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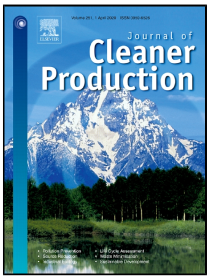

Towards a Circular and Low-Carbon Economy: Insights from the Transitioning to Electric Vehicles and Net Zero Economy.

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Towards a Circular and Low-Carbon Economy: Insights from the Transitioning to Electric Vehicles and Net Zero Economy.

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Abstract

Road transportation being a leading source of greenhouse gas emissions and air pollution, is now resulting a move away from the traditional internal combustion engine to electric vehicles (EVs), currently powered by battery technology. This paper examines end-of-first-life applications of EVs batteries in a low-carbon circular economy following global transition to EVs and net zero economy. Semi-structured interviews were conducted with key actors within the EV industry in the UK. Drawing on Stahel closed-loop solutions, a qualitative analysis of the transcripts of these interviews revealed the need for business models towards coherent low-carbon circular economy of the value chains. This paper reveals a whole range of issues relating to: extraction of battery critical raw minerals (e.g. ethical concerns); manufacturing (e.g. lack of policy frameworks addressing value chain emissions); distribution and sale (e.g. gaps in circular built economy strategy and transition plan); use (e.g. lack of a functioning market for end-of-first-life batteries) as well as research and innovation (e.g. lack of infrastructure to deal with end-of-first-life cells). The views on policy weaknesses testifies to the need for close-loop business model to not only focus on recycling battery raw minerals or repurposing battery for energy storage applications. But, should consider many aspects of an innovative policy strategy and product's global value chain, accounting for: equitable jobs, critical raw minerals dependency, circularity governance and industry standards, protecting the natural environment, tackling emissions and ensuring sustainable consumption and production patterns. The study highlights establishing key trade-offs within policy goals considering the global value chains, as well as, harnessing synergies between social, economic and environmental goals.

The paper concludes that a low-carbon close-loop business model should integrate the triple objectives of making positive impact on people, planet and profit, and developed on the basis of legislation, collaboration, research, investment, and incentives guiding to achieve the Global Goals.

Keywords: Electric Vehicles; Circular Economy; Lithium-Ion Batteries; Low-Carbon Economy; Business Models; Sustainable Futures.

1.0 Introduction

1.1 Background

Globally, road transportation constitutes about one-quarter of total greenhouse gas emissions (GHG), second only to emissions resulting from electricity and heat generation (IEA, 2016). Road transportation also remains a major source of ambient/outdoor air pollution, via exposure to Particulate Matter – (PM, that is less or equal to $PM_{2.5}$ micrometres) that contributed to 4.1 million deaths from heart disease, stroke, lung cancer, chronic lung disease, and respiratory infections in 2016 (HEI, 2018). Such environmental and health impacts from road transportation, have resulted many international policy frameworks such as *The Paris Declaration on electro-mobility and climate change*, encouraging nationally determined contributions towards low-carbon economies via sustainable transport electrification to levels compatible with less than 2-degree Celsius pathway (UNFCCC, 2015). Importantly, the global transition for cleaner air and low-carbon economies are all strongly embedded in the UN Sustainable Development Goals (SDGs), providing a shared blueprint for people, the planet and profit (UN Environment, 2017). This chimes with views that the appetite for road transport electrification should simultaneously help achieve many of the SDGs along the global value chains (ICTSD, 2017).

Europe, where road transport accounts for about 73% of all greenhouse gas emissions (GHG) has adopted a low-emission mobility strategy, a global shift towards a low-carbon, and circular economy since 2016 (EC, 2016). Indeed, the European strategy for the transport sector reflect an irreversible shift to low-emission mobility, envisioning, at least 80% of the vehicle fleet in 2050 being fossil-free or fully electrified (EC, 2016). Accordingly, a member state such as the United Kingdom heavily reliant on fossil fuels (BEIS,2017), are advancing the electrification of vehicles, aiming to ensure competitiveness and respond to the threat of climate change via reduction in GHG emissions, whilst tackling air pollution (DfT,2018).

Consequently, the low-emission mobility strategy has resulted a move away from the traditional internal combustion engine (ICE) to electric vehicles (EVs), currently *powered by lithium-ion battery technology* (LIB, the most common EV standard) for its safety and higher energy density reliability (Husain, 2010). However, the electrification of vehicles experiences a whole range of challenges and opportunities, with regards to the EV technology Global Value Chain (GVCs - see also Dinger et al. 2010; Masiero et al, 2017). GVCs identify the geography and activities of actors involved from taking a good or service from raw materials to production and then to the consumer (Frederick, 2014). A key concern regarding LIB GVCs also reflect the high raw materials prices, the rare and finite nature of the raw materials, as well as, the high manufacturing costs (Nelson et al, 2009; Nitta et al, 2015).

To date, battery technology is presently the prominent technological solution for powering EVs, as well as supporting low-carbon and grid decarbonisation via renewable energy sources. Dinger et al. (2010) highlighted that LIB carry sufficient charge for use in further applications after end-of-first-life, as it typically retains 80 % of original manufactured energy storage capacity when deemed unsuitable to meet EV standards (Cready et al., 2003; Warner, 2013). In other words, an 'end-of-life' is when a LIB capacity reduces by 20% of its original capacity.

A range of research studies evaluates and detail the prospect for end-of-life EV batteries in a circular economy (e.g. Ahmadi et al, 2014; Zhang et al, 2014; Kampker et al, 2016; Drabik and Rizos, 2018; Olsson et al, 2018; Catton et al, 2019 and Hill et al, 2019). Recently, the issue of circular economy perspectives for the management of batteries used in electric vehicles, was also discussed in a technical support to the European Commission (Hill et al., 2019). Yet, there are *no clear circular economy business model i.e. end-of-first-life or post-first-life applications pathways*, regarding what to do with EV LIBs when they pass their peak performance or become unsuitable to meet EV standards. Mechanisms and regulatory frameworks for LIBs post-first-life (repurposing/second use, remanufacturing and recycling) and integrating the potential recovery of battery cells raw materials into a low-carbon Circular Economy (CE) solutions remains unclear and presently does not transcend into current UK and EU legal and public policy frameworks enough (e.g. Busch et al., 2017; Drabik and Rizos, 2018). Strikingly, Europe's Battery Directive 2006/66/EC (Directive, 2006), to which the UK currently adheres, currently lacks specific circularity policy measures, including technological innovations that efficiently integrates LIBs into a low-carbon circular economy. Unlike the linear economy model where products "single-use" means a "take-make-dispose" pattern, CE ensures products circularity in a value chain, whilst capturing more of the value normally lost in a traditional linear system. Richa (2016) highlights that future waste management of LIBs will become a challenge, as EVs are becoming mainstream, and the domestic battery-cell manufacturing within Europe presently remains weak vis-à-vis value chain raw minerals extraction and processing.

Typically, most LIB used in new EVs constitute nickel-manganese-cobalt oxide (NMC) raw materials (Perkwoski, 2017), with desire for NMC resulting from its proneness for: specific energy (energy storage per kilo gram of weight); battery safety from explosions, performance (high-energy density and longer driving range); battery manufacturing cost and battery life span (Dinger et al., 2010). Importantly, these NMC cells materials are also classified as critical raw materials (CRMs) by the European Commission (EC, 2017), and are becoming increasingly important for the UK (POST, 2019), including Europe's low-carbon and circular economy transition (EC, 2018). Thus, a well-functional and low-carbon circular future, therefore requires an integrated global decarbonisation effort and reduction of material impacts along CRMs value chains needed for clean energy technologies (World Bank, 2019). Such a transition needs to tackle policy weaknesses, especially, raw materials sourcing and supply risks, potential LIB wastes, products manufacturing and circularity policies (EC, 2014).

To better understand the UK's *low-carbon and electrification of vehicles policy vision (DfT,2018)*, this exploratory study aims *to explore and develop a knowledge base for follow-up actions to stimulate a more integrated circular economy business model ensuing global transition to EVs and low-carbon technologies*.

1.2 Objectives

The UK's road to 2050 (DfT,2018) may yet seem far, but decisions taken now are crucial to establishing permanent value chain economies and industries, designed to harness more integrated circular low-carbon economy business models. What happens to the large number of LIBs in the UK when deemed unsuitable to meet EV standards, remains highly significant for the UK strategy towards a low-carbon circular economy. Considering a lack of reliable battery-cell manufacturing capabilities, existing 'silo policy frameworks' developed largely in isolation from one another, and unclear domestic strategy for EVs low-carbon and circular economy business models, this study seeks to:

i) *Explore relevant stakeholders' views on the opportunities and challenges/concerns that accounts for EV LIBs end-of-first-life applications in a low-carbon circular economy.*
ii) *Explore views on best-practice needed towards coherent CE value chains.*
iii) *Understand specific actions that may address raw materials supply risks; decarbonising EV infrastructure and circular economy solutions realising sustainability futures.*

Interviewee questions within a broader context explored:

i) *What are your views on strategies and best-practice standards for end-of-first-life applications for LIBs in a low-carbon circular economy?*
ii) *What are your views on best-practice needed towards a coherent low-carbon CE value chains?*
iii) *What are your views on GHG emissions within the EV life cycle?*

In addressing the study's objectives and questions, the qualitative research methods were applied (Yin, 1994). These included, primary data sources via interviewing relevant interest and stakeholder groups, as well as, secondary data sources. More importantly, the CE paradigm is becoming a well-established concept within sustainability and resource management science, and rapidly rising up in political and responsible business agendas. Thus, following the UK's EV transition strategy, this study contributes to shaping low-carbon circular economy policy strategies. The study's output also sheds light on how responsible and sustainable business models towards low carbon CE could be harnessed by the EV global business communities. Finally, these findings support a discussion of how EV deployment and global value chain cleaner energy policies can be supportive of the UN SDGs. in particular, decarbonising both the transport and mining infrastructure (SDG Goal 13), ensuring healthy lives for all (SDG Goal 3) and making a positive impact on *people, planet and profit*.

2.0 Materials and Methods

2.1 Electrification of Vehicles & Low Carbon Circular Economy – the case

National governments' policies inevitably play a crucial role in EV deployment and low-carbon CE adoption. As a result, in view of the global push towards electrification of vehicles, the UK's '*Road to Zero Emission Strategy*' published in July 2018, presents an interesting case to explore further. The strategy clearly shows the UK's commitment towards innovative ultra-low emission vehicles (ULEV) that set out an ambitious industrial strategy, designed to build a green economy across the UK for the 21st century. The strategy set two key goals towards such transformation i.e. to attain zero emission by 2040 and achieving the ULEV standard by 2050 (DfT, 2018). The UKs new Clean Air Strategy also aim to reduce particulate matter emissions by 30% by 2020, and by 46% by 2030 (DEFRA, 2019), with EV being integral to a low-carbon economy and improved air quality. As well, changes to the UK Climate Change Act, 2008, had set a goal to reduce emissions by 80%, and aiming for net zero carbon emissions by 2050.

Currently, transport remains the largest greenhouse gas-emitting sector in the UK, accounting for 27 % of greenhouse gas emission, whilst road transport accounts for 91% of this figure (BEIS, 2018). Moreover, road transport remains a major source of air pollution, contributing to 34% of Nitrogen Dioxide (NO_X), 12% of $PM_{2.5}$ and 4% of non-methane volatile organic compounds (NECD, 2017). Given the environmental and health impacts from road transportation emissions, there is a strong push and commitment from the UK Government to encourage uptake of 'cleaner cars' via ultra-low emission technologies. The National Grid 2040 '*Two Degrees*' forecast (*Figure 1*), estimates that, "*there could be as many as 36m electric vehicles (EVs) on UK roads by 2040*" (National Grid, 2018).

The UK's shift to ULEV is deemed as a solution for cleaner air, offering zero emissions, reducing greenhouse gas emissions and improving energy security (DfT, 2018). Such transition towards EVs has ensued innovation, comprehensive research and development. A case in point reflect the UK aiming to cement its position as a world leader in battery technologies, energy storage and delivering state-of-the-art innovation to support the automotive battery industrialisation (i.e. following Faraday Battery Challenge and UK Battery Industrialisation Centre funded projects - DfT, 2018).

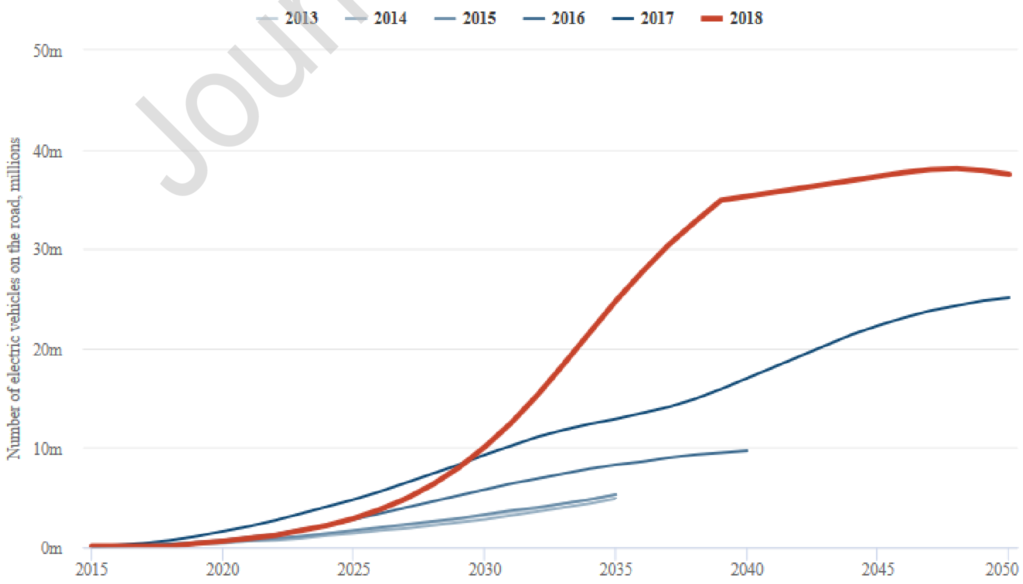

Figure 1: EVs expected growth by 2050

As show in *Figure 1*, the projected increase in EV sales, also means an increasing volume of EV batteries produced, including, increased sourcing of raw materials, with interlinked socio-environmental impacts in rich-mineral countries over the next decades (Alves et al., 2018; Work Bank, 2019).

2.2 Data Collection

According to Frederick (2014), GVC research can theoretically be viewed within the lens of industrial organization research, and usually centres on ways people, including firms, places, and processes are linked to each other in the global economy.

The aim was to select a broad range of stakeholders from different interest groups. In order to address the research questions, the qualitative methodology (Yin, 2009) was chosen, using semi-structured interviews to obtain primary data with open-ended questions (Charmaz, 2014), as well as secondary data sources. First, contact with interest groups began following a desk-study; using a priori knowledge of potential stakeholders operating within EVs landscape and identifying relevant stakeholders' from the 'The Road to Zero' policy document. Additionally stakeholders were further identified via networking from relevant workshops, social media platforms and the University of Birmingham's Business Engagement Partnership. Since the research topic and EV industry area is relatively new, the snowball technique was used after interviews, in order to identify further potential stakeholders networks that might be interviewed (Handcock and Gile, 2011).

Interviewees were asked to give their views on: strategies for end-of-first-life applications for EV battery in a low-carbon circular economy, and views on GHG emissions within EV life cycle. On average, each interview lasted about 40 minutes and were conducted during the months from October 2018 to May 2019. All interviews were voice-recorded using a digital recorder after informed consent had been obtained, with ethical review and approval from the University. In total, thirty interviews were carried out via face-to-face, Skype and phone calls to obtain the primary data. Additional information from secondary sources using corporate websites; published materials and credible newspaper publications were used to collaborate the primary data. These helped in creating an empirical understanding of relevant stakeholder's and experts views regarding the research objectives.

The various sectors, including, the interest groups that participated are shown in Table 1, along with a brief description of their interests/stake. Data collection stopped when no new insights were being revealed from additional interviewees, i.e. following the concept of saturation in theoretical sampling (Glaser and Strauss, 1967). Data gathered from secondary sources to support the analysis are referenced in the result texts.

Table 1: Description of the various stakeholders interviewed from both the national and local level.

Sectors and Interest Groups	Key interest/stake
Vehicle Original Equipment Manufacturer (OEM) / Auto Manufacturers	Vehicle Manufacturing and interest in EVs and battery technologies.
Jaguar Land Rover *Honda* *Emerald Automotive* *Cummins*	
Circular Economy & Lithium Ion Battery Experts	Consultancy businesses focused on Circular Economy and Battery end-of-life management.
Circular Energy Storage Research and Consulting *Circular Economy Growth*	

Local Authorities (LAs) *West Midlands Combined Authority* *Oxford County Council* *Surrey County Council*	Leading and laying out low-carbon and electric vehicle policy frameworks at the local level. This includes EV charging infrastructure networks and promotion of sustainable travel and transport.
Non – Governmental/Profit Organisations (NGOs) and Policy Think Thanks *CENEX* *Bright Blue* *Global Action Plan*	Not-for-profit, low carbon technology experts and policy think tanks involved in EV advocacy on low-carbon; air quality issues, and consumer and business education.
EV Fleet Operators *Lex Autolease* *University of Birmingham*	Businesses involved in EV fleet leasing and business use.
Auto Dealers *Nissan* *Jaguar Land Rover* *Renault*	Businesses in the EV supply chain involved in EV dealership and day-to-day interaction with consumers' on EV experience and knowledge.
Academics & Researchers *EV Chemical Engineering Academic* *EV Circular Economy Academic* *EV Metallurgy and Materials Academic (2×)*	Academics involved and with interest in new battery technologies, circular economy and electric vehicles.
Raw Minerals Experts *Roskill* *Benchmarking Minerals* *Circulor*	Businesses offering consulting services, market reports and briefings for metals and raw minerals, including transparency for raw mineral sourcing.
Raw Minerals Processing & Manufacturing *PRINCE* *Kamoto Copper Company*	Specializes in developing, manufacturing, and making a wide range of high quality manganese derivatives and oxides for the international battery market. Underground copper and cobalt mine.
National and Regional Policy Shapers *Energy Saving Trust* *Midlands Energy Hub* *Electric Vehicle Experience Centre* *Charge Master*	Organisations providing consumer guidance, advice on EV technology and infrastructure information in shaping Government and Local Authorities EV and Low-Carbon strategies.

2.3 Analytical Framework – Circular Economy in a Global Value Chain

The analytical framework applied in this study, was grounded on the Circular Economy (CE) theory, with an aim to explore deeper the interplay of activities and challenges considering the UK's EV transition and the LIB GVCs (*Figure 2*). According to Inomata (2018), the interplay of products GVCs within a CE, helps explore 'intangible activities', which are linked to e.g. research and development; design; marketing; support services and supply chains interaction between cross-border production-consumption nexus. CE involves remodelling industrial systems along the lines of ecosystems, recognizing the efficiency of *resource cycling* in the natural environment (Graedel and Allenby, 1995). Bicket et al (2014), highlights that CE strategy enables socio-environmental and economic growth while optimising the chain of consumption of natural resources. According to Stahel (2016), the reprocessing of goods and materials in CE generates jobs and saves energy while reducing waste, resource consumption and efficiency. CE however, turn goods at the end of their service life into resources for others, thus, '*closing loops*' in industrial ecosystems and minimizing waste (*see Table 2*). In principle, CE follows the notion that waste no longer exists, because products and materials are reused and cycled indefinitely (Den Hollander et al, 2017). CE not only reflects modifications designed to reduce the linear economy's negative impacts, but rather a shift that builds long-term resilience to economic shocks, generates business opportunities and provides societal benefits (MacArthur, 2013). In other words, CE maximizes value at each point in a products life, - whilst helping create new job opportunities, reducing waste and costs, reduced resource consumption and risks, resource scarcity and harnessing environmental benefits (Stahel, 2016). Stahel (2013), also characterised some principles for a CE, highlighting that loops should have no beginning and no end, whereas, a CE needs functioning markets. According to Charter (2018), a challenge related to CE, is to not manage business model design, product and service design, operation management, and policies as separate activities but instead to manage them as interrelated activities that have positive and negative effects on each other.

Table 2: The theoretical principles following closed-loop solutions described by Stahel (2016), and in response to the UK's policy vision towards zero emission and achieving ULEV standard by 2050.

Closed-loop Theoretical Principles	
Extracted Resources	The phase where water, energy, and natural resources enter the manufacturing process.
Manufacturing	The phase where renewing used products lessens the need to make originals from scratch, and recourse losses partly recovered by industrial symbioses.
Distribution & Sales	This phase addresses ownership transfers from manufacturer to consumer at point of sale.
Use	This phase is controlled by buyer-owner-consumer of goods, or by fleet managers who retain ownership and sell goods and services, considering reuse, repair and remanufacture.
Recycling & Innovation	Where research is needed to transform used goods into 'as-new' that considers extracted resources that may require water, energy and natural resources entering the manufacturing process. This phase also consider re-use what you can, recycle what cannot be reused, repair what is broken, remanufacture what cannot be repaired.

Notably, there are calls to consider a CE transition from the perspective of GVCs (ICTSD, 2018). GVCs provide important insights into products value chain within the global economy (Graedel and Allenby, 1995; Inomata, 2018). Importantly, the GVC theory embedded within the CE paradigm, has previously been applied in relation to urban light electric vehicles in South Korea and Japan, looking at the technological challenges for electric vehicle mobility and product recycling (Jussani et al, 2017). Dinger et al. (2010) also explored the value chains of electric-car batteries, focusing on: component production (including raw materials); cell production; module production; assembly of modules into the battery pack (including electronic control units and a cooling system); integration of the battery pack into the vehicle; use during life of the vehicle; and reuse and recycling (Dinger et al, 2010).

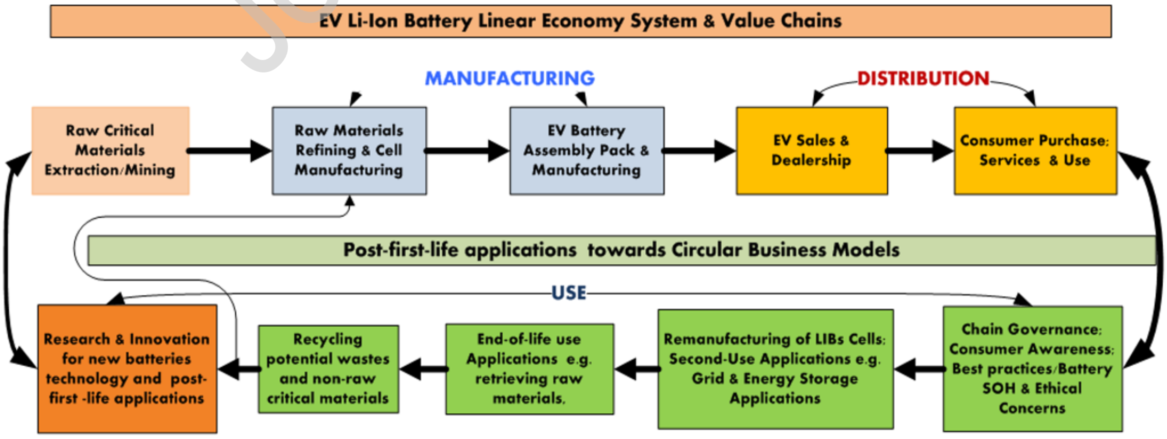

Figure 2: Circular Economy Global Value Chains for Electric Vehicle Batteries

As shown in *Figure 2*, the theoretical categorisation also embraces the notion addressing the effects on the value chain of electric mobility and challenges of the global supply access, and impact sourcing raw materials (Fournier et al., 2012).

2.4 Data Analysis

The interview scripts were transcribed verbatim, and transcripts were analysed with the aid of Nvivo 12 software. Confidentiality and anonymous representation was maintained throughout, which is why individuals and specific business names are obscured in the results, but rather generalising and representing direct quotes using sectors or the various interest groups.

Qualitative thematic text analysis was used (Aronson, 1995). The data analysis was deductive, as the data categorisation was carried out by applying a specific theoretical framework instead of establishing categories from the data itself (Kuckartz, 2014). Each interview/individual participant text was coded by the authors for emergent key themes that best described the framework attributes by the closed-loop solutions described by Stahel (2016) (See Table 2). As the analysis of datasets was exploratory study, the results were reviewed amongst other two academics to identify contradictions. During the first round of reading and coding, the data was assigned to the closed-loop solutions categories. A second academic cross-checked the coding.

3.0 Interview Results

Stakeholders believe that not much has been done in the UK with regard to EV batteries circular economy and relevant legislative frameworks. Following Stahel (2016) closed-loop solutions, views on the main challenges and relevant actions were identified (*Table 3*). Detailed description of interview results with quotes are presented to construe respondent's views.

Table 3: Stakeholders' views on the challenges in transitioning to EVs and low-carbon circular economy, including proposed policy actions.

Closed-loop Solutions	Challenges	Identified Actions
Raw Minerals Extraction	• Lack of due diligence and duty of care protocols addressing value chain sustainability and ethical issues e.g. environmental pollution, forced child labour and human rights issues. • GHG emissions and energy intensive process involved in mining and processing raw minerals. • Lack of low-carbon technologies and knowledge exchange within the value chain.	• The use of Blockchain, as a traceability tool to ensure ethical and environmental standards in mining raw minerals. • International charter and recognised ethical trading and certification standard sourcing EV battery raw materials. • Building on trust within the value chains. • Integrated manufacturing concept
Manufacturing	• The UK supply chain reliance on China and other Asia countries on EV battery cell manufacturing and raw materials sourcing. • Lack of battery cell manufacturing capabilities and lack of upstream investment. • Lack of clarity on what zero emission and low-carbon economy means. • Lack of coherent policy addressing GHG emissions within the EV life cycle.	• Government investment in raw materials sourcing and LIB manufacturing capabilities. • Regional level collaboration e.g. at the EU level having own manufacturing facilities. • Advocating responsible practices within the EV value chain. • Policies addressing raw materials embodied energy and decarbonising EV life cycle infrastructure.
Distribution & Sales	• Lack of innovation in consumer EV experience, including a Government-led transition plan from ICE to EVs.	• Clarity from Government on its upstream investment in controlling its own raw materials supply chain.

	• Lack of regulatory requirements for producer responsibility i.e. LIBs post-first-life applications. • Lack of EV and LIBs knowledge exchange and information for consumers. • Lack of a circular economy strategy for second use/LIBs post-first-life applications i.e. from both vehicle manufacturers and the Government.	• A new Government-led legislation designed to integrate low-carbon circular economy concepts into EV distribution and sales e.g. vehicle-to-grid (V2G) services, to reduce future grid reliability. • Improving customer value proposition and interaction within the EV ecosystems. • The UK or in collaboration with EU having own circular economy strategy and battery manufacturing facilities.
Use	• The lack of business models closing loops to stimulate resource efficiency in EV battery CE. • Lack of a clear functioning market for re-use, repurposing and recycling of LIBs. • Lack of information and communication for EV LIB post-first life applications amongst the different stakeholders' in the supply chain. • Lack of mechanisms assessing/testing EV consumers' batteries for second-use.	• Legal framework to make LIB repurposing or recycling in the UK a requirement. • Clarity on market, value and pricing for a second-life battery for consumers. • A 'free market-type system' for consumers to sell their EV LIB for second-life-use. • A modularity and EV leasing system where vehicle manufacturers own the EV batteries and providing replacement solutions. • Policies ensuring a standardised module in EV battery design supporting power storage applications.
Research and Innovation	• Lack of infrastructure to deal with end of life cells that comes back into the supply chain. • Lack of battery technology research breakthrough, in making the UK independent on other countries. • Lack of upstream regulatory regime (battery metal and manufacturing supply chain outside the UK) • Limitations and knowledge gaps on codes and standards impacting re-purposed battery pack. • The potential BREXIT (the UK leaving Europe) impact on overseas investments and concerns recruiting and loosing talent.	• More funding and research for alternative solutions addressing raw materials gaps, recycling infrastructure dependence and repurposing for second-use applications. • Innovation in consumer incentives in driving appetite for EVs and LIB circularity. • OEMs improving the technical evaluation process in assessing EV consumers' battery residual energy capacity or SOH. • Improving on stakeholder policy engagement and simplification of the value and supply chains information.

3.1 Raw Materials Extraction

3.1.1 Ethical & Environmental Sustainability Challenges

All interviewees expressed concerns about the human rights and child labour violations linked to mineral extraction for EV LIB, in particular cobalt mining (usually produced as a by-product of copper), resulting from places such as the Democratic Republic of Congo (DRC). A stakeholder, also highlighted the environmental and health impact of manganese processing industry in China, describing the use of toxic chemicals such as selenium dioxide to reduce electricity consumption during manganese metal processing and ore leaching.

Some stakeholders, shares the view that there is '*no functional duty of care*', in ensuring "*reduction of environmental impact and carbon emissions, particulate matter, and destroying local communities within the value chain*". Such concerns were linked to '*lack of a common global charter*' targeting environmental protection, child labour and human rights issues following EV revolution and relevant raw materials sourcing. A raw material expert expressed such concerns as:

"There are a range of initiatives. I think we suffer from having too many different regulatory approaches. It would be probably better that there's a coherent international policy now, rather than a load of acronyms that nobody understands".

The study found that, Local Authorities (LAs) responsible for taking action to accelerate the transition to EVs at the local level, are least familiar with the EV battery raw materials and chemistries, including, associated value chain ethical human rights and LIB CE challenges.

"This is really interesting and thank you for bringing that to light because I hadn't thought of the actual raw materials source and how we're going to dispose of it". Similarly, auto dealers at the forefront of selling and engaging with consumers on EV uptake are least familiar the ethical and environmental sustainability issues surrounding mining EV battery raw materials, as well as, lacking LIB circularity knowledge.

3.1.2 Supply Chain Traceability & Trust Issues

In tackling the supply chain ethical and environmental concerns, stakeholders responsible for metals and minerals supply chain solutions believe that using *Blockchain* will be a useful traceability tool. As some stakeholders are already working with major OEMs/vehicle manufacturers using Blockchain, they believe Blockchain will provide vehicle manufacturers a way of tackling child labour issues within the GVC. Vehicle OMEs interviewed are more inclined to favour an international/*UN level charter* such as the *UN Global Compact*, European Conflict Minerals Regulations and Dodd Frank Act with due diligence requirements. Local Authorities (LAs) including NGOs and policy shapers believe there should be internationally recognised *ethical trading standards (environmental and humanitarian) and certification* for EV battery raw materials. Some academics and raw material experts suggested *integrated manufacturing/on-site electrodes and battery cell manufacturing*, especially, where raw materials are sourced will become useful.

Some vehicle manufacturers believe, '*trust*' must be built within the raw minerals value chain, and China should lead on due diligence and ethical raw materials sourcing/mining, as they are the global dominant player in EVs and raw materials sourcing. Yet, some mining companies see the challenge that "*unlike major mining companies such as Glencore that ensures due diligence practices, the influx of Chinese mining operations have given rise to cases of bribing local decision-makers to mine and the challenge purchasing/mixing of cobalt artisanal sourced feed for export"*.

3.2 Manufacturing

3.2.1 Raw Materials Dependency & Manufacturing Infrastructure Challenge

Most stakeholder groups, sees *raw materials and battery supply chain dependency* as a main bottleneck for the Governments' mission putting the UK at the forefront of the design and manufacturing of zero emission vehicles by 2040. Interviewees believe there is *marginal production* of EV batteries in the UK and Europe, with '*lack of control of raw materials supply chain*', and a reliance on China and Asia EV battery cell manufacturing supply chain. A policy shaper expressed this as:

"*I don't think we should necessarily be happy with a world where all of that is happening is in China. It doesn't make sense to rely on China supply chain if you're making cars in Europe*".

Views were also expressed on control of raw materials reflecting the *lack of manufacturing capabilities and upstream investment* in developing EV battery assembly capacities in UK.

"*You have very aggressive expansion from the vehicle manufacturers, but that hasn't really been translated in terms of investment upstream for battery raw materials and securing that supply outside of Asia, where predominantly all of the supply chain lies at the moment*".

In tackling raw materials and cell manufacturing value chain conundrum, interviews believe Government should provide *clarity on its investment controlling its own raw materials supply chain*.

"The *UK should make moves towards potential battery manufacturing capabilities in replicating the mega and giga factories being built in America and Germany*". The UK Government investment in a new Battery Industrialisation Centre, including billion(s) of funding to develop cutting-edge automotive technologies, is seen as a precursor to a large-scale advanced-battery technology ecosystem and for the UK becoming competitive globally.

3.2.2 Zero Emissions and Decarbonising EV Life Cycle Infrastructure

Many interviewees quizzed what '*zero*' means in the Governments' road to zero strategy. A policy shaper highlighted that: "*we've asked for clarity on that. I don't know what that means, but the challenge is making sure there's an industry-wide definition of what 'significant zero emissions capability' means*". However, in cutting down the *UK's road transport CO_2 emissions and delivering on climate change objectives*, EV policy shapers, non-profit organisations and low-carbon experts sees positive contributions that EVs makes compared with internal combustion engines.

"*In terms of tank-to-wheel and tailpipe emissions*, *EVs are cleaner on carbon, even when the electricity is 100 % coal"*.

EV policy shapers, academics and low carbon experts are optimistic about the future of *zero carbon in the UK's electricity grid*. They believe the grid is getting cleaner, with an increasing energy mix from other renewable sources.

Interviewees, believe there should be CE frameworks ensuring innovation in production, reuse and recycling processes that use as much renewable energy sources as possible. There is a view that "*UK regulatory frameworks, policy and timelines are very much tailpipe emissions focussed, and not upstream focused*". This reflect views on the embodied energy or GHG emissions within the EV and LIB life cycle.

3.3 Distribution & Sales

3.3.1 Innovation in consumer experience

Distribution and sales concern within a LIB CE value chain reflect *'lack of innovation in consumer experience and an overarching business case'* from manufacturers to consumer at point of sale. An LA participant expressed that: "*This is a typical Government, they've launched this Road to Zero strategy, but what are the mechanisms to help local authorities to go circular"*?

Interviewees believe there is "*no strategy and collaboration amongst stakeholder vis-à-vis end-of-first-life applications, both nationally and EU levels*". The study reveals the '*lack of CE knowledge exchange and information* within the value and supply chains e.g. manufacturers information to auto dealers; information from manufacturers and auto dealers to fleet operators, which impact on consumers' relationships and next steps. These reflect gaps in circular *built economy strategy* following EV revolution in Europe *and a Government led transition plan from ICE to EVs*.

In stimulating more low-carbon circular business models along the value chain, many interviewees' share a common view that "*the industry and market just isn't there yet for batteries post-first-life applications*". This highlights *lack of regulatory requirements for producer responsibility, f*or EVs and batteries at different stages of the value chain.

3.3.2 Responsibility & Circularity Logistics Challenges

Almost all interviewees believe battery recycling or repurposing responsibility falls on the auto manufacturer/OEMs, with "*Government providing leadership to ensure legislations, policies, and perhaps rewarding or incentivising circularity*".

Surprisingly, there are *OEMs with no exiting program for second use* or strategies recycling EV batteries. An OEM expressed this as: "*essentially, we, right now don't have any plans of getting into the recycling of batteries, a few companies out there are trying to gain knowledge in that, and in new technologies, so in our mind right now, we probably want to find a recycler and work with them*".

A stakeholder affirmed this as: "*I remember speaking to a big world known car manufacturer, maybe it wasn't the most senior person, but didn't have a clue what will happen when the battery dies within five, six, seven years, so it is quite interesting*".

3.4 Use

3.4.1 Consumer Awareness & Knowledge Transfer

When it comes to LIB post-first-life applications, many interviewees believe *"the UK industry and market just aren't there yet"*. Many interviewees believe the industry is nascent and maturing, hence, there should be *the right business model in place to deal with LIBs* in a CE.

The *lack of a functioning market for reuse and recycling*, was highly stated. As many Local Authorities (LAs) are already taking action to accelerate the transition to zero emission road transport via EV uptake, there is *lack of familiarity regarding the potential LIB second-life use applications*, including *lack of consumer knowledge and information on LIB raw materials and chemistries value chain*. This was expressed as: "EV *Batteries is not something I know very much about, I'm afraid*". However, upon understanding the potential post-first-life applications value of an EV LIB, Local Authorities sees *second-life use for grid and housing stock stationary energy storage systems*, and believe such application will be useful in contributing to a low-carbon economy strategy and reducing the high cost of energy bills within households. An LA interviewee highlighted that "*there is a massive opportunity for LIBs reuse as static energy storage, but a lot more work is needed in the circular economy area*".

The *lack of LIB post-first life applications communication and knowledge exchange* amongst the different stakeholders' within the supply chain remains a key challenge. This reflects LIB post-first-life applications knowledge and information that trickles down from e.g. manufacturers to auto dealers; LAs; fleet operators; consumers and actors interested in post-first-life use.

3.4.2 Value Chain Circularity Typologies

Different typologies for strengthening business models for EV lithium-ion batteries circularity were discussed. Significantly, the *modular and market driven* concepts were emphasised. The *modular system design of EV ownership* echoes a scenario where manufacturers take leadership in owning batteries and providing battery replacement solutions. In this case, consumers own the car, thus, a shift towards *leasing*. This contrast with a *market driven business model*, illuminating a *free market-based - where a consumer could sell their EV LIB to the highest bidder in a free market world repurposing them for their own usage*. In driving such business models for post-first-life applications, interviewees believe, there should be *a new Government led legislative framework*, designed to integrate circularity concepts in EV distribution and sales. In a free market world, some interviewees believe "*there shouldn't be too much regulation and many players within the value chain",* as it could impact used battery profitability.

The modular design following a closed-loop initiative is becoming popular amongst vehicle OEMs and partnering with energy companies. Vehicle manufacturers such as: BMW; Renault and Nissan Europe are all working on second life battery projects that ensures batteries continue to provide energy storage capacity in other applications.

3.4.3 Innovative Schemes & Mechanisms

EV experts and policy shapers, in particular, believe a Government-led LIB legislative framework must be established from a linear towards any meaningful low-carbon circular economy.

"*It'd be incumbent upon the Government to ensure there are policies, rewarding or incentivising the circularity within battery use*".

To transition from linear to CE model, an OEM interviewee described the *importance of consumer incentives from manufacturers* in driving consumers' appetite for LIB circularity.

"*I think the end-user obviously has to have the incentive to want to recycle their battery to manufacturers, so there has to be some good reason for that, and eligibility could be performance-based standard, rather than a secondary-life standard*". Consequently, most interviewees wanted to see OEMs *improving technical evaluation process estimating/testing consumers' batteries state of health*. This aim to aid assessing and calculating the market price and value for the second-life batteries.

3.4.4 Recycling versus Reuse

Discourses over *recycling vs second-life use for energy storage applications* remains a burgeoning issue. There are conflicting views regarding the complexities of second-life use, concerning the lack of clarity on how much remaining capacity can be expected from a second-use application *versus* the cost, labour and energy intensive processes required recycling/recovering the raw materials.

Some stakeholders (e.g. raw material experts, fleet operators, policy shapers, academics and OEMs) see "*repurposing LIB after first-use as short term, whilst recycling raw materials into constituent parts as the longer term solutions*".

"*I think one of the benefits of the lithium ion batteries is that, they still have an active use. So, this isn't a case of recycling and stripping them down and seeing what you can get out of them; this is actually repurposing them in their current state to do a different job, which I'm thinking is very positive*".

In contrast, stakeholders including vehicle OEMs shared diverse views on *old vs new batteries* use for energy storage applications. A personal view from a vehicle OEM interviewee, prefers to see "*utilizing old batteries in poorer countries or regions, as part of an initiative supporting poorer areas where people might require those most, and haven't got sufficient ongoing electricity*".

3.5 Research and Innovation

3.5.1 Infrastructure & Technological Challenges

On an industrial level, the study reveals LIB repurposing and second-life use as "*a nascent industry which will need more work*", with emphasis on *lack of industrial infrastructure supporting LIB repurposing, recycling* LIB raw materials and value chains dependence on other countries.

"*At the moment, there is no recycle of lithium ion batteries within the UK. Used batteries are shipped over to Belgium and Berne basically*".

It was highlighted that for the UK to realize an EV performance economy, "*it will take concerted action on several fronts, in particular, having the right infrastructure in place to deal with end of life cells that come back into the supply chain*". It was underlined not to "*expect Government to establish battery recycling plants but they need to set the legislative framework to make recycling in the UK a requirement*". However, in warranting a viable recycling processes, interviewees believe such processes should account for the economic and environmental costs – addressing: time, labour and the energy intensive processes involved.

3.5.2 Standardisation

Of importance to transition to EVs and the LIB CE business model, emphasise on research and regulation *ensuring a standardised module in battery design supporting power storage applications and recycling*. Interviewees believe the onus falls on EV manufacturers and industrial body helping standardize battery components, so second-life adapters have less variety to deal with. An OEM interviewee highlighted that: "*A typical life cycle of these kind of things, starts with standardizing across manufacturers because that's where the technology's been developed, and in the supply base, so you tend to start with manufacturers specific approach, and the regulators catch up afterwards to streamline and ensure consolidation*".

3.5.3 Workforce, research collaboration challenges

In terms of Government support for research and development, interviewees believe there is *limited scope in EV funding/project schemes*, which are not sufficient, non-entrepreneurial and least drive private sector innovation in low-carbon and EV technological advancement.

Almost all stakeholder groups, including, vehicle OEMs, EV fleet operators and EV policy shapers expressed concerns about how BREXIT could negatively impact on investment in EV technologies including research and development. This was expressed as "*You stop collaboration, and you stop that knowledge exchange between people that probably know better than you do and losing out talent/highly skilled".*

4.0 Discussion

Batteries technology currently stands at the interface of powering EVs and remains the heartbeat of cleaner technologies towards low-carbon and net zero economy. Following the global appetite for EVs and low-carbon technologies, this study shows there are major challenges achieving an integrated and a more responsible low-carbon circular economy. Gaps in circular built economy strategy, and a transition plan from ICE to EVs, are all burgeoning issues.

In working towards low-carbon circular economy solutions, Stahel (2016) closed-loop solutions, helps understand the need to address challenges such as: irresponsible raw minerals mining practices and CRMs dependency; lack of CE innovation in consumer experience and the lack of a local industrial infrastructure and operational model to deal with end-of-life cells. The results of this study suggest that addressing closed-loop solutions, must not be treated in isolation, and echoes Stahel's (2013) closed-loop principle that 'loops should have no beginning and no end'. The study reveals upstream CRMs investment and component manufacturing are fundamental for the transition to a zero economy. Nonetheless, important circularity knowledge is still missing in the linkages that exist between CRMs extraction, the transition to EVs, cleaner energy and LIBs post-first-life applications.

Although key EU policies such as: Batteries Directive (2006/66/EC); ELV Directive (2000/53/EC) for end-of life vehicles, Directive 2009/125/EC and REACH (Regulation (EC) 1907/2006), provides framework to manage e.g. the environmental impact of batteries lifecycle, the collection, treatment and recycling of waste batteries, the aforementioned Directives still remains weak addressing LIBs closed-loop solutions. This study highlights that input for a mandatory legislative and a well-designed LIB circularity business model, should illuminate the cross-sectorial and cross-boundary value chain interactions. Importantly, closed-loop and EV transition plan legislative frameworks should address: competitiveness, value chain socio-environmental and ethical impacts, job creation and economic growth, investment and innovation, whilst saving money for EV consumers. Thus, a Government-led legislation should be designed to integrate the various value chain TEEPSE influential drivers (technological, economic, environmental, political/policy, social and ethical) and challenges.

The themes below explore deeper the pathways useful contributing to an integrated low-carbon circular economy business model:

4.1 Closing the loop: post-first-life applications

As the new EU action plan for the Circular Economy (EC, 2019) among others have argued, there is a need to develop better strategies and tools harnessing circularity and sustainability for battery second-life use. The study reveals lack of regulatory requirements for producer responsibility for LIBs post-first-life applications as a major challenge. New national legislative requirement addressing the Extended Producer Responsibility (EPR) required under EU Directives on waste, can put an obligation on manufacturers/producers to take operational or financial responsibility for the end-of-life phase of LIBs (i.e. creating take back programmes). This study revealed that a 3R system - recycling, remanufacturing and repurposing LIBs applications are currently not fully developed in the UK. Amid concerns of lack of LIB recycling infrastructure and technological breakthrough in the UK, this have led to the ReLiB project, aiming recycling battery raw minerals close to 100%.

4.1.1 Recycling – Opportunities and Challenges

Secondary raw materials

In addition to reducing waste generation, recycling can offer an economic incentive and resource efficiency through raw material recovery. In view of *recycling processes*, Nelson et al, (2009), highlights that an EV battery accounts for up to 40% of the entire vehicle's value-added share, whereas, Jody et al. (2011) estimated that recycling could yield up to 20% recovery of battery cost. Hence, a key challenge to closing-loop entails an efficient and cleaner recycling mechanism retrieving and maintaining all and high value battery raw materials in circulation, e.g. cobalt and the hard to recover and costly lithium mineral. With the lack of LIB recycling and circular economy legislative frameworks, transposition of the European Commission report on 'Critical Raw Materials and the Circular Economy' (EC, 2019) into a UK legislative framework will be useful. Such legislative framework should aim towards an efficient recycling processes that ensures national or local access to clean secondary LIB raw materials. This study highlight the importance to establish local, smart, efficient disassembly and safe ways recovering large quantities of raw minerals during recycling processes.

Although, LIBs current collection percentage within the UK is very low, at just 2% percent (Urban Mine Platform, 2019), there is urgent need developing an economical and greener recycling process by the time large volumes of batteries reach end of life. The ReLiB project aiming to develop the technological, economic and policy framework allowing high percentages of LIBs raw materials to be recycled in the UK will become key in a closed-loop business model design.

Several studies also highlights on the economic benefits recycling LIB raw materials, whilst mitigating raw materials supply risks and dependence on other countries (Olivetti et al., 2016; Mancha, 2016). Mancha (2016), underlined that recycling should ensure having own supply of resources without having to rely on imports from third countries. But, in view of policy goal to achieve ULEV standard by 2050, it should be noted that 'recycling alone will not be enough to mitigate CRMs dependence' on other countries and becoming a primary CRMs source.

Standardisation for battery design and recycling

The study reveals that the auto sector lacks standardisation for battery packs or cells design (also in Arora and Kapoo, 2018). Review of the EU Batteries Directive (Directive, 2006) and the Ecodesign

Directive framework (Ruiz, 2018) could aid legislative framework for recycling and standardisation towards a more circular and resource efficient economy.

Such legislative review could impel manufacturing innovative batteries that are easier and inexpensive to recycle after end of life. The Ecodesign Directive could lay down the conditions and criteria for requirements addressing issues such as the *binder materials* used in manufacturing batteries, as binders severely influence efficient recycling processes for CRMs (Belharouak, et al, 2018). Harper et al, (2019), emphasised the benefits of using low-cost water-soluble binders in cell designs to expedite CRM recovery in a recycling process.

While the EV battery technology is still evolving, the role of battery manufacturers and regulatory measures ensuring standardisation for battery design towards efficient recycling processes remains vital. Such standardisation procedures should consider that, a specific battery chemistry e.g. nickel, manganese, and cobalt (NMC) battery could soon become obsolete (see also Gaines, 2014). Already, some cell manufacturers are aiming towards a cobalt-free battery/freeing away from high value CRM, considering emerging work on new battery chemistries to compete with LIBs (e.g. solid-state, silicon and rechargeable zinc alkaline batteries). Thus, a high-tech and costly *recycling process* developed solely to separate 'high value CRM' such as Cobalt, may be deemed uneconomical recycling a 'low value battery'. Although, it takes a while for new cutting-edge battery chemistry to become mainstream, the lack of battery design standardisation could in future conflict with the 'economic viability to recycle batteries' versus 'recycling time, cost and energy intensive process'.

Policy frameworks should aim at protecting vulnerable populations, as low-value and end-of-life EV batteries could end up as electronic/e-waste in emerging poor economies. Thus avoiding potential health consequences and exposures through environmental pollution during recycling. In recognizing the efficiency of resource cycling and transitioning to low-carbon economy, this study highlights that recycling CRMs at the end of a battery second-life remains reasonable in managing potential wastes.*4.1.2 Repurposing – Challenges & Opportunities*

Energy Storage Systems

With LIBs having a high capacity of 80% of original manufactured energy storage after EV life, recycling for raw minerals just after EV life, seems inconsistent in developing a low-carbon circular economy business model. Catton et al. (2019), also questions the economic proposition and complexities (e.g. labour and energy intensive processes) in recycling batteries after EV life, considering decreasing recyclable value of the raw materials, in contrast to repurposing LIBs for energy storage after EV life (Cready et al, 2003).

The study shows a strong desire for *repurposing LIBs* as energy storage systems to address consumers and businesses growing high energy costs. Recent developments, have seen industry leaders exploring the benefits using new and second-life LIBs battery packs for grid-storage solutions in meeting peak-power demand. This including the likes of EDF Energy and Nissan's partnership to use second life batteries to power commercial projects in the UK (Pratt, 2018). Likewise, Tesla's Gigafactory in the

US, which will produce 35 gigawatt-hours (GWh) of LIBs per year, running completely on 'on-site renewable energy' (Tesla, 2013).

Despite the technological advancement and desires repurposing LIBs for energy storage, business models for repurposing and to deal with end-of-life cells which come back into the supply chain currently remains unclear. Significantly, there are persisting bottlenecks, considering the fact that second-use batteries are being applied to a system that they were not originally designed for, and that home energy storage is a relatively new concept, with few research.

Gaps following safety risks, applicable codes and standards for repurposing LIBs in stationary storage installations, are ensuing calls for new definition, a certification scheme and formal technical standards for installation and installers (REA, 2016).

Catton et al (2019), highlighted that there are gaps understanding the *safety risks measures*, applicable codes and standards for repurposing LIBs in stationary storage installations. At a national level, current regulations such as the UK Batteries and Accumulators Regulations 2008 and the Waste Batteries and Accumulators Regulations 2009 (as amended), remains weak guaranteeing an efficient, safe and coherent LIB repurposing processes in a closed-loop design. Institutions such as the Office for Product Safety and Standards in the UK, can therefore play a major role addressing such policy gaps, in managing the potential safety risks linked to repurposing LIBs in stationary energy storage installations.

Repurposing EV battery packs for secondary applications significantly increase their overall lifespan (Podias et al, 2018; Catton et al., 2019), and increasing the overall lifespan of a product remains integral to the building blocks of a circular economy vis-à-vis product manufacturing and supply (MacArthur, 2013). Hence, legislative measures optimising the life cycle of EV batteries remains significant for the development of close loop business model, reducing environment impact, and experiencing more than enough energy storage to circulate around.

Since close loop business model(s) are evolving, there is a *need for a clear definition for LIB 'end of life' and 'post-first-life applications'*. This should aim to ensure a common understanding between all actors involved in first and second use applications, with considerations for circularity pathways and tools for LIBs evaluation. It is important to also understand that the lack of information for post-first-life applications will limit the ability of the energy storage industry to grow. From a sustainability point of view, if the transport, energy and the mining sectors can share LIBs during their residual energy capacity life time, it would harness 2050 global decarbonisation goals. In consequence, a future-oriented scenario models integrating LIBs value chain challenges, including battery repurposing, will remain valuable. This can support an efficient industrial efforts positioning the UK's global leadership towards an EV and battery performance economy.

4.1.3 Remanufacturing – Opportunities & Challenges

In regard to *remanufacturing*, although it can be seen as the second best after reuse of an industrial waste process to transfer a used and worn component in a quasi-new condition or improving resource efficiency conditions, challenges and uncertainties in remanufacturing LIBs persist (Kampker et al, 2016). In principle, a remanufactured LIB should perform same as new, yet, consumers may not rate them at the same level as new, since they will require consumer rights e.g. *safe and extended product guarantees,* including *third-party verification* of LIB performance to ensure quality and market acceptance. Ruiz (2018), highlighted that remanufacturing, reconditioning, including disassembly and re-assembly of an EV battery pack, comes with higher operating costs. Whereas Zhang et al (2014), emphasised on finding the optimal battery's remanufacturing point, likewise, the need to develop special prediction models focusing on quality, quantity and time of batteries available for a possible remanufacturing. As part of LIBs remanufacturing challenges, closed-loop design must optimize lifetime and material cost savings, including energy, weight, and range or battery durability (*ibid*). Yet, the reuse of components retrieved by remanufacturing could also lead to a competitive cost structure for EVs (Remanufacturing Industries Council, 2016).

4.2 Closing the loop: regulatory measures in transitioning to circularity

4.2.1 Circularity Governance & Industry Standards

The study reveals the importance of a circular economy governance mechanisms and a Government-led transition plan from ICE to EVs. To begin with, it is important to develop a battery circular economy *ownership and liability regime* i.e. understanding who owns the battery at the point of EV sale or at end-of-first-life phase, helping facilitate decision-making for post-first-life possibilities. Frederick (2014), also argued that value chain governance network-style requires a lead firm to set parameters through coordination of production vis-à-vis the supply chain, designed to promote mutually beneficial growth for all parties.

This study reveals differing views on a free *market-based* and *modular system* CE typology for EV and battery ownership. Frederick (2014), explained that in market-based governance, pricing is typically the driving factor, whereas, a modular type is characterised by "arm's-length" relationships, to hierarchical value chains illustrated through direct ownership of production processes (vertical integration). This show the need for clear *vehicle manufacturer's responsibilities* and *harmonised policies at the regional, national and local levels* to make LIB circularity governance situation more coherent and efficient. Consequently, the recognition of EPR and LIBs post-first-life applications becomes crucial to the UK's Clean Growth and Road to Zero Strategies. The absence of manufacturer's responsibilities and LIB circularity regulations, could also result end-of-first-life LIBs ending up in emerging economies to address electric power outage or create a new market retrieving raw minerals to sell.

Since the use of battery packs for household energy storage applications is a relatively new concept, absence of standards and risk assessment procedures for the installation in emerging economies, can expose individuals and households to safety risks such as electrocution and explosions (Catton et al., 2019). Hence, key to transitioning to low-carbon economy and LIB circularity, is addressing liability challenges and improving *technical and safety evaluation process* estimating/testing EV owners' remaining battery states-of-health (SOH). SOH is estimated according to the extent of use and performance degradation of batteries and test the energy storage capacity of the battery (Lu, 2012). The ISO 12405 and IEC 62660-3:2016 international standard, specifies test procedures and best practices for lithium-ion battery packs and systems. These standards addresses requirements for performance, safety and how testing should be undertaken in EVs battery cell.

Unlike ICE vehicles, EV owners cannot simply remove, transport their battery pack, purchase a new battery from the auto dealer or dispose the used battery to a local battery waste collection point. LIBs being a large device are not designed with disassembly in mind, as it takes many hours to process, as well as, requiring expertise, training and special safety routines to disassemble, and to prevent electrocution of operators or short-circuiting of the pack (Melin; 2018 and Harper et al, 2019).

This study argues that circularity business models should have established *reverse logistics industry standards* with criteria and guidelines (reuse and recapture value and end the product's lifecycle). Such circularity criteria and guidelines should consider safety risk to explosion, as LIBs are classified under UN ADR Regulations as Class 9 (miscellaneous dangerous goods) (UNECE, 2019). Thus, post-first-life applications standards may also appraise the waste electrical and electronic equipment (WEEE) Directive (2012/19/EU), including its provisions relating to suitable design for disassembly of products (SWD (2018)36). Accordingly, guidelines on transportation of LIBs as a dangerous goods via road, should aim to prevent accidents and damage (UNECE, 2019).

With the increasing trend and desire to repurpose batteries for energy storage applications, an EV battery management system (BMS) becomes essential supporting consumer-end low-carbon circular economy decision-making (also in Monhof, et al, 2015).

4.2.2 Technological & Innovative Policy Instruments

Gaps in technological development and innovation across the EV and battery industry affirms Rizos et al., (2016) view that the lack of assessing and implementing more advanced technical options hampers the establishment of circular economy requirements. Given this, key industrial actors' access to state-of-the-art technological systems and features of *intellectual property* (IP) will remain key to shaping and unlocking the circular ecosystem for LIBs technology and low-carbon economy. Wiens (2014), argued that IP precincts can strangle circular economy, as information and innovation are the currency of circularity. Even though information-sharing can be counter-productive on information security and competitiveness, building-walls with protective approach around products can also be self-defeating in delivering transformative change (Preston, 2012; Wiens, 2014).

Den Hollander et al (2017) highlights on how unlikely OEMs will make their IP regarding products and CE processes available to the level needed by third parties. Besides, higher *premiums for insurance costs* could also remain a significant barrier, considering an increased risk of failure and the lack of statistical risk data for insurance companies to calculate premiums (Will, 2012). Thus, in stimulating a robust low-carbon circularity business model, Government should expedite *funding specialised low-carbon technologies start-ups* and in collaboration with vehicle manufactures, second-life batteries suppliers and relevant stakeholder groups, to target potential challenges that residential and businesses could encounter in this nascent industry.

Clearly, Government-led *economic incentives* and measures supportive of consumer-end acceptance i.e. in testing, recovering, replacing, repurposing and recycling LIBs remains integral to CE business models. Such legislative measures could be enhanced under the Batteries Directive and the Electricity Market Reform Act improving upon the Renewables Obligation Scheme (DECC, 2012). Measures could adopt both the Ecodesign Directive and EU Energy Local Storage Advanced system (ELSA) integrating second life electric car batteries in a wide range of applications (ELSA, 2019). This aiming to ensure battery design are considered for disassembly, re-use and recovery after an EV life, as well as improving the environmental performance and carbon emissions reduction throughout LIBs life cycle. As revealed in the study, the Vehicle-to-Grid (V2G) integration strategy through smart charging, could also help residential and businesses reducing grid reliability issues and decarbonizing the grid. V2G technology charges EVs using off-peak electricity then feeds it back into the grid at times of peak demand (National Grid, 2018).

4.3 Closing the loop: Sustainable Global Value Chain

4.3.1 Critical Raw Minerals Dependency & Low-Carbon Technologies

This study reveals overcoming raw minerals, including battery manufacturing and supply chain risks challenges in transitioning to low-carbon economy i.e. mitigating the dependency on China, non-UK and other Asia countries on raw materials sourcing, cell and module manufacturing, including pack assembly. Accordingly, addressing CRMs dependence becomes a responsible business enabler, as it contributes minimising value chain ethical, environmental and social impacts.

The modular circularity pathways, including investments in new efficient battery cells technological breakthrough (e.g. a combination of *solid state batteries, Gigafactory* and *hydrogen fuel cells*) remains key transitioning to a low carbon economy and confronting CRMs dependency. Significantly, *upstream trade partnerships and investments* to develop a UK strategy for the supply of strategic elements becomes vital addressing dependency and potential supply chain shocks. A case in point may reflect a scenario where countries with advantage in upstream CRMs supply and component manufacturing, '*weaponing or embargoing CRMs imports*' in a geopolitical tensions or trade war. Accordingly, measures required to safeguard advanced-battery and low-carbon technology investments needs to be harnessed in the phase of political uncertainties and policy conflicts e.g. BREXIT.

4.3.2 Value Chain Emissions & Environmental Sustainability Challenges

Drawing from the raw materials mining results, this paper argues that in transitioning to EVs and low-carbon technologies, the value chain socio-environmental impacts sourcing raw materials must be considered. Thus, the study argues for circular economy business models, to uphold values in reducing the societal and environmental impairment caused by industries (Stahel, 2013; Geissdoerfer et al, 2018). Influential countries such as China, - a major consumer of CRMs, accounting for 30% of the total share of GHG emissions (Boden et al, 2017), and with increased equity share in foreign mineral assets (Farooki, 2018), can play a crucial role tackling value chain sustainability and emission challenges.

Particularly, China leading in placing a legally binding regulation on Chinese companies operating in resource-rich countries vis-à-vis adopting best practices for protecting vulnerable communities, ecosystems and adopting low-carbon technologies within the mining sector. Such innovative regulatory measure could become integral achieving China's vision to green its Belt and Road Initiative (BRI). Yet, China's metals and mining investments under BRI remains unclear (Farooki, 2018). Tang et al (2015), highlights on innovative business model useful enhancing Chinese enterprises awareness of social responsibility, and achieving mutually beneficial policy under BRI.

The study reveals Governments, mining and auto manufacturers' "silo" approaches ensuing the transition EVs and demand for CRMs, have led to unsustainable policy and development choices, as policy frameworks are developed largely in isolation from one another. Hence, in pursuit of net zero global carbon emissions by 2050, resource-rich countries embracing World Bank's *Climate-Smart Mining initiative* could become a powerful tool, supporting the integration of renewable energy content into mining operations, as mining accounts for 11% of global energy use (World Bank, 2019). Such initiative, with established international standards and codes for repurposing LIBs, could result in minerals-rich poor countries (with abundant solar energy) benefiting from battery pack technology for cleaner technology and energy storage systems. The energy storage system enables optimal use of both solar photovoltaics and grid electricity retrieved at low cost from the grid. Also, this will help address societal challenges such as irregular and random electric power outage usually experienced within some of these countries. According to the Natural Resources Governance Institute (2017), resource-rich developing countries are at risk of missing out on many of these socio-environmental benefits, including the economic benefits that should come as a result of being the source for low-carbon technological progress.

This study recommends addressing the negative externalities caused by mining and resource consumption in minerals-rich countries, in the form of '*external cost of pollution and risk impact*' policy instrument(s). Long et al., (2012) also commends that the internalization of environmental costs should reflect the environmental gains and losses in the cost of a product, whereas, '*a price on carbon*' can also harness cross-boundary investment opportunities and the adoption of low-carbon technologies, including, other climate change policies towards net zero economy by 2050. According to the World Bank (2019), a carbon pricing mechanism can bring down emissions and help shift the burden for the damage back to those responsible for it or helping reduce it.

4.3.3 Improving Responsible Business Practices and Transparency

It is also useful to acknowledge that the EV and low-carbon revolution will require a substantial increase in mining several key critical raw minerals and metals such as cobalt, manganese, and nickel, as well as copper in the roll-out of EVs, charging infrastructure and wind turbines (World Bank, 2019). Whereas irresponsible raw materials sourcing also means resource scarcity, large amounts of GHG emissions, water, waste and energy, thus, having an irreversible impact on the local and natural environment. Although there are several initiatives ensuring responsible and ethical sourcing of raw minerals such as the Extractive Industries Transparency Initiative (EITI) and Responsible Cobalt Initiative (OECD, 2016), there are still weaknesses in tackling unethical and environmental sustainability issues within the raw minerals supply and value chain. A case in point echoes mining raw materials such as *nickel* in resource-rich countries such as the Philippines and Russia (Opray, 2017); the wrecking of fragile ecosystem in Chile due to *lithium* mining (Lombrana, 2019), and, forced child labour abuse cases on artisanal concessions mining of cobalt in DRC (World Bank, 2019).

Raw minerals technology experts' believe *Blockchain* could be used as an *auxiliary technological tool* to guarantee traceability in sourcing raw minerals, building trust and ensuring value chain responsible business practices. Kouhizadeh et al., (2019), similarly labels Blockchain technology as a potential enabler for many circular economic principles, and useful as digital ledgers to track EV batteries provenance (Collins, 2018; WEF, 2018). In fact, tackling raw minerals provenance issues via Blockchain, will do little to address the structural and substantive issues rooted within a system, especially, the underlying issues stemming from *artisanal and illegal mining activities*. Thus, a deeper understanding of the '*social structures*' (e.g. rules, institutions, practices, thoughts, beliefs), unemployment and livelihood challenges experienced within resource-rich mining communities' will remain key guaranteeing responsible and ethical sourcing of raw minerals. This study argues for circularity and business models to align measures addressing unemployment and environmental protection in resource-rich communities, and should be backed by legislation transforming small scale artisanal mining via the UN SDGs and Global Compact principles. Effective stakeholder collaboration, research and investment, – and all arrangements whether regulatory, incentives/schemes or administrative must be rooted within trade, sustainability and industrial innovation policy goals. Such integrated and decentralized closed-loop business model, via an *international common charter* could have a real opportunity respecting human-rights, improving the natural environment, tackling corruption and value chain bribery cases.

5.0 Conclusion

The study reveals that ensuing low-carbon technologies and global net zero carbon emissions by 2050 can be best realised via a circular domain. The study hypothesised that products circularity, must not be treated in isolation following the closed-loop principle, but rather address circularity issues as interrelated activities, as they could positively or negatively impact on each other. Policies transitioning from linear to a circular economy business model, should not only be about recycling raw minerals, addressing waste or repurposing battery for energy storage applications, but must focus on *closing-loop in an integrated manner*. An integrated manner, consider many aspects of an innovative policy strategy, accounting for equitable jobs and GHG emissions within the value chain, protecting the natural environment, and ensuring responsible natural resources consumption and production patterns.

Key trade-offs between policy goals, especially '*raw materials sourcing*' versus '*uses*' in a closed-loop design must be explored, as well as, harnessing the potential synergies vis-à-vis the technological, social, economic, political, ethical and environmental influencing factors/drivers within a system. Here, decision-makers should ensure both low-carbon and circularity objectives integrates the triple objectives of making positive impact on *people, planet and profit*, considering the geographical unbundling of economies. Although the study addresses LIBs circularity and the UK transition to EVs, the results are internationally relevant, considering the EU and global appetite transitioning to EVs and low-carbon technologies.

To conclude, it is now imperative to recognise 'circular novel thinking' in policies and future studies, -providing systemic thinking towards integrated and sustainable futures. Such approaches following the *nexus and scenarios thinking,* provides joined-up and integrated approaches useful addressing value chain cross-sectorial and cross-boundary impacts, *inter alia* accounting for the Global Goals.

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Declaration of interest

None

6.0 References

Ahmadi, L., Yip, A., Fowler, M., Young, S.B. and Fraser, R.A., 2014. Environmental feasibility of re-use of electric vehicle batteries. Sustainable Energy Technologies and Assessments, 6, pp.64-74.

Alves Dias, P., Blagoeva, D., Pavel, C. and Arvanitidis, N., 2018. Cobalt: demand-supply balances in the transition to electric mobility. EUR (Luxembourg. Online). Luxembourg: Publications Office.

Aronson, J., 1995. A pragmatic view of thematic analysis. The qualitative report, 2(1), pp.1-3.

Arora, S. and Kapoor, A., 2018. Mechanical design and packaging of battery packs for electric vehicles. In Behaviour of Lithium-Ion Batteries in Electric Vehicles (pp. 175-200). Springer, Cham.

BEIS, 2017. Department for Business, Energy and Industrial Strategy. Digest of UK Energy Statistics (DUKES), Chapter 1: Energy (online). Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/642716/Chapter_1.pdf. [Accessed: 10/11/2018].

BEIS, 2018. Department for Business, Energy and Industrial Strategy. Final UK greenhouse gas emissions national statistics: 1990 – 2016. London: BEIS. Available at: www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-nationalstatistics-1990-2016. [Accessed: 24/03/2019].

Belharouak, I., Muralidharan, N., Li, J., Luo, H., Du, Z., and Dai S., 2018. Hydrothermal Recovery Process for Black Mass. ReCell Advanced Battery Recycling Centre. Third Quarter Progress Report 2018 pg. 39-65. Available at: https://blogs.anl.gov/recycling/wp-content/uploads/sites/81/2019/08/2019_Q1Q2_ReCell_Quarterly.pdf. [Accessed: 11/11/2019].

Bicket, M., Guilcher, S., Hestin, M., Hudson, C., Razzini, P., Tan, A., Ten Brink, P., Van Dijl, E., Vanner, R. and Watkins, E., 2014. Scoping study to identify potential circular economy actions, priority sectors, material flows and value chains. Project Report. Available at: https://publications.europa.eu/en/publication-detail/-/publication/0619e465-581c-41dc-9807-2bb394f6bd07/language-en. [Accessed: 11/04/2019].

Boden, T.A., Marland, G. and Andres, R.J., 2017. National CO2 emissions from fossil-fuel burning, cement manufacture, and gas flaring: 1751-2014. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy.

Busch, J., Dawson, D. and Roelich, K., 2017. Closing the low-carbon material loop using a dynamic whole system approach. Journal of Cleaner Production, 149, pp.751-761.

Catton, J.W., Walker, S.B., McInnis, P., Fowler, M., Fraser, R.A., Young, S.B. and Gaffney, B., 2019. Design and Analysis of the Use of Re-Purposed Electric Vehicle Batteries for Stationary Energy Storage in Canada. Batteries, 5(1), p.14.

Charmaz, K., 2014. Constructing grounded theory. Sage.

Charter, M. ed., 2018. Designing for the Circular Economy. Routledge.

Collins, B., 2018. Blockchain Can Extend Battery Life by Revealing Origin: Q&A. Bloomberg NEF. Available at: https://about.bnef.com/blog/blockchain-can-extend-battery-life-revealing-origin-qa/. [Accessed: 07/04/2019].

Cready, E., Lippert, J., Pihl, J., Weinstock, I. and Symons, P., 2003. Technical and economic feasibility of applying used EV batteries in stationary applications (No. SAND2002-4084). Sandia National Labs., Albuquerque, NM (US); Sandia National Labs., Livermore, CA (US).

DfT, 2018. Department for Transport. The Road to Zero - Next steps towards cleaner road transport and delivering our Industrial Strategy: Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf. [Accessed: 11/01/2019].

DEFRA, 2019. Department for Environment, Food & Rural Affairs. Clean Air Strategy 2019: Available at:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf. [Accessed: 10/01/2019].

Den Hollander, M.C., Bakker, C.A. and Hultink, E.J., 2017. Product design in a circular economy: Development of a typology of key concepts and terms. Journal of Industrial Ecology, 21(3), pp.517-525.

Dinger, A., Martin, R., Mosquet, X., Rabl, M., Rizoulis, D.,Russo, M., et al., 2010. Batteries for electric cars: Challenges, opportunities, and the outlook to 2020. BCG. Available at: https://www.bcg.com/documents/file36615.pdf. [Accessed: 10/01/2019].

Directive, B., 2006. Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC. OJ L, 266(26.9), p.2006.

Drabik, E. and Rizos, V., 2018. Prospects for electric vehicle batteries in a circular economy. Available at: https://www. ceps. eu/system/files/RR, 20. Accessed: 10/01/2019].

EC, 2014. European Commission. Report on Critical Raw Materials for the EU - Report of the Ad Hoc Working Group on Defining Critical Raw Materials. Available at: https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/community/document/critical-raw-materials-eu-report-ad-hoc-working-group-defining-critical-raw. [Accessed: 17/02/2019].

EC, 2016. European Commission. A European Strategy for Low-Mission Mobility. Brussels. Available from: https://ec.europa.eu/clima/policies/transport_en. [Accessed: 05/01/2019].

EC, 2017. European Commission. List of Critical Raw Materials for the EU. Available at: https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF. [Accessed: 05/01/2019].

EC, 2018. European Commission. European Innovation Partnership on Raw Materials: Raw Materials Scoreboard. Available at: https://publications.europa.eu/en/publication-detail/-/publication/117c8d9b-e3d3-11e8-b690-01aa75ed71a1. [Accessed: 10/04/2019].

EC, 2019. European Commission. Report from the commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions on the implementation of the Circular Economy Action Plan. Available at: http://ec.europa.eu/environment/circulareconomy/pdf/report_implementation_circular_economy_action_plan.pdf. [Accessed: 05/07/2019].

ELSA (2019). Energy Local Storage Advanced system project. Available at: https://elsa-h2020.eu/. [Accessed: 01/10/2019].

Frederick, S., 2014. Combining the Global Value Chain and global IO approaches. In Centre on Globalization, Governance & International Conference on the Measurement of International Trade and Economic Globalization Aguascalientes, Mexico (Vol. 29).

Fournier, G., Hinderer, H., Schmid, D., Seign, R. and Baumann, M., 2012. The new mobility paradigm: Transformation of value chain and business models. Enterprise and Work Innovation Studies, 8, pp.9-40.

Geissdoerfer, M., Morioka, S.N., de Carvalho, M.M. and Evans, S., 2018. Business models and supply chains for the circular economy. Journal of Cleaner Production, 190, pp.712-721.

Glaser, B.G., Strauss, A.L., 1967. The Discovery of Grounded Theory. Strategies for Qualitative Research. Aldine Publishing Company, New York, NY, USA, pp. 62.

Graedel, T.E. and Allenby, B.R., 1995. Industrial Ecology Prentice Hall. Englewood Cliffs, NJ.

Handcock, M.S. and Gile, K.J., 2011. Comment: On the concept of snowball sampling. Sociological Methodology, 41(1), pp.367-371.

Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S. and Abbott, A., 2019. Recycling lithium-ion batteries from electric vehicles. Nature, 575(7781), pp.75-86.

Hill, N., Clarke, D., Blaire, L., and Menadue, H., 2019. Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles, Final Project Report by Ricardo Energy & Environment for the JRC. Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-10937-2, doi:10.2760/537140, JRC117790.

HEI, 2018. Health Effects Institute. State of Global Air 2018. Special Report. Boston, MA: Health Effects Institute. Available at: https://www.stateofglobalair.org/sites/default/files/soga-2018-report.pdf. [Accessed: 15/11/2018].

Husain, I., 2010. Electric and Hybrid Vehicles: Design Fundamentals, 2nd ed.; CRC Press: Boca Raton, FL, USA.

ICTSD, 2017. International Trade Governance and Sustainable Transport: The Expansion of Electric Vehicles. Geneva: International Centre for Trade and Sustainable Development.

ICTSD, 2018. International Trade Governance and Sustainable Transport: The Role of Trade Policy in Enabling the Global Diffusion of Electric Vehicles, Information note.

IEA, 2016. International Energy Agency. Key CO2 Emission Trends. Available at: https://www.green4sea.com/wp-content/uploads/2017/02/IEA-Key-CO2-Emissions-Trends-2016.pdf. [Accessed: 06/11/2018].

Inomata, S., 2017. Analytical frameworks for global value chains: An overview. Global Value Chain Development Report.

Jinrong, T., Tao, Z. and Ping, Z., 2015. An analysis of mineral resources distribution and investment climate in the" One Belt, One Road" Countries. Geological Bulletin of China, 34(10), pp.1918-1928.

Jody, B.J., Daniels, E.J., Duranceau, C.M., Pomykala, J.A. and Spangenberger, J.S., 2011. End-of-life vehicle recycling: state of the art of resource recovery from shredder residue (No. ANL/ESD/10-8). Argonne National Lab. (ANL), Argonne, IL (United States).

Jussani, A.C., Wright, J.T.C. and Ibusuki, U., 2017. Battery global value chain and its technological challenges for electric vehicle mobility. RAI Revista de Administração e Inovação, 14(4), pp.333-338.

Kampker, A., Heimes, H.H., Ordung, M., Lienemann, C., Hollah, A. and Sarovic, N., 2016, November. Evaluation of a remanufacturing for lithium ion batteries from electric cars. In 18th international conference on automotive and mechanical engineering, Sydney.

Kouhizadeh, M., Sarkis, J. and Zhu, Q., 2019. At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion. Applied Sciences, 9(8), p.1712.

Kuckartz, U., 2014. Qualitative Text Analysis: A Guide to Methods, Practice and Using Software. London: Sage Publications.

Long, G., Lei, W., Sijie, C. and Bo, W., 2012. Research on Internalization of environmental costs of Economics. IERI Procedia, 2, pp.460-466.

Lu, L., Han, X., Li, J., Hua, J. and Ouyang, M., 2013. A review on the key issues for lithium-ion battery management in electric vehicles. Journal of power sources, 226, pp.272-288.

MacArthur, E., 2013. Towards the circular economy. Journal of Industrial Ecology, 2, pp.23-44.

Mancha, A., 2016. A Look at Some International Lithium Ion Battery Recycling Initiatives", Journal of Undergraduate Research, Vol. 9, pp. 1-5.

Masiero, G., Ogasavara, M. G., Jussani, A. C., and Risso, M. L., 2017. The global value chain of electric vehicles: a review of the Japanese, South Korean and Brazilian cases. Renewable and Sustainable Energy Reviews, 80, pp.290-296.

Melin, H.E., 2018. The lithium-ion battery end-of-life market–A baseline study. Glob. Batter. Alliance, pp.1-11.

Monhof, M., Beverungen, D., Klör, B. and Bräuer, S., 2015, May. Extending battery management systems for making informed decisions on battery reuse. In International Conference on Design Science Research in Information Systems (pp. 447-454). Springer, Cham.

National Gird, 2018. Rapid rise of UK electric vehicles sees National Grid double its 2040 forecast, 2018. Available at: https://www.carbonbrief.org/rise-uk-electric-vehicles-national-grid-doubles-2040-forecast. [Accessed: 11/01/2019].

Natural Resources Governance Institute, 2017. Resource Governance Index. Available at: https://resourcegovernance.org/sites/default/files/documents/2017-resource-governance-index.pdf. [Accessed: 11/01/2019].

NECD, 2017. UK emissions inventory submitted under the National Emissions Ceiling Directive (NECD): Available at: https://www.gov.uk/government/publications/air-quality-plan-for-nitrogendioxide-no2-in-uk-2017. [Accessed: 1/10/2018].

Nelson, P., Santini, D. and Barnes, J., 2009. Factors determining the manufacturing costs of lithium-ion batteries for PHEVs. World Electric Vehicle Journal, 3(3), pp.457-468.

Nitta, N., Wu, F., Lee, J. T., & Yushin, G., 2015. Li-ion battery materials: present and future. Materials today, 18(5), 252-264.

OECD, 2016. The 3rd Edition of the OECD Due Diligence Guidance. Available at: http://mneguidelines.oecd.org/Brochure_OECD-Responsible-Mineral-SupplyChains.pdf#_ga=2.238972736.1528008313.1559572961-34983828.1559572961. [Accessed: 20/1I/2018].

Olivetti, E.A., Ceder, G., Gaustad, G.G. and Fu, X., 2017. Lithium-ion battery supply chain considerations: analysis of potential bottlenecks in critical metals. Joule, 1(2), pp.229-243.

Olsson, L., Fallahi, S., Schnurr, M., Diener, D. and van Loon, P., 2018. Circular Business Models for Extended EV Battery Life. Batteries, 4(4), p.57.

Opray, M., 2017. Nickel mining: the hidden environmental cost of electric cars. The Guardian. Available at: https://www.theguardian.com/sustainable-business/2017/aug/24/nickel-mining-hidden-environmental-cost-electric-cars-batteries. [Accessed: 30/05/2019].

Perkowski, J., 2017. EV batteries: A $240 billion industry in the making that China wants to take charge of. Forbes. August, 3, p.2017.

Pratt, D., 2018. EDF calls on Nissan's 2nd life batteries to power commercial projects in the UK. Available at: https://www.energy-storage.news/news/edf-calls-on-nissans-2nd-life-batteries-to-power-commercial-projects-in-the. [Accessed: 03/04/2019].

Preston, F., 2012. A global redesign?: Shaping the circular economy. London: Chatham House. Available at: https://www.chathamhouse.org/publications/papers/view/182376/bp0312_preston.pdf. [Accessed: 20/04/2019].

Podias, A., Pfrang, A., Di Persio, F., Kriston, A., Bobba, S., Mathieux, F., Messagie, M. and Boon-Brett, L., 2018. Sustainability assessment of second use applications of automotive batteries: Ageing of Li-ion battery cells in automotive and grid-scale applications. World Electric Vehicle Journal, 9(2), p.24.

POST, 2019. Parliamentary Office of Science and Technology. Access to Critical Materials. Available at: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0609. [Accessed: 15/09/2019].

REA, 2016. Renewable Energy Association. Energy Storage in the UK an Overview. Available at: https://www.r-e-a.net/upload/rea_uk_energy_storage_report_november_2015_-_final.pdf. [Accessed: 20/03/2019].

Remanufacturing Industries Council, 2016. What is Remanufacturing? Available: http://remancouncil.org/. [Accessed: 03/07/2019].

Richa, K., 2016. Sustainable management of lithium-ion batteries after use in electric vehicles. Available at: https://pdfs.semanticscholar.org/342d/89c4ebd8b6a9e2e86b8f05dbcbead87a23c0.pdf. [Accessed: 20/03/2019].

Rizos, V., Behrens, A., Van Der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. and Topi, C., 2016. Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers. Sustainability, 8(11), p.1212.

Ruiz V., 2018. Standards for the performance and durability assessment of electric vehicle batteries - Possible performance criteria for an Ecodesign Regulation, EUR 29371 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-94179-5, doi:10.2760/24743, JRC113420.

Stahel, W.R., 2013. The business angle of a circular economy–higher competitiveness, higher resource security and material efficiency. A new dynamic: Effective business in a circular economy, 1.

Stahel, W., R., 2016. Circular economy. A new relationship with our goods and materials would save resources and energy and create local jobs. Available at: https://www.researchgate.net/publication/298909366_Circular_economy. [Accessed: 10/11/2018].

SWD, 2018, 36. (n.d.). Commission Staff Working Document. Report on Critical Raw Materials and the Circular Economy. Available at: https://ec.europa.eu/docsroom/documents/27327. [Accessed: 16/10/2019].

Tesla, 2013. Planned 2020 Gigafactory Production Exceeds 2013 Global Production. Available at: https://www.tesla.com/sites/default/files/blog_attachments/gigafactory.pdf. [Accessed: 20/03/2019].

UNFCCC, 2015. United Nations Framework Convention on Climate Change. "Paris Declaration on Electro-Mobility and Climate Change and Call to Action: Electrifying Sustainable Transport." Available at: http://newsroom.unfccc.int/lpaa/transport/the-paris-declaration-on-electro-mobility-and-climate-change-and-call-to-action/#downloads. [Accessed: 10/11/2018].

UN, 2017. United Nations Environment Annual Report. Available at: https://www.unenvironment.org/annualreport/2017/index.php?page=1&lang=en. [Accessed: 10/11/2018].

UNECE, 2019. United Nations Economic Commission for Europe. Dangerous Goods. Available online: https://www.unece.org/trans/danger/publi/adr/adr2019/19contentse.html. [Accessed: 11/10/2019].

Urban Mine Platform. (2019). Percentage of collected batteries from waste generated in 2010. Available at: http://www.urbanmineplatform.eu/wasteflows/batteries/percentage. [Accessed: 11/10/2019].

Warner, N.A., 2013. Secondary life of automotive lithium ion batteries: an aging and economic analysis (Doctoral dissertation, The Ohio State University).

WEF, 2018. World Economic Forum, Building Block (chain)s for a Better Planet. Fourth Industrial Revolution for the Earth Series. Available at: http://www3.weforum.org/docs/WEF_Building-Blockchains.pdf. [Accessed: 27/03/2019].

Wiens, K., 2014. Intellectual property is putting circular economy in jeopardy. Available at: https://www.theguardian.com/sustainable-business/intellectual-property-circular-economy-bmw-apple. [Accessed: 7/09/2019].

Will, J., 2012. Will buying a 'green' vehicle increase my insurance rates? The Globe and Mail, 10.

World Bank, 2019. Climate-Smart Mining: Minerals for Climate Action. Available at: http://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action. [Accessed: 01/06/2019].

Yin, R. K., 2009. Case study research: Design and methods (4th Ed.). Thousand Oaks, CA: Sage.

Zhang, H., Liu, W., Dong, Y., Zhang, H. and Chen, H., 2014. A method for pre-determining the optimal remanufacturing point of lithium ion batteries. Procedia CIRP, 15, pp.218-222.

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Designed, performed experiments/data collection, analysed data and wrote the paper.

Declaration of interest

The author(s) declares no conflict of interest in preparing this article/ none.

Highlights

- A circular economy business model for transitioning to electric vehicles in a low carbon economy is examined.
- The circular economy principles has extracted raw minerals, manufacturing, distribution & sale, use, including recycling & innovation dimensions.
- Stakeholders hold views on weaknesses on lack of business model addressing value chain close-loop and low-carbon solutions.
- Lack of infrastructure, critical raw minerals dependency including transition plan and legislative frameworks are major concerns.
- Stakeholders share a common interest in addressing value chain ethical issues, the dependency on other countries and a local infrastructure dealing with electric vehicles batteries in a circular economy.