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Role of critical metals in the future markets of clean energy technologies

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ABSTRACT

The global energy sector is expected to experience a gradual shift towards renewable energy sources in the coming decades. Climate change as well as energy security issues are the driving factors. In this process electricity is expected to gain importance to the cost of fuels. However, these new technologies are in many cases dependent on various metals. This analysis evaluates the need for special metals and compares it with known resources in order to find possible bottlenecks in the market. The time perspective of the analysis reaches to the year 2050.

Following technologies have been selected for evaluation: solar electricity, wind power, fuel cells, batteries, electrolysis, hydrogen storages, electric cars and energy efficient lighting. The metals investigated belong either to the semiconductors, platinum group metals, rare earth metals or are other critical metals like silver and cobalt.

The global transition of the energy sector is modelled with TIMES. According to the results the most critical market situation will be found in silver. Other elements, for which bottlenecks in the market seem possible, include tellurium, indium, dysprosium, lanthanum, cobalt, platinum and ruthenium. Renewable energy scenarios presented by the IPCC Fifth Assessment Report seem partly unrealistic from the perspective of critical metals.

1. Introduction

The European Union has launched a Climate Action with a target to reduce greenhouse gas (GHG) emissions by 80–95% until 2050 when compared to the 1990 level. Until 2030 a reduction of 40% is sought. To achieve these targets Europe should be transformed into a low-carbon economy. A roadmap outlines possible future paths in this process [18]. A recently published report by IPCC addresses the question of climate change mitigation by assessing more than 1200 emission scenarios. The low carbon scenarios of the report emphasise an extensive implementation of either energy efficiency of renewable energy sources.

The promotion of energy efficiency and renewable energy sources relies on related technologies. These technologies unfortunately are often dependent on so called critical metals. A metal is perceived critical if it is crucial for green energy technologies and if it is scarce by its' geological occurrence. A shift in the global energy sector towards low carbon technologies will result in an increased demand of these metals. This article analyses the impacts on the

Abbreviations: Ag, silver; a-Si, amorphous silicon; AZO, aluminium doped zinc oxid; BGS, British Geological Survey; CAT, calcium tungstate; Ce, cerium; CFL, compact fluorescent lamp; CIGS, copper-indium-gallium-selenide solar cell; CIS, copper-indium-selenide solar cell; Co, cobalt; c-Si, crystalline silicon solar cells; CSP, concentrated solar power; DSSC, dye sensitized solar cells; Dy, dysprosium; EDLC, electric double-layer capacitor; EOL-RR, end of life recycling rate; EPIA, European Photovoltaics Industry Association; Eu, europium; EV, electric vehicle; FCEV, fuel cell electric vehicle; FTO, fluorine doped tin oxide; GHG, greenhouse gases; HEV, hybrid electric vehicle; HTS, high temperature superconductivity; In, indium; ITO, indium-tin-oxide; JORC, The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves; La, lanthanum; LAP, lanthanum phosphate; LED, light emitting diode; LFL, linear fluorescent lamp; mc-Si, monocrystalline silicon solar cells; MMTA, Minor Metals Trade Association; Nd, neodymium; NdFeB, neodymium-iron-boron permanent magnet; NiMH, nickel metal hydric battery; pc-Si, polycrystalline silicon solar cells; PEMFC, proton exchange membrane fuel cell; PFSI, perfluorosulfonic; PGM, platinum group metals; PHEV, plug-in hybrid vehicle; PM, permanent magnet; Pr, praseodymium; Pt, platinum; PV, photovoltaics; RC, recycled content; REE, rare earth elements; REO, rare earth oxids; rpm, rotations per minute; Ru, ruthenium; SOFC, solid oxid fuel cell; Tb, terbium; Te, tellurium; USGS, United States Geological Survey; Y, yttrium; YBCO, yttrium-barium-copper-oxid; YSZ, yttrium stabilised zirkonia.

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metals markets and seeks to find possible bottlenecks resulting from the availability of the critical metals. The evolution of the global energy market is to model by TIMES.

2. Methods – data sources and simulation

We have modelled the global demand for 14 critical metals (Ag, Nd, Pr, Dy, Tb, Yt, La, Ce, Eu, Co, Pt, Ru, In, Te) resulting from a shift towards green energy technologies from present until 2050. In the analysis a broad spectrum of green energy technologies have been chosen. Both technologies producing renewable energy as well as energy efficient technological solutions are taken into account: solar energy, wind energy, electric mobility, fuel cells, batteries, electrolysis and efficient lighting. One important criterion for the selection of the technologies has been the metals needed in the technology, and the technologys' expected future role in the metals markets. For the analysis detailed information on the specific need for metals has been collected. This data together with information on metals resources and reserves as well as annual mining is fed in to the TIMES model.

2.1. Reviewing critical metal dependencies of green energy technologies

In the following chapters the selected technologies are presented in more detail, focus being on material requirements.

2.1.1. Solar energy

2.1.1.1. Crystalline silicon photovoltaics. Crystalline silicon solar cells (c-Si) belong to the first generation of photovoltaic technology and represents still today 80% of the global PV markets [19]. Three types of c-Si cells exist: monocrystalline (mc-Si), polycrystalline (pc-Si), and ribbon silicon (ribbon pc-Si). The efficiency of the cell varies depending on the technology, but is roughly 20% [27].

The bulk material of the cell is silicon, which is one of the most common elements in the earths' crust. The cells are connected electrically to each other with metal strips consisting of an alloy rich in silver. Silver is the metal of choice because of its' superior electrical conductivity. PV manufacturers estimate the current silver content to be in the range of 8 g/m^2 [60]. Currently the technology is based on screen printed silver paste. However there are some technological approaches to reduce the dependence of silver such as the “metal wrap through technology” or “buried contact”, which are discussed by Saga [57]. Further decreases are sought by substituting silver to a large degree by copper. The expected development of the silver content per cell area is shown in Fig. 1.

2.1.1.2. Dye sensitized solar cells, DSSC. Dye sensitized solar cells are organic solar cells and belong to the third generation of photovoltaics. This technology is on the verge of commercialization. The manufacturing process brings many cost advantages, and the efficiency of the cells is in the range of 8–12% [27]. The photoactive material, the dye, can be made of several materials. However a complex based on ruthenium and osmium gives the best cell performance [22]. The metallization of the cell is based on a silver ink. Platinum acts as a catalyst. Fraunhofer ISI has published estimations on the need of critical metals [2] as shown in Table 1.

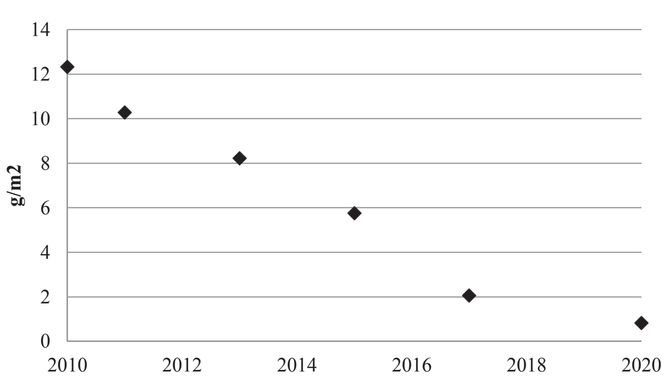

Fig. 1. Silver consumption per area in c-Si cells [4].

2.1.1.3. Thin film photovoltaic panels. Thin film cells, or second generation photovoltaics, comprise several technologies depending on the semiconducting material. The cells can consist of one or several layers of photoactive substance, each of one being very thin (in the range of nanometres or micrometres). This leads to reduced need of material.

CdTe-panels are cost efficient to produce and thus are regarded as the most promising thin film technology. The confirmed measured electricity generation efficiency is as high as 17.5% [78], however in commercial applications somewhat lower, 10–11% [19]. Tellurium is a critical metal. The need of tellurium has been estimated to be 6.5 g/m^2 [1].

CIS or CIGS (copper-indium-selenide or copper-indium-gallium-selenide) yields an efficiency of 15% whereas commercial applications show an efficiency range of 7–12% [19]. Indium and gallium are critical metals. The need of these metals is estimated to be 2.9 g/m^2 (In) and 0.53 g/m^2 (Ga) [1].

Thin film cells based on amorphous silicon (a-Si) have a relatively low efficiency, 4–8%. The cell suffers from light induced degradation, which has a negative impact on the efficiency of the cell. The degradation is not that severe, if the cell is built with a layer structure (a-Si/μc-Si). A layer with microcrystalline silicon gives the cell stability and increases the efficiency to 7–9% [19]. Doping amorphous silicon with germanium has the same effect. The front contact is an ITO layer (indium-tin-oxide), typically 60 nm thick [2]. This means the need of indium is approximately 0.4 g/m^2. The back contact can be either silver or aluminium.

2.1.1.4. Concentrated solar power – CSP. There are various technological approaches to concentrated solar power such as parabolic trough, linear Fresnel reflectors or the solar power tower, but all function according to the same principle. A system of mirrors or lenses concentrates solar irradiation. The concentrated light heats an absorber fluid, which could be water, a molten salt or synthetic oil. The heat is transformed to electricity by conventional turbine technology. Silver has highest optical reflectivity of all elements and is thus used on the surface of the mirrors to obtain high reflectance. The silver content per mirror area is constant for all technologies (1 g/m^2), but since the electrical output varies depending on the choice of technology, the silver requirement with respect to electricity generation capacity is different [2]. Table 2 comprises this information.

2.1.2. Wind energy

The wind energy concept can be classified into two categories: geared and gearless wind mills. Induction generators have high

Table 1
Material consumption of some selected raw materials in dye-sensitized solar cells [2].

Material	Needed mass/area [g/m^2]
Ruthenium	0.07
Platinum	0.03
Silver	1