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Energy-climate-manufacturing nexus: New insights from the regional and global supply chains of manufacturing industries

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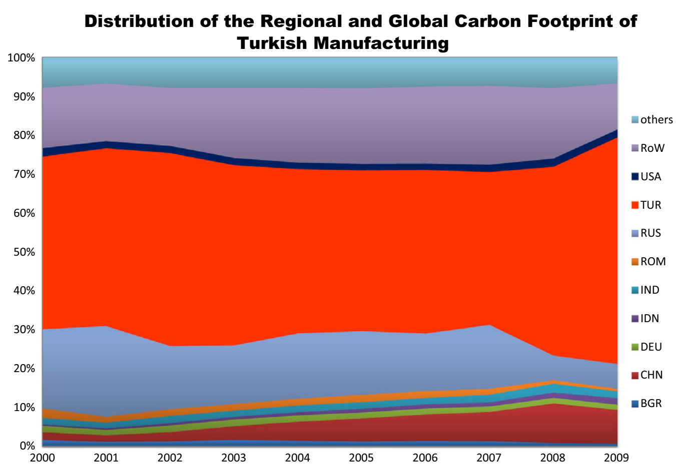
HIGHLIGHTS

- A multi region input–output sustainability assessment model is developed.
- Energy-climate-manufacturing nexus within the context of global supply chains is investigated.
- Electricity, Gas, and Water Supply sector is the main contributor to energy and carbon impacts.
- Turkish regional manufacturing accounts for approximately 40–60% of total carbon emissions.
- China, USA, and Rest-of-the World have the largest shares in the Turkish global energy footprint.

GRAPHICAL ABSTRACT



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ABSTRACT

The main objectives of this research are to improve our understanding of energy-climate-manufacturing nexus within the context of regional and global manufacturing supply chains as well as show the significance of full coverage of entire supply chain tiers in order to prevent significant underestimations, which might lead to invalid policy conclusions. With this motivation, a multi region input–output (MRIO) sustainability assessment model is developed by using the World Input–Output Database, which is a dynamic MRIO framework on the world's 40 largest economies covering 1440 economic sectors. The method presented in this study is the first environmentally-extended MRIO model that harmonizes energy and carbon footprint accounts for Turkish manufacturing sectors and a global trade-linked carbon and energy footprint analysis of Turkish manufacturing sectors is performed as a case study. The results are presented by distinguishing the contributions of five common supply chain phases such as upstream suppliers, onsite manufacturing, transportation, wholesale, and retail trade. The findings showed that onsite and upstream supply chains are found to have over 90% of total energy use and carbon footprint for all industrial sectors. Electricity, Gas and Water Supply sector is usually found to be as the main contributor to global climate change, and Coke, Refined Petroleum, and Nuclear Fuel sector is the main driver of energy use in upstream supply chains. Overall, the largest portion of total carbon emissions of Turkish manufacturing industries is found in Turkey's regional boundary that ranged between 40% and 60% of total carbon emissions. In 2009, China, United States, and Rest-of-the-World's contribution is found to

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be more than 50% of total energy use of Turkish manufacturing. The authors envision that a global MRIO framework can provide a vital guidance for policy makers to analyze the role of global manufacturing supply chains and prevent significant underestimations due to inclusion of limited number of tiers for sustainable supply chain management research.

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1. Introduction

According to the World Energy Outlook Energy Special Report published by the International Energy Agency, the world is unfortunately not on the track to achieve the global climate change targets set by the world leaders and we are running out of time to mitigate the rise of global temperature to 2 degrees Celsius [1]. While we have already fallen far behind the sustainable development goals that we have to reach for our common future, the human beings have found themselves in the midst of the environmental, economic, social and political problems fueled by lack of an energy security and steeply rising carbon emissions. European economy has also become an energy and resource dependent economy and vulnerable to rising energy prices and raw material supply shocks [2]. These facts inevitably lead the policy makers to take solid actions toward a greener and resource efficient economy, and therefore the European manufacturing industry has been identified as one of the most important policy areas that need urgent attention.

Statistics indicate that, European manufacturing represented approximately 26.8% of the European Union (EU)'s GDP and 22.6% of its employment, providing more than 30 million jobs [2]. While manufacturing activities contribute significantly to the European economies and create critical socio economic benefits to the societies, their shares in the overall energy consumption and global climate change impacts are also considerably high compared to other industries due to the resource and energy intensity embed in the processes. Recent reports indicated that manufacturing sectors responsible for substantial amount of greenhouse gas (GHG) emissions in the Europe, which are the third largest contributors after the power generation and transportation sectors [3]. In addition, European manufacturing is responsible for around 25% of total energy consumption, which is the third biggest energy consumer industry after the transportation sector and household consumption [2].

Sustainable manufacturing has inevitably become an integral part of EU's sustainable development plans to support the EU's 2020 strategic plan on promoting sustainable industrial growth through low-carbon and energy-efficient production and economy [4]. To realize these goals, the European Union developed an integrated policy strategy for climate and energy policies which aims to combat with global climate change and improve the EU's energy security, simultaneously [5]. Such an integrated approach is necessary since energy consumption and climate change are fundamentally connected issues and it is not practical to look at these environmental challenges in isolation (WBCSD, 2009). In this regard, EU's 2020 strategies on analyzing 'energy-climate nexus' are covered under the '20–20–20' targets and identified as accomplishing a 20% reduction in GHG emissions from 1990 levels, raising the share of renewable energy resources to 20%, and having a 20% improvement in the EU's energy efficiency [4]. In parallel with the EU's '20-20-20' targets, the Turkish Ministry of Environment and Urban Planning has recently made the carbon footprint reporting mandatory for industrial facilities and started to develop pilot projects on carbon emissions of selected industrial sectors. Based on the information released in the Ministry's official website, manufacturing sectors in Turkey must annually measure, report and validate their carbon emissions starting from 2015 [6]. Furthermore, the Turkish Ministry of Energy and Natural Resources developed an energy strategy plan in which a 20% primary energy intensity reduction is targeted for 2023 compared with the 2008 level [7].

To realize sustainable development goals based on the aforementioned climate and energy strategies, sustainability impacts of European and Turkish manufacturing have to be analyzed from a supply chain perspective. The supply chain encompasses all activities associated with the flow of goods and information from raw material extraction and processing through the customer [8]. The concept of sustainability in the supply chain management has become a topic of considerable interest worldwide and highly discussed in the regional policy making [9–15]. Especially, system thinking in sustainable supply chain management is very crucial due to the fact that environmental impacts are variably located in the first, second, third, and even higher tiers of the supply chains of the manufacturing sectors. The results of past studies also indicated that focusing solely on the onsite or limited tiers of upstream supply chain impacts could result in significant underestimation about the overall impacts, which might lead to invalid policy outcomes [16–18].

In the literature, process-based life-cycle assessment (LCA), economic input-output based LCA, and hybrid LCA are extensively used to quantify the environmental impacts of products or processes [19–22]. In fact, when focusing on the holistic environmental burdens of large-scaled systems such as industrial sectors, Input–Output (I–O) based sustainability assessment models are more comprehensive approaches, which provide a macro-level analysis [23–26]. The necessity of using system-based I–O models arises from the fact that process-based models involve the limited number of processes and inclusion or exclusion of processes is decided on the basis of subjective choices, which create the so-called system boundary problem [22,27]. Earlier studies on the carbon and energy footprints of economic sectors showed that process-based life-cycle inventories suffer from significant truncation errors which can be order of 50% or higher [18,28–30]. At this point, I–O based models provide a top-down analysis that uses sectoral monetary transaction matrixes considering complex interactions between the sectors of national economies [31–33]. I–O analysis is widely used and accepted as a suitable methodological approach for calculation of energy and carbon footprints [34–38]. Although, the majority of studies using I–O analysis were case studies that focus on carbon or energy footprint analysis of a single country for a single year [39], a Multi Region Input-Output (MRIO) analysis is critical in order to take into account the role of international trade over a period of time [40–42]. This is important since the majority of countries in the world prefer open economic structure, which allows the importing goods and services from foreign countries. Hence, single-region models could lead to erroneous results due to unrealistic domestic technology assumption [43,44].

In this regard, MRIO models have extensively used in carbon and energy footprint studies [45–49]. Currently, there are a number of global MRIO models available in the literature and/or online. These databases are named as EoRA, Externality Data and Input-Output Tools for Policy Analysis (EXIOPOL), Global Trade Analysis Project (GTAP), and World Input-Output Database (WIOD)

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