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Exploring the material footprints of national electricity production scenarios until 2050: The case for Turkey and UK

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ABSTRACT

In this research, a global multiregional input-output model is built to investigate the material footprint of electricity production from renewable and nonrenewable energy sources in Turkey and UK. Three national electricity production scenarios such as *S1-Business-As-Usual, S2-Official Government Plan* and *S3-Go-Green Plan* are analyzed to help policy makers to estimate the consequences of energy investment scenarios on resource footprint based on 19 minerals from 12 different electricity production sectors. The Autoregressive Integrated Moving Average (ARIMA) is used as a time-series forecasting technique in order analyze the scenarios until 2050. The findings showed that coal is the most material intensive electricity production resource. Under business-as-usual scenario, electricity production by coal in Turkey is expected to be responsible for 83.7% of metallic mineral and 80.3% of nonmetallic mineral consumption by 2050. For per kilowatt-hour of electricity produced in Turkey, coal, natural gas, and oil together cause 81% of the total mineral consumption. However, under business-as-usual scenario in UK, 84.6% of metallic mineral and 81.4% of nonmetallic mineral consumption will be due to electricity production from coal and natural gas combined while coal alone will constitute to about 41% of the nonmetallic mineral consumption in 2050. In addition, the nonmetallic mineral consumption by electricity production from coal and natural gas in UK will be around 95.5% by 2050 under all three scenarios. The findings of this research can help identifying the critical minerals and energy resources to propose the most optimum energy mix and eventually to reduce dependency on the critical materials.

1. Introduction

European Union (EU) is the third largest consumer of electricity after United States and China according to "British Petroleum report on sustainabilty, (2015)", despite Europe has pledged to reduce its energy demand by 20% compared to the forecasted level by 2020 (Monteiro et al., 2009). In 2013, the electricity generation of EU-28 was 3.10 Million GWh, which was about 14% of global electricity generation (Statistical Office of the European Communities. and European Commission., 2014). The United Kingdom (UK) accounted for 11% of total electricity production in the EU's total electricity production, which was 51.7% more than that of Turkey in 2013 (Eurostat, 2014). There was a noticeable increase in the electricity demand of Turkey form 118.7 GWh in 2000–227.7 GWh in 2013 that is 93% increase and is expected to grow in future. In contrast, UK's electricity production declined slightly from 2000 to 2013 by 5.4% (Statistical Office of the European Communities. and European Commission., 2014). As the dependence of energy is expected to increase in both Turkey and UK, their resource dependence has been an important topic to investigate (Atilgan and Azapagic, 2016, 2015; Kouloumpis et al., 2015). Therefore, this paper aims to analyze the impacts of future energy production scenarios in UK and Turkey on the material consumption in terms of metals and minerals.

Since the beginning of the 18th century, the rise of global energy demand at an unprecedented rate, which results in waste generation, global warming and damage to the natural environment (Ercan et al., 2016; Kucukvar et al., 2015; Noori et al., 2016; Onat et al., 2016a,b,c, 2014a). The serious concern is global warming which may raise the temperature of earth by 0.3–1.7 ° centigrade in the lowest emission scenario mentioned by the International Panel on Climate Change (Stocker, 2014). Therefore, all over the world stringent measures are being taken to reduce global carbon dioxide emission level (Gumus et al., 2016a; Noori et al., 2015a,b; Egilmez et al., 2015). Most of the European countries have already shifted from nonrenewable source of energy (coal, gas, oil) to the renewable form of energy like wind, solar, tide, geothermal, etc. This shift of economies from renewable to nonrenewable sources of energy have increased pressure on the consumption of scarce mineral resources available in the earth, which take

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millions of millions year to form (Hoekstra and Wiedmann, 2014; Kucukvar and Tatari, 2011; Tatari et al., 2012; Tatari and Kucukvar, 2012). Hence, the need of policy attention for natural resource security has emerged. The production of electricity by nonrenewable resources will certainly lead towards the reduction in carbon emissions but on other hand, will deplete the precious mineral resources such as aluminum, iron, copper, tin, etc. To make efficient use of these scarce minerals, it is extremely crucial to have detailed 'material footprint' analysis (Galli et al., 2012; Nansai et al., 2015; Wood et al., 2014).

There have been several methods applied for analyzing environmental footprints of products, processes, and services (Alirezaei et al., 2017; Egilmez et al., 2016; Kucukvar et al., 2014a; Park et al., 2016; Tatari et al., 2015). There are important indicators providing consumption outlook of resource use and can provide new insights into the real productivity of economies. Multi Region Input-Output (MRIO) and Life Cycle Assessment (LCA) are some of the powerful methods that are used for this purpose (Onat et al., 2015, 2014b,c). In a MRIO analysis, the input-output tables of several nations are related through the bilateral trade data (Kucukvar et al., 2014b; Onat et al., 2017). Thus, this approach is capable of tracking out the supply chain within a territorial boundary and can be used to know quantify effects in the international supply chain (Acquaye et al., 2011; Egilmez et al., 2014, 2013; Onat et al., 2016a; Park et al., 2015). This technique can reveal what effect one particular economic activity will have on the rest of the economies by taking into consideration dissimilar resource intensities in different regions (Kucukvar and Tatari, 2013; Tukker and Dietzenbacher, 2013). In this paper, a MRIO analysis is utilized using data obtained from the EXIOBASE, containing units of minerals consumption per million Euro economic activities of 163 sectors in 43 countries across the globe.

In the literature, energy, water, and carbon footprints have mostly been studied using a MRIO analysis (Hertwich and Peters, 2009). For example, Galli et al. (2012) analyzed water and ecological footprints using a MRIO analysis. Wiedmann et al. (2010) applied a MRIO analysis to monitor the carbon footprint for the UK. Ewing et al. (2012) used a MRIO framework for the water footprint accounting. Zhang and Anadon (2014) used the same method to track the traces of water footprint by the booming economy of China. Yu et al. (2010) applied a regional input-output analysis to calculate the water footprint for UK. Galli et al. (2013) extended the MRIO model to support Europe's transition for one planet economy. Kucukvar et al. (2016) investigated energy-climate-manufacturing nexus using a MRIO analysis to investigate the impacts in the global supply chain of manufacturing industries. In another paper, Kucukvar and Samadi (2015) used a MRIO analysis to link national food production of Turkey and EU-27 to global supply chain impacts for energy-climate challenge. Feng et al. (2012) developed a MRIO model to find the water consumption for particularly the yellow river basin of China and later he used the same model for UK water consumption. Fang et al. (2014) also discussed the energy footprint in their papers using a MRIO analysis.

A MRIO analysis has been also utilized for material footprint studied. For instance, Giljum et al. (2015) determined the impact of international trade flow on the minerals consumption and investigated changes over a period of year by MRIO model. Giljum et al. (2016) performed a detailed analysis of the EU's material footprint with the aim of understanding the main commodities contributing to overall material consumption to satisfy EU's final demand. In a recent work, Wiedmann et al. (2015) presented a time series material footprint analysis of 186 countries in order to trace resource flows related to production and consumption at global scale. Several other studies have also analyzed the material footprints of production and consumption using a global multiregional input-output framework (Čuček et al., 2012; Hoekstra and Wiedmann, 2014).

However, after a detailed review, there are no studies found using a MRIO modeling particularly used for analyzing scenario-based material footprints of energy production. With this motivation in mind, this paper aims to develop the first MRIO model for global and trade based material footprint accounting of electricity production sectors for both Turkey and UK. In this study, a MRIO analysis is combined with three energy production scenarios such as Business-as-Usual, Official Plan, and Renewable Energy Development Plan until 2050. For material footprint analysis, total mineral consumption in kilograms of 19 minerals from 12 different sources of electricity production from renewable and nonrenewable resources is presented for Turkey and UK based on per kWh of electricity production.

Table 1
Electricity Production Sectors and Minerals.

Electricity Production Sectors	Metallic Minerals	Non Metallic Minerals
Coal	Iron ores	Chemical and fertilizer minerals
Nuclear	Bauxite and Aluminum ores	Clays and Kaolin
Wind	Copper ores	Limestone, gypsum, chalk, dolomite
Bio Mass	Lead ores	Salt
Waste	Nickel ores	Slate
Solar	Tin ores	Other industrial minerals
Geothermal	Uranium & Thorium ores	Building stones
Gas	Zincs ores	Gravel and sand
Hydro	Precious metal ores	Other construction materials
Petroleum and Oil	Other metal ores	
Tide Wave Ocean		
NEC		

2. Methods

In this research, we aim to identify consumption of 11 metallic and 9 non-metallic mineral resources associated with electricity production from different energy sources in Turkey and UK, as shown in Table 1. The data was obtained from the EXIOBASE 2007, which is a detailed illustrative analysis of global Multiregional Environmentally-Extended Supply-Use Table (MR-EE-SUT). This project was funded by the EU to create a comprehensive global and multiregional extended supply chain tables (Ivanova et al., 2016; Schoer et al., 2013; Arnold Tukker et al., 2013a,b). The EXIOBASE data has the characteristics of 163 industries, 48 countries, 200 products, 15 land use type, employment per three skills level, 48 types of raw materials and 172 types of water uses according to Tukker et al. (2013a,b). Moran (2014) conducted an in-depth study to determine how reliable the EXIOBASE data is and found the error to be less than 10%. Several researchers have used the EXIOBASE data. For example, Tukker et al. (2014) used this database for determining nation's resource footprint. Zhao et al. (2016) used it to determine carbon and energy footprints of electric vehicles and many authors have used it to determine various environmental footprint categories (De Koning et al., 2015; Lutter et al., 2016).

In addition to the data obtained from the EXIOBASE, current paper also gathered data from the International Energy Agency (IEA), which is an independent organization and works to provide reliable data for 29 member countries and more. The IEA provided the data of electricity produced from different sources of energy until 2013, which was used in forecasting electricity production up to 2050 for both Turkey and UK. Hence, the EXIOBASE and IEA were the main sources of our data collection for this research while the data for inflation was from the Organization from Economic Cooperation and Development (OECD) for both countries. The percentage of electricity consumption was obtained from the Ministry of Energy and Natural resources for Turkey and the Department of Energy & Climate Change for UK.

The method consists of several steps to reach the results. The first step is the extraction of data from the aforementioned sources. The second step is the ARIMA forecasting that was done by the data obtained from the IEA (data of electricity produced from different energy