SUSTAINABILITY OF SUPPLY CHAINS FOR ELECTRIC VEHICLES

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ABSTRACT

Purpose: The purpose of this paper is to evaluate the sustainability of chain chains for electric vehicles (EVs).
Design/methodology/approach: This is a conceptual paper. Academic literature and – due to the novelty of the product evaluated – articles from reputed journalistic sources are analysed.
Findings: While EVs hardly pollute the air during operation, they are advertised as environmentally friendly and ethically desirable. However, there are still problems to be solved in the supply chain, from the origin of raw materials (mining of cobalt and of rare earths) to the reuse and recycle steps. The three P's of sustainability are People (society), Planet (environment) and Profit (companies need to make profit, otherwise they cannot exist much longer and are therefore not sustainable), and problems with all three have been found.
Research limitations/implications: Companies tend to be tight-lipped about sustainability problems in their EV supply chains, because "being environmentally friendly" is their main marketing strategy, so the reliability of some sources is questionable. The author tries to compensate this by using sources from different sides of the opinion spectrum. Futhermore, this research is limited to battery-electric passenger cars (BEV), not plug-in hybrids (PHEV), hybrids, or hydrogen-powered vehicles.
Practical implications: Awareness of sustainability problems in the EV supply chains should be improved, so that companies and governments invest more into new technologies to improve the production in terms of societal and environmental impact, which the added benefit of increasing profits for the companies.
Originality/value: Improvement of sustainability will improve the value of EVs to the three P's, from which society at large, the environment and lastly also the producers of EVs will benefit.

Keywords: Sustainability, supply chains, electric vehicles

Introduction

There is currently an awareness of Global Warming – even called Global Boiling by the UN (UN News, 2023) – and general environmental problems with plastic and other chemicals polluting the air, water and land which humankind needs to survive in the long term. One of the polluting factors are vehicles using internal combustion engines (ICE vehicles). Vehicles that use electric motors instead of ICE are called electric vehicles (EVs). These EVs reduce air pollution during operation to a minimum as they do not use internal combustion of fossil fuels for propulsion. This is seen as one of the solutions to fight global warming and save the environment.

Rather than focussing on reduction of pollution during operation, the authors investigate the entire supply chain of these EVs to determine the sustainability. Sustainability has three dimensions: The environment needs to be protected during both operation and production; society at large needs to benefit; and any company producing EVs needs to be profitable to survive. This research paper discusses the current situation of these three dimensions for the supply chain of EVs, specifically electric passenger vehicles, such as sedans and Sport Utility Vehicles (SUVs).

Methodology: Literature review was conducted in academic databases with search parameters "supply chains of EV batteries", "lithium mining", "cobalt mining" and "recycling of lithium batteries" Furthermore, since this is a very new field, journalistic articles from credible sources were added.

Literature Review

Sustainability

Humankind has evolved to become the dominating species on planet earth. It was known very early on that what we would term now as sustainability is important in the way we manage our environment (Monastery Mauermünster, 1144; von Carlowitz, 1713). Then came the industrial revolution which brought steam and heat engines during the mechanical age 1785-1888, and electrical machines during the electrical age 1888-1948 (Bose, 2010).

The deteriorating natural environment became an issue for the United Nations to discuss. The first Human Environment Conference was held in Sweden in 1972 (UNCED, 1992). In the UN Brundtland Report (1987), sustainability was defined as:

> "Meeting the needs of the present without compromising the ability of future generations to meet their own needs."
> (UN Brundtland Report, 1987)

The three pillars of sustainability according to the UN Brundtland Report (1987) are environmental protection, economic growth and social responsibility. The so-called "Earth Summit" in Rio de Janeiro in 1992 resulted in many declarations (UNCED, 1992), and other conferences followed. The macro-economic concepts of the UN were mapped to the business environment, as companies are the ones implementing it on a practical level. Different models were created (Süß *et al.*, 2021) and can now be applied to businesses.

The United Nations Sustainable Development Goals are 17 Goals that were adopted in 2015 by the UN General Assembly. The five dimensions of the SDGs are People, Plant, Properity, Peace and Partnership (UN, 2015).

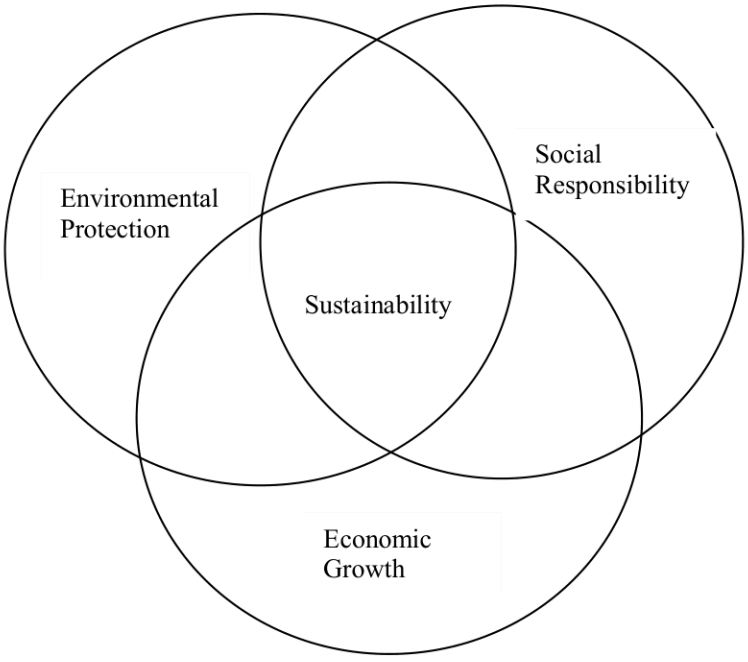

Figure 1: Sustainability. Adapted from: Carter and Rogers, 2008

The German Supply Chain Act (Bundesministerium der Justiz, 2021) which came into force on 01 January 2023 requires all companies in Germany with at least 3,000 employees to ensure that their whole supply chain is compliant with human rights and protects the environment:

The law strengthens human rights and environmental protection in global supply chains. It obligates companies in Germany to respect human rights by implementing defined due diligence obligations. These obligations apply to their own business area, the actions of their contracting partners and the actions of other (indirect) suppliers. This means that the responsibility of companies no longer ends at their own factory gate, but extends throughout the entire supply chain.(BMAS, 2023)

Circular Economy

A circular economy turns goods at their end of their life cycle into raw materials for new products, rather than following the familiar pattern of “make, use, dispose” (Stahel, 2016).

Figure 2: Circular Economy. Picture source: The Conversation (2010)

Supply Chains

Supply chains stretch from the origin of the raw materials to the final consumer. Today, reverse logistics including recycling is included:

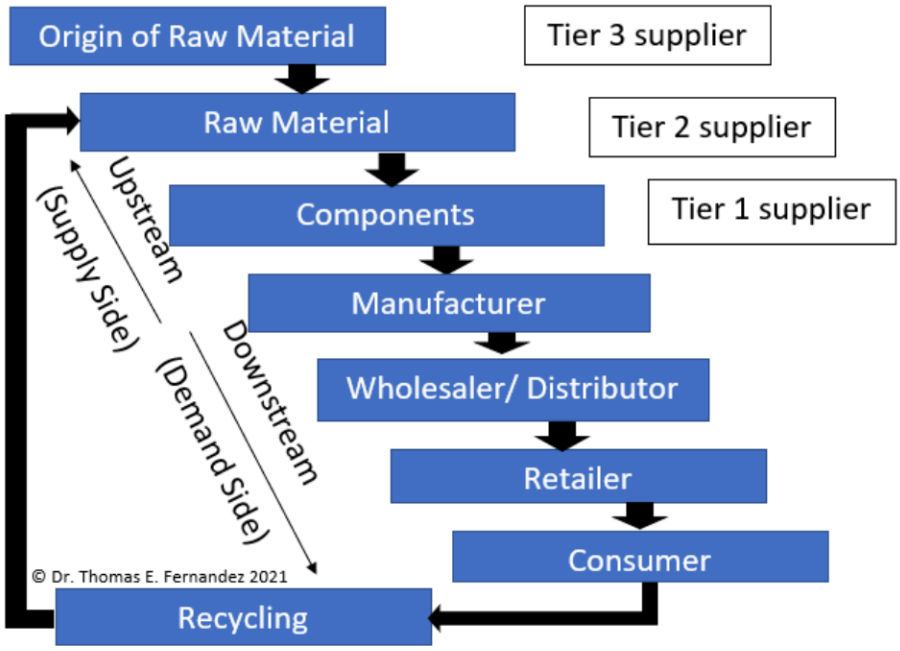

Figure 3: A simple chain for electric vehicles. Adapted from: Fernandez (2022)

The origins of raw materials for electric vehicles include steel mines, which is the case for all vehicles. EVs are different from ICE vehicles as they feature large lithium-ion batteries (LIBs). Raw materials for the batteries include lithium, cobalt, nickel, graphite and manganese. Main production countries of these materials are China (natural graphite and nickel), the DRC (cobalt), South Africa (manganese) and Chile (copper and lithium) (European Commission, 2018).

History of electric vehicles

The history of electric cars dates back to the early 19th century. The following is a brief overview (Guarnieri and Massimo, 2012):

- 1828: Hungarian inventor Ányos Jedlik builds a small-scale model electric car, considered to be one of the first electric vehicles.
- 1834: Thomas Davenport, an American blacksmith, invents the first practical electric vehicle, a small locomotive.
- Late 1800s: Electric cars gain popularity due to their simplicity, quietness, and lack of vibration compared to gasoline-powered vehicles. Companies like Baker, Detroit Electric, and Columbia Electric emerge as major manufacturers.
- Early 1900s: Electric vehicles reach their peak popularity, especially among urban dwellers. They are seen as clean, reliable, and easier to operate than gasoline cars.
- 1912: The electric starter motor is invented, making gasoline-powered cars more convenient and easier to start. This, along with the discovery of large oil reserves, leads to a decline in the popularity of electric cars.
- 1960s-1980s: Electric cars experience a resurgence due to concerns about air pollution and oil dependence. Various companies and universities develop electric prototypes and limited production vehicles, but widespread adoption remains limited.

- 1990s: The California Air Resources Board introduces the Zero Emission Vehicle (ZEV) mandate, requiring automakers to produce a certain percentage of electric vehicles. This leads to the development of modern electric cars like the GM EV1, Toyota RAV4 EV, and Nissan Altra EV.
- Early 2000s: Tesla Motors, spurred by major investor Elon Musk, introduces the Tesla Roadster, a high-performance electric car. This paves the way for the mainstream adoption of electric vehicles.
- 2010s: Electric vehicles become increasingly popular with the introduction of more affordable models like the Nissan Leaf and Chevrolet Volt. Tesla Motors introduces the Model S, a luxury electric sedan, and later the Model 3, which becomes one of the best-selling electric cars worldwide.

Electric cars continue to gain traction, with numerous automakers investing heavily in electric vehicle technology. Governments around the world are promoting electric mobility as part of their efforts to reduce greenhouse gas emissions and combat climate change. The International Energy Agency (IEA) predicts that electric car sales will continue to grow through 2023, with an expected 14 million sales by the end of the year, representing a 35% year-on-year increase. EVs could account for 18% of total car sales for the year. The report also highlights promising growth in emerging electric vehicle markets, such as India, Thailand, and Indonesia. (IEA, 2023)

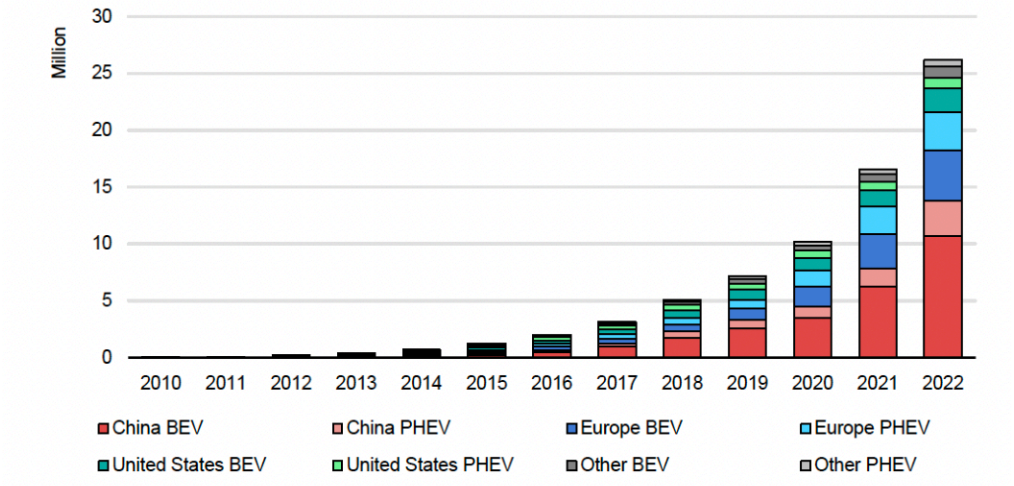

Figure 4: Global EV stock in selected regions 2010-2022.(IEA, 2023)

Mining of raw materials for batteries

More than 50% of all lithium is mined in the “lithium triangle”, namely Argentina (Salar de Olaroz), Bolivia (Salar de Uyuni) and Chile (Salar de Atacama). Lithium can be found in rock form, in which case the ore will be extracted by using drill rigs, explosives or other means, and then crushed further and roasted under intense heat, consuming nigh amounts of energy. After cooling, the ore concentrate is milled into powder and mixed with sulphuric acid and then processed further (Kaunda, 2020; Chaves *et al.*, 2021).

Lithium can also be extracted from brine (underground water reserves with saline solutions with higher concentrate of salt than that of standard seawater) and then left to dry through evaporation through sun and wind. Other processes follow. This is environmentally more desirable and is also very cost-effective (Kaunda, 2020; Chaves *et al.*, 2021), but it can take one to two years from pumping from the Salar brines to the usable product; the demand of lithium is increasing rapidly and is expected to grow by more than 500 percent by 2030 (Kaunda, 2020; Vera *et al.*, 2023). Fresh water can also be contaminated with brine, making it unusable for agriculture or fishery (Vera *et al.*, 2023).

In addition to the environmental impact, mining in general has the social impact of creating jobs and therefore income (Chavez *et al.*, 2019). However, this also results in migrations and workers leaving their ancestral sites (Augstinata *et al*, 2018).

Over half of the world's cobalt is mined in the Katanga region of the Democratic Republic of Congo (DRC) (Bamana *et al.*, 2021). Nukula *et al.* (2018) analysed the sustainability of cobalt mining in the DRC and came to the conclusion that in the sample of workers they studied, there is a high dust exposure to cobalt causing health problems. They furthermore found evidence among children of high excretion of uranium and manganese, which are metals associated with the ore. Child labour has been reported in the cobalt mining industry in the DRC (André and Godin, 2014).

According to Julia Poliscanova (2023), senior director at Transport & Environment (T&E), who carried out a study on the short-term availability of raw materials, there is enough lithium and nickel available to produce 14 million electric cars globally in 2023 even without Russian supplies.

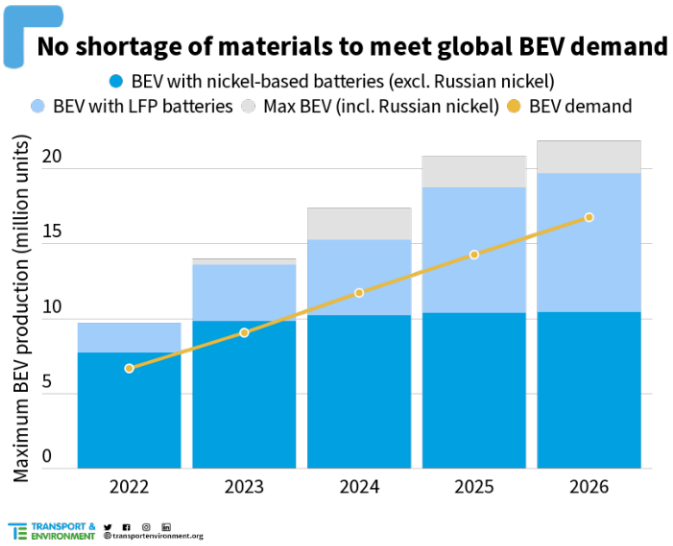

Figure 5: Available materials to meet glowbal BEV demand (Poliscanova, 2023)

Reverse logistics and recycling of batteries

According to Pitchbook.com data, globally, there are at least 80 companies involved in EV recycling, with more than 50 start-ups attracting at least US$ 2.7 billion, virtually all in the last six years, from corporate investors including automakers, battery makers and mining giants like Glencore (GLEN.L) (Carey *et al.*, 2023). The current LIB economy is quite linear rather than circular, however, in both the US and the EU, there is legislation in place that requires recycling of waste batteries (Meegoda *et al.*, 2022)

According to Mackinsey & Company (Breiter *et al.*, 2023), over five terawatt hours (TWh) per year of gigafactory capacity is expected globally by 2030. There is also considerable growth in EV battery volumes as they approach end-of-life, with over 100 million vehicle batteries expected to be retired in the next decade. With most EVs having been on the road well under six years, with almost 30% sold in 2022, there is simply not enough available data yet to articulate how long EV batteries can last. There is still have very little concrete real world data available of how batteries degrade over their lifetime - which carmakers claim should be as long as 20 years. Currently, it seems that EV batteries have much longer lifespans than anyone

could have anticipated, since very few of them have been replaced, even once the EV industry standard 8-year, 100,000 kilometres warranty period has ended (Najman, 2023).

Some industry officials anticipate rapid growth, which means 40% of battery materials used in new EVs could come from recycled stocks by 2040. (Breiter et al, 2023).

There is little existing U.S. recycling capacity today, and virtually none in Europe.

China handles virtually all EV battery recycling in a global market projected to grow from $11 billion in 2022 to $18 billion by 2028 (Breiter et al, 2023). As more EVs are introduced and age out of the vehicle fleet, that business will grow.

The minerals in those batteries - primarily lithium, cobalt and nickel - are worth on average between 1,000 euros (US$ 1,123) to 2,000 euros per car, as per BMW (BMWG.DE) sustainability chief Thomas Becker (Carey et al, 2023).

Discussion and Conclusion Coming back to the three dimensions of sustainability, namely the environment, society at large, and economic growth, we can conclude as follows: Lithium and cobalt mining is bad for the environment. Chemicals are used for extraction, and fresh water may be contaminated. Mining has positive and negative effects on society: Jobs are created and workers have income; however, workers may be moving away from ancestral grounds. In some countries, the workers are treated in a non-sustainable way, even child labour has been reported. On the economic side, there will likely be no shortage of raw materials, and the business is growing.

In conclusion, the idea of using electric vehicles to replace vehicles with internal combustion engines is very noble. It does require an update of the supply chain though; mining operations must become sustainable, for example. Stronger controls by companies that use the raw materials and governments of countries that import the raw materials or finished products need to implement and enforce laws. The German Supply Chain Act is newly in place and it must be seen how much it will be enforced.

Limitations and future research: This research focusses on the supply chains of the current lithium-ion batteries (LIBs) in EVs. There are other components, such as rare earths in the motors, which are worth evaluating. We did not take the new solid-state batteries into consideration, as they do not exist in the market yet. Also, this research does not cover comparison to internal combustions engines, especially with regards to fuel production. A comparison of the supply chains of fossil fuels versus electricity would be interesting for a future paper.

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