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Environmentally-Extended Multi-Regional Input-Output Analysis of neodymium, cobalt and lithium used in electric vehicles

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Abstract. In the transportation sector, the market share of world electric vehicle sales has changed from 0.0% in 2010 to 3.2% (2.1 million) by 2020, and according to forecasts, sales in 2030 may rise to close to 30%. This drastic change is encouraged by environmental goals set to reduce CO_2 emissions, not emitted by electric vehicles (EVs) during the use phase. However, clean technologies (such as electric cars) can cause other effects in mining, processing metals, and the manufacture of permanent magnets or batteries. In addition, the use of electric cars can increase the dependence on countries that control the mining and/or production of materials like neodymium, lithium or cobalt. This work performs an Environmentally-Extended Multi-Regional Input-Output Analysis (EEMRIO) to quantify the flow of neodymium, lithium and cobalt (through a Material Flow Analysis) and assess the CO_2 equivalent emissions (through a life cycle assessment) of these materials, needed to manufacture the permanent magnets and batteries of electric vehicles. This method is useful to analyze the origin (countries) where the environmental impact is produced, in contrast to conventional methodologies that only calculate global impacts. Different scenarios, based on the environmental objectives of the European Union and China, were considered. China shows a key role in mining, processing and manufacture of permanent magnets and batteries, with 60.8% of mining and 79% of manufacturing respectively. Due to Chinese domain, China is the country with highest emissions of CO_2-eq, a 73.11% of total emissions. Obtained results are useful to assess which environmental proposals are more effective to reduce the environmental impact of EVs and to assess the dependency of these rare earths.

Keywords: electric vehicles, critical raw materials, life cycle.

1. Introduction

According to the International Energy Agency (2019), the transportation sector generated 8200 Mt of CO_2 in 2019, which accounted for 25.7% of global CO_2 emissions. Many countries are implementing measures to reduce greenhouse gas emissions, such as increasing the use of non-fossil fuels and promoting electric vehicles. Over the last decade, the number of electric vehicles worldwide has risen by almost 5000%, reaching 6.75 million in 2021 (Orús, 2022).

Although electric vehicles (EVs) offer a clear environmental benefit over internal combustion engine vehicles (ICEVs) during their usage phase, a thorough comparison between the two requires considering all the CO_2 equivalent emissions associated with their manufacturing processes. This can be achieved through a combination of two methodologies: Life Cycle Assessment (LCA) and Environmentally-Extended Multi-Regional Input-Output (EEMRIO). On the one hand, LCA methodology calculates the global footprint but has limitations to assess the geographical origin of environmental impacts and to study the local footprint (Kitzes, 2013). On the other hand, EEMRIO Analysis can be used to study the origin of environmental impacts and calculate local footprints (Martínez, 2019).

The goal of this work is to analyze the CO_2 equivalent emissions of the CRMs (neodymium, lithium and cobalt) used in the permanent magnets (for the electric motor) and a battery of an EV. Specifically, to assess the origin and kilograms of CO_2-eq emitted throughout the supply chain of permanent magnets and batteries used in EVs.

2. Methodology

The scope of this LCA is “cradle to gate”, assessing the impact of mining, metal refining, and manufacturing of the final product (permanent magnets and battery). Ecoinvent database is used to calculate the kilograms of CO_2-eq of a specific product or material and EXIOBASE is used to study their distribution (location).

CO_2-eq emissions have been estimated for different energy mix scenarios. Scenario 1 represents the current energy mix. In Scenario 2, 40% of renewable energies are assumed for EU countries (as established in the Fit for 55 plan). In Scenario 3, 40% of renewable energies in EU countries and 25% of non-fossil energies in China (as established in The 14th Five-Year Plan of the People's Republic of China) are considered. Finally, in Scenario 4, 40% of renewable energies are assumed for all countries. The changes in the energy mix were made proportionally to the current energy mix.

3. Results

Results obtained for Scenario 1 are shown in Figure 1. This figure represents the kilograms of CO_2-eq per country associated to the mining, metal processing (neodymium, lithium and cobalt), and manufacturing necessary to produce the permanent magnets (used in electric motor) and the battery of an EV. China is the country that produces most of the CO_2-eq emissions (4,553 kg CO_2-eq), mainly because it is where more metals are processed and where more permanent magnets and batteries are manufactured.

In scenario 2, there is a reduction of CO_2-eq emissions in Finland, Estonia and Cyprus with a 3.283%, 34.528% and 0.0446%, respectively. The total reduction in this scenario is 0.65 kg of CO_2-eq per vehicle, an 0.014% of reduction. In scenario 3, China reduces the CO_2-eq emissions by 1.627%, compared to current emissions of CO_2-eq. The total reduction in this scenario is 54.89 kg of CO_2-eq per vehicle, a reduction of 1.205%. Finally, in scenario 4, China presents the highest reduction of CO_2-eq, 5.765%. The total reduction in this scenario is 216.72 kg of CO_2-eq per vehicle, a reduction of 4.759%.

In addition, emissions generated from EV battery production were estimated, comparing the difference in CO_2-eq emissions if batteries were produced in China versus the EU (in this case, Hungary was chosen as the manufacturing country as it is the third-largest global battery producer (Bhutada, 2022)). Results show that EV battery production in China cause 4,845 kg CO_2-eq per battery and 95.7% of these emissions are allocated in China. In the case of EV battery production in Hungary, total emissions are 3,348 kg CO_2-eq and 86.7% of these emissions are allocated in the EU. Thus, if the battery is manufactured in Hungary, there is a reduction of 1,496 kg of CO_2-eq per battery, 30.89% of reduction. This is in line with European Policies to reduce dependence on the production of electric batteries (European Parliament, 2020).

4. Conclusions

The shift of the vehicle fleet from ICEVs to EVs in Europe is causing a delocalization of emissions caused during mining and processing of neodymium, lithium and cobalt, and manufacture of permanent magnets and batteries used in EVs. Thus, while Europe has the 35% of EVs stock in the world, only 1.2% of CO_2-eq emissions produced in the whole EV supply chain are allocated in Europe. This fact reflects how Europe is moving the CO_2-eq emissions produced in light-duty transportations, from the consumer (Europe) to the manufacturer (mainly China). Despite the overall benefit of EVs in reducing CO_2-eq emissions, Europe needs to take responsibility of emissions produced by the products it consumes.

This work shows that European policies are not enough for a drastic reduction of worldwide CO_2-eq emissions caused by the road transport sector. The objectives of "Fit for 55" of 40% of renewable energies only produce a reduction of 0.014% in emissions. Nevertheless, Europe could contribute to the reduction of CO_2-eq emissions if it assumes part of the manufacture process, for example, the production of batteries. Thus, production of batteries in Hungary (currently main producer of batteries in Europe) causes 1.5 times lower CO_2-eq emissions than the production of batteries in China.

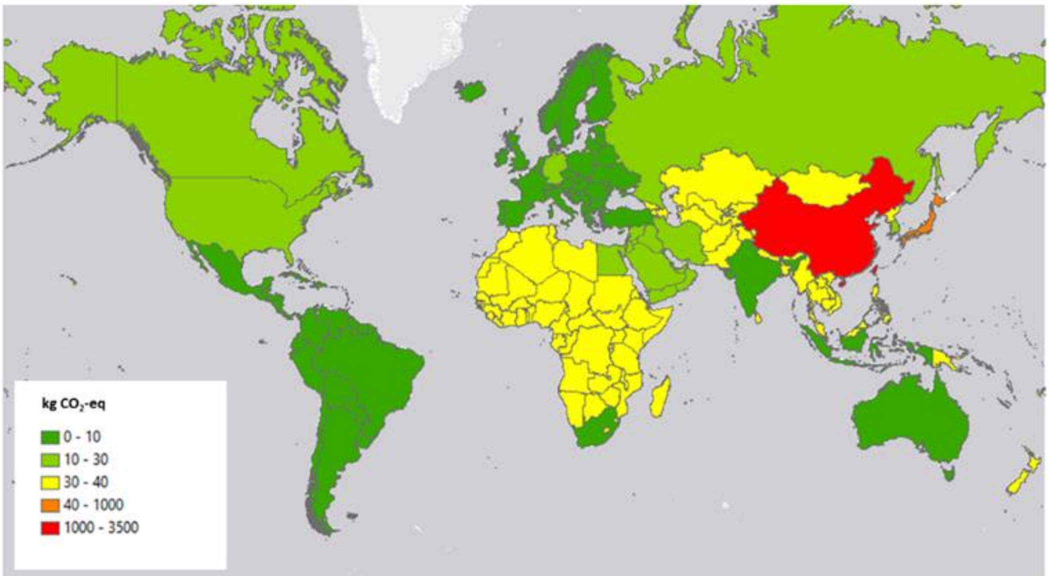

Figure 1. Kilograms of CO_2-eq per country associated to the mining, metal processing and manufacture of the permanent magnets and the battery of an EV (Scenario 1)

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