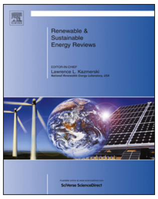
Renewable and Sustainable Energy Reviews 49 (2015) 655–671

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Assessing the need for critical minerals to shift the German energy system towards a high proportion of renewables

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ARTICLE INFO

Article history:
Received 20 December 2014
Received in revised form
30 March 2015
Accepted 23 April 2015
Available online 16 May 2015

Keywords:
Critical minerals
Renewable energy
Electricity supply
Energy transformation
Germany

ABSTRACT

The German government has set itself the target of reducing the country's GHG emissions by between 80 and 95% by 2050 compared to 1990 levels. Alongside energy efficiency, renewable energy sources are set to play the main role in this transition. However, the large-scale deployment of renewable energies is expected to cause increased demand for critical mineral resources. The aim of this article is therefore to determine whether the transformation of the German energy system by 2050 ("Energiewende") may possibly be restricted by a lack of critical minerals, focusing primarily on the power sector (generating, transporting and storing electricity from renewable sources). For the relevant technologies, we create roadmaps describing a number of conceivable quantitative market developments in Germany. Estimating the current and future specific material demand of the options selected and projecting them along a range of long-term energy scenarios allows us to assess potential medium- or long-term mineral resource restrictions. The main conclusion we draw is that the shift towards an energy system based on renewable sources that is currently being pursued is principally compatible with the geological availability and supply of mineral resources. In fact, we identified certain sub-technologies as being critical with regard to potential supply risks, owing to dependencies on a small number of supplier countries and competing uses. These sub-technologies are certain wind power plants requiring neodymium and dysprosium, thin-film CIGS photovoltaic cells using indium and selenium, and large-scale redox flow batteries using vanadium. However, non-critical alternatives to these technologies do indeed exist. The likelihood of supplies being restricted can be decreased further by cooperating even more closely with companies in the supplier countries and their governments, and by establishing greater resource efficiency and recyclability as key elements of technology development.

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http://dx.doi.org/10.1016/j.rser.2015.04.070

1. Introduction

Major reductions in greenhouse gas (GHG) emissions will be necessary in the coming decades in order for the global community to avoid the most dangerous consequences of human-caused global warming [1]. In Germany, the federal government has set itself the target of reducing the country's GHG emissions by between 80 and 95% by 2050 compared to 1990 levels [2]. To achieve this target, the energy system will inevitably need to be transformed. Alongside energy efficiency, renewable energy sources are set to play the main role in this transition. One example is the power sector, where the government seeks to meet 80% of gross electricity demand from renewables by 2050 [2].

In recent years, there have been intense discussions about the impact of a large-scale transformation of the energy system on resource demand [3–10]. The literature places a strong emphasis on minerals that are thought to be particularly scarce or “critical”, such as rare earth elements (REE). Several studies analysed photovoltaic (PV) technology, and came to the conclusion that the manufacture of some types of PV modules (above all, thin film) would probably be faced with resource constraints if deployed on a large scale [3–5]. Habib and Wenzel [7] evaluated the REE neodymium and dysprosium. The authors found that, while geological reserves were unlikely to be depleted for several centuries, a much higher extraction rate would be required in the future to meet expected demand for wind turbines, electric vehicles and other technologies. Some studies point out that alternative technologies that are reliant on more abundant resources exist for a number of renewable energy technologies that require critical minerals [3,4,8]. A number of studies stress the potential benefits of recycling critical minerals, as recycling can reduce primary resource requirements, at least in the longer term [5,7,9,10]. However, to our knowledge, no studies have systematically quantified and assessed the long-term need for critical minerals required for the deployment of renewable energy sources in an industrial country aiming to decarbonise its energy system.

This article is organised as follows: Section 2 describes the research question and an overview of the methods used. Section 3 identifies and quantifies plausible ranges for the critical mineral needs of the German power sector. This is followed by Section 4, in which the availability of the minerals identified is assessed. Finally, the results are discussed in Section 5, whilst Section 6 concludes the paper.

2. Methodology

Considering the issues that have not yet been addressed in the literature, this article aims to provide a preliminary answer to the following research question: Will the intended transformation of the German power sector (including generation, transport and storage of electricity from renewable sources) be restricted by a lack of critical minerals? We use several methods to answer this research question.

(1). In the first step, we conduct a meta-analysis of 12 existing studies on critical minerals in order to learn which, and how often, elements and minerals have been identified as “critical” in previous studies. We then screen all renewable energy technologies referred to in existing energy scenarios in Germany that are expected to be used in the decades ahead to determine whether they require any of the critical minerals identified. This enables us to narrow down the subsequent technology development and roadmap analysis to a limited number of technologies. Screening, which also includes infrastructure such as electricity storage and grids, is based on our expert knowledge and a literature analysis. We classify the technologies as “relevant”, “potentially relevant” and “non-relevant”. “Relevant” means that a technology requires a mineral that has been rated as critical in more than two studies. “Potentially relevant” means that the technology either contains an element or a mineral that has been rated as critical in one or two studies or that the future development of that technology could necessitate the use of such minerals. In the succeeding steps, only “relevant” and “potentially relevant” technologies are considered further. For the technologies classified as “non-relevant”, we abstained from a detailed analysis.

(2). The technologies classified as being “relevant” are analysed in terms of their potential long-term development based on a combination of our expert knowledge, a literature review and expert interviews. However, the demand for mineral resources in future energy systems depends strongly on the particular technologies that will actually be deployed. For this reason, we initially create roadmaps describing a number of conceivable quantitative market developments in Germany. We then estimate the current and future specific material demands of the technology options selected. In this paper, demand refers to the quantity of the material at the production site (from regional storage), including material losses due to further processing.

(3). For technologies classified as “potentially relevant” we determine the cumulated demand of the elements and minerals identified that is required to realise the most ambitious energy scenarios. If this demand is found to be sufficiently low compared to overall global demand, we downgrade the technology to “non-relevant”, otherwise we upgrade it to “relevant” and proceed as outlined in step 2.

(4). In order to identify future needs for new capacities of “relevant” technologies, we conduct a meta-analysis of nine different long-term energy scenarios created in recent years for the energy supply system in Germany. A range of conceivable future deployment levels until 2050 is derived, differentiating between three pathways: “low”, “medium” and “high”. This enables mineral resource restrictions to be considered depending on different deployment levels of renewable energy technologies.

(5). The market shares of the “relevant” technologies outlined in step 3 are combined with the future need for new plant capacities and their specific material consumption over time (step 2), enabling us to determine the cumulative material demand by 2050.

(6). In the final step, we aim to assess the availability of the critical minerals identified. This assessment is based on the proportion of Germans in the world population, which we assume will remain close to the current level of around 1%. We apply