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Growth in international spillovers of energy and relation to development

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Abstract

The production of goods and services demands direct and indirect use of energy. In this thesis, the production – based and the consumption – based use of energy is studied. Using the Multi – Regional – Input – Output (MRIO) methodology the amount of direct and indirect use of energy related with products traded internationally is determined. The energy intensities from both consumption and production perspective are used to determine the relationship between the energy carriers use and national economic growth. Furthermore, the accounts are disaggregated to individual regions aiming at understanding of the energy transfer patterns including the share of domestic inputs, exports and imports along with their relation to the regions. In the analysis are 49 countries and regions, 200 industrial sectors and 7 final demand categories are considered during the period from 1995 till 2012.

The result analysis is focused on the natural inputs extraction, energy carriers use and emissions relevant to energy use. The production and consumption accounting, as well as the single – country accounting showed a certain decline in the amounts of energy embodied in the foreign exchange of products within the developed countries. In contrast, the figures for the developing countries had an increasing tendency, but surprisingly higher shares of renewable energy within the national energy mix.

By comparing the annual amounts of energy carriers use with the national GDP of the OECD and Non – OECD countries it is estimated that the level of decoupling of the energy system from economic development is greater within the developed countries than in the developing. On the other hand, contrasting the export and import rates with the national GDP revealed an existence of an annual drop, that means less energy is used for production of internationally traded goods and services.

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List of Acronyms

BRIO – Bilateral – Region Input – Output analysis

EFTA – European Free Trade Organization

EIO – LCA – Economic Input – Output – Life Cycle Assessment

EU – European Union

GDP – Gross Domestic Product

GHG – Greenhouse Gases

GTAP – Global Trade Analysis Project

IO – Input – Output model

ISIC – International Standard Industrial Classification

LCA – Life Cycle Assessment

MEA – Multilateral Environmental Agreements

MRIO – Multi – Region Input – Output analysis

NAFTA – North – American Free Trade Agreement

OECD – Organization for Economic Co – operation and Development

PEFA – Physical Energy Flow Accounting

PHH – Pollution Heaven Hypothesis

PPP – Purchasing Power Parties

SEEA – System for Environmental – Economic Accounting

SNA – System for National Accounting

SRIO – Single – Region Input – Output analysis

TPTA – Trans – Pacific Trade Agreement

USA – United States of America

WIOD – World Input Output Database

WTO – World Trade Organization

1. Introduction

In recent decades, the main drivers of expansion of the world trade are the population growth, economic development and globalization (C. Böhringer, Löschel, & Wirtschaftsforschung, 2004). The world's population growth causes increase in both production and consumption of goods and services, and greater demand for land, energy and materials that leads to intensified global economic activity and global exchange of goods and services. In 1995 with the establishment of the World Trade Organization (WTO) an open trading system was created who aimed at overcoming the trade barriers between nations. Since than the trade liberalization impelled both the developing and developed countries to increase their competitiveness on the international market and trade internationally, achieving rapid economic growth. Globalization is an outcome of the trade liberalization and the processes related to its integration (Hillman, 2008).

The international trade and the globalized economy can have a major impact on environmental quality. In the past, a variety of Multilateral Environmental Agreements (MEA) that affected the international trade were ratified. The main objective of those agreements was prohibiting international exchange of certain species and products or restricting the trade for certain conditions. The Montreal Protocol (1989) aimed at decreasing the production and consumption of substances harmful for the ozone layer and brought trade restrictions to non-signatory countries, while the Basil Convention (1992) attempted to control the transboundary movement of hazardous and other wastes and their disposal to protect the human health and conserve the environment which resulted in trade restrictions and export bans (Organisation for Economic, Development, Organisation for Economic Co, & Development, 2000). The Convention of Climate Change (1994), the Kyoto Protocol (2005) and most recently the Paris Agreement (2016) concentrate on global warming and the climate change issues. Within the Kyoto Protocol a group of targets for greenhouse gases (GHG) reductions for the industrialized countries were established.

The economic linkage among nations through international trade created a space for spillovers of emissions or the appearance of the carbon leakage phenomenon between the industrialized countries or the so – called Annex B[1] and non-Annex B countries. The unilateral abatement strategies of the Annex B countries had the potential to create a negative impact on the emission - intensive industries so the production of emission – intensive goods was relocated to the non – Annex B countries with weaker environmental regulations (C. Böhringer et al., 2004). Many developing countries declined any carbon decreasing commitments due to the negative effect that the emission restrictions might have on their economic growth (Christoph Böhringer & Rutherford, 2002).

Economic activities, exchange and growth necessitate work and hence steady and consistent flow of energy to do that work (Hall, Lambert, & Balogh, 2014). The goods and services produced in an economy are directly or indirectly related with energy use and, due to the type of fuel utilized, also with CO2 emissions (Machado, Schaeffer, & Worrell, 2001). Globally a major concern is the depletion of the natural resources, especially the fossil fuels, which has an impact on energy security and on the environment. In terms of increased global trade, part of the goods and services consumed in one country can be produced outside of the national borders using a variety of energy carriers. To estimate the amount of energy used for trading on the international market it is necessary to consider the amount of energy used for production within the national boundaries and additionally the energy embodied in imports and export of products. With the application of input – output techniques, the amount of direct and indirect energy use and CO_2 emissions related with a product, can be estimated (Machado et al., 2001) and therefore these techniques can be used to assess the energy and carbon embodied in products traded in the national or international markets.

The growth in the international trade brought transformations into his structure and dimensions that pointed out large regional shifts in the location of emissions from the production of goods and services and the location of their consumption. In this master thesis, it is analyzed if the same situation happened with the energy embodied in the international trade. Using multi – regional input – output (MRIO) analysis the amount of energy used for production and consumption of goods and services traded internationally is determined in the period from 1995 till 2012 between the OECD[2] and non-OECD countries. The results are analyzed considering the energy intensities deriving from the production and consumption activities of the developed and developing countries. Another perspective incorporated in the

[1] Annex B is a list of 38 countries plus the European Community in the Kyoto Protocol that agreed on Quantified Emission Limitation and Reduction Commitment (QELRC), along with the emission targets they accepted.
[2] In the group of OECD countries are included the members of the Organization for Economic Co – operation and Development

results analysis is the change in the energy usage and emissions relevant to energy use due to the bilateral, multilateral, and international trade agreements. Within the same analysis, the accounts are disaggregated to individual regions aiming at understanding of the energy transfer patterns covering the share of domestic part, exports and imports along with its relation to the regions.

Lately the global emission`s rising trend stalled and as main reason for the slowdown is accounted the decrease in coal consumption on the behalf of increased usage of natural gas and energy from renewables (Peters et al., 2017). According to the projected global emission rates for 2015 presented in (Robert et al., 2015) the amount of emissions has an neglecting increase compared with the continual rise per year in the last two decades. The stable emission trend in terms of intensified international trade expansion arises a question: "What contributes the most to this condition either the decoupling of the energy system or the slowdown of the global and single – country economic growth"? The main objective of this thesis is to estimate and discuss the level of decoupling of energy and emissions relevant energy use and the level of decoupling of energy from economic growth. An absolute decoupling arises when the environmental degradation is declining in parallel with the growth of the economy. Nevertheless, the decoupling is relative when the level of degradation is increasing but slower than the economy.

In the following text, Section 1 reviews the existing literature on energy and emissions embodied in the international trade of goods and services. Section 2 discusses the energy accounting concepts presenting a deeper insight in the differences between the natural inputs, the gross energy, net energy and emissions relevant energy use in accordance with the central framework of the system for environmental - economic accounting (SEEA). Section 3 illustrates the methodology covering the multi-regional input – output analysis and the energy production and consumption intensities as well as the import and export rates per GDP and the type of data used. Section 4 contains the gained result analysis discussed from different perspectives including international trade agreements and the financial crisis from 2008-2009 that caused changes to both the international trade patterns and the global economic development.

2. Review on energy and emissions embodied in trade

As mentioned before, the international trade and the globalized economy have a major impact on the environmental quality. The linkages between the international trade and environment have been a main subject of research during the years. Most of the studies attempt to either analyse the impact of the trade liberalization on environment as presented in (Copeland & Taylor, 1994), (Antweiler, Copeland, & Taylor, 2001) and (Managi, Hibiki, & Tsurumi, 2009) or oppositely the impact of international environmental agreements on trade as discussed in (Brack, Energy, Programme, & Programme, 1996). The impact from the international trade can be discussed from different perspectives. Firstly the international trade can generate more pollution than the local production since it occurs via transportation of goods through land area, air or seas and secondly because of the energy used in transportation (Batra, Beladi, & Frasca, 1998). In order to analyze the interactions between the international trade and environmental quality, (Jayadevappa & Chhatre, 2000) considered the following three categories of spatial environmental problems, deriving from production and consumption activities: local, trans –boundary and global environmental problems. Per them in the first category environmental problems and trade are interrelated due to the exchange of goods and services, while in the other two categories they are caused by physical spillovers.

Globalization has direct and indirect effect on the natural environment. The direct effect consists from the emissions and the detrimental effect on the environment deriving from physical movement of goods in frames of trans-boundary or global import and export. In parallel the growth of the international trade has variety of indirect effects classified in three categories: scale, composition and technique effects(OECD).The scale effect refers to the growth of the economic activities and its implications on the greenhouse gas (GHG) emissions generation, the technique effect refers to the amount of reduced emissions arising from the improved methods used in the production of goods and services, while the composition effect considers the change in emissions rate associated with the change of the country`s production intensity (Tamiott, World Trade, & United Nations Environment, 2009). Through innovation and improvement of the existing technologies accompanied with higher income arising from international trade openness, the so-called technique effect is the main driver in decreasing the globalization impact on the environment. On the other hand, the growth of the trade rates leads to increased economic activity and analogously to increased pollution that point out the negative influence of the globalization`s “scale” effect on the environmental quality (Liddle, 2001). Nevertheless in case when the composition effect is determined by the differences in the environmental regulations in different countries than may be considered the so – called Pollution Haven Hypothesis (Mongelli, Tassielli, & Notarnicola, 2006). According to (Liddle, 2001) the Pollution Haven Hypothesis (PHH) claims that the low environmental standards will occasionally become a source of comparative advantage and thus cause shifts in trade patterns. (Cole, 2004) examined data for the trade flows between "North" and "South" as an evidence for the PHH and concluded that pollution havens had already emerged between the trading nations during the considered period but they are temporary and limited to certain regions and sectors.

The carbon dioxide is considered as the primary greenhouse gas that contributes in large scales on the climate change. In order to provide consumer goods and services, the production processes became a significant source of harmful emissions. (Ahmad & Wyckoff, 2003) studied the CO_2 emissions related with the domestic demand and domestic production of 27 countries and the role of the international trade in the generation of emissions, while (Peters & Hertwich, 2008) investigated how the emissions embodied in the international trade affect the environmental profile of one country. Under the term "embodied emissions" they considered the emissions emitted in the process of production of a certain product. In accordance with their study the direct analysis of country`s imports and exports underlined the distinction between domestic consumption and global production and revealed that the Annex B countries are net importers of CO_2 emissions, while the non – Annex B countries are net exporters of CO_2 emissions.

The growth in the international trade brought transformations into his structure and dimensions that pointed out large regional shifts in the location of emissions from the production of goods and services and the location of their consumption. (Le Quere, Raupach, Canadell, Marland, & et al., 2009) associated the growth of CO_2 emissions in the international trade with the unequal distribution of embodied emissions between the Annex B and non – Annex B countries. The intensification of emitted CO_2 emissions within the non – Annex B countries was due to production of products that are exported and consumed in the Annex B countries. Although the consumption – based emissions in Annex B countries, taking in account only the imports from non – Annex B countries raised more rapidly than the emissions from their domestic production. (Glen, Jan, Christopher, & Ottmar, 2011) developed a trade – linked global database for CO_2 emissions to analyze the growth in emission transfers through international trade within 113 countries and 57 economic sectors in the period from 1990 to 2008. The study considered the net emissions transfers between Annex B and non – Annex B countries that indicated growth from 0.4 Gt CO_2 in 1990 to 1.6 Gt CO_2 in 2008. Their analysis also showed a nearly double increase in the CO_2 emissions from the production of exported products, where from 4.3 Gt CO_2 in 1990 the emissions rate went up to 7.8 Gt CO_2 in 2008.

Main drivers of global emissions, from a multiregional point of view, (Arto & Dietzenbacher, 2014) pointed the change in consumption per capita, population growth, technological changes and changes in composition of the consumed commodities. The increased consumption per capita and the population growth contributed to the global emissions growth with 46% and 13.7% respectively, while the changes in the technology and commodities had lowering effect, reducing the emissions individually by 27.6% and 4.8%.

To present a more comprehensive illustration of country`s responsibilities regarding the detrimental impact on environment, for several countries single - country studies were performed. The main aim of those studies was to estimate the GHG emissions related with their international trade and final consumption. The studies mainly considered the emissions associated with the domestic production and consumption. (Lenzen, 1998) considered the Australian imports and exports, and described direct and indirect primary energy and GHG requirements for a set of final consumption categories. The energy and GHG intensities for 45 industry sectors were calculated, using an input – output methodology. Input – output techniques were also used to determine the CO_2 emissions embodied in the Japanese exports and imports (Kondo, Moriguchi, & Shimizu, 1998), the direct and indirect CO_2 emissions from the Spanish imports and exports (Sánchez-Chóliz & Duarte, 2004) as well as the industrial emissions in a trade-oriented and trade-dependent economy as Taiwan (Wu, Chen, & Huang, 2007). (Mäenpää & Siikavirta, 2007) used an input – output model of the Finland`s national economy to determine how commodities flow among industries and to the key final demand categories and how it affects CO_2 emissions associated with the domestic consumption.

The rapid economic growth and increased level of exports made China the world`s largest $CO_2$ emitter. (Lin & Sun, 2010) analyzed the $CO_2$ emissions embodied in China`s imports and exports, considering 15 industrial sectors and classifying the embodied emissions in products in four categories: domestic CO_2 emissions embodied within products manufactured and consumed domestically, domestic CO_2 emissions embodied within export products manufactured domestically, imported CO_2 emissions embodied within import products used by final consumers domestically and imported CO_2 emissions embodied within import products but not for domestic consumption. Due to this analysis in 2005 China generated 5458 Mt CO_2 emissions from domestic production and 4434 Mt CO_2 emissions from domestic consumption.

It is not precisely defined either the producer or the consumer of goods and services is responsible for the generated CO_2 emissions when trading internationally. (Munksgaard & Pedersen, 2001) developed a production – based and a consumption – based model for estimating Denmark`s CO_2 emissions. In line with the production accounting principle, presented in their study, the producer is responsible for the generated CO_2 emissions originating from production of energy, goods and services. The disadvantage of that principle was the equal treatment of CO_2 emissions deriving from production of goods exported internationally and CO_2 emissions from domestic production. Oppositely the consumption accounting principle considered the consumer responsible for the CO_2 emissions coming from the production of energy, goods and services and in this case the CO_2 emissions were associated with the final use categories even if the goods and services are imported from other countries. (Steven & Ken, 2010) used consumption – based multiregional input – output (MRIO) model to allocate global CO_2 emissions to countries and industry sectors due to the consumers demand for final goods. The results from this study showed that nearly 23% of all CO_2 emissions from fuel combustion were generated in the production of goods that have been consumed in a different country. (Wiedmann, 2009) and (Lininger & SpringerLink, 2015) discussed the relevance of consumption – based approach for policy and decision making. This approach provides better understanding of the mutual but distinguished responsibilities between countries, quantifies the economic and environmental trade linkages among countries and provides directions in creating strategies on sustainable production and consumption along with the climate change mitigation policies at local, national or regional levels.

The energy presents a major driver of economic growth and international trade. As per (Yang, Long, Yue, & Shi, 2014) the term embodied energy is defined as " the total energy consumption, both direct and indirect, in the life cycle of a product or service". In context of the international trade, this term considers energy imports and exports to estimate the impact of trade products and services on the energy consumption of trade countries. As energy embodied in exports accounts the energy transferred from the export country to the import country to meet its consumption demands and the energy consumed directly or indirectly in the manufacturing process of exported products in the production country (export country), while energy embodied in imports is the opposite of energy embodied in exports. In cases when the amount of energy embodied in exports is greater than the amount of energy embodied in imports than a net embodied energy in exports can be estimated.

The embodied energy can be calculated using two different approaches. The first approach is the input – output analysis, that presents a linear economic model usually used for estimation of economic, environmental consequences or impacts following a change in the total output produced by the economy (Mongelli et al., 2006). In (W. Leontief & Leontief, 1936) were established the fundamental concepts of the input – output analysis, creating an input – output table which represented the interrelations of the economic activities of one whole county. The main aim of the input – output analysis, according to (Wassily Leontief, 1970) is to present the level of output of each sector in correspondence with the levels of activities in the other sectors, within the national economy.

With application of input – output techniques, the amount of direct and indirect energy use and CO_2 emissions related with a product, can be estimated (Machado et al., 2001) and therefore these techniques can be used to assess the energy and carbon embodied in products traded in the national or international markets. Many international trade – oriented studies have been conducted aiming to assess how foreign commerce influenced on the domestic demand for energy and how it affected the environment locally and globally. (Wright, 1974) using an input – output analysis investigated how much energy has been used in the production of several goods and services in the US economy, (Bullard, Penner, & Pilati, 1978) combined the input – output analysis with process analysis in order to determine the energy costs for any good or service, while (Proops, Atkinson, Schlotheim, & Simon, 1999) using an input – output analysis examined the trade relationships among national economies and their environmental footprint.

For estimation of the energy embodied in international trade, using an input – output analysis, three models have been developed: Single – region input – output (SRIO) model , Bilateral – region input – output (BRIO) model and Multi – regional input – output (MRIO) model (Yang et al., 2014).

The Single – region input – output (SRIO) analysis is used to calculate the energy embodied in a single country or region based on the data from the country`s or region`s input – output table. Until now there are researches in this field conducted for UK (X. Tang, Snowden, & Höök, 2013), Brazil (Machado et al., 2001), Italy (Mongelli et al., 2006) and China (Liu, Xi, Guo, & Li, 2010), (Ying, Jiahua, & Laihui, 2011), (Zhang, Qiao, Chen, & Chen, 2016) and those studies are more comprehensively discussed below. The Bilateral – region input – output (BRIO) model is used to calculate the energy embodied in bilateral trade countries or regions using input – output tables of these countries or regions, while the Multi – region input – output (MRIO) model is also used to calculate the energy embodied in the international trade covering multiple trade countries or regions employing input – output tables of distinct national economies and ascertaining the starting point of the imports and the final point of the exports. The MRIO models can be open multiregional models in cases when in the model are not incorporated all the World economies and oppositely close when in the model included all the world economies (Rocco & Colombo, 2016).

The second approach uses the Life Cycle Assessment (LCA) to calculate the direct and indirect energy consumption during the whole production process of goods and services. (Ghertner & Fripp, 2007) used an economic input – output life – cycle, consumption – based model to measure the environmental impacts in four categories: global warming potential, energy use, toxic release and air pollution, arising from the US trade activities. (Yang et al., 2014) also used an economic input – output life – cycle assessment (EIO – LCA) model to investigate the energy flows in the international trade between China and USA. (Rocco & Colombo, 2016) as a main problem associated with embodied energy underlined the definition of appropriate and accurate ways to calculate the whole direct and indirect primary energy demands of the analysed product from a life – cycle perspective. The study provided complete and detailed theoretical formulation of single – region and multi – regional methods for trade treatments in input – output analysis that can be also beneficial support for the LCA. From the assessment of international trade treatment methods have been concluded that the use of inappropriate treatment methods can produce very inaccurate calculations of the total and specific energy embodied in goods and services deriving from the national economic activities.

- China

Due to the domestic consumption demand and the growth of export rates, China`s energy demand and related GHG emissions have grown rapidly over the last two decades, placing China on the top of the world`s list of primary energy consumers. In parallel the accelerated economic development increased China`s dependence of oil imports. (Li, Pei Dong, Chunyu, & Wang, 2007) discussed the impact of the embodied energy on the total ecological footprint and (Liu et al., 2010) combined an input – output analysis to evaluate the embodied energy and a structural decomposition analysis to identify the key factors that drive changes in the energy rates embodied in exports. The study pointed China as a great net energy exporter due to the increased export of energy intensive goods. (Ying et al., 2011) developed a quantitative calculation model for estimation of the embodied energy and its modelling method covered calculation of the energy embodied in exported and imported goods, net embodied energy and embodied emissions, instead (B. j. Tang, Shi, Chao, & Shen, 2013) focused on the energy embodied in the exports of the key industries, while (Zhang et al., 2016) applied a MRIO analysis on the China`s economy to estimate the embodied energy transfers through the domestic trade in the period from 2002 till 2007.

- Brazil

(Machado et al., 2001) analysed the Brazilian economy in 1995, to assess the total impacts of the international trade on the used energy and the generated CO_2 emissions. The study was based on a commodity – by – industry input – output model expressed in hybrid units, where the energy commodities were in physical terms, while the non – energy commodities in monetary terms. The fundamental principle of their methodology was to multiply, respectively, the total energy and CO_2 intensity coefficients by foreign trade numbers and therefore assess the energy and CO_2 emissions embodied in exports and imports. Due to the gained results, the highest total energy intensity coefficients were accounted for heavy industries, such as iron and steel, and transportation. Regarding the energy embodied in the non – energy commodities trade the results showed that the energy - intensive commodities share around 30% of the total exports of non – energy goods and nearly 20% of the total imports.

- Italy

Italy due to the requirements of the Kyoto Protocol, in the period from 2008 till 2012 needed to reduce the amount of GHG emissions for 6.5% compared with the emissions in 1990. (Mongelli et al., 2006) intended to assess if the lower environmental standards and the international trade have allowed some countries to become “a haven” for the Italian energy and related carbon – intensive industries. In this study was applied an extended input – output model primarily for calculation of energy and related GHG emissions intensity of the Italian economic sectors and moreover for calculation of the total embodied energy and carbon in the imported commodities. The results pointed out the Artificial and synthetic fibres, Cement and Ceramics, as a major energy and carbon intensive sectors in Italy.

- UK

The UK`s economic structure changed from primary producer to primary consumer during the past few decades. Since 2005 this country became a net energy importer and therefore its dependency of fossil energy significantly increased. (X. Tang et al., 2013) investigated the impact of embodied energy from trade on the UK energy imports for the period from 1997 to 2011. For the analysis, they developed an input – output model that aimed to calculate the energy embodied in the UK`s exports and imports and the net energy exports embodied in UK`s international trade. The gained results pointed the trend of UK`s embodied fossil energy imports and exports. In line with that trend, the UK`s "coal" and "oil and gas" embodied fossil energy imports went beyond the embodied fossil energy exports, ascertaining the UK`s status as a net embodied fossil energy importer. The causes for the change in the UK`s embodied fossil energy imports were found in the change of the amount of trade imports and the change in the intensity of fossil energy consumption. With the purpose of further analysis of the UK`s net embodied fossil energy imports, they considered the sector and country distributions. Due to the sector`s distribution, the so called "heavy" industries, such as electricity, cement and steel production, were the greatest net importers of embodied fossil energy, while as net exporters derived the financial and banking services. In the case of country`s distribution the results showed that the most important UK`s trade partners are Russia, China and India.

- Renewable energy

With the purpose of reducing the negative impact from the production and consumption of products, globally the focus is on improvement of the existing technologies and invention of new alternative technologies that will even further increase the share of renewable resource use within the country`s energy commodity mix. (Ben Jebli & Ben Youssef, 2015) examined the relationship between the international trade and the energy consumption. The presented model included the GDP, as output, by means of dependent variable and the renewable and non – renewable energy consumption and the international trade on the other side as independent variables. The results pointed out the mutual dependence between the GDP and trade, where any variations in the output indicate changes in the exports and imports rates and oppositely. A variety of studies researched the renewable energy consumption, for instance (Sadorsky, 2009) estimated the linkage among renewable energy consumption and the real income per capita, (Apergis & Payne, 2010a), (Apergis & Payne, 2010b) and (Apergis & Payne, 2011) assessed the relationship between the consumption and the economic growth of the OECD, Eurasia and Central America countries, respectively. (Cortés-Borda, Guillén-Gosálbez, & Jiménez, 2015) using an environmentally extended input – output model assessed to which extend the world`s wealthiest economies are moving towards more sustainable energy sources. In their analysis, they simultaneously considered the energy produced in one country and the energy used to produce the goods and services that the same country consumes, using production – based and consumption – based approach. In accordance with the gained results China is an immense net exporter of solar energy due to both approaches, while the other countries are estimated to be net importers of solar energy.

3. Energy accounting concepts

Most of the countries amass energy balances and national accounts that include two different types of energy statistics. The energy balances present the supply and energy use data by industry and by energy source on a single – country level. On the contrary, the National Accounts illustrate the monetary flows related with energy such as production of energy, intermediate consumption by industries and final use by households and governments. The differences in the classification and data source among those two energy statistic types causes inconsistencies when comparing the monetary and physical flows.

The environmental – economic accounting is a concept that integrates the environmental and economic statistics with the purpose of further analysis of the relations among those fields. Generally, this accounting concept determine the influence that the economy has on the environment and oppositely how the environment affect the economy, through an established system for national accounting (SNA), in details presented in (European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, and, & Bank, 2009).

In 2012, the United Nation`s statistical commission accepted a central framework of the system for environmental – economic accounting (SEEA). Due to the pollution increase, the natural resource depletion and the higher risk of energy scarcity, the energy and emissions relevant energy use are considered as priority field for application of the SEEA. In the frames of the SEEA a sub-system is developed, especially for energy accounting comprised from a set of tables and accounts related to energy. As per ((UNDESA), 2012), the SEEA includes the following tables and accounts categories:

- Supply and use tables in physical and monetary terms;
- Asset accounts for mineral and energy resource in physical and monetary terms and
- Accounts covering energy – related transactions.

The energy accounting distinguishes three main elements: the energy from natural inputs, the energy products disaggregated due to their purpose and the energy residuals. In the frames of the SEEA ((UN) et al., 2014) those three elements are defined as following:

Natural input are all physical inputs that are moved from their location in the environment, as a part of economic production processes or that are directly used in production;

Products are goods and services that result from a process of production in the economy;

Residuals are flows of solid, liquid and gaseous materials and energy that are discarded, discharged or emitted to the environment by establishments[1] and households through processes of production, consumption or accumulation, but may also flow within the economy.

The relationship between the main elements is illustrated in Figure 1. The accounts for physical flow of energy estimate the amount of natural inputs extracted from the environment and imported in the economy, the energy flows within the economy and the energy flows coming out of the economy to the environment in a form of energy residuals. Those flows of energy are assigned to the resident country where the energy products are produced or consumed. Through the SNA the physical flows on country level are accounted and considering the country`s imports and exports of products, the flows between one country and the rest of the world. The energy accounts of physical flows are expressed in energetic units or net calorific units, most commonly joules.

The physical flow accounting in SEEA covers flows of products, flows of natural resources and flows of residuals (Nations, Commission, Fund, Development, & Bank, 2003), due to their supply and use. The flow of products considers the balance between the total supply and the total demand. The total supply of products is comprised from the domestic production and the imports of products. On the other hand, the total product demand summarizes the intermediate consumption (goods and services used by industries for further production of other goods and services), household final consumption, government final consumption, capital formation (goods and services purchased by industries for future manufacturing of other goods and services) and exports. The flow of natural inputs counts domestic extraction and imports of natural inputs to the industries in a form of raw materials for further production of goods and services for intermediate consumption, the final household and government consumption demand on a national level and the exports to the rest of the world. Finally, the flow of residuals into the environment includes the residuals arising from the use of goods and services as intermediate inputs by the industries, accompanied by the residuals produced in the final consumption and disposal.

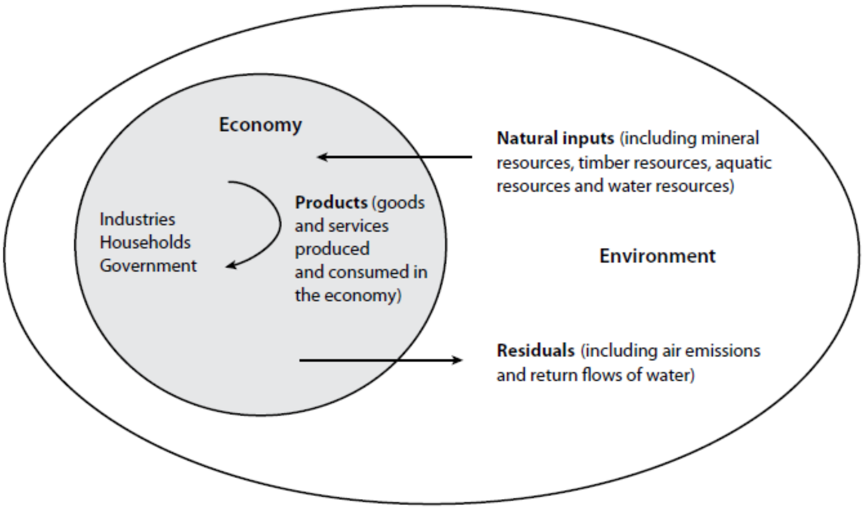

Figure 1 - Physical flows of natural inputs, products and residuals (Source:((UN) et al., 2014))

The energy accounts present data for the direct energy consumption of the households and in the production processes within the industries. Consequently, the aim of the physical accounts is to provide a continual monitoring of the energy supply and use, by type and industry and furthermore, bringing them together with the appropriate monetary values from the energy supply and use, to create consistent indicators for estimating, monitoring and evaluating the energy efficiency, energy productivity and energy intensity.

The input – output tables, as part of the physical supply and use tables, are created consequently to the need for establishment of a direct relation among the production and consumption. They can provide an insight at the effects that the change of consumption patterns has on the industrial output or import substitution. Hence, the input – output tables are constructed from the physical supply and use tables eliminating either the product or industry dimension and therefore obtaining either product – by – product table or industry – by – industry table, that presents both the supply and demand of a single category.

3.1 Natural inputs

The natural energy inputs are classified in three main groups to present the flows of the natural inputs within the economy ((UNDESA), 2012). The classification of the natural energy inputs, by type is presented in

Table 1, where the energy natural resource inputs, inputs of the energy from renewable sources and other natural inputs are distinguished.

Table 1 - Energy natural inputs (Source: ((UNDESA), 2012))

(Energy) natural resource inputs		
	Mineral and energy resources	
		Oil resources
		Natural gas resources
		Coal and peat resources
		Plutonium and thorium
	Timber resources (natural)	
Inputs of energy from renewable sources		
	Solar	
	Hydro	
	Wind	
	Wave and tidal	
	Geothermal	
	Other heat and electrical	
Other natural inputs		
	Energy inputs to cultivated biomass	

- The **natural energy inputs** include the mineral and energy resources such as oil, natural gas, coal and other metallic and non – metallic minerals that due to the Physical Energy Flow Accounts (PEFA) are further classified, divided to sub – items and distinguished as primary and secondary energy products entering in and flowing through the economy (EUROSTAT, 2014). The timber resources, as natural inputs can be used for production of energy products such as bio – fuel. This group of natural inputs is considered as a non – renewable sources of energy and the timber resources are included here as delectable inputs due to their regenerative capacity.
- The **energy inputs from renewable sources** cover the energy gained from non – fuel sources of energy such as the solar, hydro, wind, wave and tidal and geothermal energy. Those types of natural resources are used as direct inputs in the production of electricity and heat and considered as primary energy products.
- The **energy inputs to cultivated biomass** include organic materials gained either directly from plants or indirectly in a form of residuals from agriculture and forestry in

addition to the wastes from industries and households. The biomass feedstock is used by a variety of power systems instead of natural gas or coal, in the process of electricity production and the biomass fuel or bio – fuel is utilized as a replacement of the petroleum products, as gasoline or diesel.

The energy from natural inputs is extracted and captured from the environment with the intention of being further used, as a material input, either by the economic unit that conducted the extraction or to be delivered to other economic units. The “ownership” of the natural resources belongs to the resident country where the resources are extracted and consequently accounted as an input to the country`s economy that can be beyond used as an input in the domestic establishments or exported to the rest of the world.

Within the SEEA primary and secondary energy sources are distinguished. As primary energy sources, fossil fuels and renewable energy resources are accounted, while as secondary the derived electricity and heat and refined petroleum products presenting products gained with transformation of the primary energy sources. The types of energy produced from renewable energy, for instance bio – fuels, heat from geothermal reservoirs or solar panels or electricity from hydropower or windmills are accounted as primary energy products. In contrast, the energy gained from the transformation of the primary resources, such as heat and electricity produced with combustion of coal, production of charcoal from fuel wood or petroleum from crude oil are considered as secondary energy products.

3.2 Energy accounting

Since each economic activity is related directly or indirectly with energy consumption the energy supply and use is crucial input to all economic processes. In the energy accounting three categories of accounts are differentiated, depending on the accounts principles and application (Schenau, 2006). The classification of the accounts is the following:

3.2.1 “Gross” energy accounting

The gross energy accounts present all energy flows that arise between the environment and the economy as well as among the economic units within the national economy through a

$$Total\ supply\ =\ Domestic\ production\ +\ Imports$$

supply – use identity. The accounting concept is comprised from accounts for the supply of energy products and the use of energy commodities. Through the supply accounting for each commodity is presented the amount of energy products imported and domestically produced defined as following (Nations et al., 2003):

$$Total\ use\ =\ Intermediate\ consumption\ +\ Households\ final\ consumption\ +\ Government\ final\ consumption\ +\ Capital\ formation\ +\ Exports$$

In opposite, the use accounting determines the amount of energy commodities consumed on a national level and additionally the exported amount. The energy use as per (Nations et al., 2003) is calculated as showed below:

The main advantage of this accounting concept is the balance between the imports and domestic production from one side and the intermediate and final consumption and exports on the other. Nonetheless in the conversion of the energy products from primary to secondary derives a double counting that causes inconsistencies in the results for the final demand of the industries or the entire economy.

3.2.2 "Net" energy accounting

Differing from the previous accounting concept, these accounts do not include the energy uses in the process of transformation from primary to secondary energy products and consequently they are not double counted which focus the analysis on the final use of energy. The accounts incorporate the energy coming from the extraction of natural inputs on national level and the imports and the energy that in fact is finally consumed and exported. As presented in the SEEA this concept uses the input – output identity to trace the materials coming to the economy and the materials leaving the economy coupled with the net additions to stock in the

$$Materials\ into\ the\ economy\ =\ Flows\ from\ environment\ +\ Imports\ +\ Residuals\ received\ from\ the\ rest\ of\ the\ world\ +\ Residuals\ recovered\ from\ the\ environment$$

is equal to

$$Materials\ out\ of\ the\ economy\ =\ Residual\ flows\ direct\ to\ environment\ +\ Exports\ +\ Residuals\ sent\ to\ the\ rest\ of\ the\ world$$

plus

$$Net\ additions\ to\ stock\ in\ the\ economy\ =\ Gross\ capital\ formation\ +\ Accumulation\ in\ controlled\ landfill\ sites\ -\ Residuals\ from\ produced\ assets\ and\ controlled\ landfill\ sites$$

economy.

In line with the SEEA presented in ((UNDESA), 2012), the input – output identity is defined as following:

In view of the fact that not all energy flows obtain consistent monetary transaction, the net energy accounts are expressed in physical terms, but they can be straightforwardly related with the monetary transactions deriving from the National Accounts.

3.3 Emissions relevant to energy use accounting

The emissions relevant to energy use include energy use only for fuel combustion and exclude energy for other uses. This concept is quite similar with the net energy accounting concept where are accounted only the energy carriers that cause air emission, thus the energy carries like electricity, wind and solar energy and nuclear energy are not included in the accounts.

4. Methodology and Data

In this thesis for calculation of the amount of energy embodied in international trade of goods and services an Input – Output analysis is used. The input – output approach was developed by the American economist Wassily Leontief(W. W. Leontief, 1936). Generally, the standard Input – Output (IO) model is constructed for a certain economic area, such as a country or a region. The economic activity of that area is divided into a previously determined number of industrial sectors and the inter-sector transactions from each of the sectors denoted as producers to each of the sectors designated as consumers, are observed and measured for a certain period, usually for one year. Beside the industrial sectors the model incorporates other exogenous final demand consumers as households, government and international trade that demand products from each sector.

4.1 Single-region Input – Output (SRIO) model

For one economic area, inter – sector flows occur among producing sectors *i* and consuming sectors *j*, taking in consideration the economic flow Z_{ij} of goods and services. In one country or region with *n* industrial sectors, the total output *x* of each sector *i* is denoted as x_i and the final demand from the exogenous consumers is designated as y_i (Miller & Blair, 2009). The total output from sector *i* is presented in Eq. 1.

$$\textbf{Eq. 1} \quad \boldsymbol{xi} = \boldsymbol{Zi1} + \cdots \boldsymbol{Zij} + \cdots \boldsymbol{Zin} + \boldsymbol{yi} = \textstyle\sum_{j=1}^{n} \boldsymbol{Z_{ij}} + \boldsymbol{y_i}$$

For: $\boldsymbol{x}=\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$, $\boldsymbol{Z}=\begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{bmatrix}$, $\boldsymbol{y}=\begin{bmatrix} y_i \\ \vdots \\ y_n \end{bmatrix}$, the Eq. 2 can be generally rewritten as:

$$\textbf{Eq. 2} \quad \boldsymbol{x} = \textstyle\sum \boldsymbol{Zj} + \boldsymbol{y}$$

The inter–sector flows of goods and services can be presented in an input – output table, as illustrated in Table 2.

The final demand category is classified into domestic final demand that refers to the household`s purchases, national and local purchases and private investment purchases and foreign final demand that considers country`s exports.

		Consumer sectors					Final demand	Total output
		1	...	j	...	n		
Producer sectors	*1*	$Z11$	...	$Z1j$	...	Zin	y_1	x_1
	:	:		:		:	:	:
	i	$Zi1$	...	Zij	...	Zin	Y_i	X_i
	:	:		:		:	:	:
	n	$Zn1$	...	Znj	...	Znn	Y_n	X_n

Table 2 - Input - Output table of inter - sector flows of goods

The inter-sector transactions from *i* to *j* depend completely on the total output of sector *j*. The ratio between those variables is called technical coefficient and is denoted by a_{ij} , as presented in Eq. 3.

$$\textbf{Eq. 3} \quad a_{ij} = \frac{\mathbf{z_{ij}}}{\mathbf{x_j}}$$

The technical coefficient is fixed variable that determine the relationship among a sector`s outputs and inputs. In matrix notation, the technical coefficient can be expressed as in Eq. 4:

$$\textbf{Eq. 4} \quad A = \begin{bmatrix} \boldsymbol{a_{11}} & \cdots & \boldsymbol{a_{1n}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{a_{n1}} & \cdots & \boldsymbol{a_{nn}} \end{bmatrix}$$

When considering the established technical coefficients, the Eq. 4 appears in the following form:

$$\textbf{Eq. 5} \quad \boldsymbol{X} = \boldsymbol{A} * \boldsymbol{x} + \boldsymbol{Y}$$

The solution of Eq. 5 is expressed as follows:

$$\textbf{Eq. 6} \quad \boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A}) - \mathbf{1} * \boldsymbol{Y}$$

Where the notation $\boldsymbol{(I - A)^{-1}}$ is the Leontief`s inverse matrix, consisted from ***A*** presenting the total inter-sector requirements matrix and ***I*** an identity matrix.

4.2 Multi-regional Input – Output (MRIO) model

The multi – regional input – output model considers the economic transactions between several economic areas, in addition covering the internal transactions of each country. For instance when the model is comprised from *p* individual economic areas, where each of these areas is consisted from *n* – number of sectors, then the matrix ***A***, from Eq. 6 is disaggregated into *p* – number of sub-matrices $\boldsymbol{A^{rr'}}$ which illustrate the economic flows among area *r* and area *r'* (Cortés-Borda et al., 2015), as presented below.

$$\textbf{Eq. 7} \quad A = \begin{bmatrix} A_{11} & \cdots & A_{1p} \\ \vdots & \ddots & \vdots \\ A_{p1} & \cdots & A_{pp} \end{bmatrix}; \qquad \textbf{Eq. 8} \quad A^{rr'} = \begin{bmatrix} A_{rr'11} & \cdots & A_{rr'1n} \\ \vdots & \ddots & \vdots \\ A_{rr'n1} & \cdots & A_{rr'nn} \end{bmatrix}$$

Each sub – matrix expressed as $A^{rr'}_{ij}$, shows the economic flows from sector *i* of area *r* to sector *j* in area *r'*. The total output *x* is presented through a set of vectors parallel to the economy`s areas outputs (x_r), as expressed in Eq. 9.

$$\textbf{Eq. 9} \quad x_r = \begin{bmatrix} x_1 \\ \vdots \\ x_r \\ \vdots \\ x_p \end{bmatrix};$$

Regarding the final demand, in the MRIO models each area *r'* can require goods and services from local sectors or can import them from other external areas. If *Yr'* is considered as the final demand of area *r'*, then the form of $Y_{r'}$ vector will be expressed as shown in Eq. 10 and the requirement that area *r'* demand from sector *i* of area r is the vector $Y_{rr'}$ given below.

$$\textbf{Eq. 10} \ Y_{r'} = \begin{bmatrix} Y'_{1r} \\ \vdots \\ Y'_{rr} \\ \vdots \\ Y'_{pr} \end{bmatrix}; \qquad \textbf{Eq. 11} \ Y_{rr'} = \begin{bmatrix} Y'_{1rr} \\ \vdots \\ Y'_{irr} \\ \vdots \\ Y'_{nrr} \end{bmatrix}$$

4.3 Energy use estimation using production – based approach

The production accounting model covers calculations of the natural inputs, the energy carriers in general and divided in two categories of renewable and non – renewable carriers and the emissions relevant to the energy used. The main equation used for estimation of the energy use through the production – based approach is presented in Eq. 12.

$$\textbf{Eq. 12} \ f = S * x + Fh$$

Where,

f – Production factor;

S – Production coefficient;

x – Gross output;

$\mathbf{F_h}$ – Final household consumption.

The production factor f presents a 1 x 49 vector specifying the energy use from the 49 countries and rest of the world regions. The production coefficient S is a matrix dimensioned differently depending either the natural inputs (20 x 200 matrix), the energy carriers (75 x 200 matrix) or the emissions relevant to energy use (56 x 200 matrix) are calculated considering the domestic production products from 200 sectors for each country and region. In the model is included also the matrix for the domestic final consumption of the households $\boldsymbol{F_h}$ from 7 different demand categories.

The gained results from this model are expressed in physical terms in TJ per year. When intending to estimate the production intensity (I_p) of each country and region the obtained numbers are divided with the Gross Domestic Product (GDP) per year for each country respectively, as calculated via Eq. 13. The value of the GDP is considered at constant purchasing power parities (PPP). The production intensity appoints the total amount of energy carriers for production of goods and services necessary to generate one unit of GDP.

Eq. 13 $I_p = \boldsymbol{f} / \boldsymbol{GDP}$

4.4 Energy use estimation using consumption – based approach

The consumption – based approach estimate the energy used by each country or region to satisfy their final demand, considering international transactions from the multi – regional economy or global economy. The consumption accounting model is based on Eq. 14 and it determines the amounts of natural inputs, the energy carriers and the emissions relevant energy use individually, as the production – based approach.

Eq. 14 $\boldsymbol{c} = \boldsymbol{S} * (\boldsymbol{I} - \boldsymbol{A})^{-1} * \boldsymbol{Y} + \boldsymbol{F_h}$

Where,

c – Consumption factor;

S – Production coefficient

$\mathbf{(I - A)^{-1}}$ – Leontief inverse matrix;

I – Identity matrix;

A – Technical coefficients matrix;

Y – Final demand categories matrix.

The consumption factor $\boldsymbol{c}$ presents a 1 x 49 vector specifying the energy consumed through goods and services, from the 49 countries and rest of the world regions, respectively. The production coefficient $\boldsymbol{S}$ matrix and the matrix for the domestic final consumption of the households $\boldsymbol{F_h}$ is dimensioned for the same sectors and with the similar method as in the production – based accounting model. Using the Leontief`s inverse matrix this approach, through the 200 x 200 technical coefficients matrix $\boldsymbol{A}$, takes in consideration the total inter -

sector requirements that on the other hand through the 200 x 7 final demand matrix $\boldsymbol{Y}$, ascertain the end use of every sector.

The consumption intensity is expressed by means of the ratio between the consumption factor and the GDP of each country or region, as given in Eq. 15. This indicator points out the amount of energy consumed within the county`s final demand categories per unit of the national GDP.

$$\textbf{Eq. 15}\ I_c = c / GDP$$

4.5 Single – country accounting

The gained production and consumption accounts are further regionally aggregated and additionally the energy transfers between the regions are calculated. For each country and region their domestic part is determined, covering the national input in the production and consumption of goods and services. From this accounting are estimated the imports, considered as part of the products taken from other country and region and brought on the national market to satisfy the domestic demand and the exported products presenting the goods and services produced domestically but distributed internationally.

This approach can be used to identify the significant net exporter and net importer countries or regions. For each country is recognized its relationship with different countries and regions and the embodied energy and emissions relevant energy use through international trade of goods and services.

The single – country accounting model can verify the consistency of the results obtained by the production and consumption approach. The sum of the domestic part and the exports gives the production factor $\boldsymbol{f}$ (Eq. 16), while with summation of the domestic part and the imports the consumption factor $\boldsymbol{c}$ (Eq. 17) is calculated.

$$\textbf{Eq. 16}\ Domestic\ part + Exports = Production\ factor$$

$$\textbf{Eq. 17}\ Domestic\ part + Imports = Consumption\ factor$$

This accounting approach allows the physical and monetary accounts to be linked through calculation of import and export and the economic activity of the country. Those accounts are expressed as a ratio between one country`s imports and exports and the national GDP, as presented in Eq. 18 and Eq. 19, respectively.

$$\textbf{Eq. 18}\ A_i = Imports / GDP$$

$$\textbf{Eq. 19}\ A_e = Exports / GDP$$

4.6 Data

The MRIO analysis related to environmental and resource accounting, as a source of data can use several databases such as EXIOBASE, World Input Output Database (WIOD), Global Trade Analysis Project (GTAP) and Organization for Economic Co-operation and Development (OECD) databases. The data used in this thesis is retrieved from the database of the Programme for Industry Ecology on the Norwegian University of Science and Technology. The conducted analysis covered the following elements:

- 43 countries, South Africa as a region and Rest of Asia and Pacific, Rest of America, Rest of Europe, Rest of Africa and Rest of Middle East regions;
- 200 products;
- 7 final demand categories;
- 74 energy carriers, from which 44 non-renewable and 30 renewables;
- 20 natural inputs and
- 56 emissions relevant energy use.

For the certain purposes as inputs in the analysis are considered the natural inputs and the energy carriers, both renewable and non-renewable, and as outputs the harmful emissions relevant energy use are taken into account. The analysis studies the evolution of energy carriers use in the period from 1995 till 2012.

In the further analysis of the gained results the above mentioned 49 countries will be distinguished as OECD and non–OECD countries when discussing the production and consumption approaches. The relationship between the energy use along with the emissions relevant to energy use and the economic progress of one region is presented through the energy consumption and production intensities. From the 35 countries, members of the Organization for Economic Co-operation and Development, due to the lack of data are excluded Chile, Iceland, Israel and New Zealand and they are accounted in the "Rest of the countries" set of data.

In the results analysis from the single – country accounting model, the imports and exports from the analysed 49 countries will be classified and discussed in ten groups of countries or regions as following: European Union (EU), United States of America (USA), East Asia (Japan, South Korea and Taiwan), Australia, Canada, China, India, Mexico, Brazil and Russia.

5. Results and discussion

5.1 Production and consumption accounting

5.1.1 Natural inputs

The influence of the production and consumption patterns among the OECD and non – OECD countries on the natural resources and the environment is presented considering the nature inputs and the emissions relevant energy use. The analysed data from production perspective (Figure 2) showed a significant difference in the extraction of natural resources between the developed and the developing countries. The amount of extracted natural inputs within the OECD countries was constant till 2011 when this tendency considerably declined from approximately 150 million TJ per year to 120 million TJ per year in 2012. On the other side, the trend in the non – OECD countries constantly raised from around 250 million TJ per year in 1995 till 400 million TJ per year in 2012.

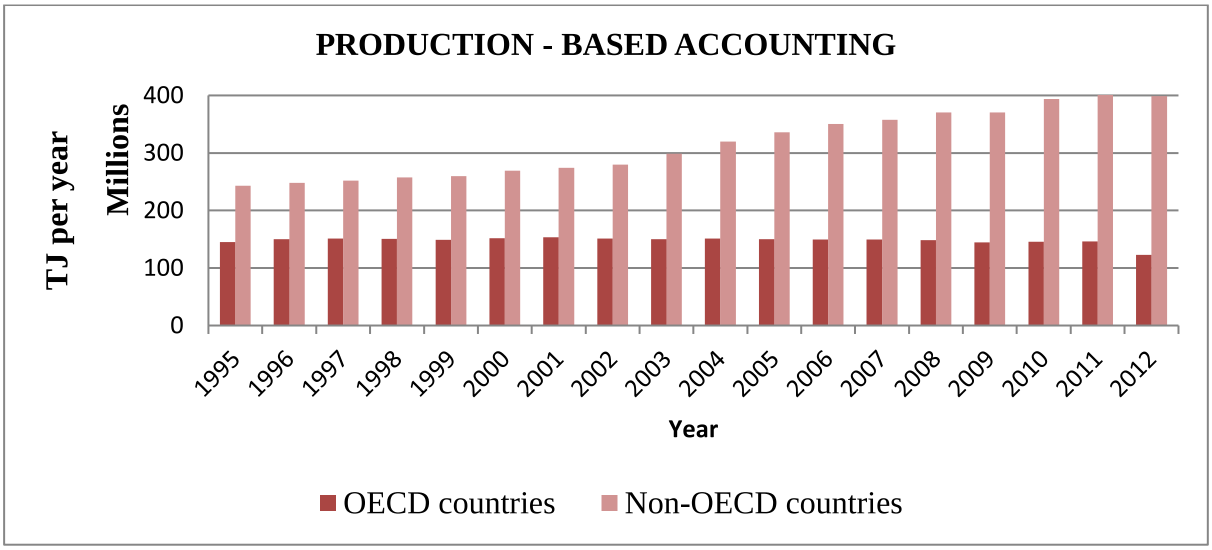

Figure 2 - Natural inputs from production accounting

The consumption approach (Figure 3) revealed a slight difference between the developing and developed countries. The consumption of the OECD countries in 1995 was 210 million TJ per year, around 15% higher than in the non – OECD countries and retained greater until 2006. In 2012 the non – OECD countries consumed 314 million TJ per year that was above than 50% compared to the OECD countries amount.

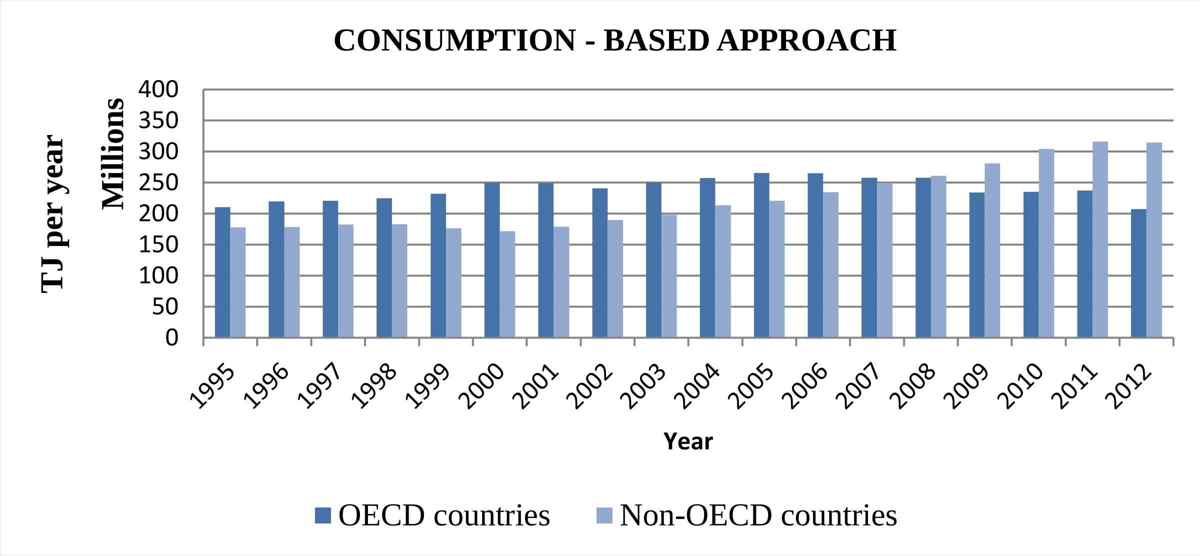

Figure 3 - Natural inputs from consumption accounting

The growth in material extraction among the non – OECD countries is attributable to the rapid industrialization of the emerging economies and the rapid economic expansion, followed by increase in the national incomes. Many of the developing countries are net exporters of natural inputs. The export dependency of one country affects the national economic development, since it is the one of the main drivers of the country`s economy. Nevertheless, the long-term dependence has a global impact on the international market causing market instability and price fluctuations.

In the OECD countries, the average income is constantly high but the natural resource extraction is relatively stable. The increased domestic resource productivity arising from the implemented policy measures and the technical improvements results in relative decoupling from the economic growth. Although the developed economies are lately orienting more to a service – based economy, replacing the resource – intensive domestic production with imported goods and relocating the resource – intensive production processes to the developing countries.

5.1.2 Energy carriers use

In the period between 1995 and 2012, an increase in the energy carriers use is registered among the developing countries for production of goods and services, as presented in Figure 4. In 1995 the industrialized countries had higher rates but since 2006 that trend had a decreasing tendency oppositely from the non – OECD countries where the trend was going upwards. From the consumption perspective (Figure 5) the OECD countries had a continual increase in the energy use from 1995 till 2006, at some points nearly double compared with the non-OECD countries. After 2006 this rate had a dropping trend, while the figures for the developing countries till 2012 were slightly rising.

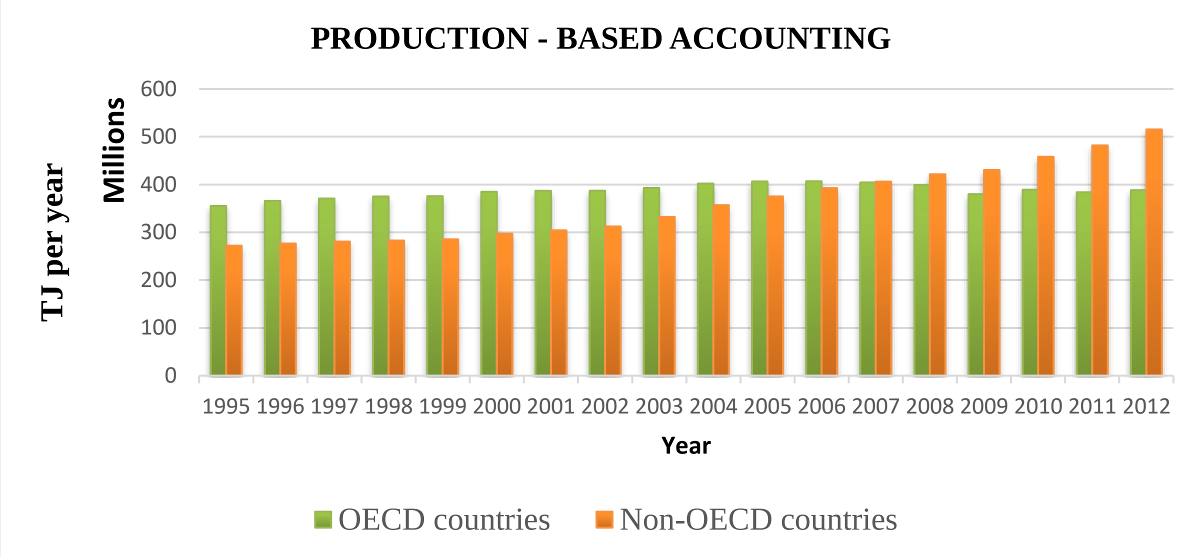

Figure 4 - Production accounting

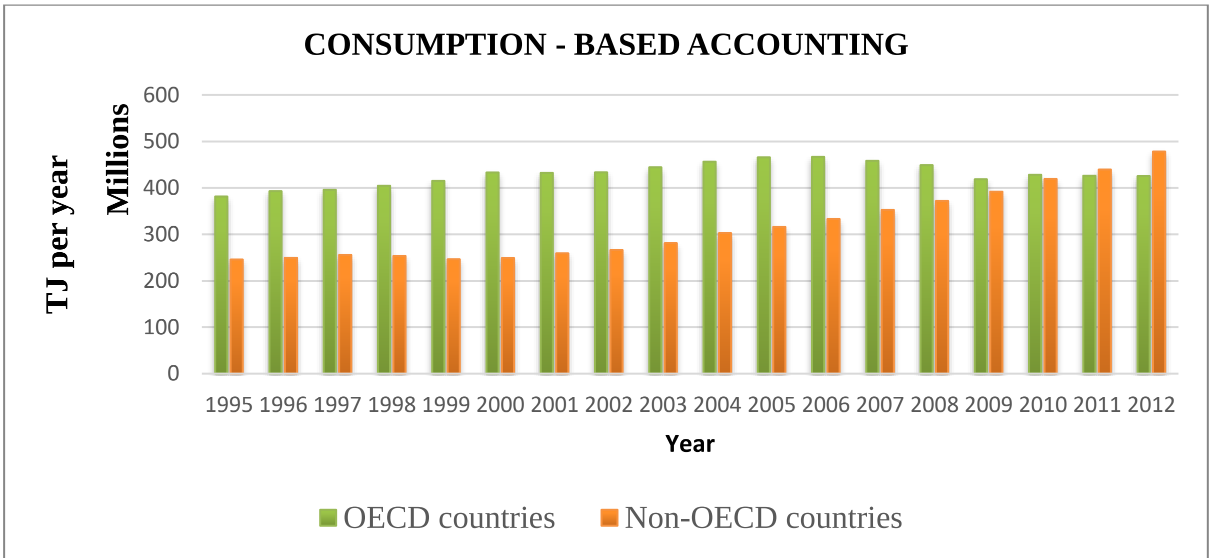

Figure 5 - Consumption accounting

The relationship between the energy use and the economic growth is expressed through the energy intensity. The change in energy intensities from both the production and consumption accounting approach are presented in Figure 6 and Figure 7 , respectively.

The production – based approach showed a trend towards declining the energy use per unit of GDP till 2010 in both the OECD and non – OECD countries. The intensity drop was between 1% and 5% per year. This tendency implies that the growth in energy carriers use is smaller than the growth in the national GDP. On the other hand, is worth noticing that the consumption – based accounts showed intensity fluctuations year by year in both the developed and developing countries. The variation of the intensities, which in 2002 and 2011 had even an increasing trend, indicate changes in the global final demand of goods and services.

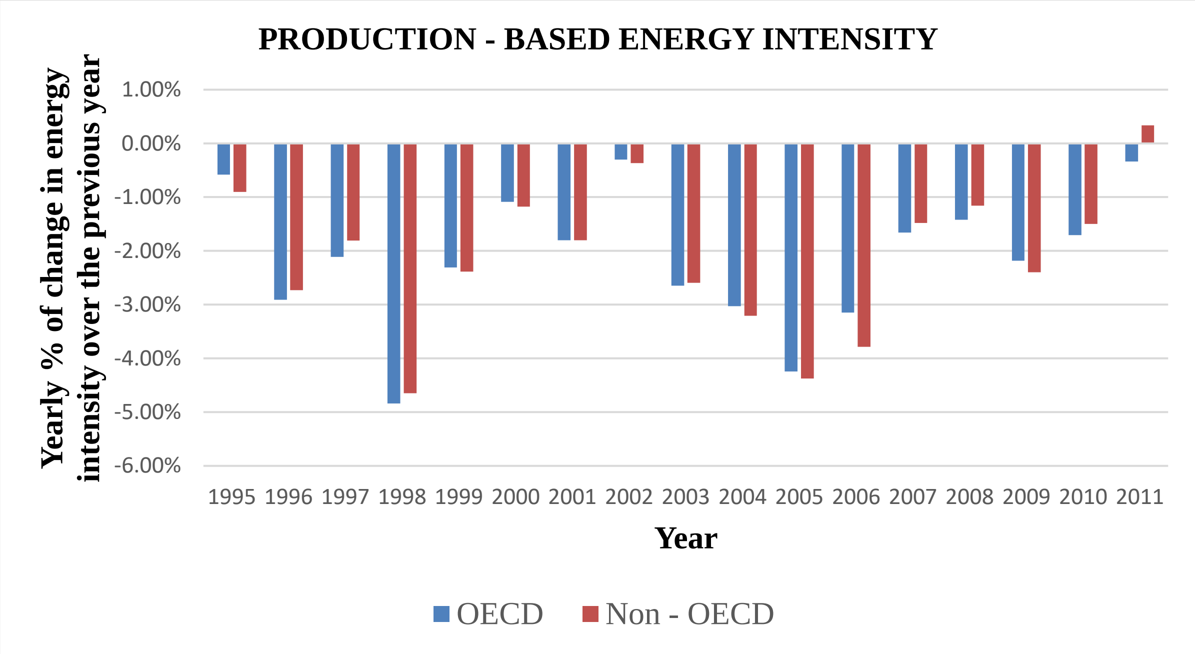

Figure 6 - Changes in energy intensity from production - based approach

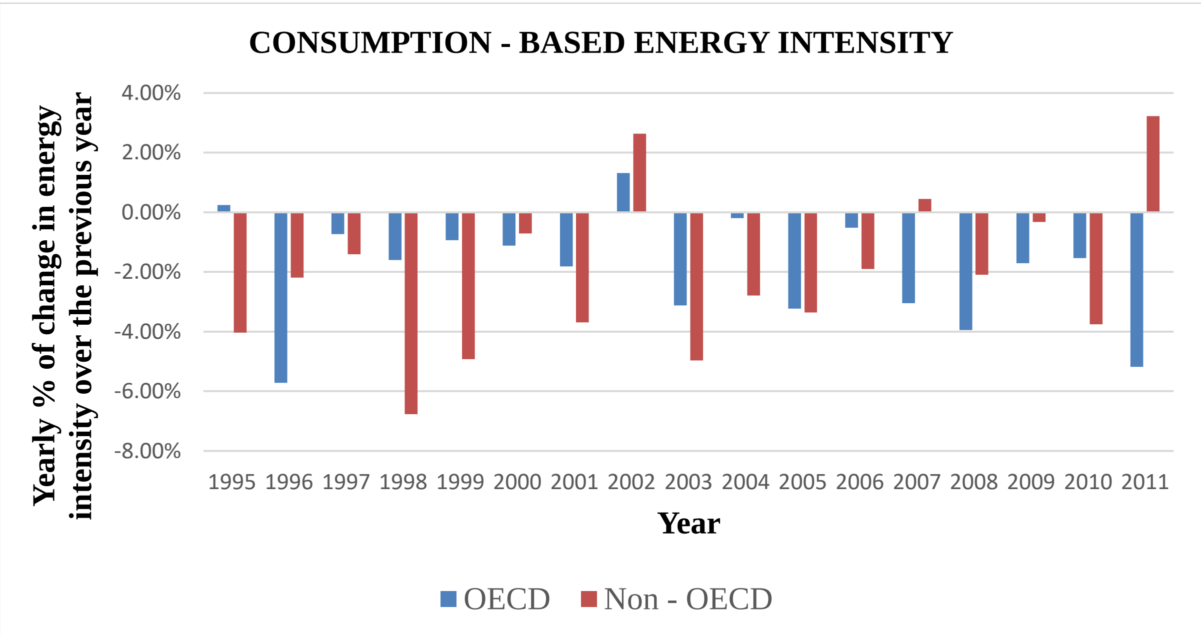

Figure 7 - Changes in energy intensity from consumption - based approach

The global financial crisis, that occurred between 2008 and 2009, had a major impact on the trade rates. The crises brought a global recession that further resulted in sharp fall in the global exchange of goods and services (World Trade Organization, 2010). The economic stagnation has an impact on the domestic final household consumption and intermediate consumption demand, the total output and the export capability of each country. As can be seen from the obtained results, during the crisis between 2008 and 2010 the energy carriers use in production within the OECD countries decreased, but the use through consumption increased. In parallel the non – OECD countries faced with the opposite situation, growth in production and drop in the domestic use demand.

To analyse to which extent the OECD and non – OECD countries are moving towards a more sustainable energy sources, the shares of non-renewable and renewable are analysed. The average amount of non – renewable resources from both the production and consumption point of view still shows a significant percentage of their use as an energy carriers. Nevertheless, the incremental decrease in the non – renewable resource use is parallel with the increase of the renewable resource use. The average amount of renewable energy carriers used was higher in the non – OECD countries, taking a share of around 35 % of the total energy carriers compared to a share of approximately 15% in the OECD countries (Figure 8).

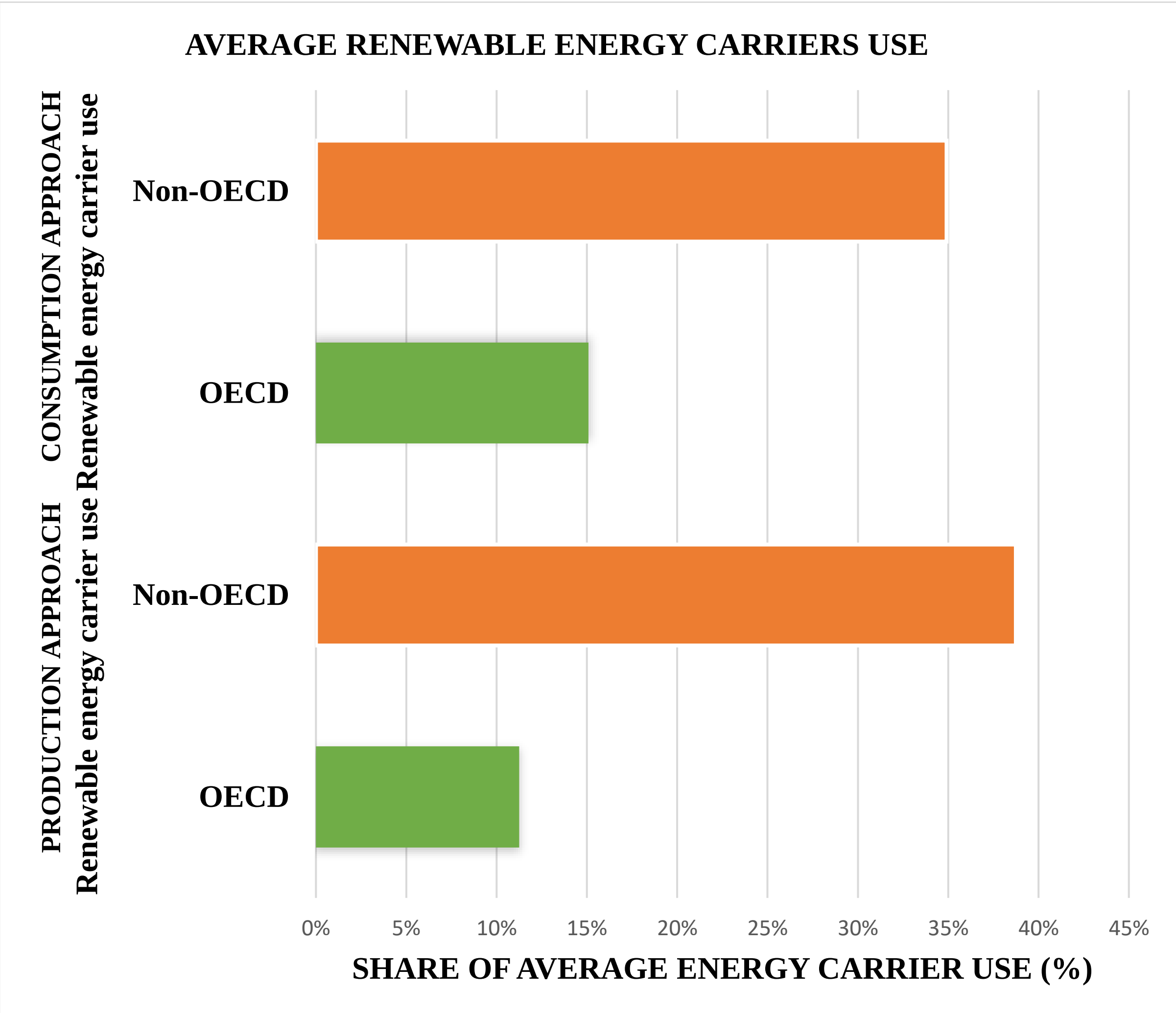

Figure 8 - Average renewable energy carrier use

5.1.3 Emissions relevant energy use

The emissions relevant energy use along international production and supply chains are accounted. In Figure 9 is presented the amount of emissions relevant energy use gained in the production – based and consumption – based accounting. Since 1995 the non – OECD countries had an increasing trend of emissions relevant energy use. The developing economies are generally net exporters of emissions relevant energy use because the production processes within those countries have more emissions relevant energy use than the domestic consumption demand. As a result of the reduction targets imposed by the Kyoto Protocol, the developed countries showed a decreasing tendency from both the production and consumption aspect. The emissions relevant energy use accounts from the non – OECD countries indicated a constant emission growth after 2006 that from one point of view can arise from the rapid industrialization and the weaker environmental regulations of the developing countries or on the other side, due to the relocation of the emission – intensive and pollution - intensive industries.

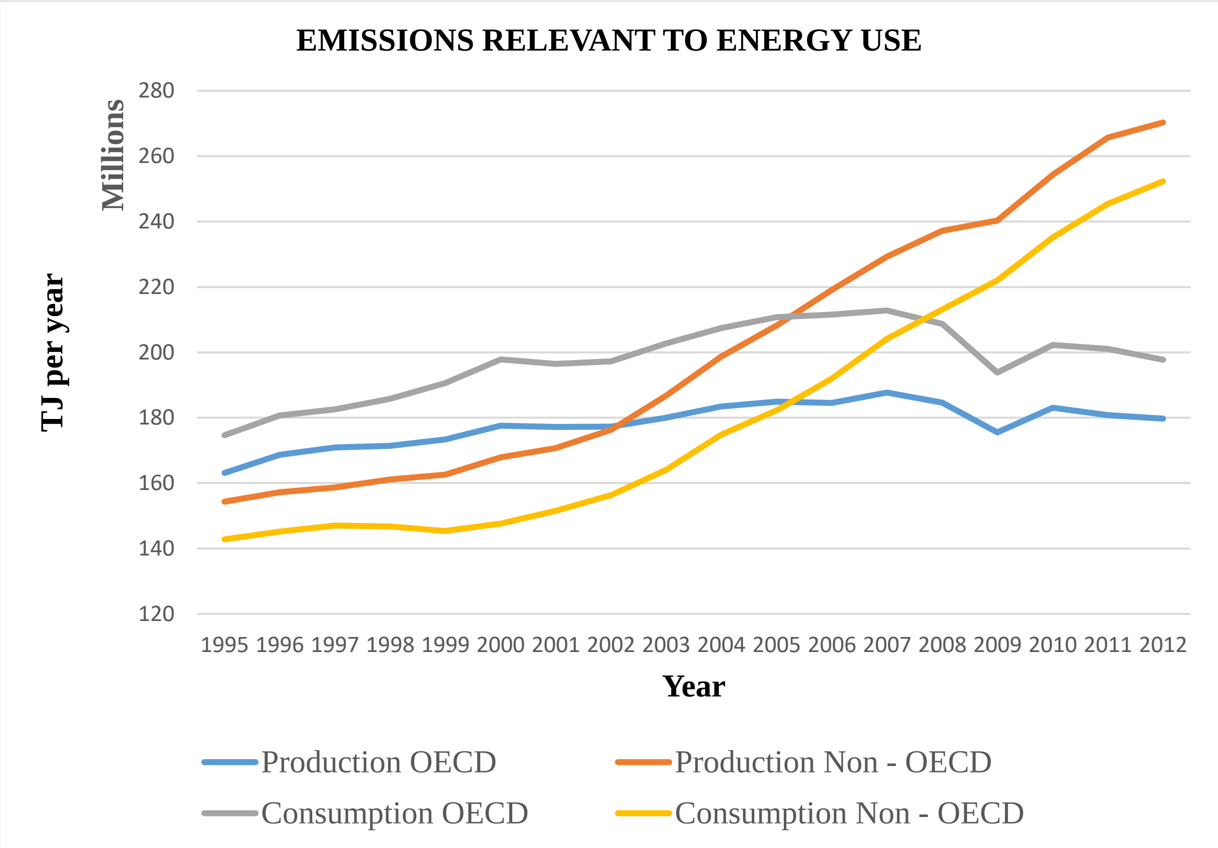

Figure 9 - Emissions relevant energy use from production – based and consumption – based accounting

5.2 Regional disaggregation of accounts and energy transfers between regions

5.2.1 Natural inputs

Many natural inputs are concentrated in a limited number of countries. The numbers from the production and consumption accounting pointed out uneven extraction between the OECD and non – OECD countries and the main reasons are the unequal geographical distribution of natural resources and export – dependency of the resource – rich countries. This inequality causes many of the countries to export a significant proportion of the domestically extracted natural resources and import a high proportion of products to satisfy their consumption demand (Michele Ruta, 2012).

Figure 10 illustrates the total amount of natural inputs embodied in trade distinguishing the domestic input, imports and exports. Leading importers of natural inputs were the EU countries, followed by the USA and the East Asia countries. On the other hand, Russia remained major exporter since 1995. From 2001 the USA and Chinese exports had an increasing tendency, reaching nearly 70% from the Russian exports between 2007 and 2012.

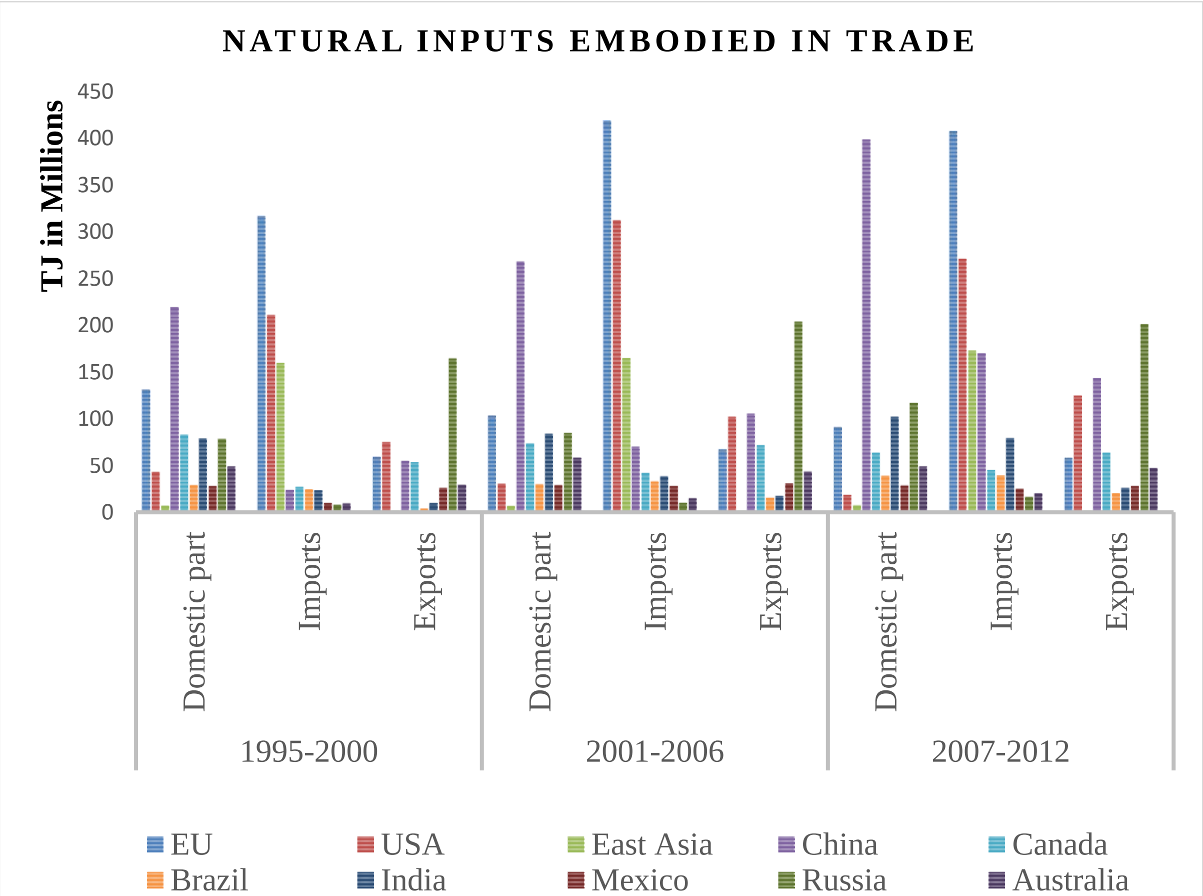

Figure 10 - Natural inputs embodied in trade

Besides the significant export growth, China the last two decades is facing with an increased domestic demand for natural inputs due to the rapid economic growth. In relation to the demand, the results indicated a double rise of the domestic natural inputs in the China`s economy.

5.2.2 Energy carrier use

The trade openness increased the foreign exchange of goods and services, expanded the international trade markets and intensified the competition among nations. Most of the international traders experienced a strong upswing in the energy demand. The emerging economies as China and India need even higher quantities of energy to satisfy the domestic consumption. The amounts present in Figure 11 point towards a substantial rise in the Chinese energy use for intermediate and final demand of the national industrial sectors and households. The rates of renewable energy in China`s energy mix went up in parallel with the increased energy carriers use, reaching a peak in 2011. The European Union and United States are the most significant trade partners of China, and from 2007 the exchange with India is intensifying. The European Free Trade Association (EFTA) and China signed a free trade agreement that is officially in effect from 2012. The free trade relation between USA and China should be established through the Trans – Pacific Trade Agreement (TPTA) that is still in a negotiation phase. Via this agreement, the USA will begin to trade liberally with Australia, Canada, Japan, Mexico and few other countries.

The European Union, as an industry – based economy, from 1995 till 2000 had the highest domestic input in production of goods and services. With the reorientation towards service – based economy the domestic input declined, while the import rates went upwards. The same situation occurred within the USA economy but at a lower rate. The North American Free Trade Agreement (NAFTA) in effect from 1994, strengthen the relationship between USA, Canada and Mexico and contributed to the increase in goods and services exchange among those countries. Mexico benefited mostly from this agreement since nearly half of its exports went to the USA.

The financial crises that took place between 2008 and 2009 had an impact on the amount of energy carriers embodied in trade, as presented in Figure 12. All the countries considered here were affected by the crisis. The trade linkages between trade partners, especially bilateral partnerships, impel the possibility for one country to be affected by the crisis.

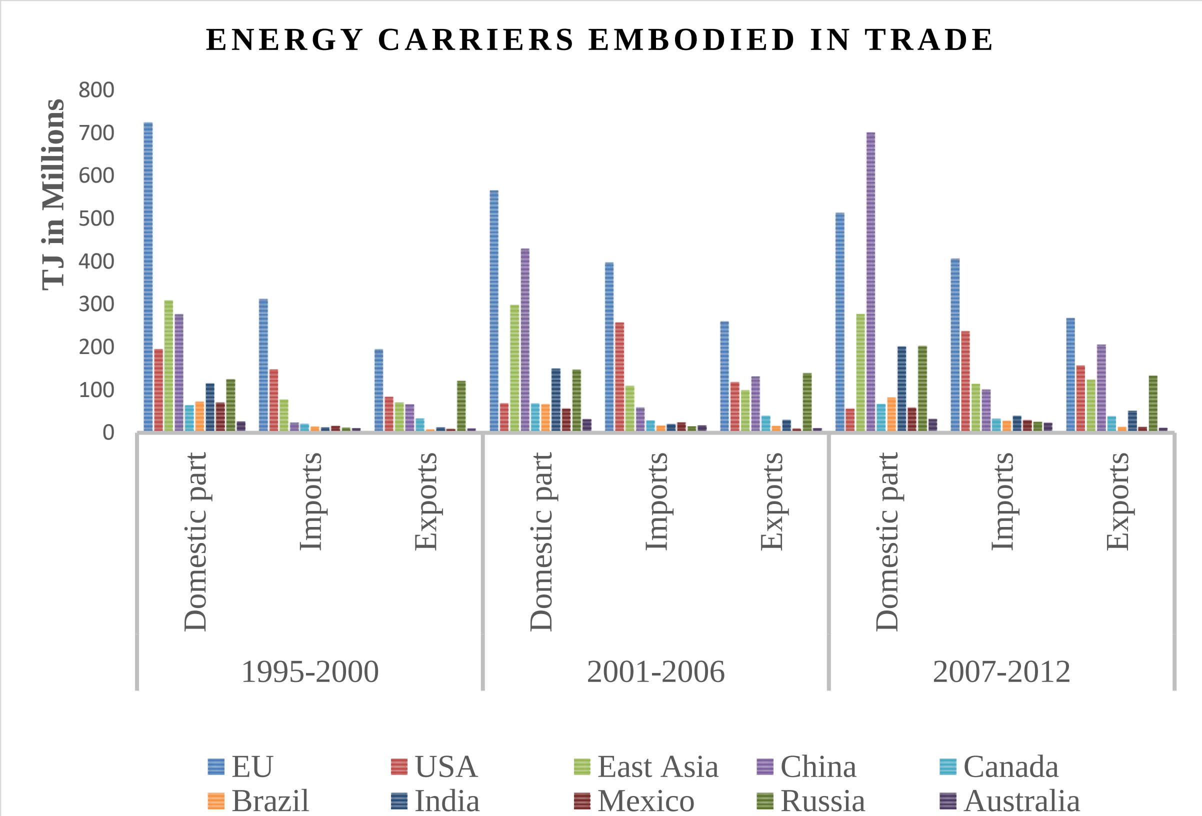

Figure 11 - Energy carriers embodied in trade

Generally, the financial crisis mostly influence on the country`s imports and exports due to the variations in the exchange rates. The devaluation of the national currency should increase the amount of exports and decrease the amount of imports (Zihui Ma, 2003).

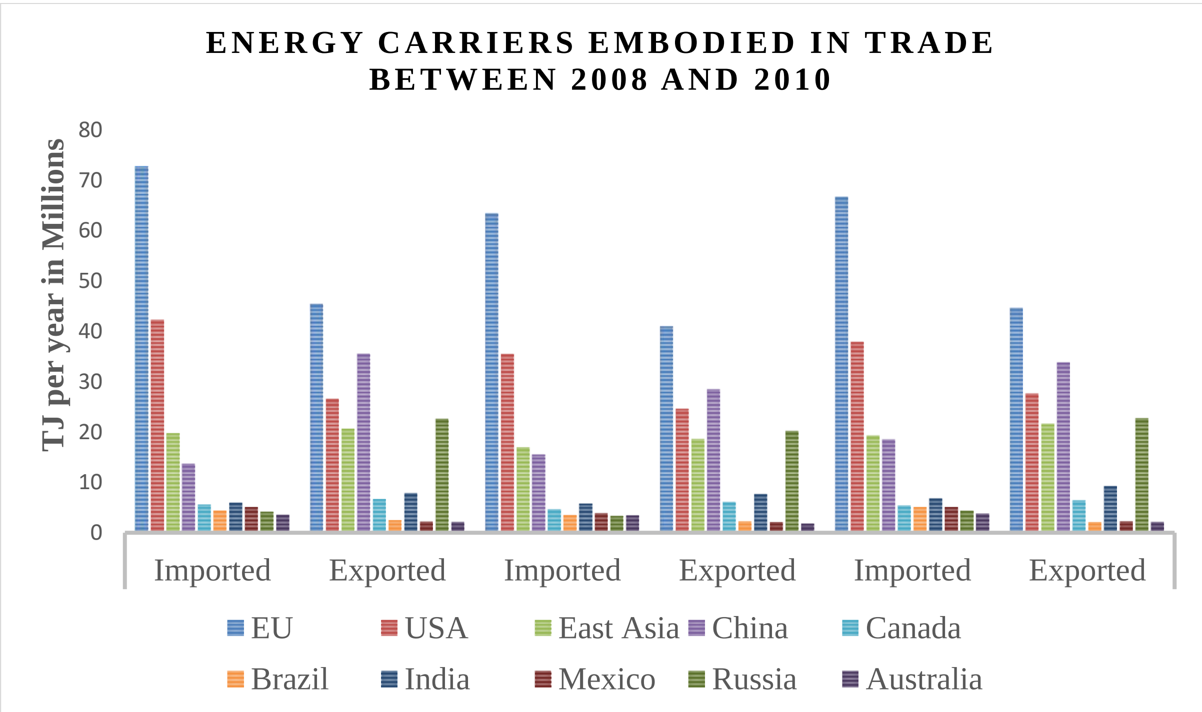

Figure 12 - Energy carriers embodied in trade during and post financial crisis

According to the presented results, in 2009 during the crisis there was a drop in both the imports and exports, compared to 2008. After the crises, the volume of imports and exports reached the same amount as in the pre – crises period.

The decoupling of the energy system can be perceived as a necessity for avoiding energy scarcity and achieving sustainable development of one country. The level of decoupling, in context of the trade impact, can be presented by comparing the changes in the GDP with the changes in export and import rates. The export and import per unit of the national GDP are illustrated in Figure 13 and Figure 14, respectively. The presented results revealed annual declining tendency in both the imports and exports for all considered countries. This trend pointed out that the growth in energy carriers embodied in the national imports and exports is smaller than the growth in the national GDP. As main drivers of this trend can be accounted the increased energy efficiency in the production processes together with the technology improvements and the increased natural input`s productivity. In all considered countries exist

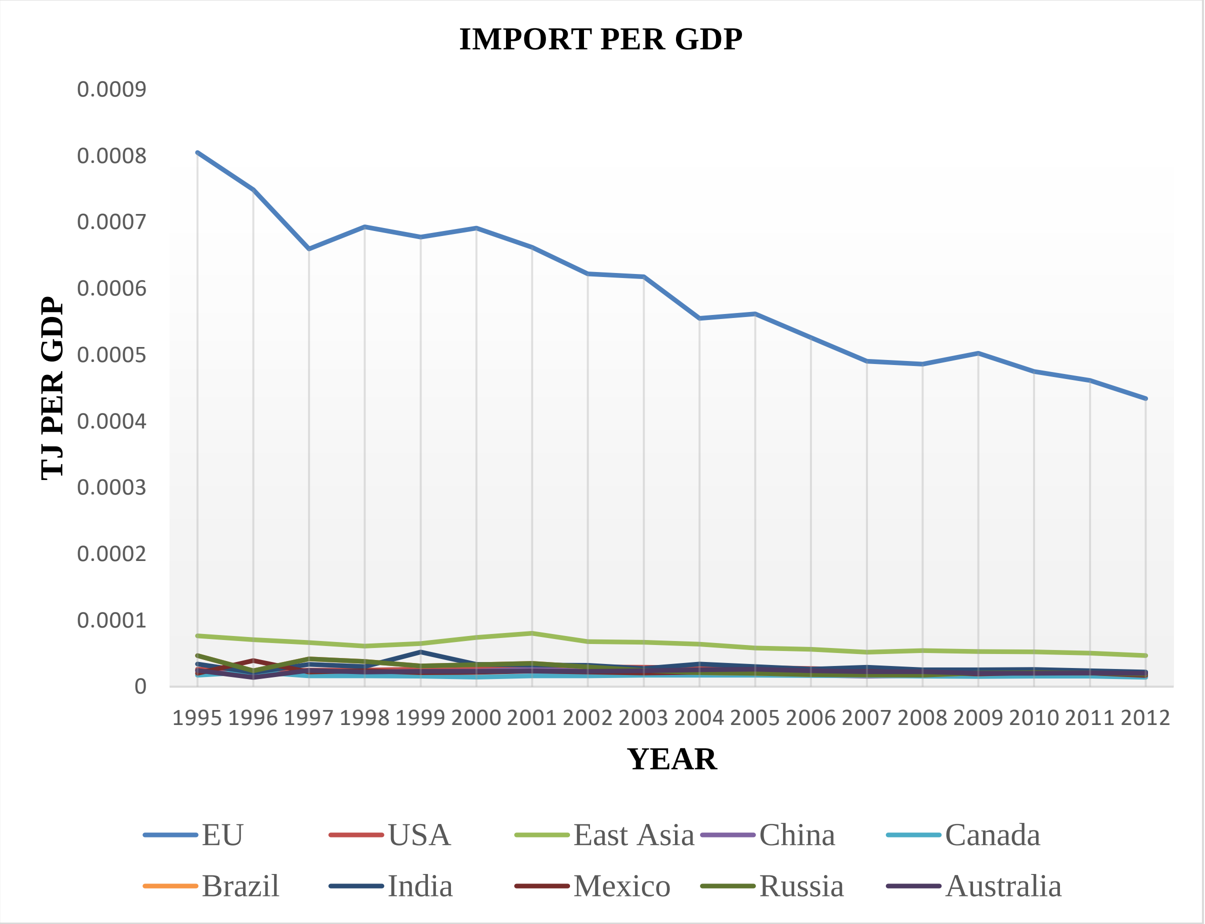

Figure 13 - Import per GDP

a relative decoupling on the exports and imports from the economic growth. The highest rate of imports per GPD and exports per GDP has the European Union followed by East Asia.

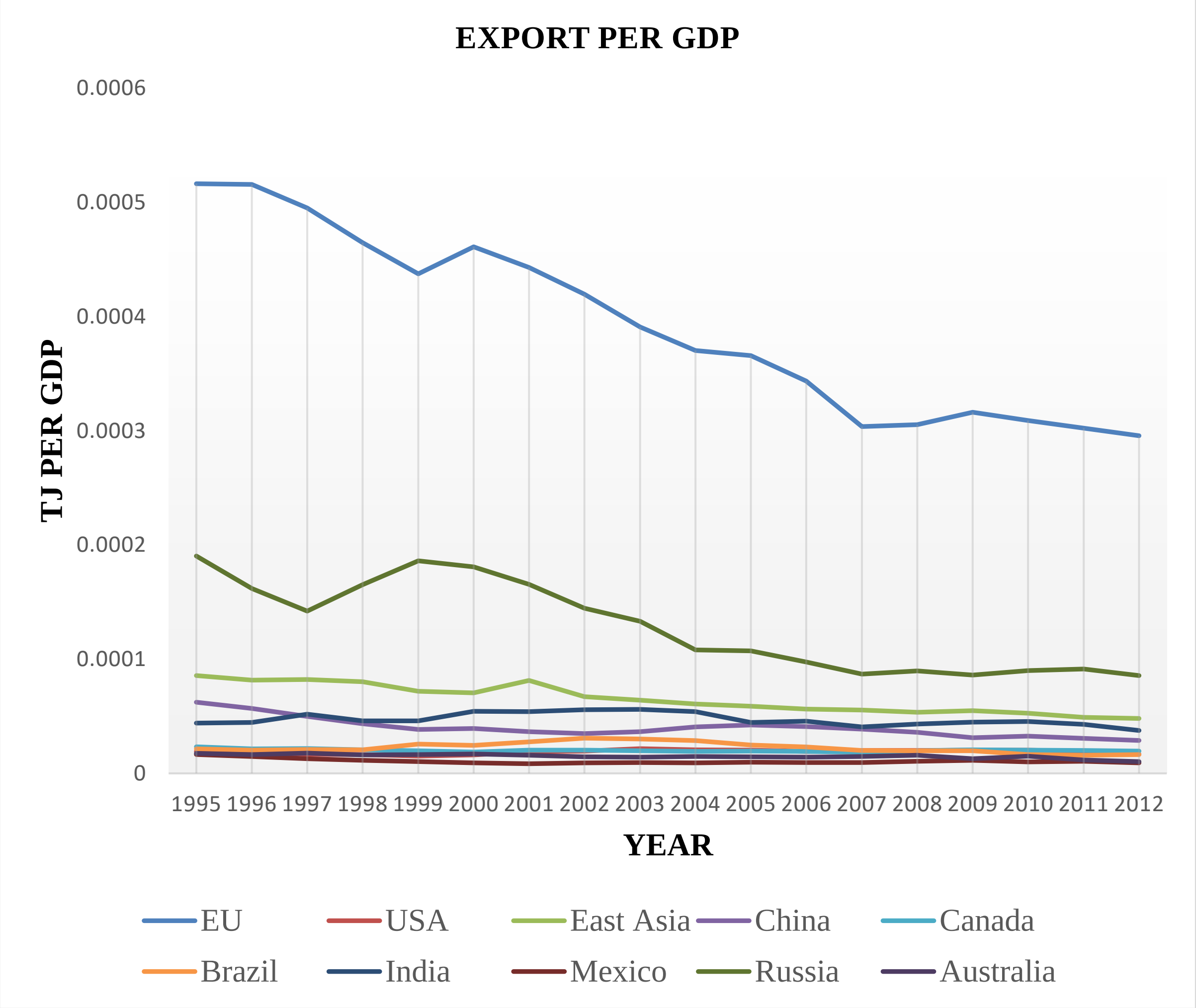

Figure 14 Export per GDP

5.2.3 Emissions relevant energy use

The emissions relevant energy use embodied in international exchange of goods and services are presented in Figure 15. Those results are quite similar with the results for the energy carriers use. Rapidly increasing trend in emissions relevant energy use generation had the emerging economies such as China and India due to the intensified domestic demand. The EU had a constantly high amount of emissions relevant energy use from the products consumed domestically and since 2001 additionally from the increased imports. The intensified imports in the USA increased the country`s rate of consumption – based emissions relevant energy use.

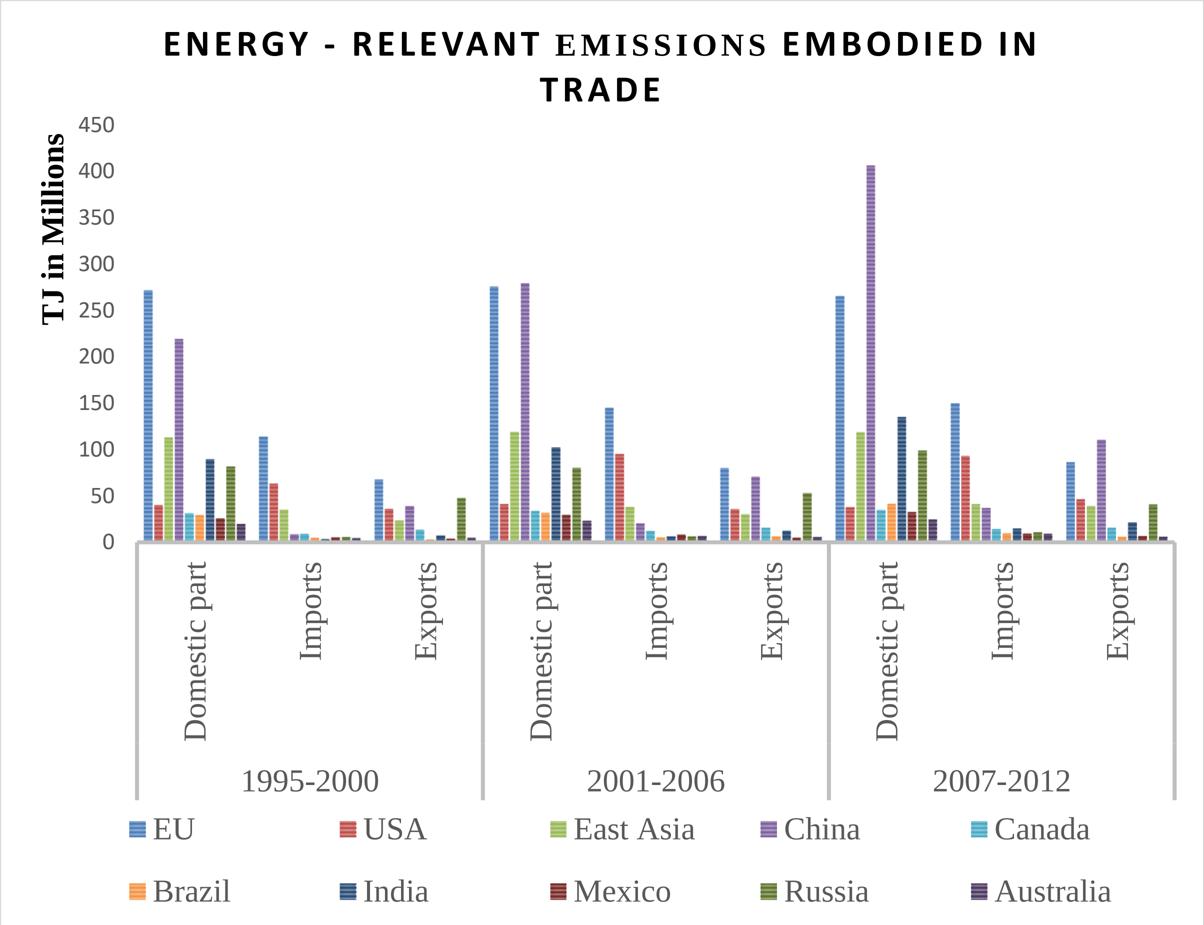

Figure 15 – Emissions relevant to energy use embodied in trade

6. Conclusion

This thesis analysed the energy embodied in the international trade using Multi – Regional Input – Output analysis. The analysis considered energy imports and exports to estimate the impact of trade products and services on energy consumption of trade countries. The result analysis focused on natural inputs extraction, energy carriers use and emissions relevant energy use.

The influence of the production and consumption patterns among the OECD and non – OECD countries on environment have been presented considering the nature inputs and the emissions relevant energy use. To conclude, the analysed data from production perspective (Figure 2) showed a significant difference in the extraction of natural resources between the developed and the developing countries, compared with the consumption - based approach (Figure 3) where the results revealed slighter difference. Recently the developing countries become important global suppliers of goods and services and according to their current economic development is expected to become significant consumers. Regarding the energy carriers use, in the period between 1995 and 2012 the use for domestic production of the developing countries rose (Figure 4). The consumption (Figure 5) of the OECD countries had a continual increase in the energy use till 2006, as well as in the amount of emissions relevant energy use, where the numbers showed a decreasing tendency after the ratification of the Kyoto Protocol, that came in effect in 2005.

The use of the consumption – based accounting provides better understanding of the mutual but distinguished responsibilities between countries, quantifies the economic and environmental trade linkages among countries and provides directions in creating strategies on sustainable production and consumption along with the climate change mitigation policies at local, national or regional levels.

The regional disaggregation of the accounts pointed out the EU countries, followed by the USA and the East Asia countries, as leading net importers of natural inputs and Russia as a major net exporter since 1995. From the obtained results, can be concluded that the trade liberalization indirectly enhanced the energy carriers use through the increase in the intermediate and final consumption demand. China as an emerging economy significantly increased the energy use for domestic production and consumption. However, the Chinese export`s growth throughout the years undoubtedly impelled the rapid national economic growth.

From the comparison of annual amounts of energy carriers use with the national GDP of the OECD and Non – OECD countries can be concluded that the level of decoupling of the energy system from the economic development is greater within the developed countries rather than in the developing. The GDP in relation with the imports and exports rates revealed an existence of an annual drop, that means less energy is used for production of internationally traded goods and services.

7. Further work

One of the steps for further work is application of Regression analysis on the obtained data in order to forecast the future trend of the energy use in relation to the economic progress of nations. This analysis can be applied to the regionally disaggregated accounts covering the natural inputs, energy carriers use and emissions relevant energy use. Regarding these elements, a forecast can provide reliable data on the upcoming trends, useful for understanding the evolution tendency of the global economy.

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