A Review on the Outlook of the Circular Economy in the Automotive Industry

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***Abstract*—**The relationship of the automotive industry with raw material supply is a major challenge and presents obstacles. Automobiles are ones of the most complex products using a large variety of materials. Safety, eco-friendliness and comfort requirements, physical, chemical and economic limitations set the framework in which this industry continuously optimizes the efficient and responsible use of resources. The concept of circular economy covers the issues of waste generation, resource scarcity and economic advantages. However, circularity is already known for the automobile industry – several efforts are done to foster material reuse, product remanufacturing and recycling. The aim of this study is to give an overview on how the producers comply with the growing demands on one hand, and gain efficiency and increase profitability on the other hand from circular economy.

***Keywords*—**Automotive industry, circular economy, international requirements, natural resources.

I. Introduction

THE aim of this paper is to give an analysis of the outlook of the circular economy in the automobile industry. The information contained are relied on previously published literature and data. New data form the authors' experiments are not presented. The function of this study is to present the most current research for the given topic, to identify pattern and trends in the literature and to recommend new research areas.

The concept of circular economy (CE) (Fig. 1) is to an increasing extent treated as a solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits. However, the concept of circularity is not novel as such. Specific circumstances and motivations have stimulated ideas relevant circularity in the past through activities such as reuse, remanufacturing or recycling [1]-[2].

Almost all existing techniques evaluate resource use based on their burden relative to value, while the central point of Circular Economy (CE) is to create value through material retention. The existing burden-orientated techniques are therefore unsuitable for guiding managers in relation to CE objectives [1]. Programs and policies for a CE are becoming key to regional and international plans for creating sustainable futures. Framed as a technologically driven and economically profitable vision of continued growth in a resource-scarce world, the CE is taken up by the European Commission and global business leaders alike [2]. Sustainability aims at addressing environmental and socio-economic issues in the long term. In general, the relevant literature on sustainability has focused mainly on the environmental issues, whereas, more recently, a CE is proposed as one of the latest concepts for addressing both the environmental and socio-economic issues. A CE aims at transforming waste into resources and on bridging production and consumption activities; however, there is still limited research focusing on these aspects [3]. The concept of CE is to an increasing extent treated as a solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits [4].

Fig. 1 Design for circular economy [21]

In the last few years, CE is receiving increasing attention worldwide as a way to overcome the current production and consumption model based on continuous growth and increasing resource throughput. By promoting the adoption of closing-the-loop production patterns within an economic system CE aims to increase the efficiency of resource use, with special focus on urban and industrial waste, to achieve a better balance and harmony between economy, environment and society [5].

II. Literature Review

A. The Legal Background of CE

In a circular economy [6], [7], products and the materials are valuable after use, as well, unlike in the linear economic model, based on a 'take-make-consume-throw away' pattern. In practice, a circular economy sets targets to reduce waste to a minimum, re-using, repairing, and recycling used products and materials. What we called 'waste' previously can be taken into account as valuable resource. Moving towards a more

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circular economy could deliver benefits, among which reduced pressures on the environment, enhanced security of supply of raw materials, increased competitiveness, innovation, and growth and jobs [14].

However, it would also face challenges, among which finance, key economic enablers, skills, consumer behavior and business models, and multi-level governance.

Improving waste management could deliver positive effects for the environment, climate, human health and the economy. As part of a transfer in EU policy towards a circular economy, the European Commission made four legislative proposals introducing new waste-management targets regarding reuse, recycling and landfilling. The proposals also strengthen provisions on waste prevention and extended producer responsibility, and streamline definitions, reporting obligations and calculation methods for targets [14].

Every year, 8-9 million tons of end-of-life vehicles (ELV) are generated in the European Union. Eurostat data indicate that across Member States, from 80% to 100%of materials from ELVs collected through regular channels are recovered or recycled. In the19 Member States for which information is available, waste portable batteries and accumulators in 2013 amounted to 40% of portable batteries and accumulators placed on the market. The used batteries and accumulators which are not collected separately, presently enter the municipal waste stream and are either landfilled or incinerated [14].

Adverse effects from waste treatment methods can include the following [8]-[10], [14]:

- impacts on the environment(in particular biodiversity and ecosystems): landfills may contaminate, depending on the way they are built, soil and water with chemicals contained in waste; littering can have severe consequences for wild animals, especially through ingestion of micro plastics;
- impacts on the climate (landfills emit methane, an effective greenhouse gas);
- impacts on human health (due to the emission of air pollutants in the atmosphere and to the possible contamination of fresh water sources and agricultural soils);
- impacts on the economy (useful and valuable resources and materials are leaving the industrial cycles).

III. Impact on the Automobile Industry

A. Raw Materials and Scarcity

Raw materials are becoming scarcer, emissions are on the increase. Careful use of resources is gaining in importance all the time. Modern technologies, new materials and highly efficient components are available to optimize vehicle design. In vehicle development, progress in the careful use of non-renewable resources is a task that involves every area of its activities [16].

More than 1 billion vehicles are on the world's roads today. Every year, the global automotive industry produces more than 85 million new vehicles – almost 10,000 new cars every hour [15].

On the other hand, at any given point in time, $7 trillion worth of passenger cars are unused around the world. This waste became wealth when viewed through a CE lens. By creating a CE value chain, automotive players gain efficiency, increase profitability and improve loyalty [17].

The materials used to make vehicles are subject to price volatility, increasing cost and supply constraints as the demand for cars continues to climb. In addition, all types of materials that can be energy and greenhouse gas intensive to produce, and may cause harm to health and the environment if not appropriately managed at all stages in the life cycle.

The supply chain starts and ends when a consumer buys a new vehicle while returning a old one to destruction [15].

Designing, making, transporting, recycling and recovering vehicles with more sustainable methods would be the best example for circular economy.

The choice of materials has a decisive effect on the CO_2 emissions that occur in component manufacturing. The range is wide, in view of the many different manufacturing and recycling methods involved [16]. With lean manufacturing many carmakers have made great strides in recycling as well. But a broader view of waste reveals much more potential still to be mined from the CE [17].

Six key enablers are required to establish and optimize a circular supply chain [15]:

1. Design: Not only the product but also the entire life cycle must be designed to optimize resource recovery and reuse.
2. Scale: Adequate quantities of used cars must be available to justify investments in recycling infrastructure.
3. Policy: Regulations must prohibit inappropriate disposal, establish appropriate incentives and enable manufacturers to recycle both their own as well as competitors' products.
4. Collection: It must be possible to integrate the collection of the used product through the same channels and partners as the distribution of new ones.
5. Cost: Economically and environmentally preferable technology must enable the cost-effective recovery and reuse of materials.
6. Continuous improvement: The ability to identify, monitor and adjust for issues and opportunities that can impede or unlock value is necessary.

The potential revenue of CE business models for automotive companies could more than double by 2030, growing by $400-600 billion. In a disruptive scenario, circular models would outpace revenue growth generated through new passenger car sales. And profitability could be more than three times higher than traditional new vehicle sales – making circular economy business models a major profit pool in the automotive industry [17].

B. The Change in the Structural Materials of Vehicles

Until the oil crisis of the seventies, there was no primary requirement for the production of vehicles for specific fuel consumption and a weaker vehicle mass. However, when crude oil became significantly more expensive, these were in the main focus of automotive designers' attention. From then on, the vehicles are trying to be designed and manufactured taking into account the aspects of weight reduction. The possibility of mass reduction is basically the choice of structural materials, not a simple game, balancing the on boundaries of traffic safety and environmental protection. The weight can be reduced by replacing conventional iron and steel materials with alloys and plastics, and steel sheets can also be made with steel sheets that allow smaller wall thickness. Although the increased use of light metals and plastics allows for a smaller vehicle size, these materials are more expensive, more demanding, and considerably worse, less recyclable than conventional iron and steel materials. This is especially true of plastics, which are not in themselves suitable for use as a vehicle structure. The reinforcing materials, flame retardants all reduce the mixability of the different plastics, which is, anyway, very low. The other item is the change in technology in the weight of the mass reduction, which also drives the automotive industry towards shorter usage times, applications that lead to shorter product life cycles. Nearly every month newer comfort, road safety and environmental solutions are emerging, moving vehicles increasingly towards the increased degree of electronicisation. Today, in a mid-size car, electronics pieces and associated electronic part-systems between 30 and 50 pieces can precipitate [18]. With this, the system's (vehicle) transparency, serviceability and repairability will be significantly deteriorated.

In today's modern automobiles, especially in the top-class booths, there are almost as many electronics as in the world's largest airliner AIRBUS 380. It follows from this that the materials used in electronic innovations, non-ferrous and precious metals and rare earth metals need to be continuously increased for the manufacturing and supply industries. The future clearly belongs to rare earth metals, which are not limited to prevalence, but are limited because of their limited access to specific countries and regions (Fig. 2). The world's demand for rare earth metals has increased considerably over the last few years and exceeded 210,000 tonnes by 2015. Due to the wide industrial application, lithium prices have tripled since 2000.

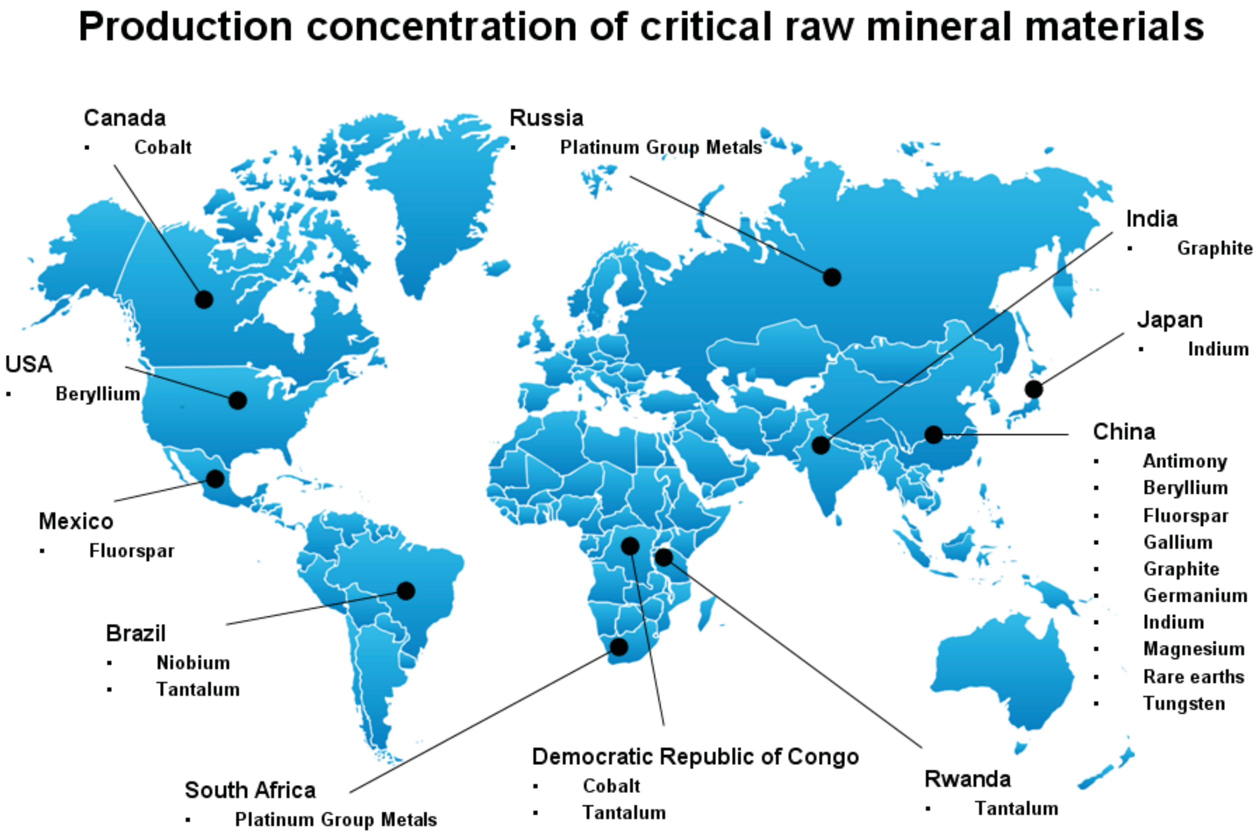

Fig. 2 Economic importance and supply risks of strategic raw materials [22]

C. The E-Mobility

In the coming decades, e-mobility is expected to completely transform some of our major systems, transport, power and raw material management. At the same time, it also poses serious challenges to the circular economy. Even though we look at them as green technologies, these systems also bring resource management and waste management to huge, unresolved challenges. In order to make fossil fuels removable with the most ecologically advantageous technologies, research on environmental impacts and resource requirements for "greener" alternatives is important. In terms of raw material demand, energy consumption, environmental impact, recyclability, no matter what type of Li-Ion batteries are used (Fig. 3). The varied chemical composition brings quite different values to lifecycle studies. The processing of lithium is still expensive and complicated, and the worthless materials get into the dump.

Based on these, it is imperative to keep the largest amount of resources used in circularity. Accordingly, the raw material management and ecological considerations as well as the utilization rates projected in e-mobility, it is essential to recapture lithium and other strategic raw materials as much as possible. For this purpose, stable collection and recovery infrastructure systems need to be created, with appropriate legal and economic incentives in the first place.

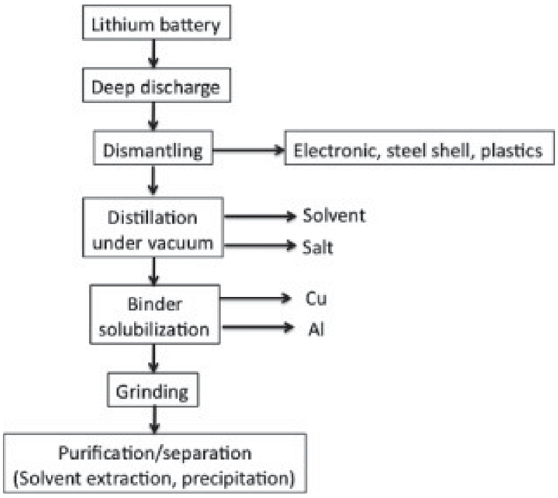

Fig. 3 Recycling process of Li-batteries [23]

Here we meet new challenges. The legal environment has not yet adapted and we do not know what these economic and legal incentives will be. It is just enough to imagine a consumer: how will he get rid of his old Tesla after 10 years? How does the car dismantling of the future look like which can handle a 800-pound battery with thousands of cells (Fig. 4)? It is estimated that, at the latest, recycling facilities and collection infrastructure for Li-ion systems related to e-mobility should be built up.

Fig. 4 Battery in a Tesla S Model chassis [24]

From the point of view of sustainable resource management, it is desirable for a higher recycling ratio specifically for Li-ion batteries with specific values for highly relevant materials (lithium, cobalt, nickel).

The substantial raw material demand in e-mobility and environmental impacts arising from the deployment of energy storage systems should be considered to replace fossil resources with truly more sustainable, less-burdensome structures [19].

IV. Conclusions

The EU proposals are expected to deliver economic and environmental benefits. According to the Commission, the four legislative proposals put forward would [10], [13], [20]

- create over 170,000 direct jobs in the EU by 2035; avoid greenhouse gases emissions (over 600 million tons of CO_2 equivalent between 2015 and 2035);
- increase the competitiveness of the EU waste management, recycling and manufacturing sectors;
- reduce the dependency of the EU on raw material imports;
- reduce the administrative burden;
- reduce the impacts on environment and human health.

However, the proposals would also generate costs, which would most likely fall on public authorities, businesses and ultimately consumers [12].

Researchers [11] report calculates, extrapolating from UK government estimates, that the cost of creating a fully efficient reuse and recycling system in the EU could be about € 108 billion.

When fully optimized, a circular economy enables economic value by minimizing volatility, while providing raw materials for new products at reduced cost with a lower environmental footprint [15].

Further, the most sustainable and responsible way to minimize the health and environmental risks of vehicles is to responsibly recycle accompanies and reuse the materials to make new ones [15]. By going the extra mile, and creating a CE value chain, automotive not only gain efficiency in their supply chains, they increase profitability and improve customer loyalty. Making these approaches possible are technological advances in areas like machine-to-machine communication, analytics, artificial intelligence and modular design [17]. Thanks to advances in digital technology, the time is right to harness the power of the CE.

Future Research

The authors' purpose is to continue the investigation to understand the deeper context of the circular economy and try to develop a model: linear thinking must be abandoned in a circular economy since every element impacts another.

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