Revealing the regional and global carbon and energy hotspots of Turkish Manufacturing Supply Chains: A global multiregional input-output analysis

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Declaration of Authorship

I, Bünyamin CANSEV, declare that this thesis titled, 'Revealing the regional and global carbon and energy hotspots of Turkish Manufacturing Supply Chains: A global multiregional input-output analysis' and the work presented in it are my own. I confirm that:

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Date: 28. 12. 2016

“Under capitalism, man exploits man. Under communism, it’s just the opposite. ”

John Kenneth Galbraith

Revealing the regional and global carbon and energy hotspots of Turkish Manufacturing Supply Chains: A global multiregional input-output analysis

Bünyamin CANSEV

Abstract

This thesis analyzes the energy-climate-manufacturing nexus within the context of regional and global supply chains. Also this shows 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. The World Input-Output Database, which is a dynamic MRIO framework on the world's 40 largest economies covering 1445 economic sectors, is used to develop MRIO model.

The method presented in this study is the first environmentally-extended MRIO model that harmonizes energy and carbon footprint accounts for Turkish manufacturing sectors. Moreover, a global trade-linked carbon and energy footprint analysis of Turkish manufacturing sectors is performed as a case study. The results were 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 was 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 was found in Turkey's regional boundary that ranged between 40 to 60% of total carbon emissions. In 2009, China, United States, and Rest-of-the-World's contribution is found to be more than 50% of total energy use of Turkish manufacturing.

This thesis envisions 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.

Keywords: Energy-Climate-Manufacturing Nexus; Multi-Region Input-Output Analysis; World Input-Output Database; Global Supply Chains; Sustainable Manufacturing

Türk Sanayi Tedarik Zincirinin Bölgesel ve Küresel Karbon - Enerji Etkin Noktalarının Açığa Çıkarılması: Bir Küresel Çok Bölgeli Girdi-Çıktı Analizi

Bünyamin Cansev

Öz

Bu tez, enerji-iklim-üretim irtibatını bölgesel ve küresel tedarik zinciri bağlamında analiz etmektedir. Ayrıca, geçersiz politika yargılarına neden olan eksik değerlendirmeleri engellemek için, bütün tedarik zinciri aşamalarının kuşatılmasının önemini göstermektedir. Bu motivasyonla, bir çok bölgeli girdi-çıktı sürdürülebilirlik analiz modeli geliştirildi. Bu modelin geliştirilmesi için 'World Input-Output Database' isimli, dünyanın 40 büyük ekonomisini ve 1445 ekonomik sektör için verileri kapsayan veritabanı kullanıldı.

Bu çalışmadaki metod, Türkiye'deki üretim sektörlerinin enerji ve karbon ayakizi hesaplamaları için uyumlu olacak şekilde genişletilmiş ilk modeldir. Ayrıca, bu üretim sektörlerinin, küresel ticaret ile bağlantılı karbon ve enerji ayakizi analizi vaka çalışması olarak uygulanmıştır. Sonuçlar 5 ortak tedarik zinciri aşamalarının ayrımını yaparak sunuldu. Bulgular, her bir endüstriyel sektörün tedarik zincirindeki 'onsite' ve 'upstream' aşamalarının karbon ayakizi ve enerji kullanımının %90' dan fazlasından sorumlu olduğunu gösterdi. Elektrik, Gas ve Su Üretimi sanayi küresel iklim değişikliğinin, Nükleer yakıt, Rafine petrol ve Kömür sanayi ise enerji kullanımının, tedarik zincirinin 'upstream' aşamasındaki ana sağlayıcısı olarak bulunmuştur. Genel itibariyle, Türk sanayinin karbon salınımının en büyük kısmı %40 ve %60 arasında Türkiye sınırları içinde olduğu bulunmuştur. Türk sanayinin 2009 yılında enerji kullanımının %50' den fazlası Çin, Amerika Birleşik Devletleri ve kullanılan veritabanında 'Rest of the World' olarak tanımlanmış, 40 büyük ekonomi dışındaki ülkeler olarak tespit edildi.

Bu tez, küresel Çok Bölgeli Girdi-Çıktı(MRIO) modeliyle politika yapıcıları için küresel üretim tedarik zincirinin rolünü analiz edebilmeyi ve tedarik zincirinin tamamını kapsamayan eksik değerlendirmelerin önüne geçmeyi sağladığını göz önüne sermektedir.

Anahtar Sözcükler: Enerji-İklim-Üretim Bağlantısı; Çok Bölgeli Girdi-ÇıktıAnalizi; World Input-Output Database; Küresel Tedarik Zinciri; Sürdürülebilir Üretim

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Abbreviations

GHG	**G**reen **H**ouse **G**ases
EU	**E**uropean **U**nion
I-O	**I**nput **C**ycle **O**utput
MRIO	**M**ulti **R**agional **I**nput **O**utput
WIOD	**W**orld **I**nput **O**ouput **D**atabase
NAS	**N**ational **A**ccounts **S**tatistics
AHFF	**A**griculture **H**unting **F**orestry and **F**ishing
BMFM	**B**asic **M**etals and **F**abricated **M**etal
CCP	**C**hemicals and **C**hemical **P**roducts
CRPNF	**C**oke **R**efined **P**etroleum and **N**uclear **F**uel
EOE	**E**lectrical and **O**ptical **E**quipment
FBT	**F**ood **B**everages and **T**obacco
LLF	**L**eather **L**eather and **F**ootwear
MN	**M**achinery **N**ec
MNR	**M**anufacturing **N**ec **R**ecycling
MQ	**M**ining and **Q**uarrying
ONMM	**O**ther **N**on **M**etallic **M**ineral
PPPPP	**P**ulp **P**aper **P**aper **P**rinting and **P**ublishing
RP	**R**ubber and **P**lastics
TTP	**T**extiles and **T**extile **P**roducts
TE	**T**ransport**E**quipment
WPWC	**W**ood and **P**roducts of **W**ood and **C**ork
RoW	**R**est **o**f **W**orld
GWP	**G**lobal **W**orming **P**otential
EPA	**E**nvironmental **P**rotection **A**gency

TJ	**T**era **J**oules
T+W+R	**T**ransportation **W**holesale **R**etail
EGWS	**E**lectricity and **G**as of **W**ater and **S**upply
TBL	**T**riple **B**ottom **L**ine
LCSA	**L**ife **C**ycle **S**ustainabily **A**ssessment
LCA	**L**ife **C**ycle **A**ssessment
LCC	**L**ife **C**ycle **C**osting
SLCA	**S**ocial **L**ife **C**ycle **SA**ssessment
ISO	**I**nternational **O**rganization for **S**tandardisation

Chapter 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 middle of the environmental, economic, social and political issues fueled by absence of an energy security and steeply increasing carbon emissions. European economy has also become an energy and resource dependent economy and exposed to increasing 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 asone 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 colossally high in comparison with 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].Going along 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 colossal interest globally and highly discussed in the regional policy making [9–15]. Especially, system thinking in sustainable supply chain management is very crucial by virtue of the fact that environmental impacts are variably located in the first, second, third, and even higher tiers of the supply chains of the manufacturing industries. 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].

This thesis analyzes the carbon and energy footprints of Turkish manufacturing industries with regard to international supply chain between 2000 and 2009. In roder to achieve this goal, economic input-output based LCA approach is used by developing multi regional input-out model. This thesis has been organised as follows; in the Chapter 1 after here, LCA and its brief history, literature review and the research questions that this thesis answers are explained. LCA and its brief history section under Chaper 1 explaines its roots and different approaches for LCA. Following section after the literature review, the objectives of the thesis is explained so as to fill the research gaps, to answer policy questions. In the Chapter 2, the method (multi regional input-out analysis) and the data (World Input-Output Database) are described. The answers to the questions mentioned in chapter1 as research questions are given in the Chapter 3 as results. Discussion and conclusions are given in the Chapter 4. And finally, future remarks for considering not only enviromental aspect, but also economic and social aspects of manufacturing are explained in the Chapter 5.

1.1 Historical Bacground of Sustainability and LCA

Today's meaning of sustainability, as a term, was first used and recognized by Hans Carl von Carlowitz in 1713 indicating that "only as much wood is removed from the forests as grows again in the long run" [19]. Therefore, he might be referred as the father of sustainability in today's modern sense. Even though a variety of definitions of sustanibility in several contexts might be found [20], all definitions have shared core components, which are environment, economy, society. These are called as three pillars of sustanablity. In the course of history of sustainability, it was first concerned as an environmental issue by biologists and ecologists [21], then it took steps into economics in terms of natural resources, and social aspects [20, 22]. For a sound sustainability assessment, these three aspects, which are environmental, economic and social, should be taken into consideration. But relative weights of these aspects differ from country to country, and from researchers in the scientific world to businessmen in the globolized competitive world. In other words, developed countries tend to give more weight to environmental aspect, while developing countries to economic aspects. Similarly, there has been a lack harmony between academia and business world [23]. Without relative weights, sustainability assessment can be expressed as in equation 1.1 (can be found in [24]). LCSA stands for Life Cycle Sustainability Assessment, LCA for life cycle assessment, LCC for life cycle costing, SLCA for social life cycle assessment. This equation defines sustainability assessment in term of the summation of environmental aspect (LCA), economic aspect (LCC), and social aspect (SLCA).

$$LCSA = LCA + LCC + SLCA \tag{1.1}$$

There are lists of indicators in order to measure sustainability in terms of aforementioned three pillars, as environmental, economic and social footprints. In the literature, the footprint family has been mostly applied to environmel pillar of sustainale develepment. There are many ecological footprints used to measure environmental sustainabiliy. Ecological, carbon, water, energy footprints are most common indicators in the footprint family [25]. These footprints as indicators for environmental sustainability assessment can be used alone or together. When these footprints are intagrated, there are some difficulties which are not concerned in this thesis. For the difficulties and methodologies in aggregating footprint family, it is referred to the studies in the literature [26–28]. As it has been mentioned above, for other two pillars of sustainability, social and economic pillars, some other indicators should be added to the footprint family. In terms of social and economic footprints, there might be found variable indicators in the literature, including unemployment, inequality, child labor, health, safety and so on [25]. The combinations of footprints or indicators so as to achive triple bottom line aims require solving multi-objective optimisation problems [29].

This thesis is focusing on only LCA part in the equation 1.1 above, in other words, environmental aspect of sustainability assessment. It does not take LCC and SLCA into account. Moreover, it is not combining indicators mentioned above. Carbon and energy footprints for Turkish manufacturing sectors were calculated in order to evaluate the nexus of carbon, energy and manufacturing sectors from the global supply chain perspective. It is not corcerned with any combination of aforementioned members of footprint family. Because of the fact that it interests in carbon and energy footprint, it is worthy to explain what are carbon and energy footprints.

Carbon footprint might be the most often heard one amongs footprint family from media, news to scientific researches and business. Even though carbon footprint is one of the most famous indicators, there is no standardised definition for carbon footprint in the literature. Carbon Trust defines carbon footprint as "A carbon footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or product" [30], Global Footprint Network as "The carbon Footprint measures CO2 emissions associated with fossil fuel use" [31]. Wiedmann and Minx give the common baseline as " the carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities." [32]. According to definition, carbon footprint measurement unit differs. For example, if carbon footprint is calculated by only carbon emissions, measurement unit will be in terms of tonnes. It also might be interms of area based unit for land appropriation and tonnes of CO2 equavalents for GWP. In this thesis, as it will be explained in the Chapter 2 (Method), carbon footprint calculated as GWP with respect to metric tons of CO2-equivalent (mt CO2-eqv).

Energy use or energy footprint was firstly recognized as a subindicator of ecological footprint. However, recently it has become independent of ecological footprint [27, 28]. In this thesis, again as it will be explained in detail in the Chapter 2 (Method), sum of all types of energy commodities in terms of tera-joules (TJ).

Now, LCA's root goes back to 1960s, such as the World Energy Conference in 1963, global modeling studies like "The Limits to Growth" [33]. The first initiatives to improve a suitable LCA tool carried out during 1990s. SETAC (Society of Environmental Toxicology and Chemistry) developed 'cradle-to-grave' approach with two conferences in 1990. 'cradle-to-grave' approach means that not only environmental impacts of a product (process, service) throughout its utilization, but also manufacturing, tranportation, disposal and so on. And then, ISO came up with ISO 14040 family for internationally standardized LCA [34]. The ISO family, such as ISO 14041 (ISO 1998) [35], ISO 14042 (ISO 2000a) [36], ISO 14043 (ISO 2000b) [37], formalized product (process, service) based LCA. Process-based LCA is a very detailed approach to specific products, processes, services. Even though it provides very detailed answers to research questions, it has also some downsides such as system boundry setting problem. As the second approach, economic input-output (EIO) based LCA covers the whole economy, which draw no boundry. However, EIO-based LCA approach does not provide detailed answers as one of its downside. It obtaines aggregate views, comprehensive assessments. The advantages and disadvatages of these two approaches is given figure 1.1 [38]. In order to defeat some disadvatages of both, process-based and EIO-based LCA, and in order to take some advantages of the both there is a third approach, hybrid LCA. Hybrid approach combines the accuracy of process analysis and the completeness of input-output analysis [39].

TABLE 1.1: Advatages and Disadvatages of Two Life Cycle Assessment Approaches

	Process Models	EIO-LCA
Advantages	•Detailed process-specific analyses •Specific product comparisons •Process improvements weak pointanalyses •Future product development assessments	•Economy-wide, comprehensive assessments (all direct and indirect (all direct and indirect environmental effects included) •System LCA:industries,products, products, services, national economy •Sensitivity analyses, scenario planning •Publicly available data, reproducible results •Future product development assessments •Information on every commodity in the economy
Disadvantages	•System boundry setting subjective •Tend to be time intensive and costly •New process design difficult •Use of proprietary data •Cannot be replicated if confidential data are used •Uncertainity in data	•Some product assessments contain aggregate data •Process assessments difficult •Difficulty in linking dollar values to physical units •Economic and environmental data may reflect past practices •Difficult to apply to an economy (with substantial non-comparable imports) •Uncertainity in data

1.2 Literature Review

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 [40–43]. 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 [44–47]. 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 [43, 48]. 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, 49–51]. At this point, I-O based models provide a top-down analysis that uses sectoral monetary transaction matrices considering complex interactions between the sectors of national economies[32, 52, 53]. I-O analysis is widely used and accepted as a suitable methodological approach for calculation of energy and carbon footprints [54–58]. 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 [59], 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 [60–62]. MRIO analyses for some period of time have been becoming very attractive by virtue of the fact that global input-output databases have been available for the last couple of years. For three Baltic countries, Estonia, Latvia and Lithuania, CO2 equivalent emissions related to household consumption between 1995 and 2011 were analyzed using MRIO model [63]. In that study significant emission increases were found from 1995 to 2011, and the indirect emissions mostly related to imports from Russia and China. In order to decrease those Baltic countries' emissions related to their consumption, it was suggested to change consumption behaviors towards lower carbon options, and to decrease trade related indirect emissions by producing domestically or importing from low carbon areas. A study used MRIO model to analyse emissions and resource consumption of sectors for the determined coutries [64]. In that study, it was found that; Electricity production and Chemical industry were the most responsible sectors for pollution amongst the countries in the study for time horizon between 1995 and 2009. These two studies [63, 64] used MRIO analysis over a perod of time. However, the next one is an example of MRIO analysis for just one year. Mercury emissions between 186 individual economies in 2010 by MRIO model were analyzed[65]. [66] analyzes sustainability assessment of Turkish manufacturing sectors between 2000 and 2009 from a global supply chain perspective, which is the main foundation for my thesis. In other words, this thesis is the output of the mentioned study.

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 [67, 68].

In this regard, MRIO models have extensively used in carbon and energy footprint studies [69–73]. 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) [74–79]. Several studies based the methodological framework on the aforementioned MRIO initiatives and focused on tracing the carbon and energy footprints of households [80, 81], consumption and production [73, 82–85], international trade [58, 78, 86], cities [87], and nations [88–90].

1.3 State-of-the-Art and Research Objectives

Although there are solid actions taken to realize a low-carbon economy and energy-efficient manufacturing simultaneously, many policy questions still remain unanswered regarding the use of methodological approaches that can better estimate the Turkish manufacturing industries' carbon footprint and energy use and identify significant energy and carbon hotspots for effective policy making. In addition, majority of research efforts focuses on particular parts of the manufacturing activates from products or processes with limited focus on regional impacts and supply chain phases. Although such efforts are necessary and useful, they lack of system perspective and therefore, underestimate the impacts from upper tiers of global supply chains. Based on the aforementioned research needs, this thesis aims to advance the body of knowledge by filling three major research gaps: "lack of application of MRIO methodology for global supply chain of national economies" and "lack of understanding of carbon-energy-manufacturing nexus", and "lack of holistic system-based decision-support methods for effective policy making". With this regard in this thesis, it has been aimed to provide answers the following questions:

- What are the direct and indirect carbon and energy footprint of Turkish manufacturing sectors at national and global level?

- What are the contributions of individual supply chain phases such as upstream suppliers, onsite manufacturing, transportation, wholesale and retail trade to overall carbon and energy footprint?
- What is the global distribution of upstream energy use and carbon footprints over a period of time?
- What is the nexus between energy and carbon footprints of each manufacturing sector based on major supply chain phases?
- What is the trend for national and global energy and carbon footprints of industries?

To be able to respond to the aforementioned policy questions adequately, a system-based holistic carbon and energy footprint accounting framework,which can capture all direct and indirect impacts at regional and global scale over a period of time, is required. Hence, in this thesis, a global MRIO model is developed by utilizing the WIOD on the world's 40 largest economies covering 1440 economic sectors. By answering these questions, this thesis will help the policy makers to

(i) identify the key industrial sectors and supply chain phases (onsite, upstream, transportation, wholesale and retail trade) with the greatest carbon and energy footprints for the period between 2000 and 2009,

(ii) determine the energy-climate nexus based on each supply chain phase,

(iii) propose effective carbon and energy footprint reduction strategies considering the regional and global supply chains of Turkish manufacturing sectors, and

(iv) show the importance of complete coverage of all supply chain tiers in order to prevent the erroneous results due to narrowly defined system boundary.

The rest of the thesis is organized as follows. Chapter 2 introduces the methods. Results are provided in Chapter 3. Discussion and conclusions were made in Chapter 4, and, Chapter 5 provides the policy recommendations and future directions of the current research.

Chapter 2

Method

The MRIO models consist of trade flow matrices covering all countries or regions in the model. These matrices are able to track international supply chains of world economies and the global trade links among the trading partners [91–93]. A MRIO model typically involves national input output (I-O) tables, which represent financial transactions between economic sectors within a country and international trade flows. In a typical MRIO framework, monetary flows present the amount of imports and exports made by economic sectors of countries. All these import and export flows are then merged into one consistent financial accounting framework [67]. This combined inter-industry transaction matrix is linked to primary inputs between economic sectors and final demand categories including household consumption, private fixed investments, and government purchases and investments [94, 95].

In this thesis, The WIOD has been used to acquire fiscal flows amongst the world's major economies represented by 40 countries. This database is supported by the European Commission under the 7th framework programme and developed a time series of symetric I-O tables during the period from 1995 to 2011 for 40 countries (27 EU member states and 13 other major countries, see Table 2.1 [68], and RoW as 41th one) distinguishing 35 industries and 59 products [68]. The National Accounts Statistics (NAS) are used so as to acquire I-O tables in the WIOD. For constructing a symetric sector-by-sector I-O tables and elaborate sector classifications, it is refered to Timmer [96] and EuroStat [97].

Table 2.1: WIOD countries and their regional aggregation

Euro-Zone	Non-Euro EU	NAFTA	China	East Asia	BRIIAT
Austria	Bulgaria	Canada	China	Japan	Brazil
Belgium	Czech Rep.	Mexico		Korea	Russia
Cyprus	Denmark	USA		Taiwan	India
Estonia	Hungary				Indonesia
Finland	Latvia				Australia
France	Lithuania				Turkey
Germany	Poland				
Greece	Romania				
Ireland	Sweden				
Italy	UK				
Luxembourg					
Malta					
Netherlands					
Portugal					
Slovakia					
Slovenia					
Spain					

2.1 The countries and industries in the WIOD

As mentioned before, the dataset used in this thesis includes 40 countries in the Table 2.1. These 40 countries covers more than 85% of gross domestic produt (GDP) of the world [98]. Other than those 40 countries, as 41th one, there is also RoW including all other countries as if they are all one country. As for the industries, there are 35 industries (see the Table A, also can be found in [99]) containing the overall economy for each of 41 countries. In other words, there are 1435 industry-country couples (41 country*35 industry =1435) that supply outputs needed or used by again these 1435 industry-counry couples as their inputs. The dataset, in a nutshell, shows the monetary transactions between those 1435 industry-country couples. In order to picture what it has been explained, the Table2.2 [98] might be very helpful.

Table 2.2: Structure of the dataset

		Country R Intermadiate industry	Country S Intermadiate industry	Country T Intermadiate industry	Country R Final domestic	Country S Final domestic	Country T Final domestic	Total
Country R	Industry	Intermediate use of domestic output	Intermediate use by S of exports from R	Intermediate use by T of exports from R	Final use of domestic output	Final use by S of exports from R	Final use by T of exports from R	Output in R
Country S	Industry	Intermediate use by R of exports from S	Intermediate use of domestic output	Intermediate use by T of exports from S	Final use by R of exports from S	Final use of domestic output	Final use by T of exports from S	Output in S
Country T	Industry	Intermediate use by R of exports from T	Intermediate use by S of exports from T	Intermediate use of domestic output	Final use by R of exports from T	Final use by S of exports from T	Final use of domestic output	Output in T
		Value Added	Value Added	Value Added				
		Output in R	Output in S	Output in T				

The MRIO model in this thesis, A_{ij}^{rs} matrix consists of multiple rows which present the input of sector i from country r (= *1*,...,n) into industry j in country s (=*1*,...,n). In this matrix,i and j equal to 35 which is the total number of sectors in each country. Also, r and s are equal to 41 which is the total number of countries including the Rest-of-the-World (RoW). The matrix goes by the name of the direct requirement matrix. In this matrix, rows represent the accretions from other industries (domestic inputs plus inputs from other countries) to manufacture a dollar of output. Overall, the MRIO analysis produces a set of multipliers that show the total environmental impacts based on per dollar economic output, and therefore quantifies a global multi regional environmental footprint of supply chains [58]. After the MRIO model is constructed and total requirement matrix is derived from the direct requirement matrix using the taylor series approximation [92], carbon and energy footprints of the Turkish manufacturing sectors (presented in the Table 2.3) could be estimated by multiplying the output of each sector by its carbon or energy impact per million dollar ($M) of economic output. The mathematical foundation of a multi region input-output analysis explained in the following sub-section.

Table 2.3: WIOD manufacturing sectors and their abbreviations

Manufacturing Sectors	Abbreviations
Agriculture, Hunting, Forestry and Fishing	AHFF
Basic Metals and Fabricated Metal	BMFM
Chemicals and Chemical Products	CCP
Coke, Refined Petroleum and Nuclear Fuel	CRPNF
Electrical and Optical Equipment	EOE
Food, Beverages and Tobacco	FBT
Leather, Leather and Footwear	LLF
Machinery, Nec	MN
Manufacturing, Nec; Recycling	MNR
Mining and Quarrying	MQ
Other Non-Metallic Mineral	ONMM
Pulp, Paper, Paper, Printing and Publishing	PPPPP
Rubber and Plastics	RP
Textiles and Textile Products	TTP
Transport Equipment	TE
Wood and Products of Wood and Cork	WPWC

2.2 A Multi-region Input-Output Analysis

For a brief explaination, the MRIO model is illustrated for the case of 3 regions with n sectors. However, this illustration can be applied to any number of regions and sectors as discussed in the Arto et al. [100]. In a typical MRIO economy, there are 3 main components such as inter-industry transactions matrix (Z), final demand vector (f), and total industry output vector (x).

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

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

$$X = \begin{bmatrix} X^r \\ X^s \\ X^t \end{bmatrix}$$

As an element of Z^{rs}, z_{ij}^{rs} accounts for the purchases of industry j in country s from industry i in country r. In addition, f^{rs} represents a column vector with final demands that can be household demand, government consumption and investments, private fixed investments, etc. For example,f_i^{rs} represents the final demand of country s for commodities produced by sector i in country r. Also, x^r denotes the column vector of total industry outputs in region r.Overall, the linear relation between total industry output (x), inter-industry transactions (Z) and final demand (f) is given in the Equation 2.1 [92]:

$$Z^i + f^i = X^i, (i = r,\ s,\ t) \tag{2.1}$$

In a standard input-output model, total industry output vector,x can be expressed as [92]:

$$x = Ax + f \tag{2.2}$$

where A is known as the technical coefficients matrix or direct requirements matrix. Using the Leontief's inverse function, the solution of the Equation 2.2 is given by $x = Lf$, where $L = (I - A)^{-1}$ is called as the Leontief inverse [101]. Because of the Taylor series expansion, the Leontief inverse covers the entire supply chains as $(I - A)^{-1} = I + A + A^2 + ...$, where I is for onsite, A is for the first layer in its supply chain, and so on so forth.

In the MRIO analysis, the multiregional technical coefficients matrix is defined as:

$$A = \begin{bmatrix} A^{rr} & A^{rs} & A^{rt} \\ A^{sr} & A^{ss} & A^{st} \\ A^{tr} & A^{ts} & A^{tt} \end{bmatrix};$$

where

$$A = Z\bar{x}^{-1} \tag{2.3}$$

In the Equation 2.3, Z matrix represents the monatary transactions, in other words internal consumption, between industries. $\bar{x}^{-1}$ is the diagonalized matrix of the reciprocal of each total output as given in the followings,

$$Z = \begin{bmatrix} Z^{rr} & Z^{rs} & Z^{rt} \\ Z^{sr} & Z^{ss} & Z^{st} \\ Z^{tr} & Z^{ts} & Z^{tt} \end{bmatrix};$$

$$\bar{x}^{-1} = diag \begin{bmatrix} 1/X^{r} \\ 1/X^{s} \\ 1/X^{t} \end{bmatrix} = \begin{bmatrix} 1/X^{r} & 0 & 0 \\ 0 & 1/X^{s} & 0 \\ 0 & 0 & 1/X^{t} \end{bmatrix};$$

and the direct requirements matrx A is calculated as

$$A = \begin{bmatrix} A^{rr} & A^{rs} & A^{rt} \\ A^{sr} & A^{ss} & A^{st} \\ A^{tr} & A^{ts} & A^{tt} \end{bmatrix} = \begin{bmatrix} Z^{rr} & Z^{rs} & Z^{rt} \\ Z^{sr} & Z^{ss} & Z^{st} \\ Z^{tr} & Z^{ts} & Z^{tt} \end{bmatrix} \times \begin{bmatrix} 1/X^{r} & 0 & 0 \\ 0 & 1/X^{s} & 0 \\ 0 & 0 & 1/X^{t} \end{bmatrix} = ...$$

$$... = \begin{bmatrix} Z^{rr}/X^{r} & Z^{rs}/X^{s} & Z^{rt}/X^{t} \\ Z^{sr}/X^{r} & Z^{ss}/X^{s} & Z^{st}/X^{t} \\ Z^{tr}/X^{r} & Z^{ts}/X^{s} & Z^{tt}/X^{t} \end{bmatrix}$$

After that, Leontief matrix and Leontief inverse matrix are calculated using the Equation 2.4 and the Equation 2.5, respectively:

$$\left[I - A\right] = \begin{bmatrix} I - A^{rr} & -A^{rs} & -A^{rt} \\ -A^{sr} & I - A^{ss} & -A^{st} \\ -A^{tr} & -A^{ts} & I - A^{tt} \end{bmatrix} \tag{2.4}$$

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

Furthermore, our MRIO model is extended with two environmental impact matrices, where C is a diagonal matrix of carbon emission coefficients and E is a diagonal matrix of energy use coefficients. Then, the total sectorial emissions and energy use are given by the Equation 2.6 and the Equation 2.7, respectively:

$$c = CBf \tag{2.6}$$

$$e = EBf \tag{2.7}$$

where c is a column vector of total carbon emissions, and e is a column vector of total energy use. Hence, the sectorialemissions of a specific country r are given in the Equation 2.8:

$$c^r = C^r B^{rr} f^r + C^r B^{rs} f^s + C^r B^{rt} f^t \tag{2.8}$$

Finally, the sectorial energy uses of a specific country r are given in the Equation 2.9:

$$e^r = E^r B^{rr} f^r + E^r B^{rs} f^s + E^r B^{rt} f^t \tag{2.9}$$

2.3 Data Collection and Preparation

In this thesis, the majority of its dataset has been gathered from the WIOD to obtain sectoral transactions table and GHG emissions and energy consumption data. Each sector's global warming potential (GWP) is computed by multiplying the total GHG emission of each sector with conversion factors acquired from the United States Environmental Protection Agency (U.S EPA, 2013). The GHG emission dataset involves the direct carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) emissions of each sector. The GWP results are given in terms of metric tons of CO2-equivalent (mt CO2-eqv). Table 2.4 [102] presents the GWPs of GHG emissions relative to CO2 for a 100-year time horizon.

Table 2.4: Direct Global Warming Potentials relative to CO2

Common Name	Chemical Formula	Conversion factors of GWP for 100-year time horizon
Carbon Dioxide	CO2	1
Methane	CH4	25
Nitrous Oxide	N2O	298

For total energy consumption, the sectorial energy use data are obtained from the WIOD. The energy data include the total fossil and non-fossil gross energy use of each sector and presented in tera-joules (TJ). The structure is given in the Table 2.5.

Table 2.5: Energy Use Data Structure in WIOD

	WIOD Fuels				
	Energy Carrier1	Energy Carrier2	...	Energy CarrierX	TOTAL
Sector1			...		
Sector2			...		
⋮			⋮		
Sector35			...		

In order to prevent a double counting issue in energy accounts, the primary energy carries (crude oil, coal, natural gas, nuclear energy, hydropower, and renewables) were only summed up, which are shown in the WIOD energy accounts. Similar approach was also used by Bortolamedi [103] and the primary energy carriers and their WIOD codes are presented in the Table 2.6 [103]. All operations related to matrices are dealt with using a MatLab programming software MATLAB, 2012 [104].

Table 2.6: Primary Energy Carriers in WIOD

Primary Energy Carriers	WIOD Code
Crude Oil	Crude
Coal	HCoal, BCoal, Coke
Natural Gas	NatGas, OthGas
Nuclear Energy	Nuclear
Hydropower	Hydro
Renewables	Waste, Biogasol, Biodiesel, Biogas Geotherm, Solar, Wind, Othsourc

The followings briefly summarize the major research steps:

- First, total economic transaction table is acquired from the WIOD and total requirement matrix is created by using the Leontief's inverse,
- Second, total economic output of each sector from all countries are gathered. Then, by dividing GWP and energy use of sectors to corresponding economic output, we obtain the C and E matrices. Each element of this matrices demonstrates the direct carbon and energy impact of 1435 sectors,
- Finally, by using the MRIO framework, we calculate the onsite, upstream and T+W+R related GWP and energy use of 16 major Turkish manufacturing sectors between 2000 and 2009.

Chapter 3

Results

3.1 Carbon footprint and energy use of manufacturing sectors and their supply chains

Figures 3.1, 3.2, 3.3, 3.4 demonsrates the total average carbon footprint and energy use of 16 manufacturing sectors based on per $M and total economic output between 2000 and 2009. The results show the contributions of upstream, onsite manufacturing and transportation (T), wholesale (W) and retail (R) trade (hereafter called the "T+W+R") to carbon emissions and energy use inventory. Figure 3.1 indicates that AHFF, FBT, TTP, ONMM, BMFM and CCP are the top-6 industrial sectors based on total amount of carbon emissions. These sectors account for over 50% of the total carbon emissions in the MRIO economy. In terms of the contribution to the supply chain phases, onsite manufacturing activities were found to be dominant only for AHFF and ONMM. For the rest of the sectors, the industries in the upstream supply chains were found to be responsible for over 90% of the total impacts and the contribution of onsite and T+W+R activities were found to be minimal.

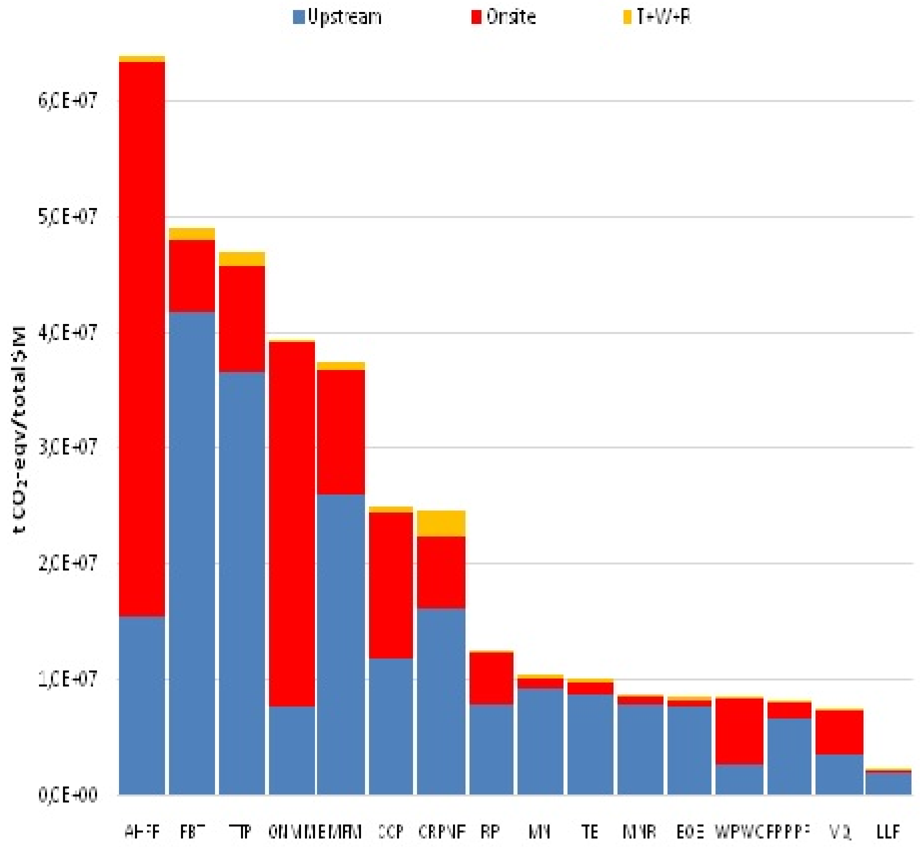

Figure 3.1: carbon footprint based on total output (t CO2-eqv/total $M)

Figure 3.2 presents the total carbon footprint of 16 manufacturing sectors based on the per $M as an average of carbon footprints during the period between 2000 and 2009. The results showed that ONMM, WPWC, CRPNF, BMFM, CCP, and RP were found to be as the top-6 industrial sectors based on total carbon footprints against per $M output. These sectors were found to be responsible for around 60% of total carbon footprints. When we look at more closely at contribution of supply chain phases, onsite manufacturing activities were found to be the major driver of footprints only for AHFF, ONMM and WPWC. The same as total carbon footprint results, upstream supply chains are responsible for over 90% of the total impacts and the contribution of direct and T+W+R related supply chain phases are quite low. Although AHFF, FBT and TTP have the largest total carbon emissions based on total economic output, their carbon emissions based on $M output are found to be lower when compared to emissions based on total economic output. On the other hand, sectors with low total carbon footprints such as WPWC and CRPNF have the highest carbon emissions per $M output. Among the major manufacturing sectors, ONMM sector is found to have high carbon emissions for both per $M and total output. In both cases, LLF sector has the lowest carbon emissions when compared with other sectors.

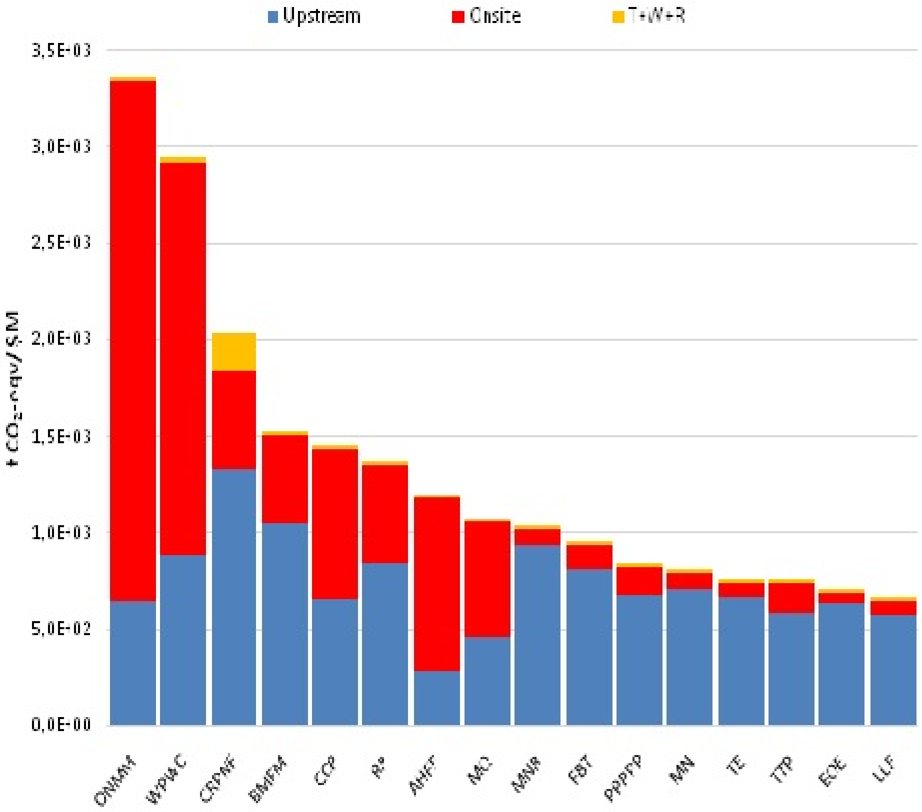

FIGURE 3.2: carbon footprint based on per $M output (t CO2-eqv/ $M)

Figure 3.3 demonsrates the total energy use of 16 manufacturing sectors based on total economic output as an average of total energy use for the period 2000 and 2009. The results showed that TTP, FBT, BMFM, CRPNF and AHFF represent the top- industrial sectors in total energy use category based on total economic output. The top sectors are found to be responsible for more than two third of total energy use. When we look at more closely at contribution of supply chain phases, onsite manufacturing is found to be dominant only for TTP and FBT. On the other hand, for the majority of the manufacturing sectors, upstream supply chains are responsible for over 65% of the total energy use. The contribution of direct and T+W+R related supply chain phases have a little contribution to overall energy use. LLF and WPWC are responsible for the least amount of energy in comparison with other sectors.

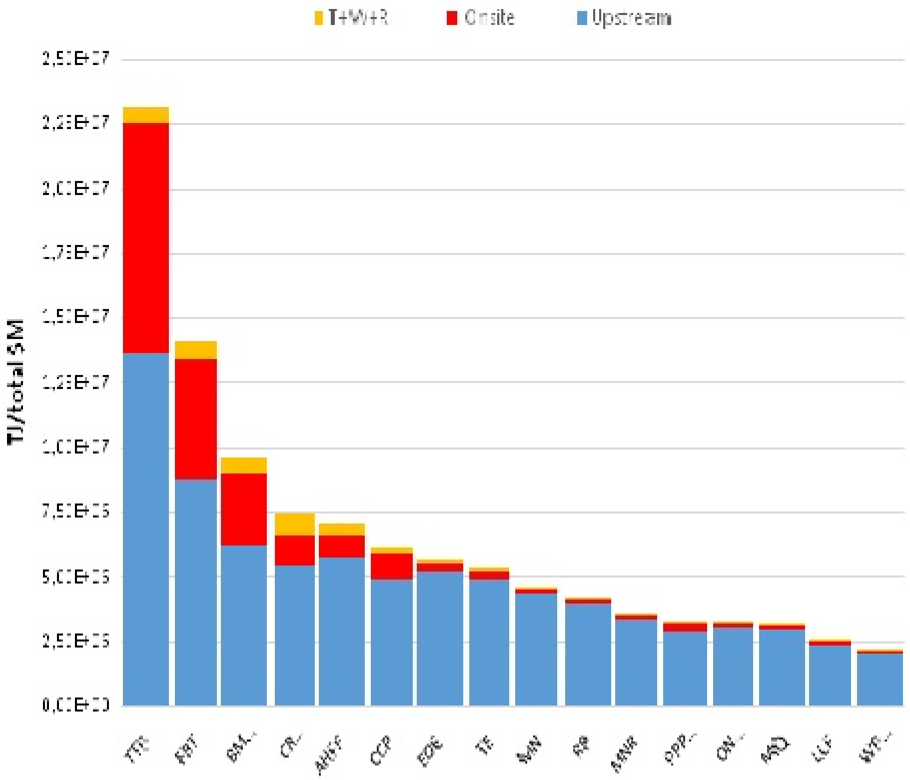

FIGURE 3.3: energy use based on total output (TJ / total$M)

Figure 3.4 shows the total carbon footprint of 16 manufacturing sectors based on per $M activity. The results revealed that CRPNF, EOE, TTP, BMFM, and TE use the biggest energy resources within the manufacturing sectors. These sectors are found to have approximately more than 50% of total energy use among the 16 manufacturing sectors. The results analyzing the contribution of supply chain stages to total energy use showed that onsite energy use of manufacturing is found to be dominant only for AHFF and ONMM. The same as total carbon footprint results, upstream supply chains were found to be guilty for more than 90% of the total impacts. The contribution of direct and T+W+R related supply chain phases were seen as having nonsignificant impact share. It is also important to emphasize that FBT is found to be as the second largest energy consumer; however its total energy use based on per $M economic output was found to be lower compared to total energy use. Furthermore, sectors with high total energy use such as TTP and BMFM have the high energy use for both per $M and economic output basis. Among the major manufacturing sectors, AHFF sector was found to be among the top-5 energy consumer based on total economic activity. However, the total energy use of AHFF based on per $M economic output was observed as the lowest when compared to other sectors.

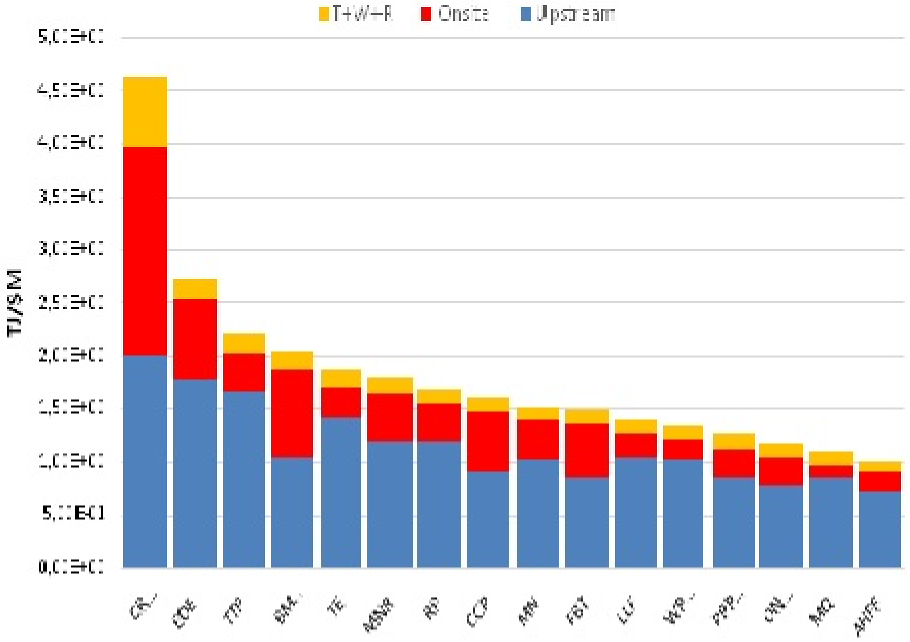

Figure 3.4: energy use based on per $M output(TJ / $M)

Figure 3.5 depicts the contribution of each supply chain phase to carbon footprint and energy use extents. This analysis is important to understand the degree of nexus between supply chain phases for carbon footprint and energy utilization. The results demonsrated that the percentage contribution of upstream suppliers, onsite manufacturing and T+W+R phases were found to be similar for the sectors of BMFM, CRPNF, EOE, LLF, MN, MNR and TE for both carbon and energy categories. For these sectors, upstream supply chain impacts were identified to be dominant compared to onsite manufacturing activities and T+W+R. For the manufacturing sectors such as AHFF, CCP, FBT, MQ, ONMM and WPWC, the contributions of different supply chain phases to total carbon emissions and energy use were found to be substantially different. For instance, upstream supply chains were found to be highly dominant in the total energy use of three manufacturing sectors: AHFF, ONMM, and WPWC. On the other hand, onsite manufacturing activities were found to have the biggest carbon emissions for these sectors in comparison with upstream supply chains and T+W+R phases. For CCP and MQ sectors, upstream supply chains were identified to be the major driver of total energy use; whereas upstream supply chains and onsite manufacturing equally shared the total carbon emissions. For FBT, which is the secondary manufacturing sector in terms of total energy use and carbon emissions, upstream supply chains were identified to be highly dominant and the percentage contribution of transportation and T+W+R phases are responsible for the minimum share of total impacts. On the average, the contribution of upstream supply chains to total energy use of the majority (75%) of the manufacturing sectors was found to 80% or higher.

In carbon emissions category, only four sectors' impacts were found to be driven by the onsite manufacturing activities and the rest of the sectors' impacts (accounts for 75% of all sectors)were found to have the largest shares attributed to the upstream supply chain industries. For most of the sectors with an exception of CRPNF, the contribution of T+W+R was found to have less than 5% of overall carbon emissions and energy use.

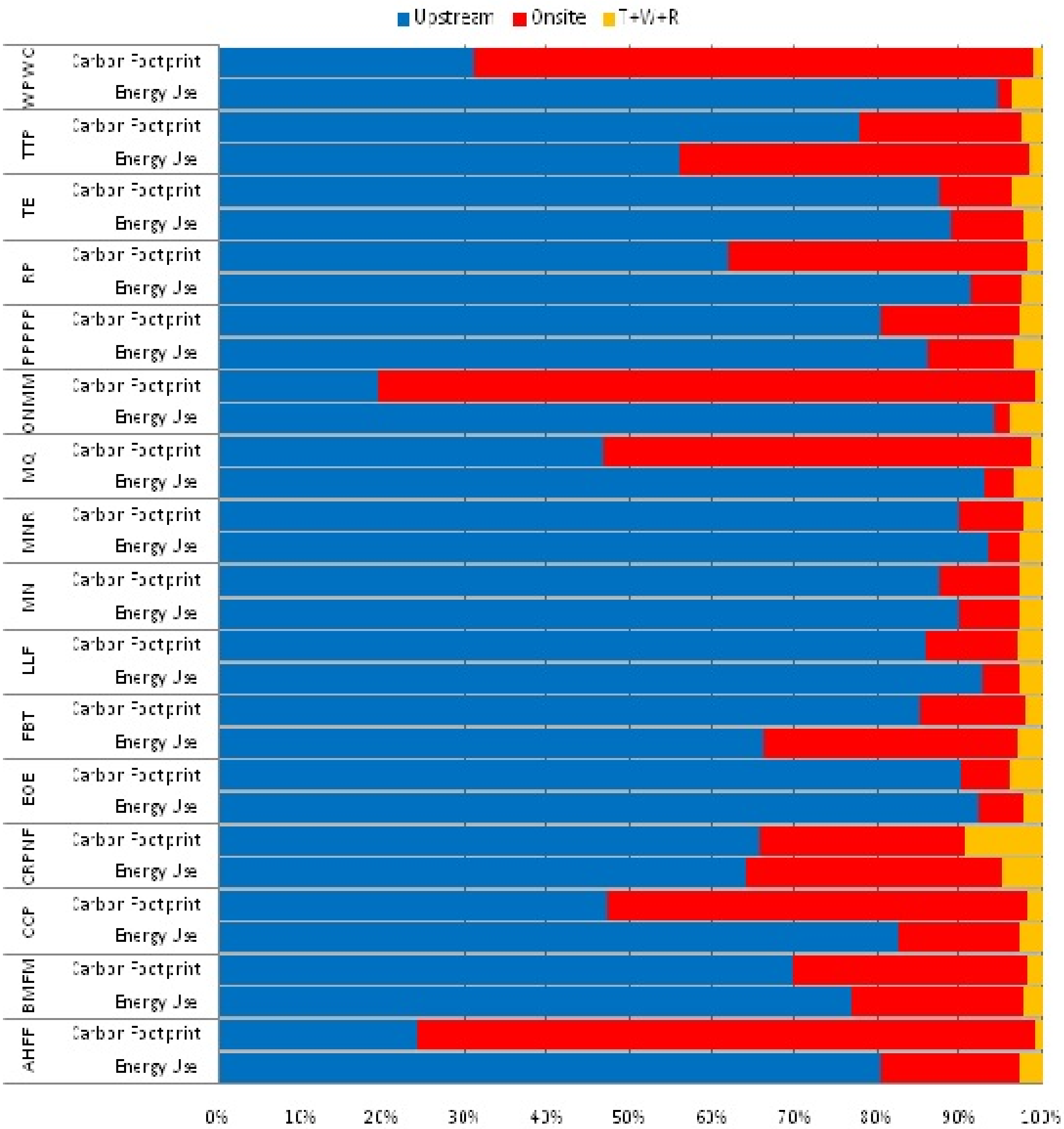

Figure 3.5: Contribution of upstream, onsite and T+W+R phases to total energy use and carbon footprint of 16 Turkish manufacturing sectors (average of 2000 and 2009)

After analyzing the direct and supply chain components as two major groups, it is important to analyze the impact share of each of the sectors in the upstream supply chains to the total energy and carbon impacts. Therefore, a supply chain decompositions analysis was utilized to trace the effect of top-5 upstream suppliers(here, the top 5 sector phrase indicates the five sectors with the greatest shares in the upstream supply chain-related impacts). Table 3.1 shows the upstream supply chains sectors' contribution to carbon emissions based on total economic output. AHFF, FBT, TTP, ONMM and BMFM industries were identified as emitting the biggest amount of carbon emissions in comparison with the remaining 11 sectors. Among these sectors, total carbon footprint of

AHFF and ONMM was found to be largely driven by onsite activities; whereas upstream supply chains of BMFM, FBT, and TTP were found to be responsible for the greatest shares in terms of total carbon footprint. For AHFF and ONMM; the percentage shares of onsite manufacturing activities were found to be 75% and 80%, respectively. For BMFM, FBT, and TTP; upstream supplier industries accounted for around 70.2%, 87.4%, and 80.3% of total carbon footprint inventory. After a detailed analysis of top-5 driving sectors' supply chain-linked impacts; Electricity, Gas and Water Supply sector was mostly found to be as the main contributor to total carbon emissions. For instance, the carbon footprint shares of Electricity, Gas and Water Supply industry within the total supply chain-linked impacts of ONMM, BMFM and TTP were found to be critically high, accounting for 42.3%, 38.2% and 33.65% of total supply chain-related carbon emissions. On the contrary, inland transportation was found to have the least amount of carbon emissions with less than 5% impact share.

Table 3.1: Supply chain decomposition analysis of carbon footprint for top 5 sectors based on total output

AHFF	Share (%)
Avg. Onsite Carbon Footprint	75.0%
Avg. Supply Chain Carbon Footprint	25.0%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	29.5%
Agriculture, Hunting, Forestry and Fishing	17.8%
Chemicals and Chemical Products	11.6%
Mining and Quarrying	8.1%
Coke, Refined Petroleum and Nuclear Fuel	7.3%
FBT	
Avg. Onsite Carbon Footprint	12.6%
Avg. Supply Chain Carbon Footprint	87.4%
Top 5 Sectors in Supply Chains	
Agriculture, Hunting, Forestry and Fishing	56.1%
Electricity, Gas and Water Supply	15.4%
Chemicals and Chemical Products	4.5%
Mining and Quarrying	3.7%
Other Non-Metallic Mineral	3.5%
TTP	
Avg. Onsite Carbon Footprint	19.7%
Avg. Supply Chain Carbon Footprint	80.3%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	33.6%
Chemicals and Chemical Products	14.7%
Agriculture, Hunting, Forestry and Fishing	12.1%
Mining and Quarrying	7.1%
Inland Transport	4.2%
ONMM	
Avg. Onsite Carbon Footprint	80.0%
Avg. Supply Chain Carbon Footprint	20.0%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	42.3%
Mining and Quarrying	20.3%
Chemicals and Chemical Products	6.3%
Other Non-Metallic Mineral	4.9%
Inland Transport	4.5%
BMFM	
Avg. Onsite Carbon Footprint	29.8%
Avg. Supply Chain Carbon Footprint	70.2%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	38.2%
Basic Metals and Fabricated Metal	24.1%
Mining and Quarrying	9.9%
Other Non-Metallic Mineral	8.3%
Inland Transport	3.2%

Table 3.2 depicts the upstream supply chains sectors' contribution to carbon emissions based on per $M economic activity. ONMM, WPWC, CRPNF, BMFM and CCP were found to have the highest carbon emissions per $M economic output. Among these sectors, carbon footprint of ONMM, WPWC and CCP is largely driven by onsite activities whereas upstream supply chains of CRPNF and BMFM were identified as guilty for the largest percentage of the total carbon footprint. For ONMM, WPWC and CCP, the percentage shares of direct impacts were found to be as 75% and 80%, respectively. For BMFM, FBT and TTP, upstream suppliers accounted for around 80%, 68.9% and 53.2% of total carbon footprint based on per $M output. When analyzing top-5 contributors in upstream supply chains, Electricity, Gas and Water Supply sector was again found to be as the main contributor of the total carbon emissions. The share of the Electricity, Gas and Water Supply among the upstream suppliers ONMM, WPWC, CRPNF, and BMFM had the greatest values, accounting for 41.9%, 29.2%, 33.5%,and 38.3 of total supply chain-related carbon impacts. The same as overall carbon emissions based on total economic output, inland transportation had the least amount of carbon emissions, which account for less than 5% of total carbon emissions with an exception of CRPNF. For this sector, the percentage contribution of transportation sector was identified to be almost 15% of total upstream carbon footprints.

Table 3.2: Supply chain decomposition analysis of carbon footprint for top 5 sectors based on per $M output

ONMM	Share (%)
Avg. Onsite Carbon Footprint	80.0%
Avg. Supply Chain Carbon Footprint	20.0%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	41.9%
Mining and Quarrying	21.1%
Chemicals and Chemical Products	6.7%
Inland Transport	4.6%
Coke, Refined Petroleum and Nuclear Fuel	4.2%
WPWC	
Avg. Onsite Carbon Footprint	68.9%
Avg. Supply Chain Carbon Footprint	31.1%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	29.2%
Agriculture, Hunting, Forestry and Fishing	27.1%
Chemicals and Chemical Products	13.4%
Mining and Quarrying	6.7%
Inland Transport	3.5%
CRPNF	
Avg. Onsite Carbon Footprint	25.1%
Avg. Supply Chain Carbon Footprint	74.9%
Top 5 Sectors in Supply Chains	
Mining and Quarrying	34.8%
Electricity, Gas and Water Supply	33.5%
Inland Transport	15.0%
Coke, Refined Petroleum and Nuclear Fuel	3.0%
Basic Metals and Fabricated Metal	2.4%
BMFM	
Avg. Onsite Carbon Footprint	29.8%
Avg. Supply Chain Carbon Footprint	70.2%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	38.3%
Basic Metals and Fabricated Metal	23.2%
Mining and Quarrying	10.1%
Other Non-Metallic Mineral	8.5%
Inland Transport	3.2%
CCP	
Avg. Onsite Carbon Footprint	53.2%
Avg. Supply Chain Carbon Footprint	46.8%
Top 5 Sectors in Supply Chains	
Electricity, Gas and Water Supply	28.6%
Chemicals and Chemical Products	17.5%
Mining and Quarrying	13.2%
Agriculture, Hunting, Forestry and Fishing	6.6%
Other Non-Metallic Mineral	5.5%

Table 3.3 presents the upstream supply chains sectors' contribution to energy use based on total economic output. TTP, FBT, BMFM, CRPNF and AHFF had the highest energy use when compared to other manufacturing sectors. The total energy consumption of these sectors was mainly driven by upstream supply chains whereas onsite manufacturing sectors have the least amount of energy use. For AHFF and BMFM, the percentage shares of onsite manufacturing were found to be noncritical, accounting for 13.38% and 17.23% of the total energy use, respectively. For TTP, FBT and CRPNF, upstream suppliers accounted for approximately 47.36%, 64.36% and 73.26% of total energy consumption. The Coke, Refined Petroleum and Nuclear Fuel sector was usually found to be as the main driver of energy use in upstream supply chains. For example, the share of Coke, Refined Petroleum and Nuclear Fuel within the supply chain paths of AHFF, CRPNF and FBT had the following energy use shares: 19.78%, 7.12% and 11.27%, respectively. In contrast, the percentage contribution of transportation and trade activities were not listed among the top-5 upstream suppliers for the energy use category.

Table 3.3: Supply chain decomposition analysis of energy use for top 5 sectors for total economic outputs

1.TTP	Share (%)
Average Onsite Carbon Footprint	52.64%
Average Supply Chain Carbon Footprint	47.36%
Top 5 Sectors in Supply Chains	
Textiles and Textile Products	9.27%
Coke, Refined Petroleum and Nuclear Fuel	6.84%
Chemicals and Chemical Products	6.23%
Renting of M&Eq and Other Business Activities	4.57%
Mining and Quarrying	4.20%
2.FBT	
Average Onsite Carbon Footprint	35.64%
Average Supply Chain Carbon Footprint	64.36%
Top 5 Sectors in Supply Chains	
Coke, Refined Petroleum and Nuclear Fuel	11.72%
Food, Beverages and Tobacco	7.45%
Renting of M&Eq and Other Business Activities	4.53%
Chemicals and Chemical Products	4.18%
Mining and Quarrying	4.69%
3.BMFM	
Average Onsite Carbon Footprint	17.23%
Average Supply Chain Carbon Footprint	82.77%
Top 5 Sectors in Supply Chains	
Basic Metals and Fabricated Metal	17.46%
Mining and Quarrying	9.14%
Renting of M&Eq and Other Business Activities	7.88%
Coke, Refined Petroleum and Nuclear Fuel	5.20%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	3.09%
4.CRPNF	
Average Onsite Carbon Footprint	26.74%
Average Supply Chain Carbon Footprint	73.26%
Top 5 Sectors in Supply Chains	
Mining and Quarrying	26.40%
Coke, Refined Petroleum and Nuclear Fuel	7.12%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	3.49%
Renting of M & Eq and Other Business Activities	1.43%
Inland Transport	1.02%
5.AHFF	
Average Onsite Carbon Footprint	13.38%
Average Supply Chain Carbon Footprint	86.62%
Top 5 Sectors in Supply Chains	
Coke, Refined Petroleum and Nuclear Fuel	19.78%
Chemicals and Chemical Products	6.19%
Mining and Quarrying	7.24%
Food, Beverages and Tobacco	4.76%
Renting of M & Eq and Other Business Activities	4.22%

Lastly, Table 3.4 shows the contribution of upstream suppliers to total energy consumption based on per \$M economic activity. The results revealed that CRPNF, EOE, TTP, BMFM and TE have the highest energy use against per \$M economic output. For these manufacturing sectors, total energy use was only dominated by upstream suppliers. Especially, the upstream supply chain portions of energy use are the highest for EOE and TE which are 96.34% and 90.31% of total energy use. For BMFM, CRPNF and TTP, the percentage shares of onsite manufacturing are 17.98%, 27.29% and 53.72%, respectively. When the researchers analyzed the drivers of upstream supply chains, the Coke, Refined Petroleum and Nuclear Fuel sector is again observed as the main contributor. The share of the Coke, Refined Petroleum and Nuclear Fuel among the upstream suppliers including CRPNF, TTP and BMFM had the highest shares, which were found as 7.63%, 7.73% and 6.60% of the total upstream energy consumption.

Table 3.4: Supply chain decomposition analysis of energy use for top 5 sectors based on per$M output

1.CRPNF	Share (%)
Average Onsite Carbon Footprint	27.29%
Average Supply Chain Carbon Footprint	72.71%
Top 5 Sectors in Supply Chains	
Mining and Quarrying	27.94%
Coke, Refined Petroleum and Nuclear Fuel	7.63%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	3.84%
Renting of M&Eq and Other Business Activities	1.63%
Inland Transport	1.09%
2.EOE	
Average Onsite Carbon Footprint	3.66%
Average Supply Chain Carbon Footprint	96.34%
Top 5 Sectors in Supply Chains	
Electrical and Optical Equipment	31.75%
Basic Metals and Fabricated Metal	9.10%
Renting of M&Eq and Other Business Activities	6.46%
Coke, Refined Petroleum and Nuclear Fuel	5.52%
Chemicals and Chemical Products	4.01%
3.TTP	
Average Onsite Carbon Footprint	53.72%
Average Supply Chain Carbon Footprint	46.28%
Top 5 Sectors in Supply Chains	
Textiles and Textile Products	8.90%
Coke, Refined Petroleum and Nuclear Fue	l 7.73%
Chemicals and Chemical Products	6.98%
Renting of M&Eq and Other Business Activities	4.88%
Mining and Quarrying	4.50%
4.BMFM	
Average Onsite Carbon Footprint	17.98%
Average Supply Chain Carbon Footprint	82.11%
Top 5 Sectors in Supply Chains	
Basic Metals and Fabricated Metal	18.09%
Mining and Quarrying	9.95%
Fuel Renting of M&Eq and Other Business Activities	8.05%
Coke, Refined Petroleum and Nuclear	6.60%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	4.71%
5.TE	
Average Onsite Carbon Footprint	9.69%
Average Supply Chain Carbon Footprint	90.31%
Top 5 Sectors in Supply Chains	
Transport Equipment	19.59%
Basic Metals and Fabricated Metal	13.67%
Renting of M&Eq and Other Business Activities	8.56%
Coke, Refined Petroleum and Nuclear Fuel	6.46%
Mining and Quarrying	4.17%

The aforementioned analysis indicates that the total carbon and energy impacts of sectors were largely attributed to the upstream suppliers and onsite activities; whereas T+W+R have the lowest contribution. Although these sectors have a little contribution, Figure 3.6 presented the contribution of transportation and trade activities to the total energy consumption for the top-5 manufacturing sectors: TTP, FBT, BMFM, CRPNF and AHFF. The results indicated that inland transportation had higher share compared to water and air transportation. On average, the share of transportation was found to be 50% or over among the downstream supply chain phases. The wholesale and retail trade phases had lower impact share than inland transportation with an exception of CRPNF sector. For this sector, until 2007, wholesale trade had the biggest share compared to retail trade and allother transportation sectors. In general, the total share of transportation phase started to increase during the period between 2008 and 2009, and showed a decreasing trend for wholesale and retail trade. This proved the growing dependency of manufacturing sectors to inland transportation sector, mainly the truck mode. The contribution of air transport was found to have a minimal impact in comparison with inland air transportation.

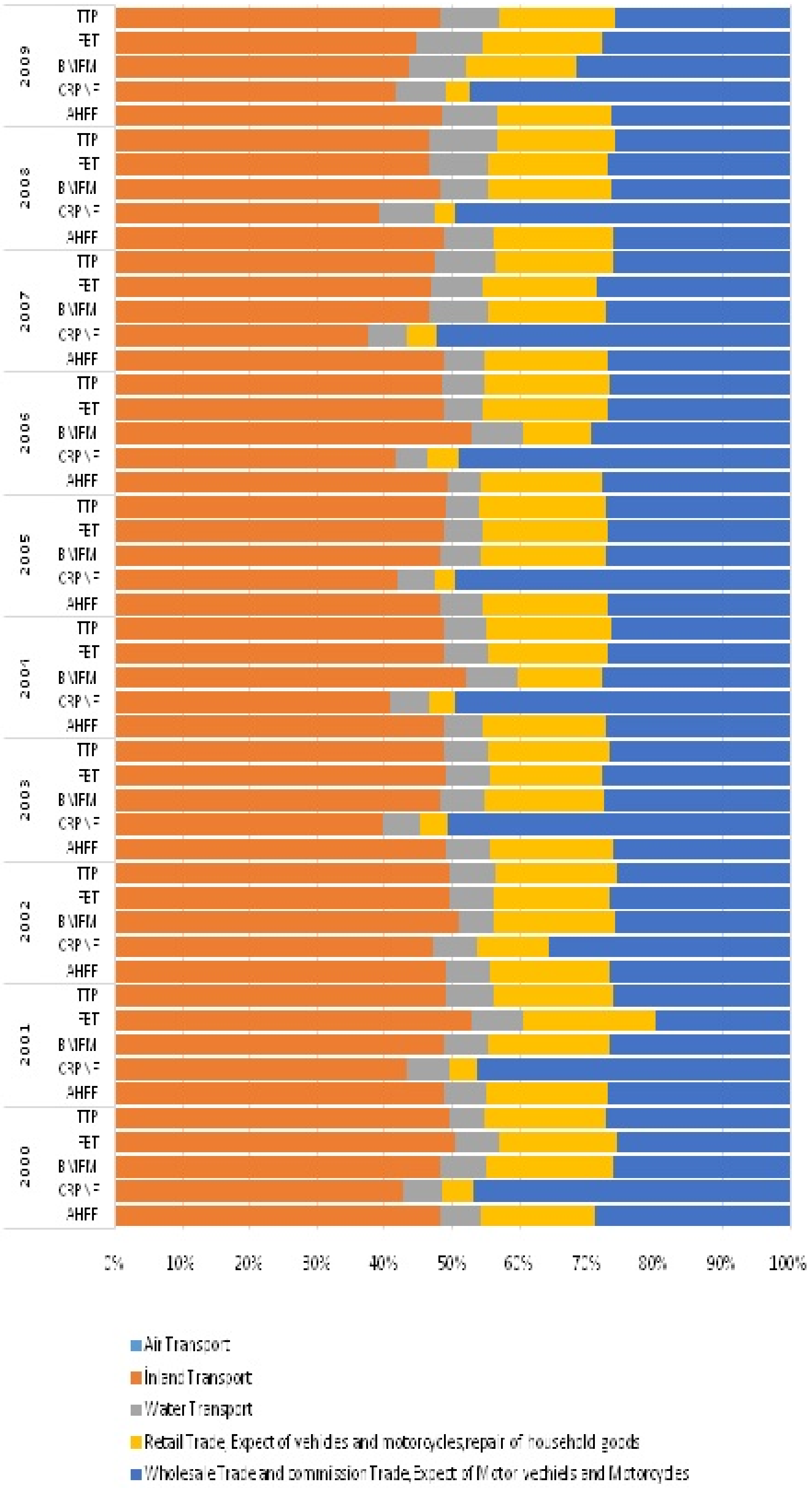

FIGURE 3.6: Contribution of transportation and trade activities for energy use of top-5 sectors based on total energy use (average of 2000 and 2009)

Figure 3.7 represents the contribution of air, water and inland transport, wholesale and retail trade to total carbon emissions. The sectors presented in Figure 3.7 were the ones which had the highest total carbon footprints between 2000 and 2009. The results showed that inland and water transportation modes had the biggest carbon emissions whereas the share of air transport in carbon emissions is found to be minimal. After air transportation, retail and wholesale trade were found to have the lowest portion of total carbon footprint. For ONMM, the share of inland transportation in total emissions was observed as the largest. On the other hand, the water transportation's share in carbon footprint of AHFF and FBT was found to be as highly dominant compared to other transportation sectors and trade activities. Overall, the percentage share of transportation modes and trade activities were not changed significantly between 2000 and 2009 period. Although water transportation was found to be responsible for the lowest energy use; its contribution to total carbon emissions was found to be quite high.

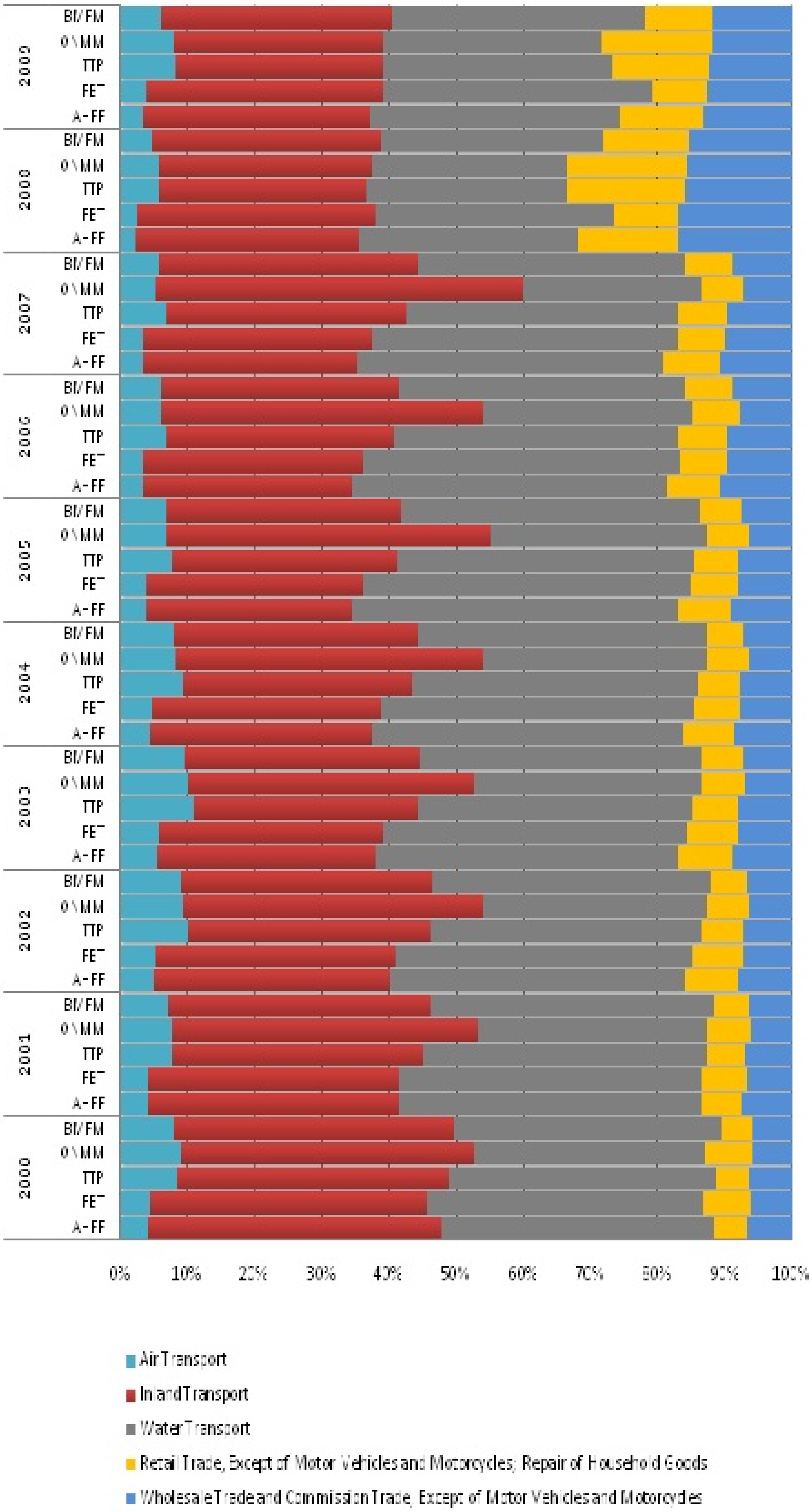

Figure 3.7: Contribution of transportation and trade activities for carbon footprint of top-5 sectors based on total carbon footprint (average of 2000 and 2009)

3.2 Global distribution of energy use and carbon footprint

Figure 3.8 presents the global carbon and energy distribution of each sector based on major world countries and RoW. For carbon emissions, the results showed that Indonesia (IDN), Russia (RUS), and RoW had the largest share in total carbon emissions. For TTP and EOE sectors, China (CHN)was also listed among the major contributing countries such as IND, RUS, and RoW. Overall, the carbon footprints of majority of manufacturing sectors were found in Turkish region and the RUS, CHN, and RoW were listed after Turkey (TUR) as major contributors. Among the manufacturing sectors, FBT had the highest regional carbon emissions and the contribution of global supply chains are found to be lower compared to other countries (see Figure 3.8a). The situation was also similar for MQ industry and the highest portion of carbon emission were located in TUR. As an important finding, for CRPNF sector, RUS was found to have the largest carbon emissions due to high dependence of Turkey to Russian energy.

Figure 3.8b shows the share of world countries in total energy use of each manufacturing sector. The RoW wasfound to have the largest share in total global energy footprint of all manufacturing sectors. This is because TUR is a highly energy dependent country and imported the significant amount of its energy demand from neighbouring countries such as Iran, Iraq, Azerbaijan, etc. Overall, CHN, Deutschland (DEU), TUR and USA were the most dominant countries based on total global energy use of Turkish manufacturing. Especially, the China's contribution to the total energy footprint is observed as the highest for TTP and EOE sectors. This was an expected result due to high import of textile and electronic products produced in CHN to Turkey. For the majority of manufacturing sectors, the contribution of Turkish energy production sector wasaround 10% of the total produced energy worldwide. Interestingly, the share of USA in total energy footprint of each manufacturing sector was found to be close enough to the share of Turkey. The results also showed that the energy shares of other world countries such as GBR, ITA, JPN, NLD, KOR and RUS were ranged between 1% and 5% and did not show significant variations among the production sectors.

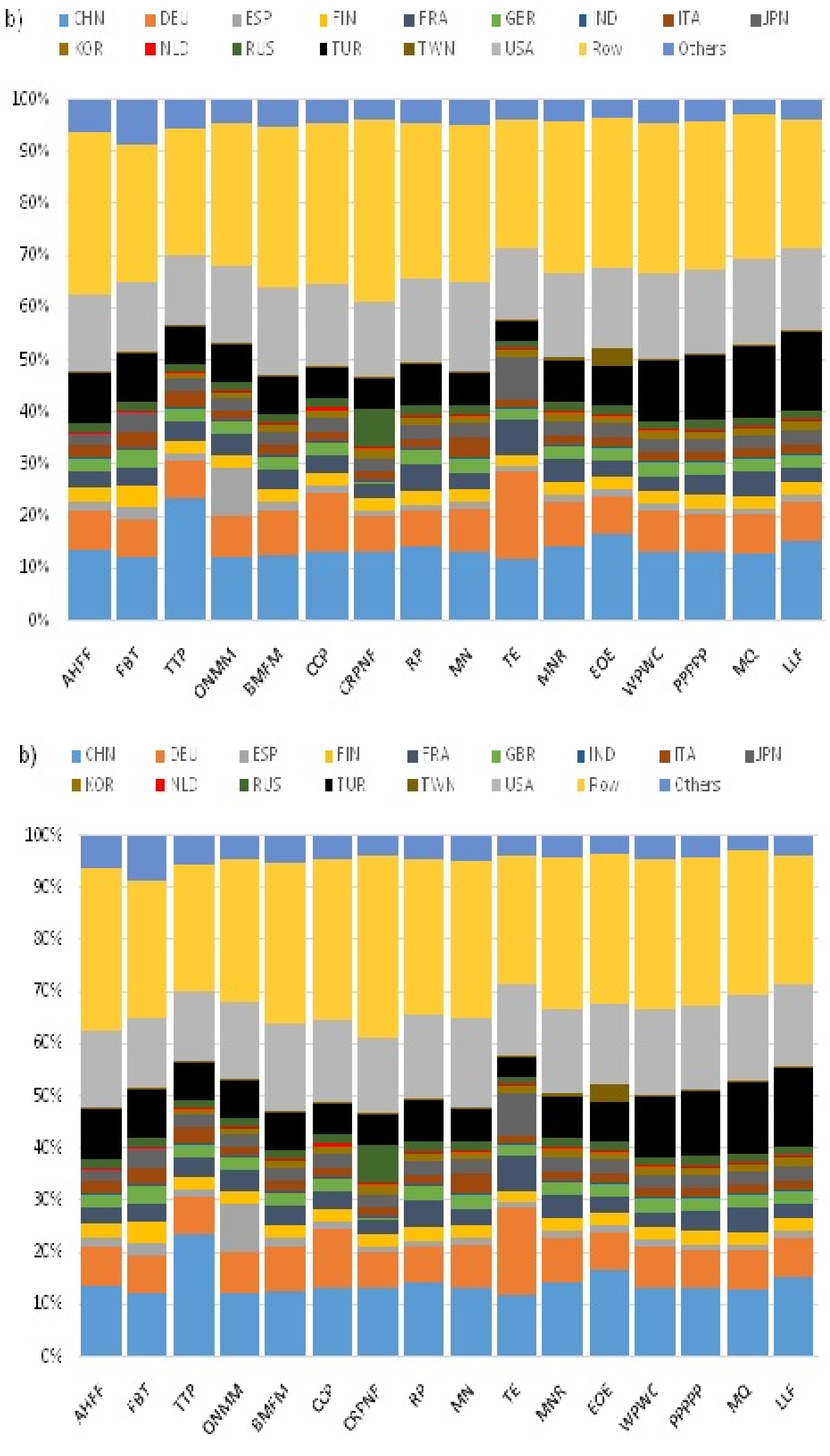

FIGURE 3.8: Aglobal carbon footprint and energy use distribution of 16 Turkish manufacturing sectors as an average of impacts between 2000 and 2009(a: carbon footprint, b: energy use)

Finally, Figure 3.9 presents the global distribution of energy and carbon impacts of manufacturing sectors for the period between 2000 and 2009. This analysis is significant to see the variation of global distribution of energy and carbon effects of each manufacturing sector. The results indicated that CHN, RUS, TUR and RoW had the greatest shares of carbon emissions over the 9-year period. The shares of CHN and RUS showed a declining trend from 2000 to 2009. On the other hand, TUR's share started to increase in 2007. Overall, the largest portion of total carbon emissions was found in TUR's regional boundary,which ranged between 40% and 60% of total carbon emissions. For instance, in 2009, TUR was identified to be guilty for around 60% of total carbon emissions and the rest was distributed to other world countries (see Figure 3.9a).

Figure 3.9b also showed the contribution of trading countries to total energy use of Turkish manufacturing. Among the nations, CHN, DEU, FRA, TUR, USA and RoW had the biggest share of energy production to support Turkish manufacturing sectors. As an important finding, the share of CHN showed a steady increase between 2000 and 2009. In 2009, China, United States, and Rest-of-the-World's contributions, as a whole, werefound to be more than 50% of total energy use of Turkish manufacturing. The CHN's contribution in 2009 wasfound to be more than 10% of total energy use while over 20% of total energy was attributed to production activities of other countries grouped under RoW. Starting from 2001, USA has shown a declining trend for its contribution to total energy use. TUR's energy share varied between 9% and 23% of total impacts, and had its highest value in 2008, and 2009. The countries such as ESP, FIN, FRA, GBR, ITA, JPN, KOR and RUS had the least portion among the global trading partners of TUR, and their share in total energy footprint of Turkish manufacturing did not show a considerable fluctuations over the 10-years period.

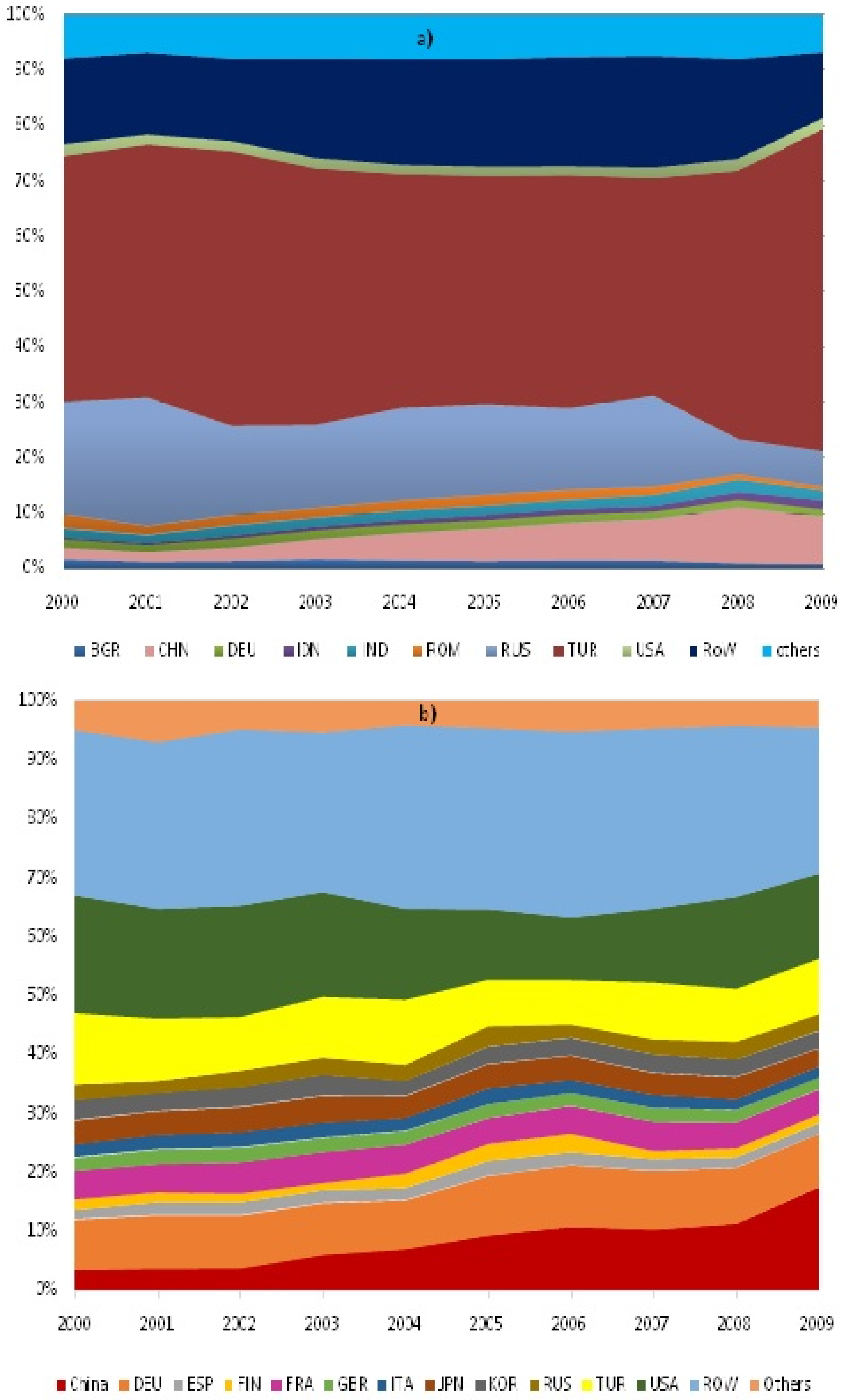

FIGURE 3.9: Carbon footprint and energy use trend of Turkish manufacturing sectors between 2000 and 2009 (a: carbon footprint, b: energy use)

Chapter 4

Discussion and Conclusions

This study addresses the energy-climate-manufacturing nexus for the Turkish manufacturing industries and showed the importance of consumption-based approaches with the inclusion of global manufacturing supply chains. Furthermore, it provides crucial insights for policy makers, industry stakeholders, and the scientific community and can pave the way for further development in manufacturing sustainability assessment research. For practical applications, the proposed decision-support framework should include further collaborations with industry stakeholders. Since the major hotspots in global supply chains were revealed, policy makers can identify the major stakeholders in each sector and can investigate the root causes. The major insights and conclusions are presented as follows:

4.1 One size does not fit all: The need for sector-specific strategies

The international trade-linked carbon footprint and energy consumption of the manufacturing industries highlighted the need for sector-specific strategies to mitigate GHG emissions and shift to a more energy-efficient economy. Consequently, strategies should be developed based on the supply chain characteristics reflecting the contribution of onsite, upstream and T+W+R segments, and energy and carbon footprint reduction potential of each sector. While carbon and energy intensity of some sectors were attributed to supply chain, for other sectors such as ONMM, WPWC, TTP, FBT and AHFF, reducing onsite impacts should be prioritized. The percentage contribution of upstream suppliers to the total carbon emissions is found to be much higher (80% or higher) for majority of the sectors (about 75% of the sectors), whereas onsite emissions of sectors such as WPWC, ONMM, and AHFF have much greater shares. On the other hand, upstream energy consumption of these sectors is greater than their onsite emissions. Hence, the policies aiming to increase energy efficiency may not necessarily reduce the GHG emissions effectively. While AHFF sector had the highest carbon emissions based on their total output, the total energy use of AHFF was not the highest. Although there might be strong correlation between energy and carbon footprints, different trends can also be observed in such sectors. Another example is the ONMM sector:The results showed that ONMM is the most carbon-intensive sector with respect to emissions per $M of output and it is the fourth largest contributor in the terms of its relative size. However, ONMM sector was not found to be among the top-5 sectors based on its total and per $M output energy consumption. Similarly, WPWC was responsible for the least amount of energy in comparison with other sectors; whereas it was found to be asone of the top contributors of carbon emissions per $M basis.

4.2 Carbon and energy hotspots: Insights for Turkish manufacturing sectors and supply chains

Revealing the most carbon and energy intensive supply chain components is crucial to be able to identify the root causes and detect the right domains to focus on. Results indicate that the total carbon and energy impacts of sectors are largely attributed to upstream suppliers and onsite activities; whereas T+W+R have relatively much smaller impact. Among the upstream suppliers,Electricity, Gas and Water Supply (EGWS)was found to be most dominant supply chain component of the top carbon intensive sectors. Although this is an expected finding, it highlights the fossil fuel dependence of electric power generation. Hence, use of renewable energy for electricity production is vital to mitigate carbon emissions and stabilize the global warming threat in the long run. Furthermore, any improvement in EGWS sector can result in credible footprint reductions compared to other supply chain components since it is a major component of the supply chain of manufacturing sectors and the largest contributor to carbon emissions. On the other hand, major supply chain contributors to the energy consumption of manufacturing sectors have a different structure. The Coke, Refined Petroleum and Nuclear Fuel sector was found to be the main driver of energy use in upstream supply chains. Similarly, energy efficiency improvement for this sector will increase performance of other sectors significantly. Furthermore, CRPNF was the most energy intensive sector and supply chain energy consumption account for about 70% of the sector's total. The most influential component of its supply chain is the MQ sector whose energy consumption trend is expected to increase due to expanding coal mining in Turkey in recent years.

4.3 Lack of Communication in a Globalized World

In a globalized world, which is woven by highly complex web of global supply chains, sustainability of any region depends on the sustainability of many other regions [105]. Considering that individual companies does not have control over their higher order upstream suppliers; top-down approaches and communication among international authorities, organizations, policy makers are essential actions need to be taken in order to address issues related to climate change as well as energy efficiency, and trigger transformation of long talks into actions. Lack of communication about the risks of climate change is a major problem preventing science contributing the decision making processes and playing appropriate role in policies addressing issues related to Climate [106, 107]. Mental models of individuals and prejudices prevent the communications and result in biases [108]. A long term commitment and strategy is needed to coordinate and improve the effectiveness of policies.

Chapter 5

Recommendations & Future Remarks

This thesis is an important step toward integrating a global MRIO perspective into macro level energy and climate effects of manufacturing supply chains. While the majority of researchers have been focusing on particular parts of the manufacturing activities from product or process perspectives with a limited focus on regional impacts and supply chain phases, sustainability assessment research often lacks a systems-level approach. In this context, current research methodology will be a robust framework since it provides a comprehensive sustainability assessment that addresses the supply chains and global impacts as an "umbrella" type of research methodology. For future research, it is also proposed that the important extensions of current sustainable supply chain research for manufacturing activities as 'using high sector and country resolution global MRIO frameworks', 'considering the social and economic aspects of manufacturing in addition to the environment' and finally 'considering the dynamics relationships between the indicators of sustainability and their ripple effects on the long-term sustainability of manufacturing'.

5.1 High-resolution sectors, more detailed regions, improved data availability, quality, and accuracy

In this thesis, the WIOD, which has become very popular and is widely cited global MRIO database [109], was used. Although the proposed methodology is robust and sound as it is capable of capturing global trade-links through time, there is need for certain improvements to develop more effective and accurate framework. First, the level of aggregation is crucial mark that needs to be addressed in future. Additionally, the findings of current researches demonstrated that disaggregation of I-O data are superior to aggregating environmental data in determining I-O multipliers and minimize uncertainties in LCI results [110, 111]. Second, the comprehensive review on I-O studies strongly emphasized that sustainability implications of manufacturing sectors must be analyzed with a set of environmental metrics as extensive as possible, covering the globe and discerning as many as possible sectors and countries, including long-time series [59, 67]. Therefore, this thesis aims to expand the methodology of current analysis with high country and sector resolution MRIO data and even more intra-country regional detail. This level of disaggregation will be so critical for analysis of industrial sectors with upstream supply chain dominance. For instance, the EXIOPOL covers the 27 EU member states as well as 16 non-EU countries with RoW accounts [79]. This global MRIO database aims to have a detailed view of economic sectors discerning 129 sectors. This global MRIO database used more detailed sector and product accounts to split up product and industry totals; however current version is limited to 2000 data which does not enable us to conduct a time series analysis. Furthermore, it should be noted that global MRIO modes are subject to uncertainties due to sectoral aggregation and gathering the environmental accounts data [112]. Also, combining regional models with MRIO analysis can be a sound methodology in order to consider the role of regional variations [71, 113].

5.2 The Balancing Act: Towards triple bottom line sustainability assessment of manufacturing sectors

Although the primary goal of supply chain management is considered as supply chain surplus through minimizing total supply chain cost and maximizing profits, this understanding has to be shifted to a broader concept that aims to find balance between the economic, social and ecological consequences of supply chain operations. To be able to manage the technological advancements towards realizing the goals of sustainable development, it is crucial to evaluate the TBL sustainability impacts of industrial activities in order to achieve economically viable, environmentally benign and socially acceptable policies towards realizing the objectives of sustainable development[114]. In the literature, several studies emphasized the importance of the three pillars of sustainability in supply chain management research [8, 115, 116]. However, only a handful of studies have focused on integrating all dimensions of sustainability into sustainable supply chain management research [46, 117, 118].Furthermore, globalization is an important factor for shaping the global supply chain networks of production activities and associated TBL impacts. There are important efforts towards presenting the critical TBL measures for domestic economies and their global effects. In near future, a global MRIO analysis can be primary policy making framework for world economies in order to trace the TBL sustainability performance of their production supply chains at regional and global scale [119].

5.3 Revealing the causal relationship and the system behavior

Effective decision-making requires a system thinking approach and an understanding of the behavior of the growing dynamic complexity of the globally linked manufacturing sectors [120–123].The global warming, energy consumption and economic output of manufacturing sectors are interconnected with feedback relationships, ripple and side effects. While MRIO models are very significant, they are not capable of capturing the causal relationships among the manufacturing sectors and environmental impacts. System dynamics modeling serves best to reveal these relationships since it helps to quantitatively define the feedback mechanisms, potential delays, and multi-dimensional causal relationships of a particular system [124, 125]. With the integration of system dynamics modeling, the nexusbetween the energy use and global climate change and the system's behavior over time can be identified and more effective policies can be developed.

Appendix A

35 Industries in WIOD

Table A.1: Sectors in WIOD

Sectors
Agriculture, Hunting, Forestry and Fishing
Mining and Quarrying
Food, Beverages and Tobacco
Textiles and Textile Products
Leather, Leather and Footwear
Wood and Products of Wood and Cork
Pulp, Paper, Paper , Printing and Publishing
Coke, Refined Petroleum and Nuclear Fuel
Chemicals and Chemical Products
Rubber and Plastics
Other Non-Metallic Mineral
Basic Metals and Fabricated Metal
Machinery, Nec
Electrical and Optical Equipment
Transport Equipment
Manufacturing, Nec; Recycling
Electricity, Gas and Water Supply
Construction
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
Hotels and Restaurants
Inland Transport
Water Transport
Air Transport
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
Post and Telecommunications
Financial Intermediation
Real Estate Activities
Renting of M&Eq and Other Business Activities
Public Admin and Defence; Compulsory Social Security
Education
Health and Social Work
Other Community, Social and Personal Services
Private Households with Employed Persons

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