METAL DEMAND ASSESSMENT OF BATTERY ELECTRIC VEHICLES

Dorota BURCHART-KOROL, Piotr FOLĘGA

Silesian University of Technology, Faculty of Transport, Krasińskiego 8 40-019 Katowice, Poland, EU
dorota.burchart-korol@polsl.pl, piotr.folega@polsl.pl

Abstract

Management of metal and fossil fuels resources is one of the goals of the electromobility development. The aim of this study was to evaluate cumulative metal demand in battery electric vehicles (BEVs) based on life cycle assessment (LCA). Metal and mineral demand covered the whole life cycle with a special focus on the electric vehicle batteries. Previous papers focused primarily on one category of environmental impact - greenhouse gases emission from electric vehicles with the Well To Wheel method. The paper presented results of LCA for electric vehicles with a lithium-ion battery use for mechanical drive. Based on the LCA carried out it was shown that battery and car production are the main determinants for BEVs in Poland. It is associated with the amount of used different metals demand, particularly manganese, copper, iron, molybdenum and chromium. The work addresses important problems associated with the metals management. This is the first attempt at a cumulative metal demand of BEVs life cycle in Poland.

Keywords: Metal demand management, electromobility, electric vehicle batteries, life cycle assessment

1. INTRODUCTION

In Poland battery electric vehicles (BEVs) become an important element in the development strategies of the automotive industry. On 28 December 2017, the Electromobility Law was adopted by the Polish Government. The Act of 11 January 2018 on Electromobility and Alternative Fuels came into force on 22 February of this year. Reducing resources demand is one of the priorities of the European Commission, therefore necessary is to evaluate the consumption of resources, including metals and minerals of developed electric vehicles in Poland. The method that enables performing the metal demand assessment in the life cycle of BEVs is life cycle assessment (LCA). The LCA is a new approach to the assessment of environmental aspects and allows identification of environmental burdens related, both directly and indirectly, to the life cycle of a vehicle, taking into account the construction, operation, and decommissioning phases [1]. Up till now management of resources for supply chains were presented in the papers [2-4]. Previous work on environmental assessment in road transport using the LCA focused mainly on greenhouse gas (GHG) emissions analysis. Till date many publications presented GHG emissions results from BEVs [5-7]. Several LCA studies have compared the LCA of battery electric vehicles (BEVs) versus internal combustion engine vehicles (ICEVs) [8-11]. These studies found that BEVs have significant potential to reduce GHG emissions. Several studies have identified the primary life cycle inventory and life cycle assessment of batteries production [12-16]. Five different Li-ion battery chemistries were covered by these studies: lithium iron phosphate, manganese oxide and composite oxides, all with graphite anodes, and lithium iron phosphate with a lithium titanate anode. Inventory of the batteries production such as nickel metal hydride and lithium nickel cobalt manganese batteries were shown in the paper [15]. A well-documented inventory for the comparison of two prospective production processes of a new generation of batteries containing lithium-iron phosphate was presented in the paper [16]. The analysis focused on battery production and its contribution to the BEVs life cycle. The metal and mineral requirements of individual vehicle model and can vary depending on the design and manufacturing process. In current Tesla models, lithium, graphite, cobalt, copper, titanium, aluminum and nickel are used. For a Nissan Leaf the battery uses quantities of manganese. Other cars use different metals including rare earth elements (REEs) in electronics and steel in electric vehicle.

The purpose of this work was to assess the cumulative metal demand of battery electric vehicles. In this paper, we outline the main sources of impact for metal demand for the BEVs analyzed.

2. ASSUMPTIONS AND METHODS

The goal of this paper was to perform an LCA of BEVs life cycle in Poland taking into account the Polish electricity production for charging car batteries. The main sources of cumulative metal demand in BEVs were identified. The life cycle assessment was conducted in accordance with the ISO 14040:2006. The LCA was made using the SimaPro v. 8.5 package with the Ecoinvent v. 3 database, which was used as the background dataset. Pursuant to the ISO 14040:2006 standard, the purpose and scope of the work, including the functional unit, system boundary, and basic assumptions for analyses, were defined. The second phase involved analyzing the sets of inputs and outputs, the life cycle inventory (LCI), which is an inventory of all the data necessary for the assessment of the life cycle. The next phase, the life cycle impact assessment (LCIA), enabled calculation of the values of the environmental impact categories according to the assessment methods selected. The last phase was interpretation of the results obtained. The system boundary includes the range of processes from cradle to grave: vehicle production, battery production, fuel supply (Polish electricity mix for BEVs), use phase of the vehicles (including vehicle maintenance), road construction, disposal, and maintenance. The paper presented results of LCA for a lithium-ion battery use for an electrical vehicle. For environmental impact assessment of metal demand, the LCA was performed using ReCiPe Midpoint method from the hierarchical perspective [18]. The primary objective of the ReCiPe method is to convert the long list of data for the life cycle into a limited is number of indicators that express the relative intensity of the impact category [18]. A vehicle equipped with a lithium-ion battery ($LiMn_2O_4$ battery) was chosen for the analysis. The choice of this type of battery was justified because it is the most frequently used battery for BEVs. Battery inventories were adapted from the paper [15]. It should be noted that the ReCiPe method doesn't include characterization factors for lithium [9].The basic assumptions and the sets of input and output data used for individual phases of the BEVs life cycle were from the paper [19]. The analyses were performed for metal demand category which is significant problem in circular economy model.

3. RESULTS AND DISCUSSION

3.1. Metal demand impact category of electric vehicles

Based on the LCA carried out it was shown the main factors exerting influence in cumulative metal demand impact category for electric vehicle life cycle in Poland are battery production (which constitutes 57 %) and passenger car production (which constitutes 39 %) (**Figure 1**). Polish electricity production for charging car batteries constitutes only 3 % share of metal demand in electric vehicle life cycle which means that this factor is negligible.

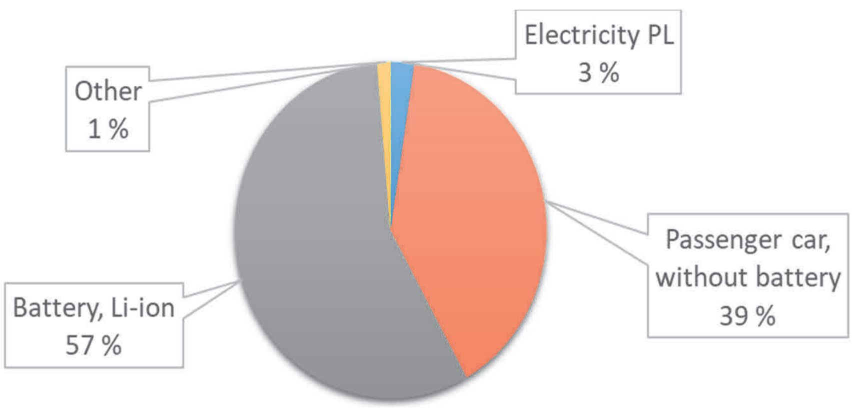

Figure 1 Cumulative metal demand of electric vehicle life cycle in Poland

To establish the determinants of metal demand impact category, an analysis of the impacts of elements contained in the system boundary was carried out. The determinants of metal demand of electric vehicle life cycle are shown in **Figure 2** and **Figure 4** respectively.

3.2. Determinants of metal demand for vehicle batteries and passenger cars

According to the analyses carried out, the main determinants of metal demand for electric vehicle batteries are the cathode ($LiMn_2O_4$, for lithium-ion battery) and anode (graphite, for lithium-ion battery) (**Figure 2**). Cathode constitutes 33 % of the metal demand from vehicle batteries and anode constitutes 67 % of the metal demand from vehicle batteries. Metal demand in process of vehicle battery production is shown in **Figure 3**.

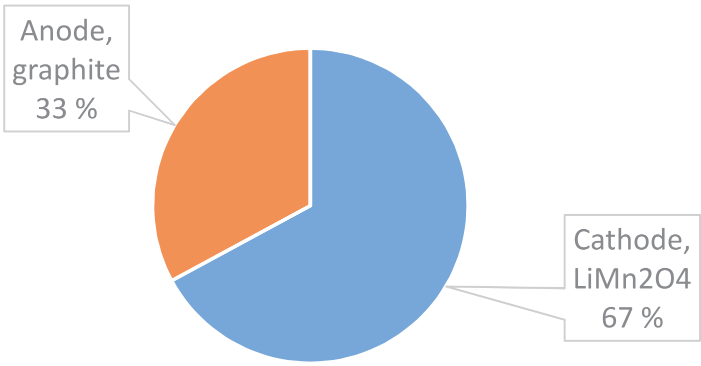

Figure 2 Determinants of metal demand for electric vehicle batteries

In the case of cathode almost 100 % shares of the metal demand indicator are attributed to the demand of the manganese. In the case of anode almost 88 % shares of the metal demand indicator are attributed to the demand of the copper, 6 % shares are attributed to the demand of the molybdenum, 1.5 % indicator is attributed to the demand of the chromium and the others are 4.6 %.

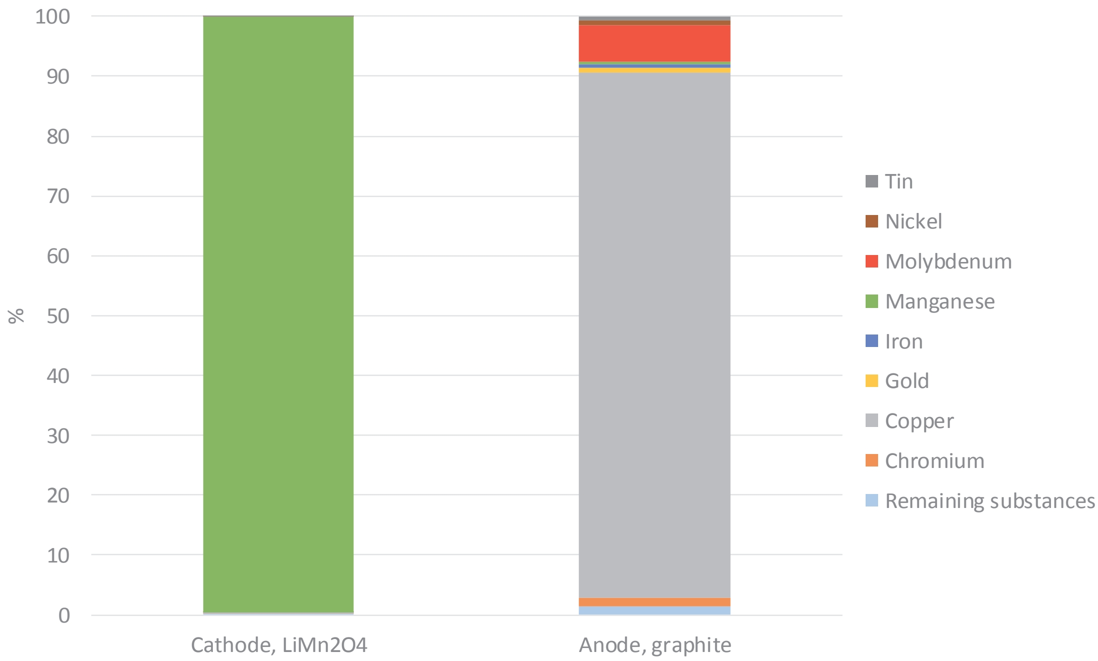

Figure 3 Metal demand in process of vehicle battery production

The main determinants of metal demand of passenger cars are shown in **Figure 4**. For the electric passenger car (without battery) the largest portion of metal demand is related to the glider (constitutes 65 %) and powertrain (constitutes 35 %). The glider includes the body of the car, the steering, braking and suspension system, cockpit equipment (seats and belts), tires, and non-propulsion related electronics. The powertrain includes the manufactured modules in the electric drivetrain (motor, inverter, converter, charger, power distribution unit and cables) and assembles them together. The results of metal demand impact category of passenger car are presented in **Figure 5**.

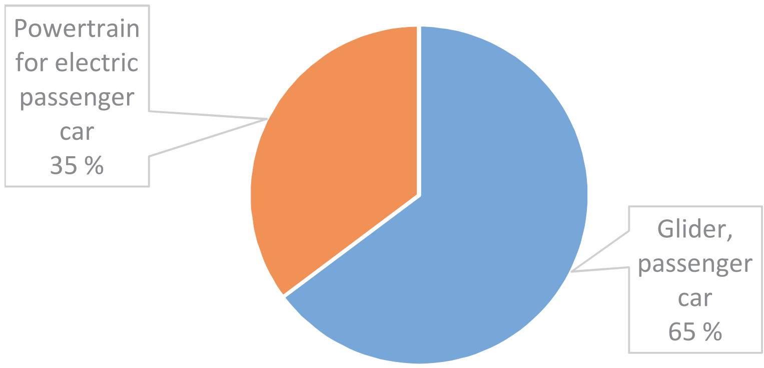

Figure 4 Determinants of metal demand for passenger cars

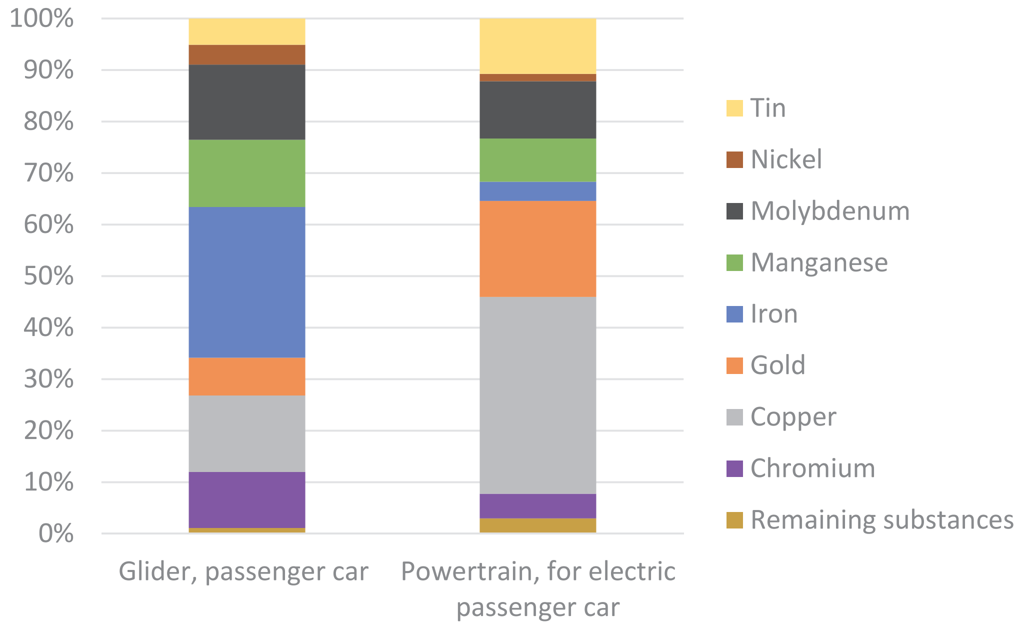

Figure 5 Metal demand in process of passenger car production

In the case of glider 33.6 % shares of the metal demand indicator are attributed to the demand of the iron, 17.1 % shares are attributed to the demand of the copper and 16.8 % shares are attributed to the demand of the molybdenum, 15 % shares are manganese, 12.5 % is the chromium and 8.4 % is gold demand.

In the case of powertrain almost 42 % shares of the metal demand indicator are attributed to the demand of the copper, 20.4 % shares are attributed to the demand of the gold, 12.1% shares are attributed to the demand of the molybdenum, 11.7 % shares are attributed to the demand of the tin, 9.1 % shares are attributed to the demand of the manganese and 5.2 % is the chromium demand.

4. CONCLUSIONS

Efficient use of metal and minerals resources is one of the essential elements of transport development aimed at promoting sustainable development, that is why analyses are important to identify the demand of these resources in production processes.

This paper addresses important problems associated with the assessment of metals management. Metal and mineral demand covered the whole battery electric vehicles life based on the LCA the cumulative metal demand for battery electric vehicles was assessed.

Based on the LCA carried out it was concluded that battery and car production are the main determinants for BEVs in Poland. It is associated with the amount of different metals used. It was concluded the metal demand indicator in battery production process is determined by the amount of used cathode, which is directly associated with the manganese demand and amount of used anode, which is directly associated most of all with the copper demand. It was concluded the metal demand indicator in passenger car production process is determined by the glider and powertrain.

The highest metal demand is related to the manganese (which constitutes 40 %) and copper demand (constitutes 28 %). Iron consumption is also high (constitutes 12 %). Gold and chromium consumption are also high indicators of metal demand and constitute 7 % and 5 % respectively. Other metals and minerals constitutes 9 % (including tin, molybdenum and nickel).

This is the first attempt at a cumulative metal demand of BEVs life cycle in Poland. The analyses carried out so far will be used for assessment of other impact categories of BEVs.

REFERENCES

[1] CZAPLICKA-KOLARZ, Krystyna, BURCHART-KOROL, Dorota and KOROL, Jerzy. Application of life cycle assessment and exergy to environmental evaluation of selected polymers. *Polimery*. 2013. vol. 58, no.7-8, pp. 605-609.

[2] LENORT, R., WICHER, P. Concept of a system for Resilience Measurement in Industrial Supply Chain, In *METAL 2013: 22nd International Conference Metallurgy and Materials*. Ostrava: TANGER, 2013, pp. 1982-1988.

[3] PUSTĚJOVSKÁ, P., JURSOVÁ, S. Measures to reduce CO_2 emissions in metallurgy according to processes in blast furnace, In *METAL 2011: 20th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2011, pp. 32-37.

[4] SANIUK, S., SANIUK, A. Prototyping of Production Networks in Regional Metallurgical Cluster. In *METAL 2012: 21st International Conference Metallurgy and Materials*. Ostrava: TANGER, 2012, pp. 1796-1802.

[5] MORO, Alberto and HELMERS, Eckard. A new hybrid method for reducing the gap between WTW and LCA in the carbon footprint assessment of electric vehicles. *The International Journal of Life Cycle Assessment*. 2017. vol. 22, no. 1, pp. 4-14

[6] NORDELÖF, Anders, MESSAGIE Maarten, TILLMAN, Anne-Marie, LJUNGGREN - SÖDERMAN, Maria, VAN MIERLO Joeri. Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles what can we learn from life cycle assessment? *The International Journal of Life Cycle Assessment*. 2014. vol. 19, no. 11, pp. 1866-1890

[7] RIEVAJ, Vladimir and SYNÁK, Frantisek. Does electric car produce emissions? *Scientific Journal of Silesian University of Technology. Series Transport*. 2017. vol. 94, pp.187-197.

[8] CASALS, Lluc Canals., MARTINEZ-LASERNA, Egoitz, GARCÍA, Beatriz Amante and NIETO Nerea. Sustainability analysis of the electric vehicle use in Europe for CO2 emissions reduction. *Journal of Cleaner Production.* 2016. vol. 127, pp.425-437.

[9] HAWKINS, Troy, SINGH, Bhawna, MAJEAU-BETTEZ, Guillaume and STRØMMAN, Anders Hammer. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. *Journal of Industrial Ecology*. 2013. vol. 17, no. 1, pp.53-64.

[10] FOLĘGA, Piotr and BURCHART-KOROL, Dorota. Environmental assessment of road transport in a passenger car using the life cycle approach. *Transport Problems*. 2017. vol. 12, no. 2, pp.147-153.

[11] FERNANDEZ, Roberto Alvarez. A more realistic approach to electric vehicle contribution to greenhouse gas emissions in the city. *Journal of Cleaner Production.* 2018. vol. 172, pp.949-959.

[12] ELLINGSEN, Linda Ager-Wick, MAJEAU-BETTEZ, Guillaume, SINGH, Bhawna, SRIVASTAVA, Akhilesh Kumar, VALØEN, Lars Ole and STRØMMAN, Anders Hammer. Life cycle assessment of a lithium-ion battery vehicle pack: LCA of a Li-Ion battery vehicle pack. *Journal of Industrial Ecology.* 2014. vol.18, no.1, pp.113-124.

[13] PETERS, Jens, BAUMANN, Manuel, ZIMMERMANN, Benedikt, BRAUN andJessica, WEIL, Marcel. The environmental impact of Li-Ion batteries and the role of key parameters - a review. *Renewable and Sustainable Energy Reviews*. 2017. vol. 67, pp.491-506.

[14] PETERS, Jens and WEIL, Marcel. Providing a common base for life cycle assessments of Li-Ion batteries. *Journal of Cleaner Production.* 2018. vol. 171, pp.704-713.

[15] MAJEAU-BETTEZ, Guillaume, HAWKINS, Troy, and STRØMMAN, Anders Hammer. Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. *Environmental Science & Technology.* 2011, vol. 45, no.10, pp. 4548-4554.

[16] ZACKRISSON, Mats, AVELLÁN, Lars and ORLENIUS, Jessica. Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles-critical issues. *Journal of Cleaner Production.* 2010. vol.18, pp.1517-1527.

[17] GOEDKOOP, Mark, HEIJUNGS, Reinout, HUIJBREGTS, Mark, DE SCHRYVER, An, STRUIJS, Jaap, VAN ZELM, Rosalie. *ReCiPe 2008 A Life Cycle Impact Assessment Method Which Comprises Harmonized Category Indicators at the Midpoint and the Endpoint Level Report I: Characterization*. [online]. Version 1, Last updated: 01 May 2013. PRe Consultants 2013. Netherlands [viewed 2018-04-19]. Available from: https://www.pre-sustainability.com/download/ReCiPe_main_report_MAY_2013.pdf

[18] DEL DUCE, Andrea, GAUCH, Marcel, ALTHAUS, Hans-Jörg. Electric passenger car transport and passenger car life cycle inventories in ecoinvent version 3, *The International Journal of Life Cycle Assessment*. 2014. vol. 21, pp.1314-1326.