, NFTs can transform customer experiences as well as influence business models in automotive industry by equipping each car with a complimentary NFT digital certificate, which continuously updates the essential operational data to ensure a consistent and reliable record of the vehicle's operational history. This well-documented vehicle history offers an added value to the owner in case the vehicle should be sold. By doing so, the use of NFTs offers an innovative solution for a sustainable product life cycle by mitigating information asymmetry on the used car market and difficulty and thus contributing to better customer value (Deventer *et al*., 2024; Kadam *et al*., 2024; Pirnay *et al*., 2023; Razi *et al*., 2023)

Hence, the use of NFTs opens new pathways of managing and verifying ownership as well as enable tracking of product life cycles and creation of digital twins of physical assets (Kirchherr *et al*., 2017; Pang *et al*., 2021; Tapscott & Tapscott, 2016). Consequently, NFT-enriched smart contracts have also gained significant attention in recent years for their potential use in Circular Economy models to safeguard a maximal use of products, by reducing resources' use or by enhancing opportunities to reuse and recycling them. Thus, the use of these technologies opens a pathway in developing frameworks for dwelling into NFT-enabled and driven passport production, preventing duplicate issuances, enhancing transparency, improving trading efficiency and securing transaction records. A prototype of the framework was developed and found to be feasible with satisfactory performance, serving as a reference for future blockchain NFT-enabled passport applications in the Circular Economy.

4. Methodology

The research is based on desktop research about recycling of batteries of e-cars, i.e. on the recycling of lithium-ion batteries. Since the evaluation of the health status of e-batteries as well as the recycling technology of lithium-ion batteries is still under development, the study has been complemented with the empirical data gathered in form of expert interviews and case studies. The empirical inquiry took place between June 2022 and September 2024 in the frame of the EU projects "UnWaste", "Connect2SmallPorts" and "DigiPort2030" focusing on digitalisation and sustainable transportation in the partner countries of the South Baltic Sea Region (SBSR). The underlying empirical data stem from different sources so that we followed the methodology of triangulation by applying and combining several research methods in the study of the same phenomenon. The used qualitative studies combine different theories, methods, and empirical data to resolve tentative weaknesses or intrinsic biases related to the research questions, by following Altrichter's principle of giving a more detailed and balanced picture of the situation (Altrichter, 2020; Altrichter *et al*., 2005).

The literature review reveals that research on NFT-technology in the nexus of battery recycling of e-cars has not sufficiently investigated so far (Gerasimova *et al*., 2023). Hence, to the best of our knowledge, currently there exist no published work that discussed how NFT technology can facilitate the evaluation and recycling of Lithium-Ion batteries of e-cars. According to Creswell and Creswell (2017), if a concept or phenomenon needs to be understood, because less research has been done on a specific topic, especially the qualitative research approach is suitable. Therefore, in the frame of the current research study, the decision was made to favour a qualitative research approach. Hence, the authors gathered primarily qualitative and combined empirical enquiry that they received. The analysis was done in the frame of the interpretation process that is reflected by the presented holistic research results. The qualitative research in the present research study represents narrative research. During the narrative research, the gathered information from experienced individuals is condensed and accumulated by the researchers. The authors of the present research study performed 20 semi-structured expert interviews. These expert interviews mainly embraced open-ended questions, whereby a quarter of the questions represented closed-ended questions. Building upon this, additional case studies were performed in the current research study. The research was complemented by field research, an extensive literature review, analysis and examination of respective theories and approaches, topic-related policy regulations and guidelines, representing a systematic research procedure for the elaboration of a process, action and / or interaction about a substantial subject (Creswell and Creswell, 2017; Merriam *et al*., 2008; Stake, 1995).

Relevant information and observations were gained from a broad field of project actions, like project partner meetings, workshops, trainings, matchmaking events as well as logistics and open seaport-related conferences with project interest groups. In addition, focus group meetings had been performed for a stronger target-oriented investigation of topics of interest. These focus group meetings were conducted during the EU-projects “UnWaste”, “Connect2SmallPorts” and “DigiTechPort2030”, representing one ERASMUS+ project and two Interreg Projects with partners from the South Baltic Area (Interreg South Baltic Programme). Moreover, additional primary information was gathered from individual meetings with experts from ICT, logistics and recycling sector. Phone conferences and Skype meetings assisted this data and information collection process. Hence, the exchange and collaboration with numerous different stakeholder groups allowed the achievement of a more comprehensive perspective on the topic.

To sum up, the qualitative research approach safeguarded the examination of the identified research problem in a comprising manner. Thereby, observations, expert interviews, focus group meetings and case studies were used as the main methods of the present research study. Based on the presented research findings, the authors were capable to achieve the indicated research objective and to answer the related research question in a qualitative manner. Lastly, the presented research results were validated and verified by the abovementioned primary target groups in the frame of project-induced workshops, trainings and seminars. A potential bias was reduced by means of cross-sectional work method, by which the authors made field research or interviewed stakeholders within the projects they are themselves less assigned to and / or involved in.

5. Findings and Discussion

The Tonale case, as briefly mentioned above, bears a huge potential to revolutionise the automotive industry’s business model towards a servitisation concept, i.e. a “product-as-a-service” model, where customers pay for the use of the vehicle rather than its ownership (Vandermerwe & Rada, 1988). Such a model could encourage manufacturers to design more sustainable, repairable, and recyclable vehicles and components, since they would be responsible for their end-of-life management. Additionally, the Tonale case can serve as a blueprint for PLM model, since transferred to the e-car battery case, an adapted NFT solution is able to monitor and file the operational history of an e-car together with its battery. This is done with the purpose to record data that are able to support or even to replace the retroactive test of the state of health of the battery by means of an up-to-date measurement, including an online estimation of the battery evaluation. The NFT approach records during utilisation of the e-car itself the operational conditions, such as an inefficient driving style, high driving speed, heat or cold, as well as mileage, charging cycles, and many other factors that can reduce battery capacity and its related value.

Batteries are expendable goods, i.e. they are subject to degeneration, and they are losing their utility for their clients, no matter of which components they are done. Nevertheless, they enjoy during each phase in their life cycle a certain value so that the owner of the battery has the choice between three main options in the context of a sustainable business models (Prause, 2015):

- Second-hand market;
- Renovation; and
- Recycling

Regarding the ranking, in combination with the second-hand market, huge potential for battery reuse and revival is associate by introducing blockchain and NFTs in private households of rural areas (Bokolo, 2024; Sharma *et al*., 2024). The project idea borne between Germany and Poland "Seaside 4.0" combines the use of innovative technology concepts that have been hardly implemented in the South Baltic Sea Region (SBSR) so far. In a first step, the project concept aims at drafting and developing a forecasting tool, which can clearly determine the financial and ecological benefits of novel technology implementation, i.e. algorithms that allow calculating energy consumption, local distribution and electricity sharing potential based on availability from regenerative installations and power storage capacity. In a second step, a SBSR-wide, locally adaptable concept is planned to be designed, which should represent relevant technologies and tools for the implementation of the "local and mobile energy storage as supplements to the electrical grid approach" ("Seaside 4.0 approach"). The cross-border consortium plans and aims at implementing a pilot study that involves one cluster and two satellite communities. Local adaptations of the concept, based on related infrastructure and storage facilities implemented under ongoing assessment and documentation of the cross-border consortium in mutual exchange can facilitate optimisation and follow-up project guidance. These core activities shall be circled around pilot implementation and information / promotion aimed at presenting "Seaside 4.0" (approx. 2024-2025) technology solutions for potential followers and future users that will contribute to the pilot project or later capitalisation of the solutions via a related internet platform and guidebook. In addition, wide public should be engaged and involved in the partner locations (Denmark, German, Lithuania, Poland and Sweden) to rise interest in the technology, by raising awareness of the benefits, ensuring widest possible support in the communities via platform and marketing campaign. Finally, third parties and other regions within the SBSR area outlining the developments, practical experience gained and best practices and recommendations. In this sense, using an NFT and blockchain technology seems to be a promising venue to involve citizens from more rural and remote areas in the region.

Similarly, the ENERVERSE project consortium aims in the next future at creating demand for deployment of renewable energy (mainly geothermal) in the region through demystification of its untapped potentials. It encourages to deploy diverse scenarios for heating, lighting and consumption by commercial, civil and individual users. By means of user (public) engagement into creation of solutions, new ownership and financing schemes as well as dynamic environmental responsibility patterns can and will facilitate sustainability and energy transition pathways as well as make use of Quadruple helix cross-border experimenting within Living Labs for energy transition. In this sense, using NFTs to increase value creation would make an extra and advantage at the same time. The project aims at tapping into renewable energy potentials via virtual solution experimentation combined with physical piloting on geothermal energy and its energy symbiosis with solar (photovoltaic) and wind energy. Focusing on geothermal energy exploitation and its benchmarking in the region is new – no projects so far have dealt with this topic in the SBSR, neither in the Baltic Sea Region (BSR). In addition, the project aims at introducing new terms and concepts, not utilised so far, such as energy symbiosis, renewable energy coaches and transition brokers. Above that, given the rapid pace of digital technologies, like metaverse, the project aims at developing virtual reality tool enabling simulation of energy preparation, launch, monitoring and control, backed up by the physical embedding. Accompanying supportive toolbox can raise awareness of and increase capacity among the SBSR actors for strategic orientation and facilitation of renewable energy introduction and roll-out, in collaboration with society and by use of advanced digital and virtual technologies.

The transnational work aims in achieving the following three solutions:

1) ENERVERSE app – interactive virtual tool for 3D based virtual renewable energy project implementation with virtual twin used for simulation and configuration tool for renewable energy introduction in SBSR communities, enables to simulate renewable energy projects under different framework conditions (location, time, market, regulations, etc.) with technical and financial feasibility, interactive value and investment calculator; cost, time and risk saving solution, supporting decision-making over small-scale or large-scale renewable energy projects;
2) Renewable Energy in the Box – physical modular and mobile "play and plug" renewable energy showcase – a 20-feet container equipped with different energy technologies for flexible demonstration, plug-in, installation and transportation purposes (based on adoption of the existing EBox solution by Mega Watt Solutions, Sweden). This solution adopted for identified SBSR demands can be used for a) testing energy supply and storage to individual, civil and / or public buildings; b) educational and learning; c) trans-local SBSR Living Lab for Renewable Energy Transition (LILARET) as a competence and excellence centre backed up by the established Renewable Energy Transition Network for All, available for testing any ideas of small- or large-scale energy projects in virtual or physical environment (projects partners with research infrastructure, e.g. universities, technology parks, renewable energy coaches and transition brokers).

Mastering of the second post-Covid-19 crisis – energy one – yields a next huge conundrum for all – governments, communities and citizens themselves. Over the last years, as a result of missed climate change mitigation policies and the outbreak of the war in the Ukraine, transition to sustainability in the energy domain became a crucial imperative. This project tackles energy crisis in heating, lighting and consumption of energy for public and industrial applications. The partnership explores potentials associated with such mainly unexploited renewable resource, as shallow and deep geothermal, combined with solar and wind energy in four action fields – a) heating / cooling of residential / commercial buildings and private households; b) lighting of public spaces; c) aquaculture (fish and algae) farming and d) food growing & processing.

In the South Baltic Sea Region, in particular, the coastal areas of the Mecklenburg-Pomerania (MV), after the suspension of the Nord Stream 2 commissioning in Germany, soaring energy prices are pushing Small and Medium-Sized Enterprises (SMEs), but as well as smaller municipalities (local authorities) and communities (private households) into the corner, thus limiting any commercial actions and bringing high risk of poverty for vulnerable groups. Thus, there is little room and capacity for public entities and authorities to deal with the exploitation of renewable energy pathways, while combating the current oil and gas crisis and introducing new energy saving measures takes up most of the time. Looking at the breakdown of energy mix in 2021, the situation in the SBSR is diverse. While Denmark (DK) and Germany (DE) are mainly dependent on the use of fossil fuels, such as gas, oil, which is used both for commercial and private appliances (DE – 55% gas, 27% oil, 46% coal from Russia; DK – 75% gas; PL – 50%), Sweden (SE) uses less than 1%, and Lithuania (LT) has dropped Russian energy imports in 2022 as the first EU country. As a result, the SBSR is very uneven, when it comes to energy related measures. However, all countries have already introduced energy saving behaviour on a short run, which has helped to overcome the winter / spring season 2023-2024. Yet, there is no common coordination among SBSR countries, neither shared knowledge nor practices. When it comes to renewable energy sources, there is low to no collaboration in the area of introduction or exploitation of renewables for heating, lighting and consumption of energy. Each country has own development strategies until 2035 or 2050 pursuing the Green Deal and EU Fit for 55 strategies or the recent REPower EU Plan.

Bearing in mind that ending the dependency on Russian fossil fuels is a paramount task for all countries and economically strong regions, in this context, the SBSR is struggling even more. Being remote and rather distant from economic, cultural and social centres of agglomeration, smaller SBSR municipalities and communities are even more vulnerable to such energy shocks and fragile for introduction of novel energy technologies and resources, with less financial capacity and bargaining power used for credibility and investments. Above that, time pressure (need to prepare energy crisis plans for 2023-2024), insufficient human and infrastructural resources, limited knowledge and access to other markets, low command of digital tools supporting monitoring of energy and transition to renewables deteriorate such energy crisis and situations in smaller municipalities and leave usually communities in their endeavours for energy transition alone. Similarly, less community incentives and collaboration between municipal leaders and communities (also private households) limit introduction of novel solutions, as well as slows down co-creation of sustainable solutions. As recent studies and agencies confirm, citizens, business and institutions can support deployment of renewable energy and reduce fossil fuel dependency by becoming prosumers – energy producers and consumers (European Environmental Agency Report 2022). Given the growing importance of Artificial Intelligence (AI), Virtual Reality (VR), and using virtual 3D technical / human avatars / appearances, simulation and projection of big-scale investments into renewable energy, exploration of best suitable locations (e.g. in case of geothermal, wind, water wave exploitation), active engagement and empowerment of citizens, capitalisation and risk plans become alternative reality – metaverse and bring economic and social benefits. Indeed, a virtual word – metaverse – promises savings in time, costs and risk reduction and safety increase. This is due to possibility to test and simulate all kind of situations, in which renewable energy is used in the most optimal terms, e.g. wind park operation in different locations, wind or heat turbine 3D visualisation for workers training and operationalisation or maintenance, etc. Therefore, this project connects burning challenges (reduction of dependency on fossil energy and energy transition), people's need (co-creation) and advanced technology (digital twin of the real applications and operations) to kick out and accelerate sustainable development of renewable energy – an approach promoted by the industry 5.0 concept by the European Commission (EC).

In order to reduce this challenge and respond to the ambition to accelerate public acceptance, roll-out and further market uptake of renewable energy in the SBSR communities for heating, lighting and consumption, municipalities as principal agents and accelerators need a holistic approach, including both short-term and long-run tools. As a result, this initiative aims at developing a toolbox to enable costly renewable energy roll-out and exploitation in smaller SBSR communities. Short-term tools include, e.g.

renewable energy saving and its prosumption actions (citizens engagement in energy production, crowdfunding schemes), introduction of decision tree algorithm and value calculators, and long-term solutions, e.g. integrated renewable energy / energy diversification systems, renewable energy installation plans, alternative financing models as well as sustainable life cycle models are favouring the second-hand use of e-car batteries due to precious materials used inside the products.

Consequently, a growing part of literature is dedicated to incentive and motivation schemes for supporting the implementation of sustainable business models as well as to development of the consumer's mindset for Circular Economy. Often discussed among scholars are refund systems, tax incentives and technical solutions. The literature review as well as expert interviews revealed a lack of existing Circular Economy models in the context of blockchain technology and NFTs, especially around batteries of e-cars. However, as more as recycled resources gain importance in Circular Economy and as more price levels for certain raw materials will rise due to shortage of supply, recycling will become a key element in production processes even without additional incentives.

An NFT based digital certificate for the battery of an e-car, comparable to the Tonale model, helps the owner to maintain a higher value of his e-car. Moreover, it motivates the user of the e-car to behave more sustainably, i.e. according to Circular Economy objectives, since her / him wants to keep own battery healthy. This motivation is facilitated by the knowledge that the operational history of the battery is monitored and issued by a digital certificate providing value to potential future buyers. Thus, the case of the battery for e-cars highlights that an innovative NFT solution represents safeguarding and sustainable life cycle management of batteries. In addition, it helps to regenerate transparency and trust in the used e-car market. Furthermore, the NFT technology facilitates repair and recycling technology for e-batteries towards sustainable business models. Hence, the study reveals that the benefits of the use of the NFT solutions in the context of sustainable PLM in Circular Economy (CE) open new horizons for the creation of sustainable business models that are linked with:

1. Lowered Carbon Footprint by better maintenance;
2. Second-Life Utility with improved resource efficiency; and
3. Promotion of awareness and Economic Incentives for Sustainability behaviour.

Hence, the case of batteries of e-cars aims to spur the transition towards cleaner and more sustainable business model linked to higher energy and material efficiency as well as to reduced consumption of resources. The incorporation of a blockchain technology and NFTs supports sustainability and enhances customer experience and operational efficiency (Geissdoerfer *et al*., 2017; Morrow & Zarrebini, 2019). The innovation through the integration of NFTs provides not only unique identifier of the product along its life cycle but also introduces a digital log of the product's history that promotes extended vehicle life cycles and responsible ownership. Hence, the use of NFT solutions unlocks new features for the classical business models towards CE comprising digital accountability, market valuation by well-documented operational histories, life cycle traceability and responsible ownership (Gerasimova *et al*., 2023).

Conclusively, as smart contracts and NFTs steadily penetrate industry, sustainable business model innovation increases the competition towards a cleaner and more efficient future requiring a steady commitment of the industry for sustainable improvement and for the long-term survival of the company.

6. Conclusions

Smart contracts, blockchain technologies and NFTs are reshaping the contours of supply chain management and the broader scope of the Circular Economy. These technologies offer potential far beyond cost reduction, by facilitating cross-organisational business processes, promoting transparency and traceability and paving the way for innovative business models. By doing so, NFTs offer a technical solution for the unique identification problem of a product over its full life cycle with the additional feature to monitor and store the product history. In combination with blockchain technology and smart contracts, NFTs are easy to create and handle and they can get transferred and traded so that owner changes during product life cycle are simple to realise.

The study demonstrates how NFTs become an integral part of the product life cycle, constantly updating with product information including maintenance and other services. This unlocks new features in sustainable product life cycle management. Case studies demonstrate how innovative technological applications can promote product durability, repairability and recyclability, all cornerstones of the Circular Economy. In summary, implementation of smart contracts and NFTs facilitates the creation of robust, well-documented product life cycles, thus paving the way for dynamic and adaptable supply chains that respond to evolving needs of stakeholders and contributes towards a sustainable and Circular Economy.

References

1. AB. (2023). *So prüfen Sie den Akku eines gebrauchten E-Autos*, Auto Bild, 12.06.2023.
2. Alfa Romeo. (2023). *Tonale hybrid SUV and its digital integration*. Alfa Romeo Official Communications.
3. Ali, O., Momin, M., Shrestha, A., Das, R., Alhajj, F., & Dwivedi, Y. K. (2023) A review of the key challenges of non-fungible tokens. *Technological Forecasting and Social Change*, 187, 122248.
4. Alivojvodic, V., & Kokalj, F. (2024) Drivers and Barriers for the Adoption of Circular Economy Principles towards Efficient Resource Utilisation. *Sustainability*, 16(3), 1317.
5. Altricher, H., Feldman, A., Posch, P., & Somekh, B. (2005) *Teachers investigate their work: An introduction to action research across the professions*. Routledge.
6. Altrichter, B., Parry, G., & Tuladhar, A. (2022) Content trading in the future decentralized creative economy: exploring current weaknesses and potential resolutions. In: *Competitive Advantage in the Digital Economy (CADE 2022),* 2022, 1-3. IET.
7. Altrichter, H. (2020) The concept of quality in action research: Giving practitioners a voice in educational research. In: *Qualitative voices in educational research*, 40-55. Routledge.
8. Alves, L., Cruz, E. F., Lopes, S. I., Faria, P. M., and Cruz, A. M. R. d. (2021) Towards Circular Economy in the textiles and clothing value chain through blockchain technology and IoT: A review. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, 40(1), 3-23. DOI: 10.1177/0734242x211052858.
9. Ameri, F., & Dutta, D. (2005) Product lifecycle management: closing the knowledge loops. *Computer-Aided Design and Applications*, 2(5), 577-590.
10. Aviloo (2024). Aviloo.com.
11. Ayan, B., Güner, E., and Son-Turan, S. (2022) Blockchain technology and sustainability in supply chains and a closer look at different industries: A mixed method approach. *Logistics*, 6(4), 85. DOI: 10.3390/logistics6040085
12. Baars, J., Domenech, T., Bleischwitz, R., Melin, H. E., & Heidrich, O. (2021) Circular Economy strategies for electric vehicle batteries reduce reliance on raw materials. *Nature Sustainability*, 4(1), 71-79.
13. Barclay, I., Cooper, M., Preece, A., Rana, O., & Taylor, I. (2021) Tokenising behaviour change: optimising blockchain technology for sustainable transport interventions. *arXiv preprint arXiv*: 2104.01852.
14. Bardhi, F., & Eckhardt, G. M. (2012) Access-based consumption: The case of car sharing. *Journal of consumer research*, 39(4), 881-898.
15. Baum, Z., Bird, R., Yu, X., Ma, J. (2022). Lithium-Ion Battery Recycling─Overview of Techniques and Trends. *ACS Energy Letters,* 2022, 7(2), 712-719, https//:doi.org/DOI: 10.1021/acsenergylett.1c02602.
16. Bokolo, A. J. (2024) *A decentralized prototype framework for peer-to-peer based electric car sharing services towards sustainable road transportation*.
17. Brousmiche, K. L., Heno, T., Poulain, C., Dalmieres, A., & Hamida, E. B. (2018) Digitizing, securing and sharing vehicles life-cycle over a consortium blockchain: Lessons learned. In: *2018 9th IFIP international conference on new technologies, mobility and security* (NTMS), 1-5. IEEE.
18. Butera, A., Gatteschi, V., Pratticò, F. G., Novaro, D., & Vianello, D. (2023) Blockchain and nfts-based trades of second-hand vehicles. *IEEE Access*, 11, 57598-57615.
19. Carvalho, H., Azevedo, S. G., & Cruz-Machado, V. (2012) Agile and resilient approaches to supply chain management: influence on performance and competitiveness. *Logistics research*, 4, 49-62.
20. Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F., & Gao, W. (2013) The evolution, challenges, and future of knowledge representation in product design systems. *Computer-aided design*, 45(2), 204-228.
21. Chen, C. L., Deng, Y. Y., Hsu, Y. Y., Chen, H. C., Huang, D. C., & Liu, L. C. (2024) A Survey and Planning Advice of Blockchain-Based Used Car Bidding Platform. In: *International Conference on Advanced Information Networking and Applications*, 207-216. Cham: Springer Nature Switzerland.
22. Chen, S., Cai, X., Wang, X., Liu, A., Lu, Q., Xu, X., & Tao, F. (2022) Blockchain applications in PLM towards smart manufacturing. *The International Journal of Advanced Manufacturing Technology*, 1-15.
23. Chirumalla, K., Kulkov, I., Parida, V., Dahlquist, E., Johansson, G., & Stefan, I. (2024) Enabling battery circularity: Unlocking circular business model archetypes and collaboration forms in the electric vehicle battery ecosystem. *Technological Forecasting and Social Change*, 199, 123044.

24. Creswell, J. W., & Creswell, J. D. (2017) *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.
25. Da Silva, E. R., Lohmer, J., Rohla, M., & Angelis, J. (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.
26. Das, D., Bose, P., Ruaro, N., Kruegel, C., & Vigna, G. (2022) Understanding security issues in the NFT ecosystem. In: *Proceedings of the 2022 ACM SIGSAC Conference on Computer and Communications Security*, 667-681.
27. Davidová, M., Sharma, S., McMeel, D., & Loizides, F. (2022) Co-De| GT: The gamification and tokenisation of more-than-human qualities and values. *Sustainability*, 14(7), 3787.
28. Deventer, C., de Sousa, V. A., & Pirnay, L. (2024) Nftbybrands: Value identification framework for analysis and design of nft initiatives. *International Journal of Electronic Commerce*, 28(1), 33-62.
29. Dos Santos, R. B., Torrisi, N. M., and Pantoni, R. P. (2021) Third party certification of agri-food supply chain using smart contracts and blockchain tokens. *Sensors*, 21(16), 5307. DOI: 10.3390/s21165307
30. Dunn, J., Slattery, M., Kendall, A., Ambrose, H., & Shen, S. (2021) Circularity of lithium-ion battery materials in electric vehicles. *Environmental Science & Technology*, 55(8), 5189-5198.
31. El Jalbout, S., & Keivanpour, S. (2024) Development of a body of knowledge for design for disassembly and recycling of high-tech products: a case study on lithium-ion batteries. *Journal of Industrial and Production Engineering*, 41(1), 19-39.
32. Ellen MacArthur Foundation. (2019) *Completing the picture: How the Circular Economy tackles climate change*. https://www.ellenmacarthurfoundation.org/publications
33. ElMaraghy, H., Schuh, G., ElMaraghy, W., Piller, F., Schönsleben, P., Tseng, M., & Bernard, A. (2013) Product variety management. *Cirp Annals*, 62(2), 629-652.
34. Eshghie, M., Li, Q., Kasche, G. A., Jacobson, F., Bassi, C., and Artho, C. (2022) *CircleChain: Tokenizing products with a role-based scheme for a Circular Economy*. DOI: 10.48550/arxiv.2205.11212.
35. Estebanez, G. (2023) *Energy Storage System Forecast*, https://www.linkedin.com/pulse/energy-storage-system-forecast-guillermo-estébanez/.
36. European Commission. (2020). Proposal for a regulation of the European Parliament and of the Council concerning batteries and waste batteries, releasing Directive 2066/66/EC and the amending Regulation (EU) No 2019/1020, Brussels, 10 December 2020.
37. European Parliament (2022). EU Legislation in Progress New EU Regulatory Framework for Batteries Setting Sustainability Requirements (Issue February).
38. Gallab, M., & Di Nardo, M. (2023) New Innovation, Sustainability, and Resilience Challenges in the X. 0 Era. *Applied System Innovation*, 6(2), 39.
39. Geissdoerfer, M., Savaget, P., Bocken, N., and Hultink, E. J. (2017) The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757-768. DOI: 10.1016/j.jclepro.2016.12.048
40. Gerasimova, V.; Prause, G.; and Hoffmann, T (2023) NFT-enriched smart contracts for smart Circular Economy models. *Journal of Entrepreneurship and Sustainability Issues*, 11(2), 93−110. DOI: 10.9770/jesi.2023.11.2(7).
41. German Circular Economy Initiative Deutschland (CEID) (2020) Resource-efficient battery life cycles–driving electric mobility with the Circular Economy. Kwade A *et al.*, acatech/SYSTEMIQ, Munich/London. www. circular-economy-initiative. de/publikationen.
42. Gianvincenzi, M., Marconi, M., Mosconi, E. M., & Tola, F. (2023) Eco-design Framework for a Battery Sustainable Lifecycle Management. In: *International Conference of the Italian Association of Design Methods and Tools for Industrial Engineering*, 75-82. Cham: Springer Nature Switzerland.
43. Gotsch, M., Kelnhofer, A., & Jäger, A. (2019*) Environmental product innovations and the digital transformation of production: Analysing the influence that digitalising production has on generating environmental product innovations (No. S07/2019)*. Fraunhofer Institute for Systems and Innovation Research (ISI).
44. Götz, T., Berg, H., Jansen, M., Adisorn, T., Cembrero, D., Markkanen, S., & Chowdhury, T. (2022) *Digital product passport: the ticket to achieving a climate neutral and circular European economy?*
45. Gutsch, M., & Leker, J. (2024) Costs, carbon footprint, and environmental impacts of lithium-ion batteries–From cathode active material synthesis to cell manufacturing and recycling. *Applied energy*, 353, 122132.

46. Hart, J., Adams, K. T., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019) Barriers and drivers in a Circular Economy: The case of the built environment. *Procedia CIRP*, 80, 619-624. DOI: 10.1016/j.procir.2018.12.015
47. Hartley, K., Baldassarre, B., & Kirchherr, J. (2023) Circular Economy as crisis response. *Journal of Cleaner Production*, 140140.
48. Heines, R., Dick, C., Pohle, C., & Jung, R. (2021) The Tokenization of Everything: Towards a Framework for Understanding the Potentials of Tokenized Assets. *PACIS*, 40.
49. Hislop, H. and Hill, J. (2011) *Reinventing the wheel: A Circular Economy for resource security*. Green Alliance.
50. Hobson, K. and Lynch, N. (2016) Diversifying and de-growing the Circular Economy: Radical social transformation in a resource-scarce world. *Futures*, 82, 15-25. DOI: 10.1016/J.FUTURES.2016.05.012
51. Kadam, S., Sah, R., & Jain, S. (2024) Towards Transparency and Loyalty: Leveraging Blockchain NFTs in Hotel and Food Supply Chain. *International Journal of Computing and Digital Systems*, 16(1), 189-200.
52. Khaqqi, K. N., Sikorski, J. J., Hadinoto, K., & Kraft, M. (2018) Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application. *Applied Energy*, 209, 8-19. DOI: 10.1016/j.apenergy.2017.10.070
53. Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018) Barriers to the Circular Economy: Evidence from the European Union (EU). *Ecological economics*, 150, 264-272.
54. Kirchherr, J., Reike, D., & Hekkert, M. P. (2017) Conceptualising the Circular Economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221-232. DOI: 10.1016/j.resconrec.2017.09.005
55. Kirchherr, J., Yang, N. H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023) Conceptualising the Circular Economy (revisited): an analysis of 221 definitions. *Resources, Conservation and Recycling*, 194, 107001.
56. Koppelaar, R. H., Pamidi, S., Hajósi, E., Herreras, L., Leroy, P., Jung, H. Y., Concheso, A., Daniel, R.,Francisco, F.B., Patrradop, C., Dell'Ambrogio, S., Guggiari, F., Leone, D., Fontana, A. (2023) A digital product passport for critical raw materials reuse and recycling. *Sustainability*, 15(2), 1405.
57. Kumar, A., Abhishek, K., Nerurkar, P., Ghalib, M. R., Shankar, A., & Cheng, X. (2022) Secure smart contracts for cloud-based manufacturing using Ethereum blockchain. *Transactions on Emerging Telecommunications Technologies*, 33(4), e4129.
58. Lai, X., Chen, Q., Tang, X., Zhou, Y., Gao, F., Guo, Y., Bhagat, R. & Zheng, Y. (2022) Critical review of life cycle assessment of lithium-ion batteries for electric vehicles: A lifespan perspective. *Etransportation*, 12, 100169.
59. Lamrani Alaoui, Y., Gallab, M., Tkiouat, M., & Di Nardo, M. (2024) A hybrid-fuzzy-decision-making framework for digital technologies selection. *Discover Applied Sciences*, 6(10), 522.
60. Leal Filho, W., Abubakar, I. R., Kotter, R., Grindsted, T. S., Balogun, A. L., Salvia, A. L., Aina, Y.A. & Wolf, F. (2021) Framing electric mobility for urban sustainability in a Circular Economy context: An overview of the literature. *Sustainability*, 13(14), 7786.
61. Lee, Y., Kim, M., & Kim, K. (2024) Revisiting actors' role in Circular Economy governance: A case of electric vehicle waste batteries in South Korea. *Environmental Engineering Research*, 29(3).
62. Leng, J., Ruan, G., Jiang, P., Xu, K., Liu, Q., Zhou, X., & Liu, C. (2020) Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey. *Renewable and sustainable energy reviews*, 132, 110112.
63. Li, P., Luo, S., Zhang, L., Liu, Q., Wang, Y., Lin, Y., Xu, C., Guo, J., Cheali, P. & Xia, X. (2024) Progress, challenges, and prospects of spent lithium-ion batteries recycling: a review. *Journal of Energy Chemistry*, 89, 144-171.
64. López-Pimentel, J. C., Morales-Rosales, L. A., Algredo-Badillo, I., & Del-Valle-Soto, C. (2023) NFT-vehicle: A blockchain-based tokenization architecture to register transactions over a vehicle's life cycle. *Mathematics*, 11(13), 2801.
65. Maisel, F., Neef, C., Marscheider-Weidemann, F., & Nissen, N. F. (2023) A forecast on future raw material demand and recycling potential of lithium-ion batteries in electric vehicles. *Resources, Conservation and Recycling*, 192, 106920.
66. Mao, J., Ye, C., Zhang, S., Xie, F., Zeng, R., Davey, K., Guo, Z., Qiao, S. (2022) Toward practical lithium-ion battery recycling: adding value, tackling circularity and recycling oriented design. *Energy & Environmental Science*, Doi: 10.1039/d2ee00162d

67. Marin, O., Cioara, T., Toderean, L., Mitrea, D., & Anghel, I. (2023) Review of Blockchain Tokens Creation and Valuation. *Future Internet*, 15(12), 382.
68. Melin, H. E., Rajaeifar, M. A., Ku, A. Y., Kendall, A., Harper, G., & Heidrich, O. (2021) Global implications of the EU battery regulation. *Science*, 373(6553), 384-387.
69. Merriam, S.B. (1998) *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education"*. Jossey-Bass Publishers: San Francisco, CA, USA.
70. Milian, Y. E., Jamett, N., Cruz, C., Herrera-León, S., & Chacana-Olivares, J. (2023) A comprehensive review of emerging technologies for recycling spent lithium-ion batteries. *Science of The Total Environment*, 168543.
71. Morrow, M. J., & Zarrebini, M. (2019) Blockchain and the tokenization of the individual: Societal implications. *Future Internet*, *11*(10), 220.
72. Nadini, M., Alessandretti, L., Di Giacinto, F., Martino, M., Aiello, L. M., & Baronchelli, A. (2021) Mapping the NFT revolution: market trends, trade networks, and visual features. *Scientific reports*, 11(1), 20902.
73. Naik, M., Singh, A. P., Pradhan, N. R., Kumar, N., Nayak, A., & Guizani, M. (2024) Tokengreen: a versatile NFT framework for peer-to-peer energy trading and asset ownership of electric vehicles. *IEEE Internet of Things Journal*.
74. Neramballi, A., Milios, L., Sakao, T., & Matschewsky, J. (2024) Toward a policy landscape to support the product-as-a-service design process for a Circular Economy. *Journal of Industrial Ecology*, 28(5), 1045-1059.
75. Osterland, T., & Rose, T. (2020) From a use case categorization scheme towards a maturity model for engineering distributed ledgers. *Blockchain and Distributed Ledger Technology Use Cases: Applications and Lessons Learned*, 33-50.
76. Pang, T. Y., Pelaez Restrepo, J. D., Cheng, C. T., Yasin, A., Lim, H., & Miletic, M. (2021) Developing a digital twin and digital thread framework for an 'Industry 4.0'Shipyard. *Applied Sciences*, 11(3), 1097.
77. Philipp, R., Prause, G., & Gerlitz, L. (2019) Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains. *Transport and Telecommunication Journal*, 20(4), 365–378. https://doi.org/10.2478/ttj-2019-0030
78. Pinto-Gutiérrez, C., Gaitán, S., Jaramillo, D., & Velasquez, S. (2022) The NFT hype: What draws attention to non-fungible tokens? *Mathematics*, 10(3), 335.
79. Pirnay, L., Deventer, C., & de Sousa, V. A. (2023) Providing customer value through non-fungible tokens: A preliminary study. In: *56th Annual Hawaii International Conference on System Sciences, HICSS 2023*, 4543-4552. IEEE Computer society.
80. Potau, X., Leistner, S., & Morrison, G. (2018) *Battery Promoting Policies in Selected Member States* (Batstorm work package 5). https://energy.ec.europa.eu/system/files/2019-06/policy_analysis_-_battery_promoting_policies_in_selected_member_states_0.pdf
81. Prause, G. (2014) A Green Corridor Balanced Scorecard. *Transport and Telecommunication Journal*, 15 (4), 299‒307. DOI: 10.2478/ttj-2014-0026.
82. Prause, G. (2015) Sustainable business models and structures for industry 4.0. *Journal of Security and Sustainability Issues*, 5(2), 159-169. DOI: 10.9770/jssi.2015.5.2(3)
83. Prause, G. (2019) Smart contracts for smart supply chains. *IFAC-PapersOnLine*, 52(13), 2501-2506. DOI: 10.1016/j.ifacol.2019.11.582
84. Razi, Q., Devrani, A., Abhyankar, H., Chalapathi, G. S. S., Hassija, V., & Guizani, M. (2023) Non-fungible tokens (NFTs)-survey of current applications, evolution and future directions. *IEEE Open Journal of the Communications Society*.
85. Rizos, V., & Urban, P. (2024) Barriers and policy challenges in developing circularity approaches in the EU battery sector: An assessment. *Resources, Conservation and Recycling*, 209, 107800.
86. Roy, J. J., Rarotra, S., Krikstolaityte, V., Zhuoran, K. W., Cindy, Y. D. I., Tan, X. Y., Carboni, M., Meyer, D., Yan, Q., Srinivasan, M. (2022) Green recycling methods to treat lithium-ion batteries E-waste: a circular approach to sustainability. *Advanced Materials*, 34(25), 2103346.
87. Saaksvuori, A. (2008) *Product Lifecycle Management*. Springer. ISBN 9783540781738.
88. Sharma, D. D., Singh, S. N., & Lin, J. (2024) Blockchain-Enabled Secure and Authentic Nash Equilibrium Strategies for Heterogeneous Networked Hub of Electric Vehicle Charging Stations. *Blockchain: Research and Applications*, 100223.

89. Schmidt, R., Möhring, M., Keller, B., & Zimmermann, A. (2019) *Potentials of smart contracts-based disintermediation in additive manufacturing supply chains.*
90. Schröder, M., Prause, G. (2015) Risk management for green transport corridors. *Journal of Security and Sustainability Issues*, 5(2), 229−239.
91. Schröder, M., Prause, G. (2016) Transportation of dangerous goods in green transport corridors - conclusions from Baltic Sea region. *Transport and Telecommunication Journal*, 17(4), 322−334.
92. Schweitzer, F. M., Handrich, M., & Heidenreich, S. (2019) Digital transformation in the new product development process: the role of it-enabled PLM systems for relational, structural, and NPD performance. *International Journal of Innovation Management*, 23(07), 1950067.
93. Singh, S., Bansal, H., Sharma, S. K., Sundaramurthy, S., & Kansal, S. K. (2024) The Future Perspectives of Global Circular Economy Transition and Comprehensive Cost Analysis. In: *Energy Materials*, 347-363. CRC Press.
94. Sopha, B. M., Purnamasari, D. M., & Ma'mun, S. (2022) Barriers and enablers of Circular Economy implementation for electric-vehicle batteries: from systematic literature review to conceptual framework. *Sustainability*, 14(10), 6359.
95. Sopjani, L., Arekrans, J., Laurenti, R., & Ritzén, S. (2020) Unlocking the linear lock-in: Mapping research on barriers to transition. *Sustainability*, 12(3), 1034.
96. Stake, R. (1995) *Case study research. thousand oaks*, CA: Sage.
97. Stefan, I., & Chirumalla, K. (2025) Enabling value retention in circular ecosystems for the second life of electric vehicle batteries. *Resources, Conservation and Recycling*, 212, 107942.
98. Sunyaev, A., Kannengießer, N., Beck, R., Treiblmaier, H., Lacity, M., Kranz, J., Fridgen, G., Spankowski, U., Luckow, A. (2021) Token economy. *Business & Information Systems Engineering*, 63(4), 457-478.
99. Tapscott, D. and Tapscott, A. (2016) *Blockchain revolution: How the technology behind Bitcoin is changing money, business, and the world*. New York, NY: Penguin.
100. Teslya, N. (2019) Industrial socio-cyberphysical system's consumables tokenization for smart contracts in blockchain. In: *Business Information Systems Workshops: BIS 2018 International Workshops*, Berlin, Germany, July 18–20, 2018, Revised Papers 21, 344-355. Springer International Publishing.
101. Thompson, D., Hartley, J., Lambert, S., Shiref, M., Harper, G., Kendrick, E., Anderson, P., Ryder, K., Gaines, L., Abbott, A. (2020) The importance of design in lithium ionlithium-ion battery, recycling – a critical review. *Green Chemistry*, 22, 7585
102. Torjesen, S., & Isaksen, A. (2023) *Rethinking the role of landscape in the multi-level perspective: The case of electric vehicle battery production in Europe and China*. Available at SSRN 4357817.
103. Umicore. (2022) German consortium launches project battery pass to support EU circular battery data, Umicore, 26 April.
104. Uusitalo, T., Karhu, M., Majaniemi, S., Kivikytö-Reponen, P., Hanski, J., & Vatanen, S. (2024) Digital Product Passports in Circular Economy: Case Battery Passport. In: *EcoDesign for Sustainable Products, Services and Social Systems I*, 175-186. Singapore: Springer Nature Singapore.
105. Vandermerwe, S. and Rada, J. (1988) Servitisation of business: Adding value by adding services. *European Management Journal*, 6(4), 1988.
106. Vasan, K., Janosov, M., & Barabási, A. L. (2022) Quantifying NFT-driven networks in crypto art. *Scientific reports*, 12(1), 2769.
107. Wang, M., Liu, K., Dutta, S., Alessi, D. S., Rinklebe, J., Ok, Y. S., & Tsang, D. C. (2022) Recycling of lithium iron phosphate batteries: Status, technologies, challenges, and prospects. *Renewable and Sustainable Energy Reviews*, 163, 112515.
108. Wang, Q., Li, R., Wang, Q., and Chen, S. (2021) *Non-Fungible Token (NFT): Overview, Evaluation, Opportunities and Challenges*, DOI: 10.48550/arXiv.2105.0744.
109. Yu, W., Guo, Y., Xu, S., Yang, Y., Zhao, Y., & Zhang, J. (2023) Comprehensive recycling of lithium-ion batteries: Fundamentals, pretreatment, and perspectives. *Energy Storage Materials*, 54, 172-220.
110. Zeng, A., Chen, W., Rasmussen, K. D., Zhu, X., Lundhaug, M., Müller, D. B., Tan, J., Keiding, J.K., Liu, L., Dai, T., Wang, A., Liu, G. (2022) Battery technology and recycling alone will not save the electric mobility transition from future cobalt shortages. *Nature communications*, 13(1), 1341.