The Assessment and Integration of Material Footprint in National Energy Development Plans

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

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“Your remedy is within you, but you do not sense it. your sickness is from you, but you do not perceive it. you presume you’re a small entity, but within you is enfolded the entire universe. Therefore, you have no need to look beyond yourself. What you seek is within you, if only you reflect.”

Rumi

The Assessment and Integration of Material Footprint in National Energy Development Plans

Muhammad Ali Haider

Abstract

In this research, Multi Region Input-Output (MRIO) model is used for to investigate the nexus between electricity production from various renewable and non-renewable energy sources and their material consumption in Turkey and UK, enabling a global trade-based analysis for material footprint accounting. Three national electricity production scenarios such as Business-as-Usual, Official Plan, and Renewable Energy Development Plan were analyzed to help policy makers to estimate the consequences of energy investment scenarios on resource footprint based on 19 minerals from 12 different sources of electricity production. The Autoregressive Integrated Moving Average (ARIMA) forecast method is used to analyze the scenarios until 2050. The study revealed that electricity generation using coal is the most material-intensive energy source. 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. In Turkey, coal, hydro and wind have been identified as the critical sources for electricity production under business-as-usual scenario, which are anticipated to constitute 72% of the total minerals consumption in 2050. For each kWh of electricity is produced by each energy source in Turkey, coal, natural gas, and oil together cause 81% of the total mineral consumption. However, 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. Also, the non-metallic mineral consumption by electricity production from coal and natural gas in UK will be 95.5% by 2050 under all three scenarios. The findings of this research can help identifying the critical minerals and energy resources to propose most optimum energy mix and eventually, to reduce dependency on the critical material consumption.

Keywords: MRIO, Material footprints, Material Energy nexus, Input output table, Electricity production, sustainable Energy Policy

Ulusal Enerji Geliş tirme Planlarında Malzeme Ayak İzi Değerlendirilmesi ve Entegrasyonu

Muhammad Ali Haider

Öz

Bu araştırmada, Türkiye ve İngiltere'de çeşitli yenilenebilir ve fosil enerji kaynaklarından elektrik üretimi ile bunların materyal tüketimleri arasındaki ilişkileri araştırmak ve malzeme izdüşümü analizi yapmak üzere ilk defa küresel ticarete dayalı analiz sağlayan çok bölgeli girdi-çıktı (MRIO) modeli geliştirildi. Politika yapıcılara yardımcı olması amacı ile, Olağan, Resmi Plan ve Yenilenebilir Enerji Geliştirme Planı gibi ulusal elektrik üretim senaryoları analiz edildi. 12 farklı kaynaktan gelen 19 materyale dayalı enerji yatırım senaryoları ve bu senaryoların etkileri incelendi. 2050 yılına kadarki (olası) senaryoları analiz etmek için Otoregresif (öz bağlanımlı) bütünleşik yürüyen ortalama tahmin metodu kullanılmıştır. Çalışma göstermiştir ki, kömür kullanımına dayalı elektrik üretimi materyal tüketim yoğunluğu en yüksek enerji kaynağıdır. Türkiye'de kömürden üretilen elektriğin, 2050 yılında, metalik materyal üretiminin %83.7'sinden, metalik olmayan materyal üretiminin ise %80.3'ünden sorumlu olması beklenmektedir. Olağan senaryoya göre, kömür, su ve rüzgar, Türkiye'deki elektrik üretiminin materyal tüketimi bakımından en kritik kaynakları olarak tanımlanmaktadır. 2050 yılına gelindiğinde bu durumun, toplam materyal tüketiminin %72'sini olusturacağı beklenmektedir. 2050 yılında İngiltere'de metalik olmayan materyal tüketiminin yaklasık %41'ini yalnız kömür oluşturmaktadır. Kömür ve doğalgaza dayalı elektrik üretimi metalik materyal tüketiminin %84.6'sını ve metalik olmayan materyal tüketimi %81.4'ini oluşturacaktır. Ayrıca, İngiltere'de, bütün senaryolarda, 2050 yılına kadar kömür ve doğalgazdan elektrik üretiminden dolayı oluşan metalik olmayan materyal tüketimi toplam materyal tüketiminin %95.5'i olacaktır. Bu araştırmanın bulguları kritik madenleri ve enerji kaynaklarını belirlemede ve sonuç olarak enerji üretiminin kritik malzeme tüketimine bağımlılığını azaltmaya yardımcı olabilir.

Anahtar Sözcükler: Materyal ayakizi, çoklu bölge girdi-çıktı analizi, elektrik üretimi, tahmin, senaryo analizi, çevresel politika

Dedicated to My Parents and Sisters

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Abbreviations

MRIO	**M**ulti **R**egional **I**nput **O**utput
BAU	**B**usiness **A**s **U**sual
OP	**O**fficial **P**lan
ARIMA	**A**uto **R**egressive **I**ntegrated **M**oving **A**averages
LCA	**L**ife **C**ycle **A**ssesment
IEA	**I**international **E**nergy **A**gency
DWIA	**D**anish **W**ind **I**ndustry **A**ssociation
OECD	**O**rganization for **E**conomic **C**ooperation and **D**evelopment
I-O	**I**nput **O**utput
WWF	**W**orld **W**ide **F**und
TBL	**T**ripple **B**ottom **L**ine

Chapter 1

Introduction

1.1 Introduction

The global energy demand is on rise as and has a tendency to reshape our lives to a great extent [1]. The policy makers are deeply concerned to find out efficient ways for energy data analysis. European Union is still the third largest consumer of electricity after USA and China according to British Petroleum report [2], despite Europe has pledged to reduce its energy demand by 20% compared to the forecasted level by 2020 [3]. In 2013, the electricity generation of EU-28 was 3.10 million GWh, which was about 14% of global electricity generation [4]. The 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 [4]. There was a noticeable increase in the electricity demand of Turkey form 118.7 GWh in 2000 to 227.7 GWh in 2013 that is 93% increase and is expected to grow in future, However, in contrast with this, UK's electricity production declined slightly from 2000 to 2013 by 5.4% [4]. Halicioglu founded that Turkey's GDP has a direct relationship with its energy consumption [5], which makes efficient energy policy necessary to foster economic progress. As the dependence of energy is expected to increase in both Turkey and UK, their resource dependence has been an important topic to investigate. The demand for sustainable development is increasing as governments are becoming more environment conscious [6] and also it have become more popular debates to use scarce resources efficiently [7]. Due to rising concerns of global warming and energy security [8], finding ways to handle the resources in the most optimized way have become significant.

Along with the same lines, this paper aims to analyze the impacts of the current and future energy production scenarios of the UK and Turkey on the material consumption.

Since the beginning of the 18th century the rise of global energy demand at an unprecedented rate has resulted in waste generation, global warming and damage to the natural environment [9]. The serious concern is global warming which may raise the temperature of earth by 0.3 to 1.7 degrees centigrade in the lowest emission scenario as mentioned by IPCC (2013) [10]. Therefore all over the world stringent measures are being taken to reduce global carbon dioxide emission level. The developed world which has most of the share in global energy consumption is drifting towards the green energy production as a part of this scheme [11]. 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. The electricity production in Germany has increased from 6.5% in 2000 to 30% in 2014 as discussed by Burger [12] and Winter [13], while Denmark taking the lead has planned to increase its share of electricity production by wind to 50% person by 2020 according to Danish Wind Industry Association (DWIA) [14]. This shift of economies from renewable to nonrenewable sources of energy have generally increased pressure on the consumption of scarce mineral resources available on earth that took millions of years to form [15]. 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 CO2 emission but on other hand, will deplete the precious mineral resources like Iron, copper, tin, etc. To make efficient use of these scarce minerals it is extremely crucial to have detailed ‘material footprint’ analysis.

There have been several methods applied for analyzing material footprints of products, processes, and services. They are important indicators providing consumption outlook of resource use and can provide new insights into the real productivity of economies. Life Cycle Assessment(LCA) is most widely used method to determine environmental implications [16]. Onat [17] used LCA to do sustainability assessment of alternative passenger vehicles. LCA was used to analyses sustainability impacts of several alternative vehicles and passenger cars by Onat [18–21]. The main disadvantage of LCA is that it does not provide for the indirect consumption though it uses cradle to grave approach. Given that the indirect consumption is always greater than the direct ones [22]. In a study it was found that indirect consumption constitue to 56.5% of the carbon emissions by manufacturing industry [23]. In a Mutli Region Input Output (MRIO) analysis, the input-output tables of several nations are related through the bilateral trade data. Thus, this approach is capable of tracking out the supply chain within a territorial boundary and can also be used to know quantify effects in the International supply chain [24]. It 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 according to Tukker [25]. Other approaches like System Dynamics approach and Tripple Bottom Line which were used by Onat [26] to model to GHG emission stocks by US residential building and also for broadening the LCA framework for electric and alternative vehicles [27–30]. Onat also assessed carbon footprints of US public transportation and road safety to climate change nexus using system dynamics approach [31–33]. In this thesis, 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 MRIO analysis [34]. For example, Druckman [35] analyzed the carbon footprints of UK household using MRIO analysis. Kucukvar [36] established a nexus of energy, elimate and manufacturing using MRIO model. Onat [37] used MRIO to determine carbon and energy footprints of electric trucks in US. Fan [38] used the MRIO analysis to determine China's regional energy requirements and carbon emission. Wiedmann [39] integrated the existing method to calculate water and ecological footprints using a MRIO analysis. Tan used a similar modeling approach to determine biomass production and environmental footprints [40]. Also, Galli and Alessandro [41] used a MRIO analysis to determine the water consumption of different economies and extended it for carbon footprint as well. Wiedmann [42] applied a MRIO analysis to monitor the carbon footprint for the UK. Wilting and Wiedmann used similar model to analyze the global environmental impact from the database provided from the Global Trade Analysis Project (GTAP) [43]. Brad R. Ewing [44] used a MRIO framework for the water footprint accounting. Chao Zhang [45] used the same method to track the traces of water footprint by the booming economy of China. Zang [46] applied the regional input-output analyses to calculate the water footprint for UK. Alessandro [47] extended the MRIO model to support Europe's transition for one planet economy. Kucukvar [48] investigated energy-climate-manufacturing nexus using MRIO analysis and used WIOD database to investigate the impacts in the global supply chain of manufacturing industries. Kucukvar [49] used

MRIO analysis to link national food production of Turkey and EU-27 to global supply chain impacts for energy-climate challenge. Feng [50] 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. Wiedmann [51] made a first empirical comparison of energy footprints embodied in trade and also used it to evaluate the greenhouse gases footprint for UK. Feng [24] and Wiedmann [51] they both discussed the energy footprint in their papers using MRIO analysis.

MRIO analysis has been also utilized for material footprint analyses. For instance, Giljum [52] determined the impact of international trade flow on the minerals consumption and investigated changes over a period of year by MRIO model. While in other researches like Ramaswami [53] established a relation of urban mineral consumption to the energy flows and the implication of the carbon footprint in the study without using MRIO and Bruckner [54] conducted a structural decomposition analysis to estimate the Australian mineral consumption from 1995 to 2007. Giljum [55] 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 [56] presented a time series material footprint analysis of 186 countries in order to trace resource flows related to production and consumption at global scale.

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 thesis aimed to utilize MRIO model for global and trade based material footprint accounting of electricity production sectors for both Turkey and UK. MRIO analysis results were combined with three energy production scenarios such as Business-as-Usual, Official Plan, and Renewable Energy Development Plan which were projected till 2050. For material footprint analysis, total mineral consumption in kilograms of 19 minerals by 12 different sources of electricity production from both renewable and nonrenewable forms of energy was obtained for Turkey and UK. The material consumption needed to produce unit kWh electricity from different energy sources were also ascertained.

Chapter 2

Methodology

2.1 Methodology

In this research, we aim to identify consumption of 11 metallic and 9 nonmetallic mineral resources associated with electricity production from different energy sources in Turkey and UK, as shown in Table 2.1. The data was obtained from the EXIOBASE 2007 [57], 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 [58]. 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 [25]. It was developed by conglutinating and detailing Supply and Use Table (SUT) for a number of economies and forecasting emissions, mineral consumption by industry. It is an international input-output table that can be used for the analysis of the environmental impacts associated with the final consumption of product groups. Moran [59] conducted in depth study to determine how reliable the EXIOBASE data is and found the error to be less than 10%. Already several researchers have used the EXIOBASE data in their research for example Schmidt et al. [60] used it for life cycle analysis of global food consumption, Tukker [61] used it for determining nations resource footprint, Zhao [62] used it to determine carbon and energy footprints of electric vehicles and many authors have used it to determine various ecological footprints.

TABLE 2.1: 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		

In addition to the data obtained from the EXIOBASE, for this thesis data was also gathered 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 till 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 Department of Climate Change for UK. Figure 2.1 describes how the data from these sources was utilized to produce the results.

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 was the Auto Regressive Integrated Moving Average (ARIMA) forecasting that was done by the data from IEA (data of electricity produced from different energy sources till 2013) and the results of forecast were in KWh. The third step was to apply Leontief inverse on the EXIOBASE data which was in million tonnes per million Euro per KWh. The fourth step was to multiply the results we obtained from steps 2 and 3 that will yield the consumption of mineral in Kg for per unit price for KWh electricity produced from the particular energy source. The final step was to multiply the results we got from step 4 by the weighted average price of electricity (that was calculated by taking the weighted mean of electricity consumed by industrial and residential sector) that will yield the final result which shows the total mineral consumption in kilograms of 19 minerals from 12 different sources of electricity production in Turkey and UK. All aforementioned steps will be discussed comprehensively in the following sections. The result is used for further data analysis and different scenarios has been developed in this paper to help policy makers grasp a complete overview of future sustainability situation of the scarce minerals resources.

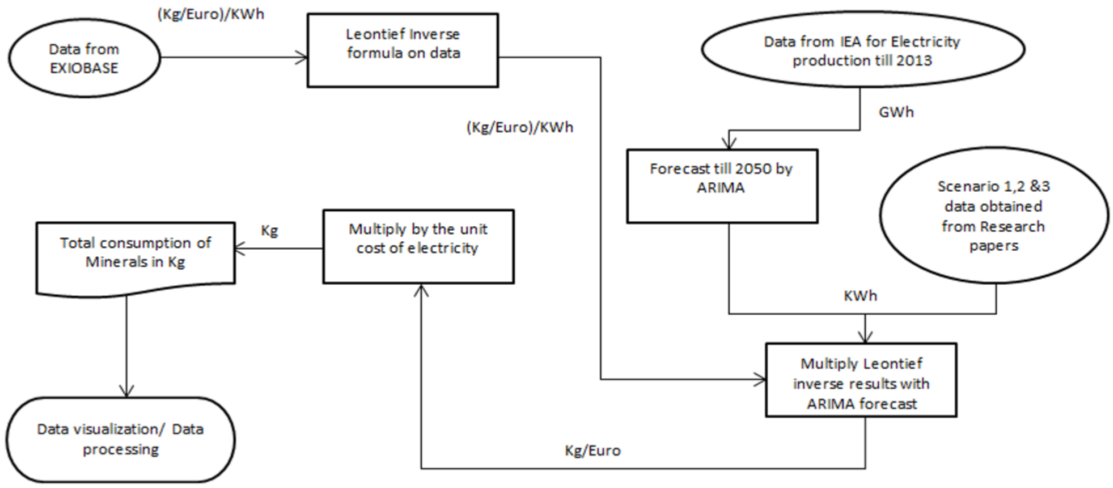

FIGURE 2.1: The Workflow of Analysis

2.1.1 MRIO Analysis

MRIO model readily emerged in 1987 according to Jensen [63]. In MRIO model the economic interdependence is not only ascertained in terms of different industries but it also shows the relationship among the regions [64]. The MRIO framework comprises economic transaction matrices for multiple regions. These matrixes are able to track the global supply chain between different sectors of the economies, as they represent the financial transaction between several countries and their corresponding economic sectors [65]. In this research, we acquired data for MRIO analysis from the EXIOBASE. A MRIO framework usually contains countrywide input-output (I-O) tables that show financial trade between economic sectors within national and global transactions. It is an I-O used to quantify the inter dependencies between various branches in economy. In a typical MRIO model, the monitory values represent the quantity of imports and exports done by the different industries belonging to different countries. All of these imports and exports are then combined into one single model. This final matrix is made to link the financial transaction between the inputs required for industries within countries with the final demand generated from domestic consumption, investments by private and public sectors [66].

In the MRIO framework, $\mathbf{A_{ij}^{rs}}$ matrix contains rows that represents the intake demanded by sector i of country r from sector j of country s. In this matrix, i and j have a maximum value of 12 which is the total number of sectors in each country we are considering in this research. Also, r and s have a maximum value of 48 which is the total number of countries in the EXIOBASE data. This matrix is also called direct requirement matrix, the rows give information about the input from other sectors (both national and international) to generate output of unit euro. Generally, the MRIO analysis generates a matrix that represent the total impact one economic activity of a particular country will have on the economic sectors of rest of the world based on per unit euro output [67].

2.1.2 Mathematical formulation of MRIO

The Leontief model is a model for the economics of a whole country or region. In the model there are n industries producing n different products such that the input equals the output or, in other words, consumption equals production. After acquiring the data from EXIOBASE we applied Leontief inverse on it. It tells what effect one particular economic activity will have on the other since in economy all the activities are linked with each other. With this model we can even calculate the indirect involvement. The Leontief inverse was applied on the data set to find the total consumption of the chosen 19 mineral resources by the production of electricity from different sources. The formula used for the Leontief inverse is shown in Equation (2.1)

$$(\mathbf{I}\text{ - }\mathbf{A})\boldsymbol{x} = \boldsymbol{y} \tag{2.1}$$

Where $\boldsymbol{y}$ represents the final result or the ultimate consumption, $\boldsymbol{x}$ the activity we are interested in and $(\mathbf{I} - \mathbf{A})^{\mathbf{-1}}$ being the Leontief inverse matrix. All the calculation was done by the help of MATLAB programming software and the final result showed the total consumption of the mineral by the production of electricity in Turkey and UK from different energy sources.

To make a precise description, the MRIO framework is explained for the case of n sectors within three regions. However, this explanation can be used for any number of region we are interested in. In a general MRIO economy, there are three factors that to consider, as inter-industry trade matrix $\mathbf{Z}$, final consumption vector $\boldsymbol{f}$, and total industry output vector $\boldsymbol{x}$.

$$\mathbf{Z} = \begin{bmatrix} Z^{rr} & Z^{rs} & Z^{rt} \\ Z^{sr} & Z^{ss} & Z^{st} \\ Z^{tr} & Z^{ts} & Z^{tt} \end{bmatrix}; \boldsymbol{f} = \begin{bmatrix} f^{r} \\ f^{s} \\ f^{t} \end{bmatrix} = \begin{bmatrix} f^{rr} + f^{rs} + f^{rt} \\ f^{sr} + f^{ss} + f^{st} \\ f^{tr} + f^{ts} + f^{tt} \end{bmatrix}; \boldsymbol{x} = \begin{bmatrix} x^{r} \\ x^{s} \\ x^{t} \end{bmatrix}$$

As an element of $\mathbf{Z^{rs}}$, $\mathbf{Z^{rs}_{ij}}$ represents the purchases made by the sector i of country r by the sector j of country s. Moreover, $\boldsymbol{f^{rs}}$ represents the value which is the final consumption by the domestic, private and public sectors. For example, $\boldsymbol{f^{rs}_{i}}$ represents the final demand of country s for commodities produced by sector i in country r. While, $\boldsymbol{x^{r}}$ represents the column vector of final industry production in country r. The relation between the quantities, total industry production $\boldsymbol{x}$, inter-industry transactions $\mathbf{Z}$ and final consumption $\boldsymbol{f}$ is shown in Equation (2.2)

$$\mathbf{Z}i + \boldsymbol{f} = \boldsymbol{x} \tag{2.2}$$

where i denotes the total of the column. In a typical MRIO model, total industry output vector, $\boldsymbol{x}$ can be denoted as shown in Equation (2.3)

$$\boldsymbol{x} = \mathbf{A}\boldsymbol{x} + \boldsymbol{fx} = \mathbf{A}\boldsymbol{x} + \boldsymbol{f} \tag{2.3}$$

Where $\mathbf{A}$ is the Technical coefficient matrix. In the MRIO analysis, the multiregional technical coefficients matrix is known by: $\mathbf{A} = \begin{bmatrix} A^{rr} & A^{rs} & A^{rt} \\ A^{sr} & A^{ss} & A^{st} \\ A^{tr} & A^{ts} & A^{tt} \end{bmatrix}$; where,

$$A^{rs} = Z^{rs}\boldsymbol{x^{-1}} \tag{2.4}$$

Then the next step is to calculate the Leontief matrix and Leontief inverse matrix by using the Equation (2.4) and (2.5), respectively:

$$\textbf{[I-A]} = \begin{bmatrix} 1 - A^{rr} & A^{rs} & -A^{rt} \\ -A^{sr} & I - A^{ss} & -A^{st} \\ -A^{tr} & -A^{ts} & I - A^{tt} \end{bmatrix};$$

$$\mathbf{L} = [\mathbf{I} - \mathbf{A}]^{-1} = \begin{bmatrix} 1 - A^{rr} & A^{rs} & -A^{rt} \\ -A^{sr} & I - A^{ss} & -A^{st} \\ -A^{tr} & -A^{ts} & I - A^{tt} \end{bmatrix} = \begin{bmatrix} B^{rr} & B^{rs} & B^{rt} \\ B^{sr} & B^{ss} & B^{st} \\ B^{tr} & B^{ts} & B^{tt} \end{bmatrix}; \tag{2.5}$$

The Leontief function is shown in Equation (2.5). Furthermore, a MRIO model is extended with 11 metallic and 9 non-metallic mineral consumption matrices, where **M** is a diagonal matrix of these material footprint coefficients. Then, the total sectoral material use is given by Equation (2.6) as follows:

$$\boldsymbol{m} = \mathbf{MB}\boldsymbol{f} \tag{2.6}$$

where $\boldsymbol{m}$ is a column vector representing total material footprints. Hence, the material used by electricity production from sectors of a specific country r given in Equation (2.7)

$$m^r = M^r B^{rr} f^r + M^r B^{rs} f^s + M^r B^{rt} f^t \tag{2.7}$$

2.1.3 ARIMA forecasting

There are several techniques for predicting time series such as naive forecast, exponential soothing, artificial intelligence, averaging and the one we used in this research is the ARIMA forecasting which stands for Auto Regressive Integrated Moving Average. It is basically the combination of Auto regressive model and the moving average as from its name. The purpose of each of the model is to fit the data as precisely as possible. Already many authors have used this technique for data forecast like Ediger [68] used it to predict Turkey's energy demand by fuel. The ARIMA forecast takes use of the past data to predict future points in the series.This model is particularly used when the data is non-stationary which has to be made stationary by differencing and taking log of the data. The non-seasonal ARIMA models are usually represent by ARIMA (p,d,q) where p, d and q are positive integers. The parameter p denotes the order of time lag, d is the amount or degree of differencing which is the number of times the stationarizing operation have been performed on the data and$q$ refers to the order of the moving average model. In mathematical formulation for ARIMA model, X_t is the data value with t being a non-negative integer index. An ARMA (p,q) model is given by the Equation (2.8) below.

$$\mathrm{X}_t \alpha_1 X_{t-1} ... \alpha_{p'} \mathrm{X}_{t-p'} = \varepsilon_t + \theta_1 \varepsilon_{t-1} + ... + \theta_q \varepsilon_t - q \ \varepsilon_t - q \tag{2.8}$$

This can also be expressed as:

$$(1-\sum_{i=1}^{p'}\alpha L^i)X_t = (1+\sum_{i=1}^{q}\theta_i L^i)\varepsilon_t \tag{2.9}$$

Where L is the lag operator, a_i are the values for the autoregressive part of the model, θ_i are the values for the moving average part and ε_t are the error terms associated with the actual and the fitted value. The error term is assumed to follow normal distribution curve with zero mean and is considered to be independent. If we assume that the polynomial $(1-\sum_{i=1}^{p'}\alpha L^i)$ in Equation (2.9) has a unit root of divisibility d, then it can be simplified further to Equation (2.10) below

$$(1-\sum_{i=1}^{p}\phi_i L^i)(1-L)^d X_t = \delta + (1+\sum_{i=1}^{q}\theta_i L^i)\varepsilon_t \tag{2.10}$$

The annual production electricity production data from 12 different energy sources (Production of electricity by, coal, oil, gas, wind etc.) was given in GWh till 2030 which we obtained from IEA. For ARIMA forecasting on the data we used XLNUM software which generated the results of forecasted value till 2050 in GWh that was later converted into KWh for further calculations. We used ARIMA (1,1,1) model to generate the results for ARIMA forecast that can be seen in Figure 2.2 which shows Turkey's and UK's electricity consumption from different energy sources in MWh and up till 2050.

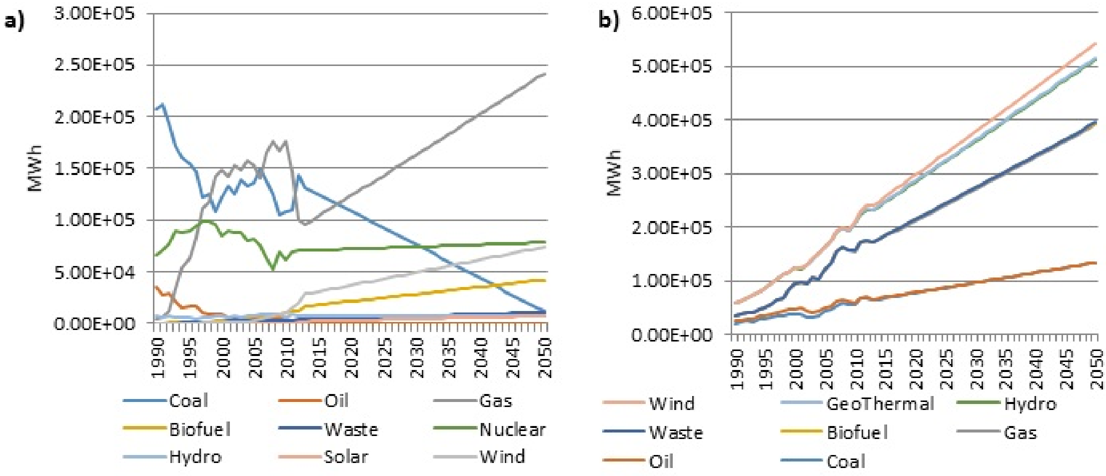

Figure 2.2: ARIMA Forecasting for Turkey **a)** and UK **b)** electricity production by different energy sources

To calculate the cost associated with energy consumption of per unit KWh in Turkey and UK, we calculated the weighted cost as the rates were different for sectors. The industrial sector constituted for is 32% of the total energy consumption in Turkey while the household sector consumption accounted for 37%, according to the Ministry of Energy and Natural resources (2013). The unit cost of household electricity consumption in Turkey was charged at rate is 35.3 kr/KWh, while industrial sector rates were 23.4 kr/KWh. Thus, calculating the weighted average to get a more reasonable estimate of mean from this data the answer turned out to be as shown in Equation (2.11):

$$Weightedaverage = 35.5 * 0.32 + 23.4 * 0.37 = 29.78kr/KWh \tag{2.11}$$

$$WeightedaverageinEuros = 29.78 * 3.3 = 0.09Euro/KWh. \tag{2.12}$$

The result of average is 29.78 kr/KWh which was then converted into Euro/KWh by multiplying the result with the current Lira rate against Euro as shown in Equation (2.12). Thus, the average cost was 0.09 Euro/KWh in Euros for per unit kWh consumption of electricity in Turkey. Since the EXIOBASE data obtained was of 2007 and therefore by the help of percentage inflation statistics we converted this 0.09 Euro per KWh cost of 2013 to 2007 considering an inflation of 8% according to the OECD. The final cost calculated was be multiplied with the result we got form Leontief Inverse application on data that yielded the total consumption of the 19 minerals of interest by the energy production from various sources of energy in Turkey. For the finding out the results for UK, the same procedure was adopted as that of Turkey.

2.1.4 ARIMA Validation and Goodness of Fit

The Goodness of fit results will enable to evaluate how perfect the forecasting technique is for the data on which it is used. Figure 2.3 shows the Goodness of fit results for forecasting the electricity production in Turkey by Oil till 2050 using ARIMA model. It can be seen from the figure that the ARIMA generated values have very closely fitted the data as shown by the blue and red lines representing the actual series and the ARIMA fitted values respectively. The green line shows the forecasted after 2013 within the 95% confidence interval. The residual analysis of the the data can also be done using the same figure which shows that the maximum residual error in the data value with

TABLE 2.2: Goodness of Fit Statistics for ARIMA fit on electricity production by oil data of Turkey

Observations	24	MAPE	27.99
DF	22	-2Log(Like.)	415.96
SSE	42350587.06	FPE	1918051.95
MSE	1764607.794	AIC	419.96
RMSE	1328.39	AICC	420.53
WN Variance	1764607.794	SBC	422.31
MAPE(Diff)	27.99	Iterations	1

ARIMA generated values lies in year 2007, 2008 and 2009 which is very less as compared to the actual value of electricity produced in respective years. Therefore ARIMA forecast results are close to accurate for the particular data set we used in our research.

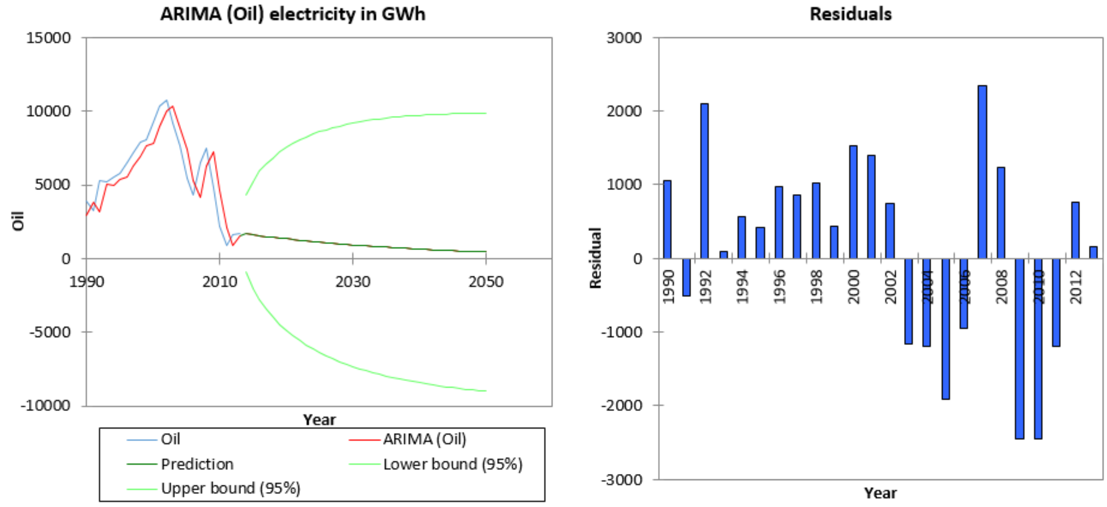

FIGURE 2.3: Goodness of Fit for ARIMA on Turkey's electricity production by Oil forecast

Table 2.2 shows more about the Goodness of fit for ARIMA forecast results in the statistical terms for electricity production in Turkey by Oil's forecast. The results were generated by the 'Numxl' forecasting software that used ARIMA forecasting method. After analyzing the result from several statistical tools shown in the table it is reasonable to conclude that ARIMA forecast has very well fitted the data with low errors.

2.1.5 Assumptions

In MRIO framework the data with regard to the country specific technology is used in the calculations is an advantage. Furthermore MRIO model is very useful in tracking the individual supply chain of the activity. However, such a big data volume demand creates disadvantages over the benefits of this model as discussed by Lutter [69]. The MRIO model creates uncertainty in the calculations. Weber [70] presented an extensive literature on the uncertainties associated with MRIO model. Multi-regional models receive uncertainties particular to a country input-output analysis which constitute uncertainties in data collection, and in assumption of linearity according to Lenzen [71]. Apart from the uncertainties that are associated with MRIO analysis we used the estimated value for the price of per unit KWh of electricity in UK and Turkey. Estimation was made on the bases of percentage consumption of electricity by household sector and the commercial sector. Then to calculate the price in 2007 we used the average inflation to get the values as close as possible. The last assumption was that despite unavailability of large data we forecasted electricity production till 2050 and assumed the results to be close to actual. Hence, there are four assumptions listed; (1) uncertainties associated with MRIO modeling; (2) Estimation of the cost per unit KWh of electricity by taking weighted average; (3) Considering average of the inflation; (4) Long forecast with limited data. Despite these assumptions the accuracy of the result is affected to a negligible extent and the result is still meaningful greatly for information to be extracted and analyzing the data.

2.1.6 Scenarios Construction and Visualization

Scenario building is an important step towards simulating the possible aspects of future and this makes it a symbolic foresight of the future trends. It is basically visualizing situations from different perspectives to get prepared for the possible circumstances that might be encountered in future. It is different from the prediction as it not forecasting but a simulation of the events that might take place. More generally scenarios are stories created on historical data analysis and understanding to resemble with the cases that might happen. The development of these scenarios helps in discerning the possible pathways to the future. Since it's not possible to predict future accurately [72], it's always better to plan with vision considering multiple scenarios.

The practical world is full of uncertainty in every aspects and the best way to mitigate these uncertainties is by planning under the view of possible future scenarios. It's like developing multiple strategies based on the historic facts and stories, then using the most suitable one to be executed under a circumstance that was anticipated by story building. The prediction tools may enables to make plans for the forecast but it does not accommodate for the unpredictable events that might take place. In order to avoid disaster if the things do not go according to the forecast we developed several back up plans which are based on the scenarios. Therefore scenario building is particularly helpful According to Mahmoud [73] scenarios development is believed have originated first by the US air force to prepare themselves for the alternative plans to use under different situations. However as Liu [74] says that today it is being widely used by the cooperate sector in the midst of uncertain market situations and it use has been extended to the government for the policy making purposes as discussed by Means [75]. The application of scenario building has also emerged in the field of environmental science as mentioned by Mahmoud [73] and in every field it is being used as important tool for planning.

The scenarios modelling task comprises of first understanding the scenarios narrative, then devising suitable policies for each scenario and examining the effect caused by it. In all cases there is one scenario called Business As Usual (BAU) which act as a reference case from which other alternative scenarios are to be compared. The alternative scenarios are developed considering the possible policies to be made to achieve a particular goal which can be anything like cost saving, green energy plan, economic development plan or increasing employment. The main purpose is to simulate how good or a bad situation will be and evaluate the consequences if we opt for different scenarios. Scenarios does not tell about how probable an event is to occur, rather it depicts how the future will be if a particular scenario takes place. Mahmoud [73] says that there are some disadvantages associated with scenarios building that it does not take probability into account but that disadvantage has very little to do with the use we are deriving from it that is simulating the conditions. As said it does not matter how low or highly probable of a scenario is to occur, it has nothing to do with the purpose of scenario building whose aim is to study the impacts and changes it will bring as the consequences.

To visualize the possible consequences of some anticipated scenarios of electricity production from different energy sources and their impact on material footprint of humanity, in this research three scenarios are used which are similar for both Turkey and UK to provide a fair comparison between the two countries. (1) First one is the Business-as-usual (BAU) which is the simulation of what will happen in the future if everything remains unchanged and keep on working as they are currently. BAU plan was developed by the help of data from International Energy Agency (IEA) which showed the historic electricity production data that enabled to forecast the future electricity generation from

Table 2.3: Turkey and UK's different scenarios for electricity production used

Scenario 1	The business as usual plan (BAU) obtained from International Energy Agency.
Scenario 2	The official plans of both countries that are set as part of policy making.
Scenario 3	The plan for reducing carbon emission and going green.

different energy sources considering the past trend. The BAU plan also serves as a reference point to compare other scenarios. (2) Second scenario used is the Official Plan (OP) which is made by the policy makers in the government of the two countries (Turkey and UK) to achieve their desired National energy goals. The OP was developed from National Renewable Energy Action Plan (NREP) for Turkey and for UK the government OP scenario was obtained by Stamford [76] research work. (3) Third scenario is the Go green plan which is developed because of the ever growing global environmental concern and more stringent polices are being made as it has now become a serious economic, political and social issue according to Philip [77]. For Turkey, the Scenario 3 used was developed from WWF report for Turkey's policy recommendation by Berke to focus on renewable energy. The Go green scenario for UK was obtained from scenario developed by Stamford [76]. Table 2.3 shows briefly the scenarios developed for this research that is used to simulate their impact on the mineral footprints.

All scenarios developed will help in visualizing the impacts of electricity production from different energy sources for Turkey and UK are shown in. Three scenarios used for both countries will be discussed comprehensively below. The electricity productions for Turkey and UK as per the scenarios are shown in the figures, which are forecast of electricity production from different energy sectors for both Turkey and UK.

2.1.6.1 Business As Usual scenario (BAU)

The BAU scenario serves as a reference point to compare with the alternative scenarios. It simulates the consequences that may happen if everything keeps on working the same way. It basically use the historic data to forecast the scenario that will be created in future based on the past trend. In other words it is a scenario which depicts the situation that might be caused if nothing is changed. In this research we used the data from the International Energy Agency (IAE) which was of electricity produced from different energy sources in GWh between 1990 till 2013. IAE statistics were used to get the electricity production data for both Turkey and UK and performed ARIMA forecast on this data to get the prediction till 2050. In this way, BAU scenario was developed for both the countries which depicted the electricity generated from the energy sources if the present trend prevailed in both the countries.

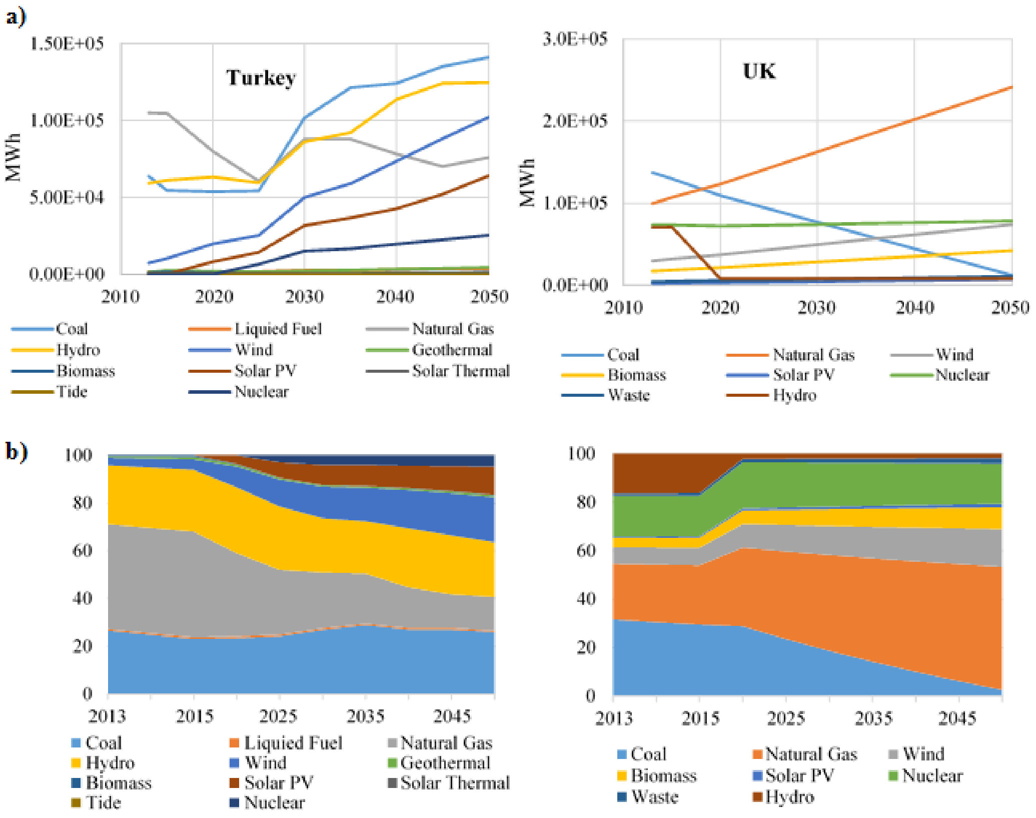

Figure 2.4: Business As Usual scenario for Turkey and UK (a) Electricity production in MWh by energy sectors, (b) Percentage electricity production by energy sectors

Figure 2.4 (a) shows the BAU scenario developed for both the countries in a graphical form. For Turkey it can be seen that electricity production from all energy sources are on rise accept for the natural gas that will show a steep decrease in 2025 and will have an overall decreasing trend which is due to the growing economy. Coal, hydro, wind, solar and nuclear will be the main sources of electricity generation of Turkey till 2050 while tide and biomass will still be in the emerging phase. For UK production of electricity by coal and hydro shows a significant downward trend because of the European climate policy to reduce the energy produce from coal and move towards the renewable source of energy. Biomass, wind and nuclear will show a very little increase over the years for BAU scenario of UK. Discussing quantitatively from figure 2.4 (b) which shows that for Turkey the production of electricity by natural gas will decrease from 40% in 2013 to around 20% by 2025. This decrease can be explained by Turkey's policy of reduction in its dependence on natural gas for energy supply. In contrast with UK whose electricity production from natural gas is expected to increase from 30% in 2020 to around 55% by 2050. It can also be notices that for UK there will be a constant decline in the use of coal for electricity production. From 30% in 2013 the coal usage is expected to finish completely by 2050 due to the European strict environmental measure policies UK has been working on. The other sources of energy usage for electricity production seems to remain the same for both Turkey and UK.

The electricity forecast from the BAU scenario will help us in determining the metallic and nonmetallic mineral consumption in Kg, the dependency of the Turkey and UK will have on other countries to meet their electricity production and many other analysis which will be discussed by the help of the figures in the BAU scenario result section.

2.1.6.2 The Official Plan scenario (OP)

OP is a scenario in which governments try to achieve their goal by acting on their policy whose purpose is to achieve the national interest goals. The OP scenario for Turkey was developed from the National Renewable Energy Action plan (NREP) while for UK OP scenario building we used the research work of Stamford [76] according to which the government is working to achieve 80% carbon reduction by 2050. Turkey's economy is growing and the government has set the plans and targets to achieve. If the things goes according to what the government has planned then consequences will be of scenario (2) that is OP. Turkey has an official plan to shift from non-renewable energy sources to the renewable energy form due to its agreement on European climate policy. Turkey has planned to develop nuclear power by 2020 thus adding to a new source of energy which they will keep on increasing gradually. As far as UK OP is concerned there will be notable changes in the energy source usage. Figure 2.5 (a) shows how the production of electricity will be affected under the scenario to achieve the government's goal by having an official plan. It can be seen that for Turkey there is addition of nuclear power while UK is set to reduce it nuclear use due to environmental hazard associated with the dispose of the nuclear waste.

According to Figure 2.5 (b) for Turkey it can be clearly seen that coal, biomass and wind as a source of electricity production will increase in 2022. This will be a result of the government's policy to move towards the renewable energy. While the natural gas usage will drop to 10% in 2050 and production of electricity by coal will remain fairly constant that is around 22% of the total electricity production. For UK the production by coal will remain constant too around 40% of the total production throughout and nuclear energy usage will be close to zero by 2050. Electricity production by coal and natural gas will account for 70% of UK's total electricity generated and this percentage will remain nearly the same. This means that in OP for UK heavy reliance will be made on nonrenewable sources.

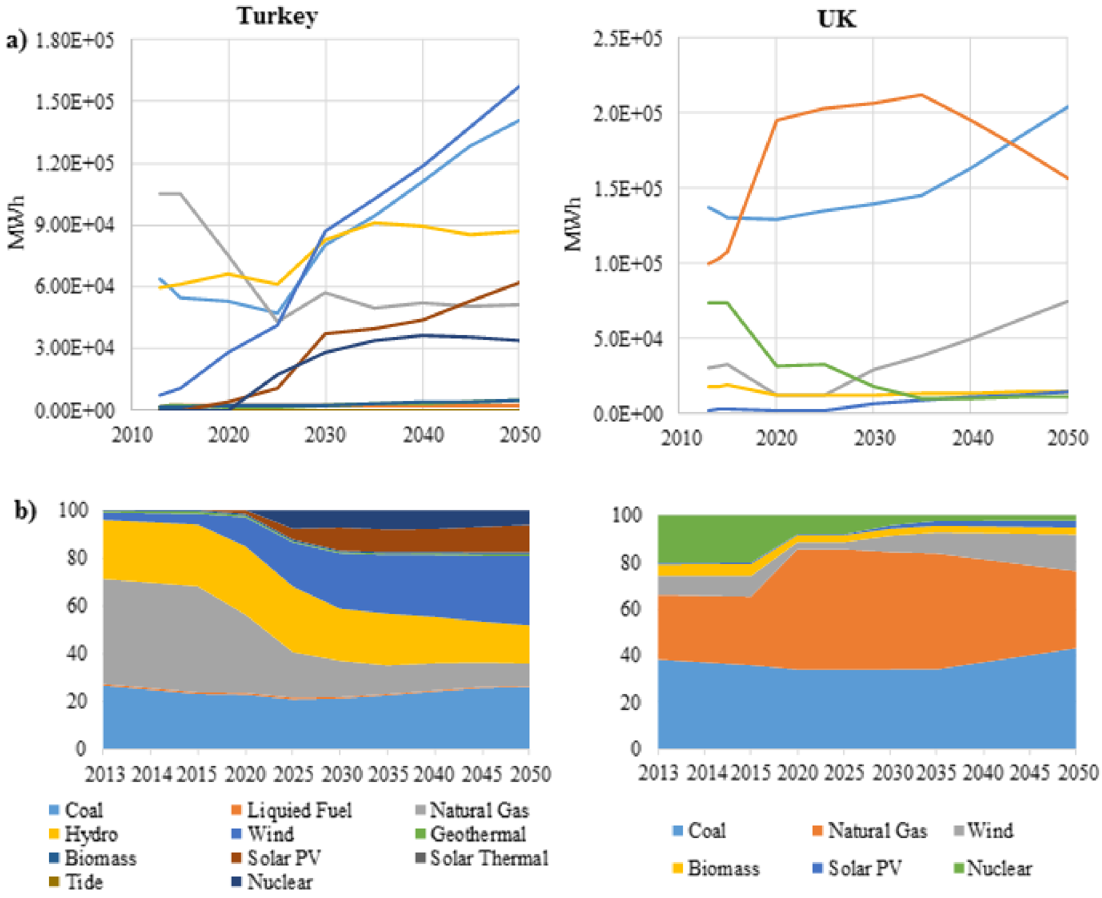

FIGURE 2.5: Official Plan scenario for Turkey and UK (a) Electricity production in MWh by energy sectors, (b) Percentage electricity production by energy sectors

2.1.6.3 The Go green plan scenario

Due to ever increasing dependence on the non-renewable resources, the natural environment have also made people more conscious about it as mentioned by Kraft [78]. In addition, According to Arsel [79], there is a boom with regard to the debates and policies on the environment that have triggered the need to work for sustainable solutions. The environmental issue has become a social and political one now, therefore European countries have already set target to reduce the carbon footprints and are successful to a significant extent. Therefore, the Go green scenario for UK and Turkey have been developed to simulate the consequences and impact the energy policy will have on the scares mineral resources if strict Go green plan is perused.

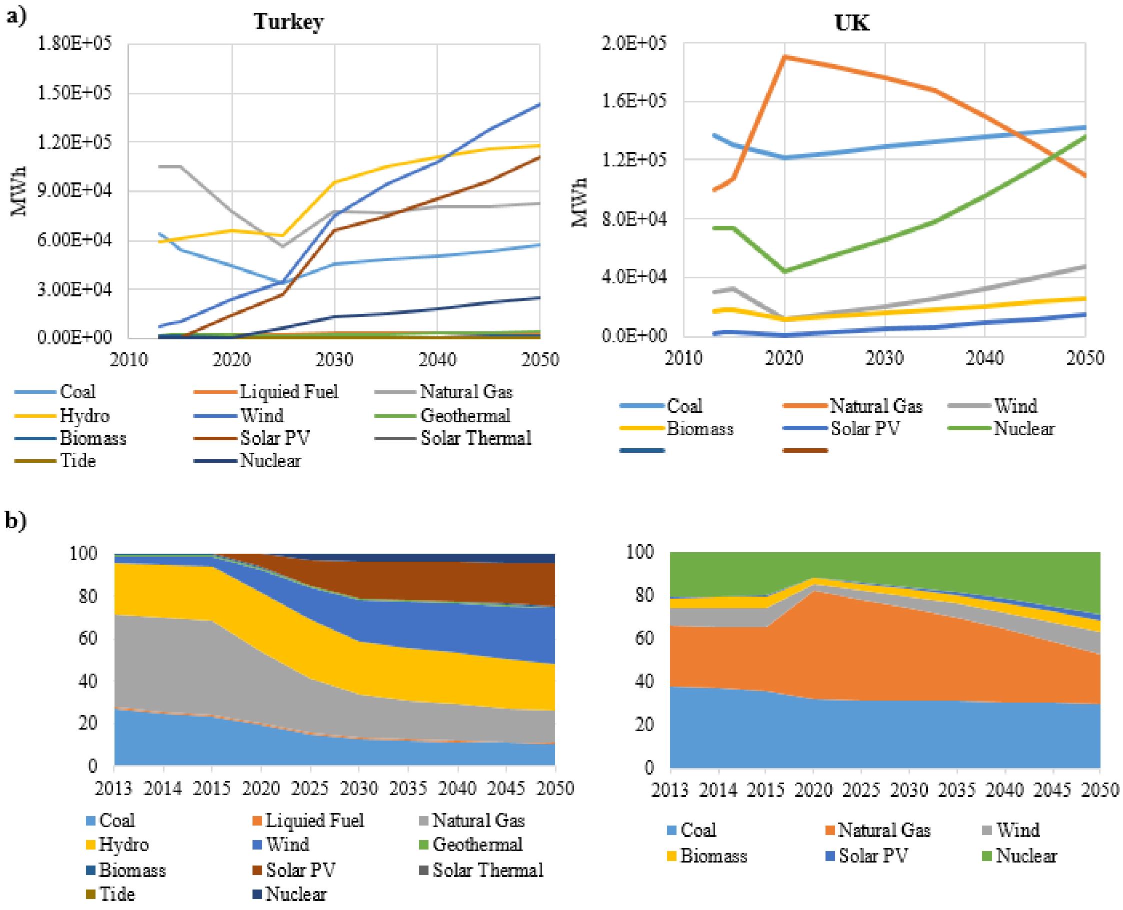

FIGURE 2.6: Go green Plan scenario for Turkey and UK (a) Electricity production in MWh by energy sectors, (b) Percentage electricity production by energy sectors

For Turkey the Go green scenario was obtained from the report of World Wide Fund (WWF) which was prepared by Berke [80]. The Go green scenario was developed for turkey to achieve reduction in natural gas use for electricity production to 26% by 2030, reducing coal share to just 18% by 2030 while production of electricity by wind will contribute 55% and solar will share 30% of the total electricity production by 2030. For UK, the go green plan was developed by Stamford [76], which is one of the extreme plans to cut down carbon emission by 100%. This will reduce the total energy demand by 30% in 2070 but will increase the electricity demand by 60% due to shift in electrical energy from the combustion engines. This scenario will enable us to analysis the maximum impact conserving environment will have on our scare mineral resources if extreme policies are taken.

Figure 2.6 (a) compares the environmental conservation energy policy of Turkey with UK. It can be seen that increase in the electricity supply from the renewable energy sources in Turkey has reduced electricity production share of the nonrenewable ones like coal and natural gas. While for UK one notable pattern is of natural gas which shows peak production of electricity in 2020 and then keep on decreasing till 2050. Nuclear energy show a considerable upwards trend in terms of usage for electricity for UK in this scenario. Figure 2.6 (b) shows that for Turkey by 2050, all the energy sources will come to have a more equal share as non-renewables source of energy has increased its share continuously from 2013 to 2050. While UK has tried to cut its increasing natural gas share.

Chapter 3

Results and Discussions

3.1 Results and Discussions

As can be seen from Figure 3.1 that both country's electricity need will be heavily dependent on coal and natural gas, these sources should be given additional weightage while policy making. Figure 3.1 (a) represents the metallic mineral consumption of both countries in kilograms. For Turkey, it is obvious that Iron, Aluminum, Tin and Uranium consumption is high and the main contributor of this high consumption pattern is production of electricity by coal. It can also be seen that in 2050 about 84% of the metallic mineral consumption will be by electricity production from coal. While for UK electricity production from natural gas is responsible for 85% share of metallic minerals consumption. Tin ores will be at high pressure in terms of consumption under scenario 1 for UK, constituting about 44% of the total metallic mineral consumption while Iron ore consumption will be the highest. Production of electricity by coal will increase its share of metallic mineral consumption in BAU scenario. It can be seen from the Figure 3.1 (b) that in 2050 UK's iron ore consumption will increase to about 840 tones in OP scenario. Another notable observation is that UK's minerals consumption by electricity production from coal will be 53% of the total metallic mineral consume. However contrasting scenario BAU and OP with the go green plan shown in Figure 3.1 (c) that the total metallic mineral consumption of both the countries will decrease. That is due to more stress on producing electricity from nuclear energy which has comparatively low mineral consumption rate per unit KWh. Electricity production in Turkey by geothermal, wind and hydro will increase percentage share in metallic mineral consumption in 2050 under

Go green scenario. Therefore, analyzing electricity production under different scenarios, we labeled Coal*, Natural Gas*, Wind*, Solar* and Hydro* as the critical energy sources for Turkey while Coal*, Natural Gas*, Wind* and Nuclear* for UK in our research as shown in Table 2.3. The asterisk '*' sign refers to the critical nature attitude of the entity. It can be noted that for UK in Scenarios 1 and 3 the critical sources of energy will be natural gas, coal and nuclear while natural gas and coal will be only for Scenario 3.

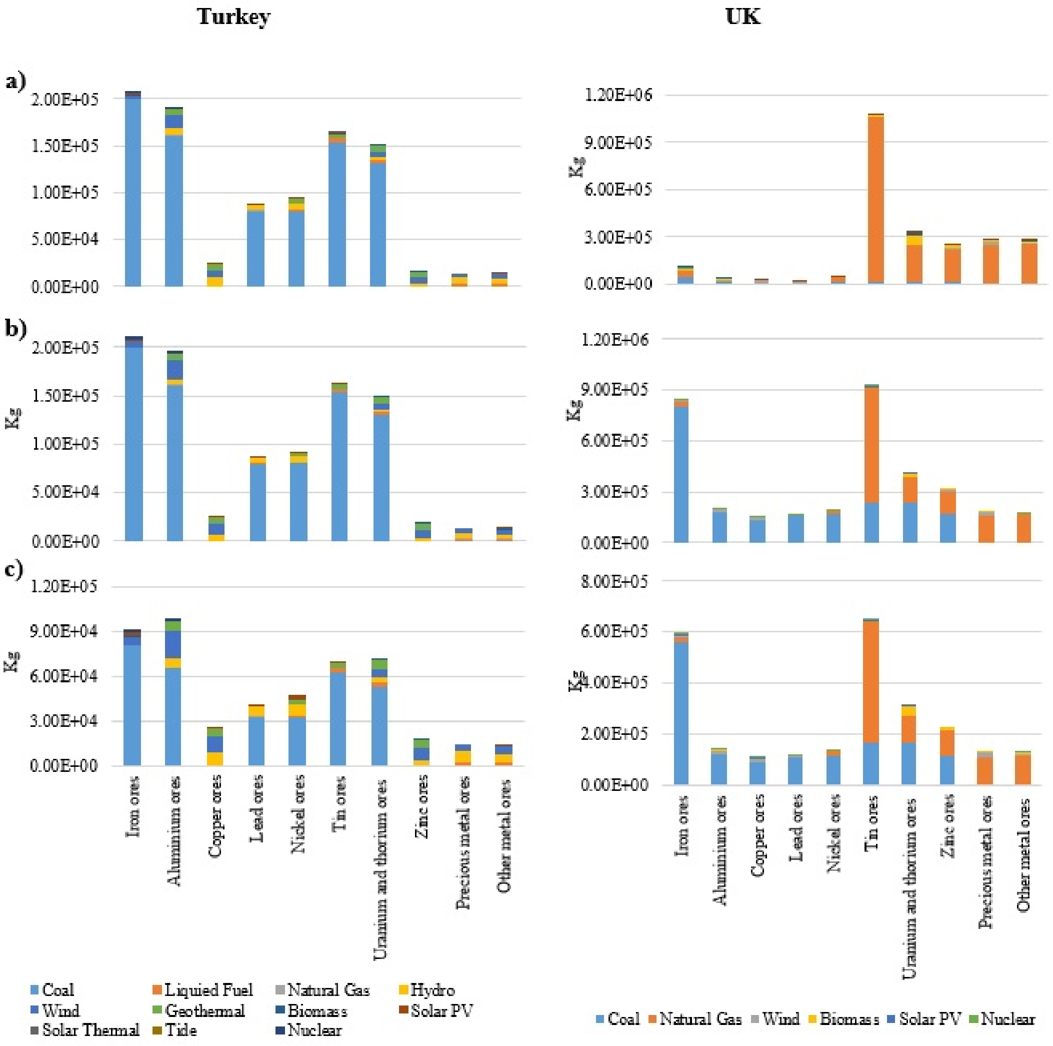

FIGURE 3.1: Metallic minerals consumption in Kg for Turkey and UK in 2050 for (a) scenario, 1 (b) scenario 2 and (c) scenario 3

For Turkey as can be seen from Figure 3.2 (a) that nonmetallic mineral consumption for Turkey is largely caused by the production of electricity from coal like it was for metallic minerals while for UK it is the production of electricity by natural gas that exhaust most of the nonmetallic minerals. It can be observed that production of electricity by

Table 3.1: Critical energy sources for each scenario

	Turkey	**UK**
Scenario 1	Coal, Hydro, Wind	Coal, Natural gas, Nuclear
Scenario 2	Wind, Coal, Hydro, Solar PV	Coal, Natural gas
Scenario 3	Wind, Hydro, Solar PV, Natural gas	Coal, Natural gas, Nuclear

coal in Turkey will be responsible for 80.3% of the nonmetallic mineral consumption in 2050. While for UK production of electricity by Natural gas constituted 79% if the total nonmetallic minerals consumption share. Another notable observation is that UK will have much lesser consumption of slate, other industrial material, salt and other construction material in comparison with Turkey to meets its electricity need in 2050. It's hard to distinguish critical materials from the non-critical ones under all scenarios as all the energy sources electricity production differ by a close margin. Fig. 3.2 (b) shows that with regard to nonmetallic mineral consumption there is not a significant observable change in scenario 1 and scenario 2 for Turkey while for UK the production of electricity by coal will constitute to about 41% of the nonmetallic mineral consumption in 2050. The combine share of nonmetallic mineral consumption by electricity production from coal and Natural gas in UK will be 95.5%. Hence in scenario 2 these two energy sources will be critical for mineral consumption by electricity production in UK. Fig. 3.2 (c) shows that in go green scenario the nonmetallic mineral consumption for both of the countries drop. In scenario 3 UK will increase its electricity production from Nuclear energy therefore it can be seen from the figure that Nuclear energy will increase its percentage share of nonmetallic mineral consumption in 2050.

From the analysis done from both figures of metallic and non metallic consumption, three energy sources will be marked critical for Turkey and UK. Table 3.1 shows the critical energy sources identified under different scenarios from these figures. Now from the critical material identification, we will focus our analysis on these minerals to further break down their supply chain impacts and reach at the major root causes of these consumption. Now summarizing the results from Figure 3.1 and Figure 3.2 under the three scenarios, it can be concluded that for electricity production by Coal*, Hydro* and Wind* in Turkey under Business-as-usual scenario will constitute 72% of the proportion of total minerals consumption in 2050. For 90% of the total mineral consumption will be by Coal*, Hydro* and Wind*. Therefore, the priority should be placed on reducing the iron* consumption from the energy production by coal in these countries.

From Figure 3.2 it can also be noted that for non-metallic critical mineral like chemical and fertilizer's* consumption ranges from 70% to 90% under all three scenarios when electricity production is by coal* in Turkey. For UK, it is Natural gas* and nuclear* which constitute a significant proportion for chemical fertilizer composition in scenario 1 and 2. Tin ore* will cause 27% of the total mineral consumption for Turkey in Scenario 1 in 2050 while for UK its Iron, Aluminum and Tin ore consumption will be 35% of the total mineral consumption in Scenario 1. Figure 3.2 (a) shows that slate's consumption was least in the scenario 1 with around 10,000Kg and electricity production by hydro. Production of electricity by geothermal energy contributed to very less minerals consumption comparatively. Likewise for UK in Scenario 1, the consumption of chemical fertilizers, clays, limestone and building stones was significantly large as compared to the other non-metallic minerals and this trend is maintained in all the scenarios. Figure 3.2 (b) shows that for Turkey the total nonmetallic mineral consumption decreases slightly but the trend remains the same like in scenario 1. While UK's stress on the nonmetallic minerals decreases slightly and production of electricity by coal increases, its share significantly in minerals consumption and the percentage consumption by electricity production from nuclear energy decreases. Figure 3.2 (c) shows that for Turkey and UK, the overall nonmetallic mineral consumption decreases considerably while production of electricity by hydro will increase its share of mineral consumption in this scenario. For UK, in Scenario 3, production of electricity by nuclear will increase its share as compared to Scenario 2.

Thus, summarizing the findings, Turkey's production of electricity by coal* is heavily responsible for consumption of both metallic and non-metallic minerals under all three scenarios. For UK, coal* and natural gas* constitute a great proportionate of consumption of the minerals while for Turkey it is just coal*. Hence, for Turkey, the energy production by coal will treated as critical according to these figures. Remember that coal was also treated as critical in Table 3.1 thus adding to the degree of criticality. We will have more analysis on the critical sources of energy and will try to go through the causes that make them critical. Second notable observation is that for Scenario 1 for Turkey will lead towards greater consumption of the overall minerals while scenario 3 will cause the least consumption. For UK, it will be vice versa. The third observation is the critical minerals can be identified which are those under pressure to meet electricity production demand. The critical metallic and nonmetallic minerals identified are

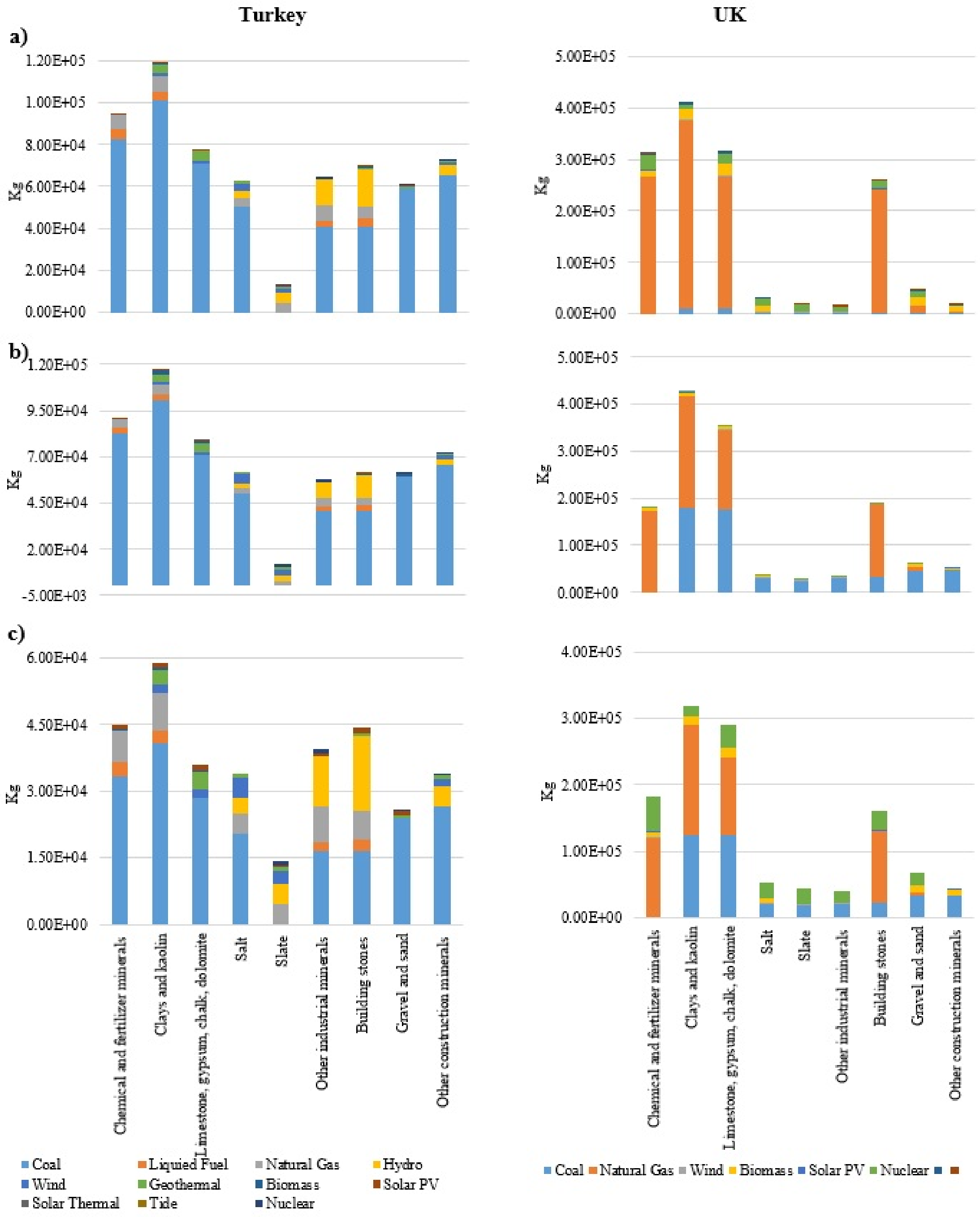

FIGURE 3.2: Nonmetallic minerals consumption in Kg for Turkey and UK in 2050 for (a) scenario, 1 (b) scenario 2 and (c) scenario 3

Table 3.2: Critical metallic minerals identified

	Turkey	**UK**
Scenario 1	Iron, Aluminum, Tin, Uranium	Tin, Uranium, precious metal
Scenario 2	Iron, Aluminum, Tin, Uranium	Iron, tin, uranium
Scenario 3	Iron, Aluminum, Tin, Uranium	Iron, tin, uranium

Table 3.3: Critical nonmetallic minerals identified

	Turkey	**UK**
Scenario 1	Chemical, clays, limestone	Chemical, clays, limestone
Scenario 2	Chemical, clays, limestone	Clays, limestone, building materials
Scenario 3	Clays, limestone, building materials	Chemical, clays, limestone

summarized in Table 3.2 and Table 3.3, respectively.

After analyzing the critical energy sources and minerals for both Turkey and UK, Figure 3.3 helps to identify percentage wise consumption of the metallic and nonmetallic minerals. It can be seen that for electricity production in Turkey by coal, all minerals share almost the same consumption share in all scenarios. It shows the metallic minerals percentage consumption in kilograms under different scenarios. From Figure 3.3 (a) it can be seen that in Scenario 1 all energy sources of electricity production have a great mix of metallic mineral consumption accept for the nuclear energy in Turkey and the trend is similar for UK. Figure 3.3 (b) and Figure 3.3 (c) show the percentage share of metallic mineral consumption by each energy source.

In contrast with the nonmetallic minerals percentage consumption as shown in Figure 3.4 (a), for Scenario 1 in Turkey shows a very significant finding that for Turkey the nonmetallic mineral consumption share will remain the same in scenario 2 and 3 while it will differ widely for UK as can be seen from Figure 3.4 (b) and Figure 3.4 (c). It can also be noted that since chemical fertilizer's* consumption for Turkey will decrease in Scenario 3 because production of electricity by nuclear energy will cause the least consumption of chemical fertilizer.

Figure 3.5 shows the mineral consumption in Kilograms per unit euro for one KWh of electricity production by the respective energy sources. For Turkey, it can be seen from that electricity production by coal* has the greatest consumption of metallic minerals like Iron*, Bauxite* and Tin* for per unit KWh of electricity produced. While Tin*, Aluminum* and precious metal* are consumed heavily by electricity production by gas* and oil in UK. In Turkey, if one KWh of electricity is produced by each energy source than coal, natural gas and oil will cause 81% of the total mineral consumption. Also,

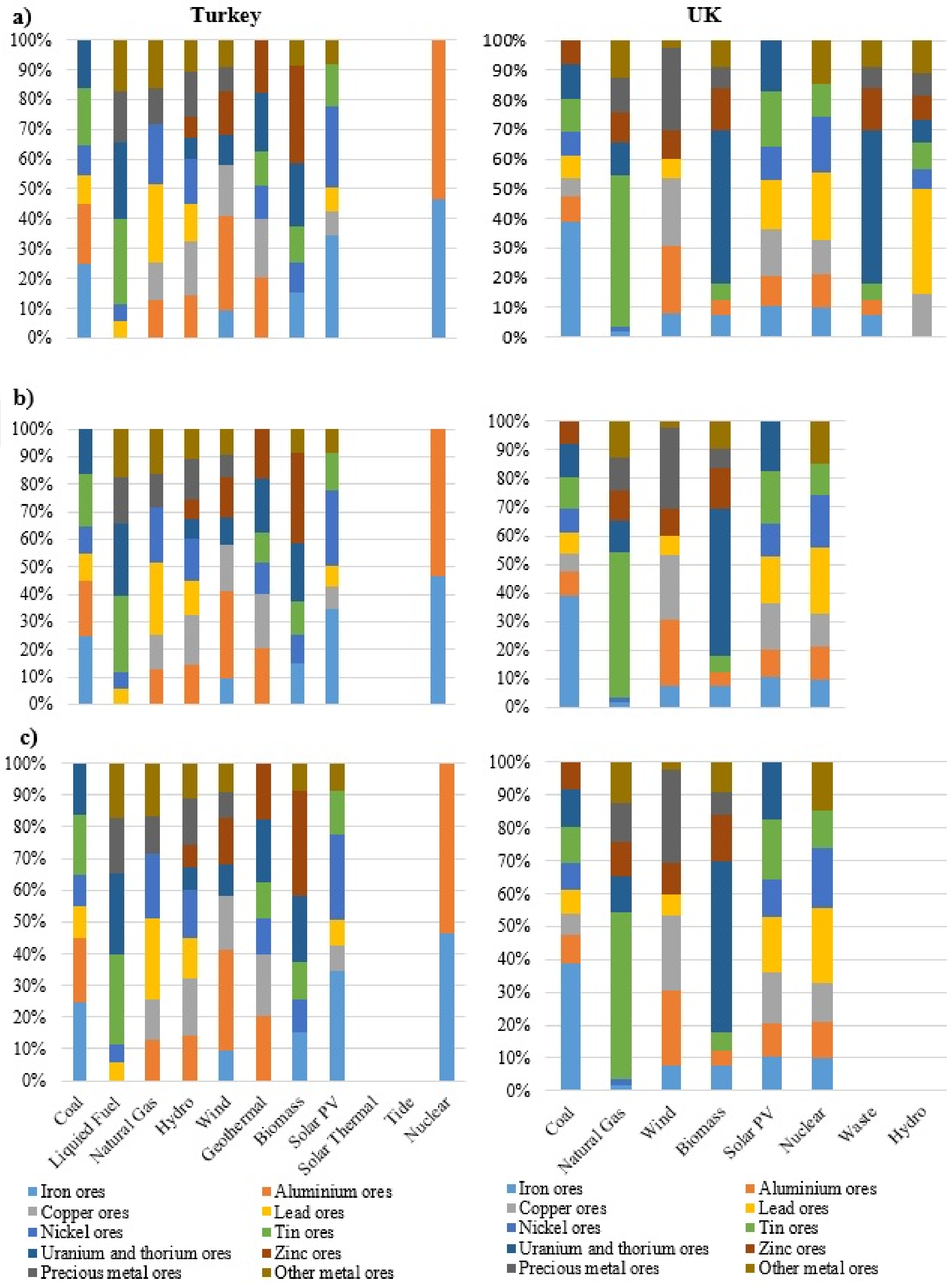

FIGURE 3.3: Metallic minerals percentage consumption in Kg for Turkey and UK in 2050 for (a) scenario, 1 (b) scenario 2 and (c) scenario 3

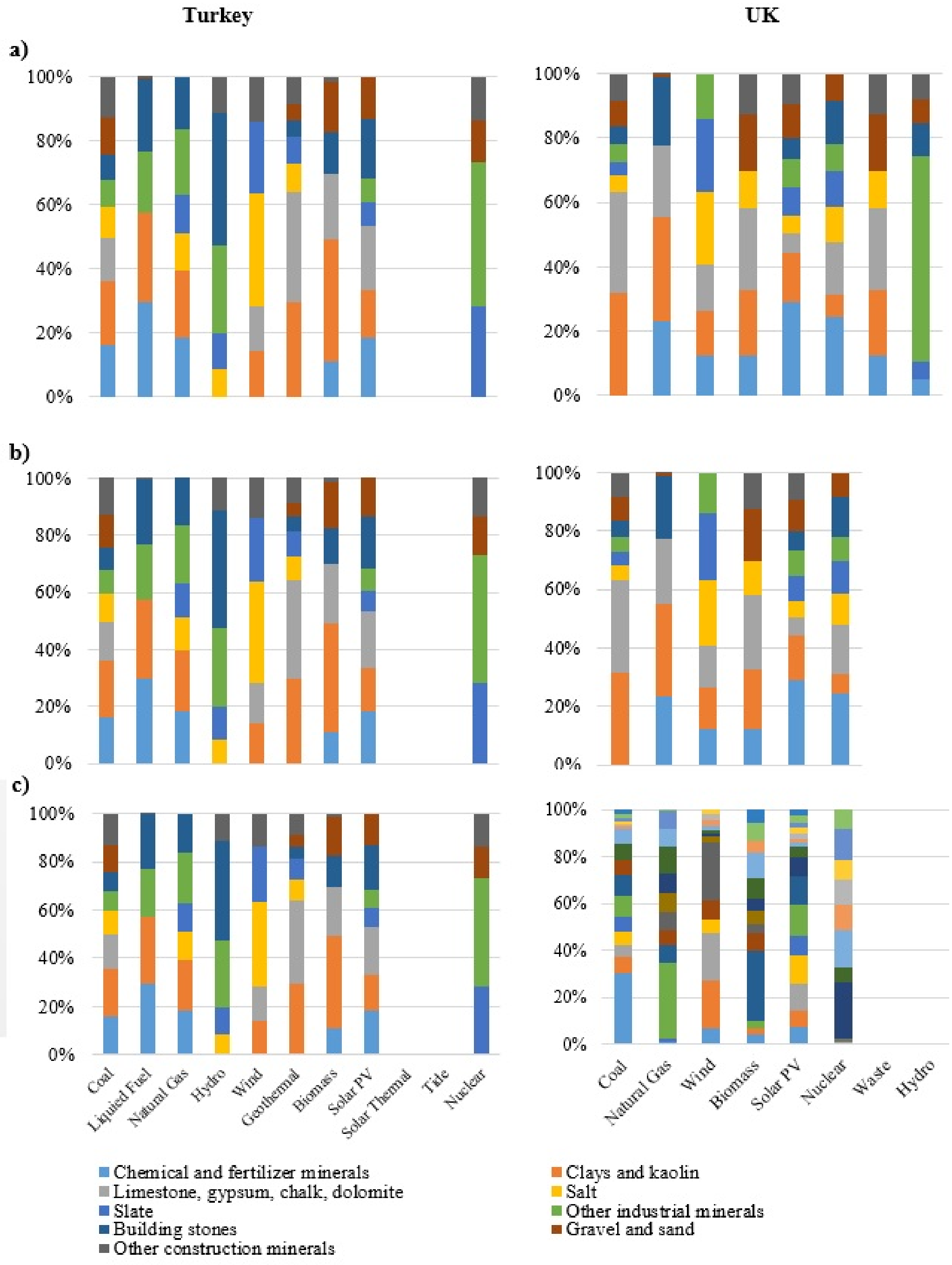

FIGURE 3.4: Non-Metallic minerals percentage consumption for Turkey and UK in 2050, under (a) scenario 1, (b) scenario 2 and (c) scenario 3

Turkey will have highest proportion of Uranium per unit of euro consumption while UK will have of Aluminum. It can also be observed that iron ore is consumed heavily by all sources of electricity production for Turkey.

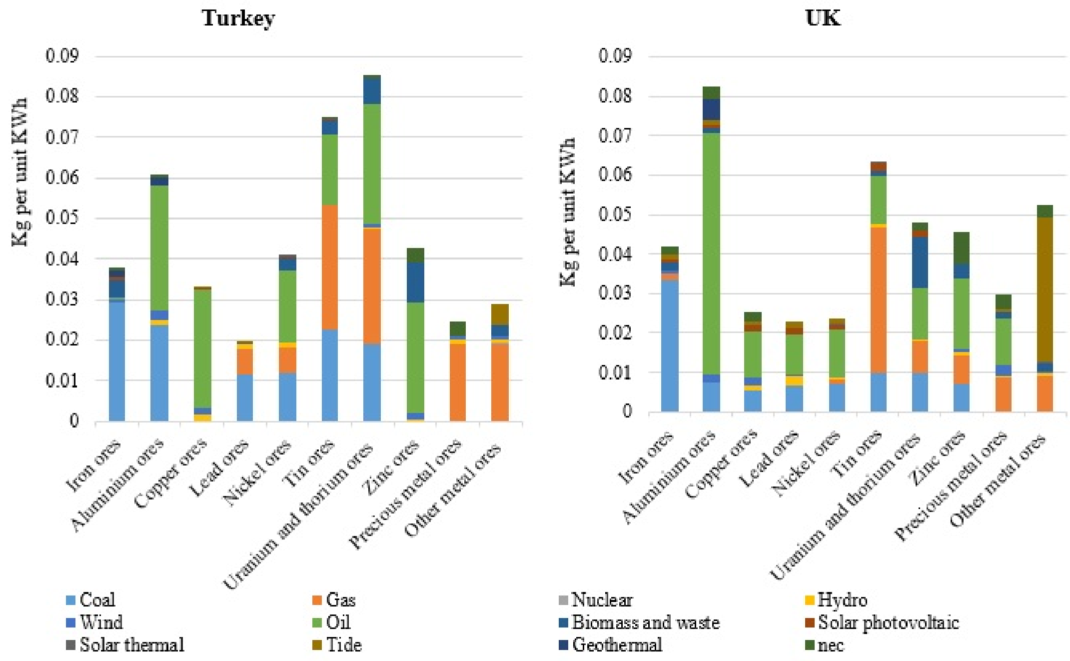

Figure 3.5: Metallic minerals consumption in Kg per unit KWh of electricity produced by Turkey and UK in 2007

Like wise Figure 3.6 shows the mineral consumption in Kg/Euro for non metals. It can be seen that electricity production by gas has a greater mix in the resource consumption by both the countries. The second most non metallic mineral resource consuming energy source is oil. While lead ores are least consumed by each of the energy sources.

Figure 3.7 shows the projection of total material consumption up to 2050 under different scenarios. As can be seen that the consumption of mineral in Turkey will be rising due to increase in energy demand while it will be same for UK. Figure 3.7 (a) and (b) shows that general trend for both the countries will remain the same.

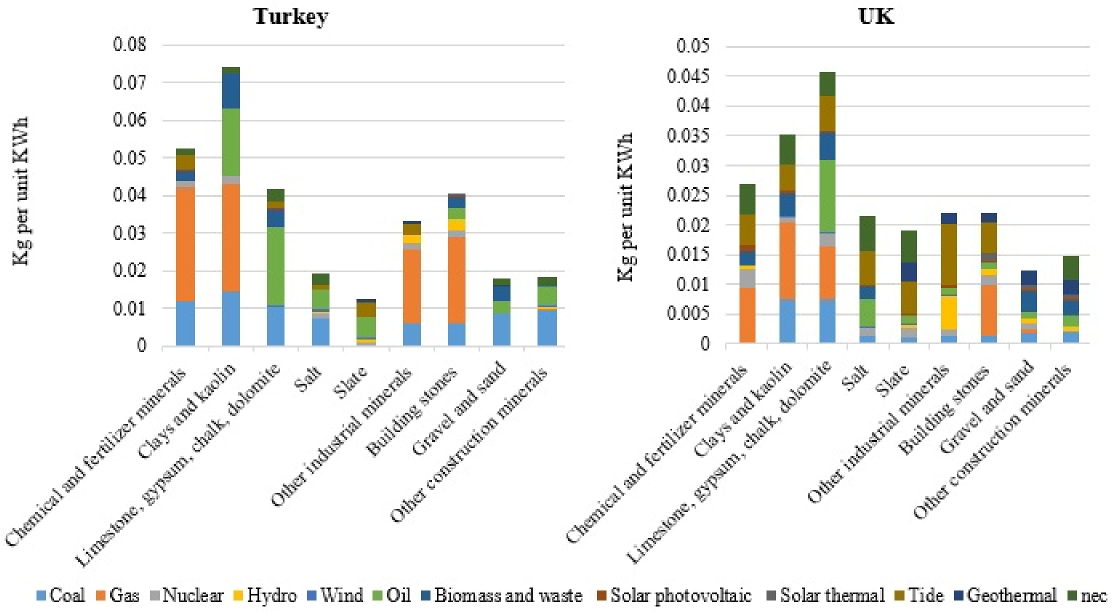

FIGURE 3.6: Nonmetallic minerals consumption in Kg per unit KWh of electricity produced by Turkey and UK in 2007

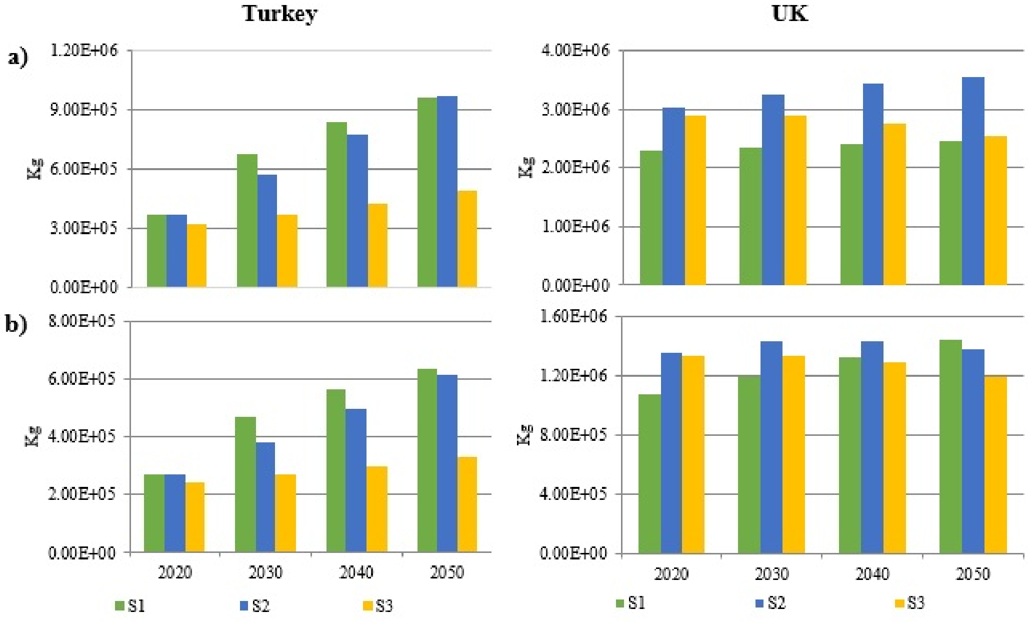

FIGURE 3.7: Nonmetallic minerals consumption in Kg per unit KWh of electricity produced by Turkey and UK in 2007

Chapter 4

Discussion and Conclusions

4.1 Results and Discussions

This research is the first in-depth study for the environmental footprints of the limited minerals resources which by the help of MRIO framework and Leontief inverse helped to establish a relation with production of electricity by different energy sources for Turkey and UK. The results showed the effect of electricity production from different sources will have on different minerals consumed. The results showed what effect one economic activity will have on the consumption by other regions. The results also helped us to break down supply chain to find out the major contributor towards the critical resource consumption. Furthermore, to extend our analysis we used ARIMA forecasting, three scenarios were used for both countries to have a complete overview of the mineral consumptions. Some very important conclusions were reached from the findings which are discussed below.

The production of electricity by coal in 2050 forecasted will alone be responsible for Turkey's consumption for 83.7% of all the metallic minerals and 80.3% for the nonmetallic minerals in Scenario 1 and it will almost be the same for scenario 2. However, in scenario 3 the metallic mineral consumption by coal will be 66.4% and 62.3% for nonmetallic minerals. Thus to reduce pressure on minerals consumption Turkey should follow scenario 3. For UK in 2050 it will the production of electricity by coal and natural gas that will consume most of the resources. In scenario 1 production of electricity by Natural gas alone will be responsible for 84.6% consumption of the metallic minerals while 81.4% for the nonmetallic minerals. However in scenario 2, production of electricity by coal and natural gas combined will cause 96% of the metallic mineral consumption and 95.3% of the nonmetallic minerals. Therefore stress should be on to reduce the dependencies on coal and natural gas UK for producing electricity under scenarios 2 and 3. Metallic mineral consumption of UK in 2050 in scenario 2 will be 45% and in scenario 3 will be 3.5% more than scenario 1. Therefore scenario 3 is most feasible for UK to follow which also considers carbon emission along with mineral consumption. According to the result of mineral consumption per unit euro for 1 KWh of electricity produced in Turkey, production of electricity by coal, liquid fuel and natural gas consumes significant amount of both metallic and nonmetallic minerals while for UK its electricity production by coal and natural gas.

This thesis is a vital development for establishing a global integrated version of MRIO analysis with meteorological impact of economic activities pertaining to different regions. A number of research were aimed at investigating the process aspect of the supply chain only while in this thesis we addressed the global supply chain of the minerals resources and the activities associated with their consumption. The authors will continue to analysis the minerals footprint for the EU countries and developing a Tripple Bottom Line (TBL) model which will be the extension of this work. The programming code developed in this research can also be used to find out the impact any economic activity in a particular region will have on the resources of the other regions. There can be numerous analyses that can be derived from the results generated by this research to monitor the environmental sustainability and policy making.

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