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Title: “Carbon Footprint Analysis of Neodymium Magnet Production for Wind Turbine Generators with Consideration of Circular Economy Principles”

Summary

The dissertation entitled “Carbon Footprint Analysis of Neodymium Magnet Production for Wind Turbine Generators Considering the Principles of Circular Economy” led to the development of a methodology for determining the carbon footprint over the full life cycle of a wind turbine generator, as well as identifying ways to reduce it through the application of recycling processes. The main motivation behind undertaking the research was the growing need to develop effective methods for managing waste generated in the wind energy sector, resulting from the end-of-life phase of turbines and the necessity of implementing circular economy principles.

The structure of the dissertation includes both theoretical and research parts. The work consists of an introduction, nine chapters, conclusions, bibliography, lists of tables and figures, and appendices.

In the introductory section, the scientific and utilitarian objectives of the work were formulated, a thesis was stated, and the scope of research was defined. The literature review covers issues related to wind energy, the design of turbines and micro wind installations, the challenges of turbine recycling, neodymium magnet production processes, and methods of determining the carbon footprint.

In the research section, a PMzg132-8B household synchronous generator, typically used in small wind turbines, was analysed. A methodology for its disassembly was developed, a detailed material analysis was carried out, distinguishing nine main material groups, and identification tests were performed using FTIR spectroscopy. Using ICP-MS, the share of critical and strategic raw materials, including rare earth elements in NdFeB magnets, was determined, and a risk assessment was conducted regarding their availability, recycling indicators, and substitution potential.

For each stage of the generator’s life cycle – from raw material acquisition, through production, transport, operation, to disassembly – the carbon footprint value was calculated using dedicated databases and software. The total carbon footprint amounted to 496,08 kg CO₂ eq, with the largest share attributed to neodymium magnet production. As part of a sensitivity analysis, the impact of different magnet transport scenarios on emission levels was examined.

Recycling scenarios for individual material groups were also analysed, including an original method of electrostatic separation of a copper–plastic mixture, comparing emissions from recycling processes with those from primary raw material production. In every case, recycling contributed to a significant reduction in the carbon footprint, and for neodymium magnets the reduction reached 87,03%.

The total achieved reduction in carbon footprint for the full life cycle of the generator amounted to 213,29 kg CO₂ eq. Comparing this result to the carbon footprint value associated with producing components from primary raw materials (496,08 kg CO₂ eq), a reduction of 43,06% was achieved.

The research findings clearly confirm that the application of recycling of neodymium magnets and strategic raw materials in wind turbine generators, in line with circular economy principles, allows for a significant reduction of the carbon footprint, limits the consumption of natural resources, and decreases dependency on unstable supply chains. The research results were implemented at ITG KOMAG, enabling the practical application of the developed methods in industry.

Keywords: wind turbine, neodymium magnets, carbon footprint, recycling, circular economy, critical raw materials, LCA.