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Role of substitution in mitigating the supply pressure of rare earths in electric road transport applications

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ABSTRACT

The development of new high-efficiency magnets and/or electric traction motors using a limited amount of critical rare earths or none at all is crucial for the large-scale deployment of electric vehicles (EVs) and related applications, such as hybrid electric vehicles (HEVs) and e-bikes. For these applications, we estimated the short-term demand for high-performing NdFeB magnets and their constituent rare earths: neodymium, praseodymium and dysprosium. In 2020, EV, HEV and e-bike applications combined could require double the amount used in 2015. To meet the global deployment target of 7.2 million EVs sales in 2020 proposed by the International Energy Agency, the demand for NdFeB in the EV sector might increase by up to 14 times in only 5 years (2015–2020). Due to concerns about the security of supply of rare earths some manufacturers have decided to develop and adopt alternative solutions. By assessing up-to-date available component substitutes, we show that the permanent magnet synchronous-traction motor (PSM) remains the technology of choice, especially for hybrid vehicles (HEV and PHEV). Better material efficiency and a larger adoption of motors free of rare earths have the potential to reduce the pressure on rare earths supply for use in electric road transport applications. However even if such substitution measures are successfully implemented, the demand growth for rare earths in the EV sector is expected to increase significantly by 2020 and beyond.

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1. Introduction

Countries gathered at the 2015 Paris Climate Conference (COP21) agreed to increase their efforts to limit climate change. Transport is a growing sector that contributes almost one-quarter of current global energy-related GHG emissions. More than half of this is related to road passenger transport [1,2]. For example, in Europe, transport accounts for more than 30% of final energy consumption and the European Commission is already taking actions to decarbonise the transport sector [3]. Limiting global temperature increases to below 2 °C requires sustainable transportation solutions. Electromobility for various transport modes coupled with a low-carbon power system is seen as a promising sustainable solution. Electrified road transport is not a new concept, but it is only recently that electric vehicles (EVs) have gained relevant mass-market sales through third-generation technology. Several factors push up the electromobility trend, such as the increasing volatility of oil prices, air quality concerns, climate change agreements, more stringent emission standards and market momentum for EVs. At the end of 2015, the global EV stock accounted for over 1.26 million units and global EV sales in 2015 amounted to over 550,000 cars [4]. Although the number of electric vehicles on the road is still very low when compared to the total number of passenger cars worldwide (0.1%), the shift towards electrified powertrains is becoming more apparent. For instance, in 2015 the share of passenger EVs exceeded 1% of new market sales in Norway, the Netherlands, Sweden, Denmark, France, China and the UK [4].

Several countries have set up ambitious sales and/or stock targets regarding vehicle electrification as guidance for creating national roadmaps and for gathering support from policymakers. Among various uptake scenarios, the International Energy Agency (IEA) and the Electric Vehicles Initiative (EVI), a multi-government policy forum composed today of 16 members, presented an aggregated global deployment target of 7.2 million in annual sales of EVs and 24 million in EVs stock by 2020 [5]. This is an important milestone in meeting the global deployment target of 100 million EVs by 2030 as announced at COP21 in the Paris declaration on electromobility and climate change and call for action [4]. An even more ambitious target (140 million EVs by 2030) is presented by IEA under the 2 °C scenario [4]. For instance in Europe the combined targets aim to reach up to 8–9 million EVs on the road by 2020, but specific targets and timelines are subject to negotiation with the EU's member states [6].

It is important to consider here the impact of availability of material resources and their secure supply on the future deployment pathway of EVs in view of the overall concerns about the supply of certain materials in the global transition to a sustainable energy future [7–10]. In previous studies conducted by the European Commission's Joint Research Centre (JRC) we showed that several low-carbon energy technologies could be at risk because of potential bottlenecks in the supply chains of certain metals [11–13]. Among these technologies, electric vehicles are of particular concern due to the dependence on critical rare earths used in NdFeB permanent magnets (PM), which are essential for producing light, compact and high efficiency traction motors. Such magnets contain neodymium (Nd), praseodymium (Pr) and dysprosium (Dy) rare earths in their composition. Dysprosium is used as an additive to improve the magnet coercivity at high temperatures [14].

In recent years, traditional asynchronous motors have been continuously replaced by more efficient devices containing permanent magnets, e.g. high efficient PM synchronous-traction motors (PSM) in EVs, HEVs and e-bikes [15]. Due to the high energy density of NdFeB, this magnet is also increasingly used in high-tech applications and energy-related devices such as generators in wind turbines [16,17]. Consequently, it is expected that the global demand for Nd, Pr and Dy elements will increase in the coming years as the market in these sectors will most likely increase [16,18–20].

A series of events, such as imposing export restrictions on rare earth elements (REEs) by the near-monopolist China, caused the supply crisis from 2010 to 2011 that drove up prices by between 4 and 9 times in less than a year [21–24]. As a result, the costs of products containing rare earths increased. Although prices for rare earths have declined since 2013, concerns regarding the supply of rare earths continue among industry and governments as another supply crisis remains a distinct possibility [16,18]. These supply concerns are also due to the current reorganisation of rare earth market as well as introduction by the Chinese government of various measures to limit REE production, driven by environmental, social and resources preservation aspects.

Based on specific risk assessments, rare earths are in general evaluated as ‘critical materials’ [25–30]. Different mitigation strategies such as the development of new mines and recycling are being considered, but both are seen as unrealistic to be implemented in the short-term.

From one side many barriers prevent a fast and sustainable primary production and on the other side large volumes of secondary rare earth-based products are not expected to enter soon into the recycling circuit [24,31,32]. In the midst of this is the substitution. A complete and direct (one-by-one) replacement of all critical materials by other more readily available or less critical without decreasing product performance, raise the price or both, is very limited [33]. However, the substitution of rare earths and other critical materials appears to be a feasible solution, especially in cases where the substitution takes place at the product, component or technology level rather than the element level [34–36]. According to Smith and Eggert [36], material substitution has ‘multifaceted’ dimensions and the authors identify five types of substitution in the case of NdFeB magnet: element-for element, technology-for-element, grade-for-grade, magnet-for magnet and system-for-system substitution. The literature seems to agree on the fact that substitution represents an essential component of the strategy towards a sustainable use of scarce resources or environmentally problematic materials [37–40].

Comprehensive information about the substitution of rare earths in permanent magnets and the impact of this approach on reducing reliance on rare earths in relation to the widespread adoption of electric vehicles is limited in the literature. The state-of-the-art of some rare earths-free propulsion motors was addressed in several reviews [15, 41,42]. Here we intend to complement the literature by assessing the current technological status of these components and offer an outlook on further developments. We are focusing on the most promising electric propulsion motor concepts that could be applicable at a large scale within a short period in electric road transport applications (i.e. electric vehicles, HEVs and e-bikes).

In this paper we first estimate the demand for permanent magnets for reaching the global deployment targets for electric vehicles in 2020 and describe its link to material resources availability. The competition for PM-based traction motors from other applications, in particular HEVs and e-bikes, is also evaluated. Then we analyse in-depth the possible substitutes for rare earths-based traction motors and assess their ability to enter into serial production in the short-term (2020). Finally, we evaluate the impact of substitution on reducing the demand for rare earths in electric traction motors under different scenarios.

2. Sources and approach

The research was carried out during 2015–2016 based on information collected from a wide variety of sources, including academic articles, relevant documents and reports on critical raw materials, industry publications, etc. Although an exhaustive survey on the most recent industrial developments is difficult to carry out because of the high level of confidentiality in automotive industries research, this paper integrates the best available information with additional information gathered from interviews with material scientists, technical experts from industry and academics. Over ten interviews have been conducted with European automakers (e.g. Daimler, BMW, etc.) and research project consortium (e.g. MotorBrain, CRM_Innonet, etc.) inquiring about their concerns on rare earths supply and feasibility of substitution of