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An Assessment of the Effectiveness of Actions to Implement the Principles of Circular Economy in the Electromobility Ecosystem

Keywords: mobility; eco-system electromobility; circular economy

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Abstract

Theoretical background: The article concerns the concept of electromobility ecosystem development, understood as a multidimensional, multisectoral network with the features of systemic innovation. In scientific discussion and policy strategies, the transformation towards an integrated electromobility network is one of the most important paths leading to emission neutrality while maintaining the principles of closed loop. The article presents the impact of the circular economy assumptions on shaping the electromobility ecosystem.
Purpose of the article: Identification of activities determining the development of the electromobility ecosystem in accordance with the principles of circular economy and a declarative assessment of their effectiveness.
Research methods: The desk research method and qualitative and quantitative analysis methods were used to present and discuss the results of own research.
Main findings: The concept of sustainable development of the electromobility ecosystem is a comprehensive look at the process of transforming mobility, in line with the idea of circular economy. Due to the complexity of activities, it can be concluded that its implementation will be a gradual and long-term process that requires a systemic approach. ReSOLVE's activities are the result of using breakthrough technological innovations, business models and a new mobility culture in the process of shaping the electromobility eco-

system. Their identification and assessment, based on the results of the survey, adds value to the literature on the subject in the context of the development of a competitive, sustainable and circular economy, for which an emission-neutral and innovative mobility network is necessary.

Introduction

The development of the electromobility ecosystem is extremely important from the perspective of implementing the assumptions of the circular economy concept. The aim of electromobility systems' functioning, based on the values characterizing this concept, is to support the sustainable development of urban mobility. The implemented solutions should reflect synergy effects between global ecological challenges, technical, economic and social megatrends, leading to the creation of new network connections between enterprises, institutions and consumers. This means a transition from the current fragmentary electromobility networks to an integrated network operating in accordance with the system principles. Therefore, the electromobility ecosystem should be considered as a multidimensional, multisectoral concept with the features of system innovation, combining technological and organizational solutions (Augenstein, 2015, p. 20).

The long-term vision of a climate-neutral economy up to 2050 states unequivocally that electromobility will be one of the most important paths leading to emission neutrality in line with the principles of closed loop (COM(2018)773, 2018, p. 12). The electromobility ecosystem will become an area of multidimensional international competition in which traditional drives will compete with alternative drives, cars with drivers will compete with autonomous ones, and car users will choose between owning and using. Enterprises already recognize the economic potential associated with the value chain of vehicle electrification.

The transition to electromobility has already begun around the world, and its pace has significantly accelerated. The development of electrification of road transport in accordance with the principles of the circular economy is a global challenge, common to an increasing number of countries and cities in the world. It creates global demand for environmentally friendly products that meet the needs of society, technologies and new business models, creating the so-called network effects. These effects are an added value in the sphere of management and management of network industries.

The electric vehicle market is developing very dynamically. The total number of BEV (battery electric vehicle) and hybrid PHEV (plug-in hybrid electric vehicle) cars in the world was estimated at 5.6 million units at the end of 2019. This means an increase of approx. 40% compared to 2018 (BloombergNEF, 2020). According to data from the European Automobile Manufacturers Association (ACEA, 2020) there were almost 460,000 BEV and PHEV passenger cars and hydrogen passenger cars registered in the EU in 2019. This means an increase of 53% compared to 2018. In January 2020, 9,099 BEV (60%) and PHEV (40%) electric passenger cars were present on Polish roads, i.e. twice as much as in the corresponding period of 2019

(OPRA.PL, 2020). Further development of the electric vehicle market is expected in the coming years. Current forecasts show that the annual sales of EVs in the world will increase to 10 million in 2025, 28 million in 2030 and 56 million by 2040. It is estimated that by 2040, 57% of total passenger vehicle sales and over 30% of the global passenger vehicle fleet will be electric (IEA, 2019, pp. 15–18).

Optimistic forecasts for the steady increase in demand for electric cars do not mean, however, that electrification of vehicles does not face a number of challenges. From the point of view of circular economy assumptions, the creation of a new mobility culture should be considered as a significant challenge in the process of promoting electromobility, apart from breakthrough technological innovations and business models.

The purpose of the article is to identify activities determining the development of the electromobility ecosystem in accordance with the principles of the circular economy and a declarative assessment of their effectiveness.

Literature review

The circular economy is a strategy for the development of the economy that allows to increase prosperity while reducing and optimizing resource consumption. This goal is achieved by deeply transforming production and consumption chains and implementing new business models. Their implementation is aimed at eliminating the concept of the product end of life (Deloitte, 2018, p. 16). At the heart of the circular economy is the assumption that it is a continuous cycle of development characterized by designed renewal and reproducibility (Korhonen, Honkasalo, & Seppälä, 2018, p. 37). Available routes are reuse of materials, extension of product life and use of the potential of waste streams, which are currently largely wasted. The resulting cycle closing model reduces the negative impact of production and consumption on the environment, in particular in the context of reducing GHG emissions and generated waste (Burchard-Dziubińska, 2017, p. 12).

The EU Action Plan concerning the circular economy has been in force since July 2018. It is a package of directives and initiatives for building a circular economy, the so-called Circular Economy Package (2018) and the strategy on plastics. The adopted EU regulations cover the product life cycle: from product design and processes, through production, consumption, to waste management and the secondary raw materials market. The aim of the circular economy implementation is to create an economic model in which the value of products, materials and resources will be kept as long as possible and the generation of waste will be kept to a minimum (COM(2015)614, 2015, p. 2). It is forecasted that the EU could record net economic benefits of EUR 1.8 trillion by 2030, which would also create more than 1 million new jobs and a 7% increase in GDP. The estimated environmental benefits would include, among others, a reduction in the use of raw materials by an additional 10%

and a reduction in annual CO_2 emissions by 17% compared to the current development model (*Growth…*, 2015, p. 15).

In the ongoing scientific and political discussion, the thesis that the circular economy is a factor at least beneficial or even necessary to achieve sustainable development and achieve the goals of the UN 2030 Agenda is being widespread. A closing model that minimizes the flow of materials, energy and environmental degradation, without limiting economic growth or technical and social progress, is also relevant in the context of global agreements on climate change (Gallego Schmid, Chen, Sharmina, & Fernandez Mendoza, 2020).

The circular economy is getting more and more interest from business representatives who see its significant potential. This is confirmed by the values of indicators monitoring its development. In 2017, closed-loop activities generated EUR 155 billion of value added in the EU, contributing to investments worth EUR 18.4 billion (Eurostat, 2020). Creating value in a closed cycle, however, requires increasing the scale of operations. Sector analysis showed significant losses in sectors that are considered mature and optimized. Currently, the way products are manufactured and used costs the EU EUR 7.2 trillion per year for three key sectors of the economy, i.e. mobility, food and the urban environment. At the same time, 47% of this amount are costs related to transport congestion, CO_2 emissions, pollution and noise, while, e.g. an average European car is parked daily for 92% of the time. Meanwhile, the analysis carried out by Haas, Krausmann, Wiedenhofer and Heinz (2015, p. 774) shows that reducing the accumulation of long-term material resources along with the development of renewable energy and eco-design are the most important actions for the transition to the circular economy. In the study, they proved that the level of circularity and recovery of materials in the global economy is limited. As the main reasons, they indicated the consumption of large amounts of fossil fuels, biomass and long-term material resources, which have low recovery potential.

A new look at the relationships between the circular economy model and the mobility system creates an opportunity to achieve long-term environmental, economic and social value for all participants of the electromobility ecosystem. The attitude towards mobility is changing thanks to new technologies and digital solutions. Consumers want better quality, more convenience, flexibility and an affordable price (Bergman, 2017, p. 187). They prioritize the issue of easy access to travel information and the ability to smoothly change modes of transport. At the same time, public awareness of environmental and climate protection is increasing (Rodrigue, Comtois, & Slack, 2017, p. 42).

The transformation of electromobility towards a circular cycle is the subject of studies and reports conducted, among others, by the European Environment Agency, Organization for Economic Co-operation and Development, the United Nations Environment Program, the European Climate Foundation and the Ellen MacArthur Foundation. The activities and models presented in them concerning the effective implementation of the circular economy principles are combined by designed renewal and reproducibility as a prerequisite for strengthening competitiveness (*Achieving…*, 2017).

Research methods

In the study entitled *Growth Within: A Circular Economy Vision for a Competitive Europe*, Ellen MacArthur Foundation & McKinsey Center for Business and Environment (2015, pp. 54–55) presented a set of six activities to help entrepreneurs and governments in the transition to a circular economy. These are: regeneration, sharing, optimization, closing of loops, virtualization and exchange.

The set of activities, ReSOLVE is a universal tool that was used to build the model of the electromobility system, in accordance with the idea of a circular economy. The activities included in the ReSOLVE set allow to increase the efficiency of using physical resources, extend their life and eliminate the use of non-renewable resources for renewable resources (Table 1). Each of the activities strengthens and accelerates the operation of the others, increasing the efficiency of implementing the circular economy principles in the electromobility ecosystem. As research shows (Bloemhof, Vorst, Bastl, & Allaoui, 2015, pp. 101–117), companies that call themselves sustainable cannot forget that their suppliers are also testified about their responsibility. The company is responsible not only for its activities, but for the entire value chain, within which it manufactures and supplies products or services to consumers (Cossu, 2016, p. 1524). The process of transforming the electromobility system in accordance with the concept of circular economy requires, therefore, a comprehensive and integrated approach, taking into account economic, social, environmental and spatial aspects.

The effects of actions presented in Table 1 are the results of interactions in the electromobility ecosystem, occurring between the improvement of environmental quality and resource-efficient management of natural resources, and the increase in tangible and intangible assets in the circular economy. The transition from a linear economy to a circular economy can significantly change the value chain of the electromobility ecosystem and affect all its participants, from raw material suppliers, vehicle suppliers and manufacturers, to distributors, after-sales service providers, mobility services and consumers. The development of the electromobility ecosystem has two dimensions: internal and external. The internal dimension concerns the economic, social and environmental responsibility of ecosystem participants. The external dimension is related to customer expectations, relations with stakeholders, regulatory pressure and support from governing bodies.

Table 1. A set of ReSOLVE activities for the electromobility ecosystem

Main activities	Specific actions	Effects of actions
Regenerate	– repair – development of new material technologies – recovery of land intended for transport infrastructure	– net material savings – increasing the availability of transport infrastructure – slower aging of vehicles – development of renewable energy sources
Share	– ride sharing development – carpooling development – extending the life of vehicles	– new work places – reduction of negative externalities – increase in land productivity
Optimize	– big data – automation – improved efficiency – Internet of things – intelligent transport systems	– development of new business services – economic growth – job allocation – increased usability of EV vehicles
Loop	– vehicle regeneration – recycling materials – waste-free design	– reduce consumption of primary materials – increase in environmental safety
Virtualize	– providing practical tools (applications, systems) – autonomous EV vehicles – virtualization of materials – virtual travels	– integration of means of transport at the system level – improving operational safety of transport – increased mobility and accessibility
Exchange	– use of new, more advanced non-renewable materials – use of new technologies, e.g. 3D printing – selection of new products/services, e.g. V2G, smart charging	– improved security – innovation development – increase of competitiveness – development of Corporate Social Responsibility – reduction of the costs of functioning of the electromobility ecosystem

Source: Author's own study based on (*Growth…*, 2015).

Basing on a critical analysis of the literature on the subject and own research, it can be concluded that in the next decade the electromobility system will develop being influenced by five main levers: electrification of passenger transport, sharing economy, new material technologies, renewable energy sources and waste elimination (GEOTAB, 2020, pp. 3–12). The sixth lever – integration of means of transport at the system level – has not yet achieved the appropriate degree of integration of all entities, but it can provide users with the possibility of smooth transition between individual and public transport. These levers strengthen each other and shape a new mobility paradigm (Motowidlak, 2016, pp. 172–179).

The effectiveness of the electromobility ecosystem development has been declaratively assessed in four dimensions: economic (G), environmental (E), social (S) and spatial (P). A survey was conducted using the PAPI (paper & pen personal interview) method. The choice of the method of collecting information was primarily determined by the possibility of controlling the structure of the research sample. The survey was directed to people aged 20–40. The efficient and effective implementation of changes for the transformation of mobility towards environment-friendly and intelligent solutions requires building knowledge and awareness of planned activities among people who will show the highest demand for mobility in the next three decades of the 21st century. In addition, they may be potentially involved in the implementation of the process of mobility transformation, due to official tasks. The study was of a pilot nature. It was carried out in the Łódź Voivodeship. The research sample was representative. The time range of the study covered the period from October to December 2019.

The logic of the questions and the rules for providing answers referred to the degree of effectiveness of activities for the development of the electromobility ecosystem in the circular economy. The degree of effectiveness was expressed in point values that were assigned to the main activities. It was assumed that the total number of points evaluating activities within six categories of activities is 100. According to the fuzzy set theory, the sum of the percentages for each of the activities is 100%. These values create a four-level scale of effectiveness of partial actions. The highest of these values indicates the most effective and the lowest the least effective partial action. In the ReSOLVE quantitative model, input variables indicate the direction of the impact of partial actions. Indicators of achieving partial goals play the role of the model's output variables.

Results

The assessment of the effectiveness of activities for the electromobility ecosystem development in the circular economy, which is the goal of the study, is presented in Table 2.

Table 2. A quantitative model for the electromobility ecosystem

Main actions	Value	Indicators of partial actions* (%)				Indicators of the direction of partial actions impact**				Indicators of partial objectives' achievement			
		G	E	S	P	G	E	S	P	O_G	O_E	O_S	O_P
Regenerate	10	15	45	25	15	-1	1	1	1	-1.50	4.50	2.50	1.50
Share	30	20	35	30	15	1	1	1	1	6.00	10.50	9.00	4.50
Optimize	20	40	20	25	15	1	1	1	0	8.00	4.00	5.00	0.00
Loop	10	25	40	25	10	0	1	1	0	0.00	4.00	2.50	0.00
Virtualize	18	20	30	35	15	1	1	1	1	3.60	4.80	6.30	2.70
Exchange	12	25	35	30	10	1	1	1	1	3.00	4.20	3.60	1.20
Total	100	x	x	x	x	x	x	x	x	19.10	32.00	28.90	9.90
										89.90			

*four dimensions: economic (G), environmental (E), social (S), spatial (P); **1 (favorable), 0 (neutral), -1 (unfavorable)

Source: Author's own study.

The obtained results clearly indicate the high effectiveness of ReSOLVE activities for the development of the electromobility ecosystem, in accordance with the assumptions of circular economy, ensuring at the same time the achievement of objectives in the economic, environmental, social and spatial dimensions. The value of the goal achievement indicator, showing the degree of effectiveness, is 89.90 points. Referring the above description of the quantitative features of the model to individual categories of activities, it can be stated that by assigning 30 points to the "Share" activities, the study participants considered them the most important for the development of the electromobility ecosystem, in accordance with the concept of circular economy. Indicators of partial actions for the "Share" show that it will be to the greatest extent, i.e. 35% involved in the implementation of environmental objectives (E). In addition, it was assumed that 30% of the value of this measure would directly translate into achieving social goals, 20% into achieving economic goals, and 15% by spatial order.

Indicators of the impact of partial actions inform about the positive impact of the "Share" action on the implementation of all partial goals, i.e. economic, environmental, social and spatial order. Calculations made using the model allowed for a point assessment of these impacts. The positive contribution of "Share" activities amounts to: 10.50 points for environmental purposes, 9.00 points for social purposes, 6.00 points for achieving economic goals and 4.50 points for spatial order. The distribution of indications for the next two activities, i.e. "Optimize" and "Virtualize, shows that these activities were considered relatively effective in the study.

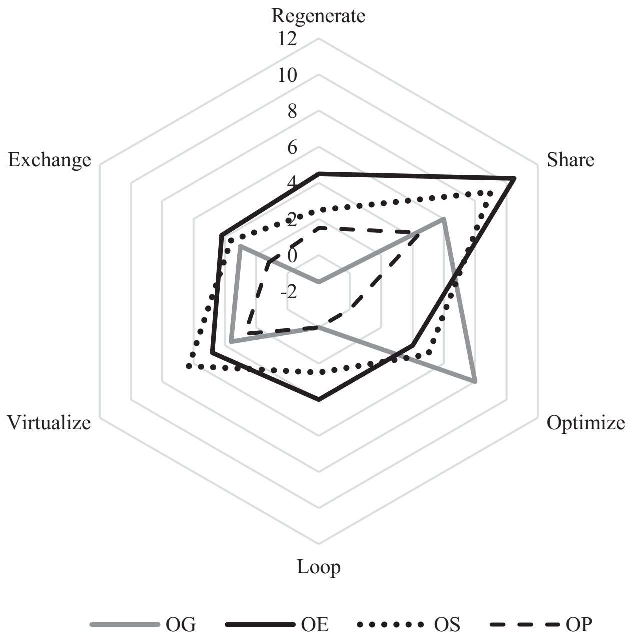

Figure 1. The effects of ReSOLVE's activities regarding the development of the electromobility ecosystem in the circular economy

Source: Author's own study.

The determined values of indicators for the implementation of O_G, O_E, O_S and O_P objectives show that ReSOLVE's activities will achieve the highest degree of effectiveness in the environmental and social dimension (Figure 1). The values of indicators for achieving the objectives are 32.00 points for O_E and 28.90 points for O_S. The lowest degree of effectiveness can be achieved for spatial aspects, which is indicated by the value of the O_P target achievement indicator reaching 9.90 points.

Discussions

In scientific and research works devoted to the development of low-emission mobility, the subject of particular interest are primarily: digitization and automation, alternative energy sources for transport and the development of appropriate infrastructure and means of transport, as well as mobility on the basis of renting, sharing or connected to the network as the so-called mobility-as-a-service (MaaS) (Holden, Gilpin, & Banister, 2019, p. 6).

According to current and forecasted development trends, it can be stated that digital services will play an important role in disseminating the concept of closed cycle in the electromobility ecosystem. Business models that move from ownership to use contribute to increasing the utility value of electric vehicles (SITRA, 2018, pp. 134–139). Enterprises with significant shares in the mobility ecosystem and controlling several stages of the linear value chain have recognized the potential of putting access above ownership. Travel by car sharing or the choice of ride hailing are beneficial not only in economic and spatial terms, but also environmental and social. They contribute, among others, to the reduction of demand for raw materials and energy, necessary in the production process of electric cars and batteries, reduce CO_2 emissions and pollution, promote effective urban space management, meeting at the same time social needs in the field of mobility and transport accessibility (Ferrero, Perboli, Rosano, & Vesco, 2018, p. 508). In addition, shifting the responsibility from the consumer to enterprises for the quality of mobility services provided is conducive to innovation for improving the viability of transport.

New business models in the field of electromobility and enterprises dealing in providing means of transport, including electric ones, are developing very dynamically. Currently, joint mobility services account for less than 5% of the total distance traveled by passenger vehicles annually, but they are characterized by very high growth dynamics. Over one billion people around the world are currently using some form of mobile application. In Europe, car sharing increased on average by 40% per year between 2010 and 2015. By 2040, we expect the share of shared mobility services to increase to 19% of the total number of kilometers traveled by passenger vehicles, causing a decline in demand for private cars. At the same time, shared electromobility will be characterized by higher growth dynamics than traveling by private electric cars due to its economic availability. Electric vehicles currently represent

1.8% of the shared mobility fleet. In 2040, their share in this fleet should increase to 80% (BloombergNEF, 2019). Investors recognize the business potential of services in the area of mobility. Car sharing through the fleet operator, which also has electric vehicles, is offered, among others, by Autolib' cooperating with Renault, DriveNow belonging to BMW, Sixt, Quicar belonging to Volkswagen, Car2Go belonging to Mercedes-Benz and Flinkster belonging to Deutsche Bahn.

Conclusions

The mobility system is undergoing transformation, mainly due to technological development. The increase in mobility needs is accompanied by changes in consumer behavior and demand patterns, as confirmed by the results of the survey. They want better quality, convenience, flexibility and an affordable price. Consumer awareness of the impact of individual vehicle traffic on climate change, air quality and health is also increasing. Therefore, the society is currently looking for new mobility options that are conducive to increasing mobility and at the same time may contribute to reducing CO_2 emissions and decreasing air pollution.

The concept of sustainable development of the electromobility ecosystem is a comprehensive look at the process of transforming mobility, in line with the idea of circular economy. Due to the complexity of activities, it can be concluded that its implementation will be a gradual and long-term process that requires a systemic approach. The proposed solutions are innovative with high potential. This potential relates primarily to reducing CO_2 emissions from transport, improving the competitiveness of the mobility ecosystem, creating new jobs and implementing new mobility services. Activities related to building the value chain of batteries in Europe are also of great importance for the forecasted development of electromobility, which will translate into improved security of supply and increase in the competitiveness of the broadly understood electromobility industry. At the same time, one should reckon with the fact that due to the innovation of the proposed solutions in relation to the concept of the electromobility ecosystem, their significant effects may appear in the long run. Making this concept a reality is an important element in the development of a competitive and low-carbon circular economy in the EU.

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