INTERNATIONAL TRADE AND EMISSIONS: A LONGITUDINAL INPUT-OUTPUT ANALYSIS[1]

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Abstract: Since the beginning of industrialization it is possible to observe an increase in the levels of greenhouse gas (GHG) emissions caused by human activities (WTO, 2009). Given this issues, the problem of greenhouse gas (GHG) and related climate change are relevant points today. Discussions began to gain the attention of the world with the Kyoto Protocol and they are in vogue due to the fact that the growth of GHG remained, even with emergence and advancement of climate policies. Moreover, they are in vogue due the sudden globalization of world economies and the expansion of international trade. Thus, this paper seeks to make an empirical investigation of the responsibility for CO_2 emissions and international trade for the 27 countries of the European Union and 13 other selected countries for the period of 1995-2009. This paper also permeates issues and discussions about the environmental theories and hypotheses involving international trade. The input-output matrices were used for 40 countries plus the "rest of world" for the period of 1995-2009, through the database of the WIOD project. The following results can be highlighted: i) the increase of CO_2 emissions in developing countries (*e.g.* Brazil , Russia, India and China) ; ii) the opposing behavior of the USA and BRIC (Brazil , Russia, India and China), with the exception of India, in terms of net balances of emissions embodied in international trade; iii) evidence that the decrease of CO_2 emissions in some countries comes from greater interaction in terms of trade with other countries; iv) the developed countries have an internal production process increasingly less polluting, and contrary to, developing countries have an internal production process more polluting, given the pairing between them. Furthermore, this study, through the different results, makes a discussion on the theory of environmental Kuznets curve, the pollution haven effect, the pollution haven hypothesis, trade's patterns between North and South, and others.

Keywords: CO_2 Emissions; International Trade; Input-Output.

JEL Classification: C67; Q56.

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1. INTRODUCTION

According to the report of World Trade Organization (WTO, 2009), since the beginning of industrialization it is possible to observe an increase in the level of greenhouse gas (GHG) caused by human activities. As a result, the concentration of GHG in the atmosphere has also increased. Given this scenario, the issues around GHG and related climate change are relevant in the global economy discussion.

Discussions began to gain the attention of the world with the signing of the Kyoto Protocol in December 1997, where an international agreement was reached to reduce global emissions to the atmosphere. Thus, in terms of CO_2 emissions, the majority of European countries, including the European Union as a whole, agreed to reduce such emissions (MUNKSGAARD and PEDERSEN, 2001). However, as shown by Bastianoni (2004), the debate is in vogue, for example, due to the policy adopted by the last governments of the United States, in contrast to the Kyoto Protocol.

Moreover, the growth of global CO_2 emissions remained, even with the emergence and advancement of climate policies. On the one hand, from 1990 to 2008 CO_2 emissions in developed countries has stabilized and, on the other hand, emissions in developing countries doubled (PETERS *et al*., 2011).

International trade has expanded in recent centuries and this is one reason why trade is increasingly being involved with discussions about climate change (WTO, 2009). According to Peters and Hertwich (2006), given that production networks are increasingly global, it is observed that many production processes occur outside the country of final consumption.

In this context, Peters *et al.* (2011) show that net emission transfers by international trade from developing countries to developed countries increased from 0.4 Gt CO_2 in 1990 to 1.6 Gt in 2008, *i.e.*, it is an indication that international trade is significant to explain the changes in CO_2 emissions.

Thus, there is a growing concern with the problem of carbon leakage and consequently many studies have taken into consideration the estimated emissions embodied in international trade through, for example, input-output analysis (*e.g.* WYCKOFF and ROOP, 1994; SCHAEFFER and DE SÁ, 1996; LENZEN, 1998; MACHADO et *al*., 2001; MUNKSGAARD and PEDERSEN, 2001; PETERS and HERTWICH, 2004; HOEKSTRA and JANSSEN, 2006; PETERS and HERTWICH, 2006).

In this context, it is important to incorporate issues involving GHG emissions and international trade, focusing in the interactions among countries with respect to CO_2 emissions. Moreover, the debate behind environmental issues also involves discussions about trade liberalization and related environmental consequences of economic growth and international trade (*e.g.* COPELAND and TAYLOR, 1994, 2004; NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002; BRUNNERMEIER and LEVINSON, 2004).

Consequently, this paper seeks to make an empirical investigation of the responsibility for CO_2 emissions from international trade for the 27 countries of the European Union and 13 other selected countries for the period of 1995-2009. Furthermore, this work permeates issues and discussions around environmental theories and hypotheses involving international trade (*e.g.* the pollution haven effect, the pollution haven hypothesis, patterns of trade between North and South).

The overall aim is to measure emissions embodied in international trade and to analyze the interactions in regional terms, among such countries. We propose the following specific aims: a) to observe the behavior of countries regarding CO_2 emissions, if there is concentration and whether this behavior is maintained over the years 1995-2009; b) to measure CO_2 emissions embodied in production and consumption, c) to measure the CO_2 emissions embodied in exports and imports of each country; d) to construct a carbon balance for each country; e) to verify if the international trade has been used as a way to reduce emissions by countries, and f) to analyze the degree of economic interaction between two regions[5] in terms of pollution (CO_2 emissions); and g) to evaluate environmental hypotheses and theories about CO_2 emissions and international trade.

Thus, this paper seeks to contribute with the use of an interregional input-output model and analyze the economic interactions through Miyazawa multipliers. It is important to note that the choice of the method (input-output models and multipliers Miyazawa) is given by the ability to look at the interaction effect (interdependence) and the types of synergistic interactions among countries, and the possibility of extension for interactions in terms of CO_2 emissions.

In order to achieve these aims and to have a more detailed view, it makes in some sections of this work a selection of countries, *i.e.*, we use exercises to show the behavior of countries in terms of absolute emissions, economic interactions, and other aspects. It is noteworthy that such exercises are intended to motivate the discussions in the light of the theories described in the literature review. Furthermore, the selection is made taking into account the importance of the countries in the global context and with respect to the discussions of international trade and CO_2 emissions.

Furthermore, it is important to note that the issues around international trade refer to a discussion of the intermediate flows among countries, *i.e.*, only trade relations in terms of the intermediate consumption (inputs flows) are taken into account.

In order to contextualize the research problem and achieve these objectives, the present work is divided as follows: besides this introduction, the second section provides a literature review. The third shows the database. The fourth section provides a description of the methods. The fifth presents the empirical results. Finally, the sixth section presents some concluding remarks.

2. LITERATURE REVIEW

This section aims to present discussions in the literature, without exhausting the subject, which are related to the environment, emissions of greenhouse gases (GHG), and international trade. Thus, given the objective of this paper, the section is divided into four sub-sections. The first presents discussions of responsibilities for emissions of GHG by different principles. The second presents the issues related to GHG emissions and international trade. Finally, the third and final sub-section shows discussions involving the technique of ecological footprint and input-output.

2.1. Responsibility for emissions

Research efforts have taken into account sustainable consumption. However, according to Tukker *et al.* (2006) although it has been possible to observe some progress, real initiatives for more sustainable consumption have not materialized. Thus, efforts to develop more efficient and effective consumption systems are still unknown, with little practical advance.

Therefore, policymakers are seeking a better understanding of how environmental impacts are related to the choices and specific activities of consumption. In addition, despite some certainties, Tukker *et al.* (2006) argue that there are many gaps unfilled, such as the environmental impacts of consumption in developed countries on trading partners, especially those considered as developing countries.

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[5]The choice of regions is given by the importance of these in economic terms, applications and discussions on literature review of emissions and international trade. It is noteworthy that such selection have the intention to do an exercise, *i.e.*, an example for interactions between countries and economic blocs.

The assumption behind this, according to Wiedmann *et al.* (2007) is that given the growing demand in the world by the developed countries for imported goods and services, we have consequently increased pollution (*e.g.* GHG emissions) in the production process in other countries.

Thus, in the context of emissions Bastianoni *et al.* (2004) argue that in order to reduce GHG emissions it is necessary to investigate not only the major sources of emissions, but also the location of such emissions and the sectors involved. For the authors, attribution of responsibility for emissions is important to ensure the reduction of GHG. Similarly, there is a huge literature that approaches this question (*e.g.* WYCKOFF and ROOP, 1994; KONDO *et al.*, 1998; EDER and NARODOSLAWSKY, 1999; MUNKSGAARD and PEDERSEN, 2001; FERNG, 2003; WIEBE *et al.*, 2012).

In the context of allocating responsibility for GHG, Ferng (2003) suggests that a system of fair burden sharing involves the proper choice of the principle of responsibility. Furthermore, Shin (1998) argues that in order to prevent the advent of globally undesirable state (*i.e.* tragedy of the commons) it needs an international coordination and regulation. Hence, the author defends the issue of burden sharing and, in particular, the participation of developing countries.

Given the different allocation of responsibilities, it is important to note that discussions about rights of emissions and allocation of accountability started from a principle of territorial responsibility (*e.g.* SHIN, 1998; GUPTA and BHANDARI, 1999).

A first approach considering the principle of territorial responsibility, proposed by IPCC (The Intergovernmental Panel on Climate Change), suggests just an application of a geographical approach, where only emissions directly involved in each sector and within the borders of a country are accounted for (FERNG, 2003; BASTIANONI *et al.* 2004). However, such as discussed by Bastianoni *et al.* (2004), whether we consider an importer of manufactured goods (without changing them within the limits of the country) we observe a paradoxical situation of a high standard of living with a very low level of GHG emissions.

In spite of different ways to allocate emissions rights, Neumayer (2000) “argues in defense of equal per capita emissions with historical responsibility as a general rule for allocating the right to emit greenhouse gases”; *i.e.*, it requires that those responsible for past emissions will be responsible for the largest reductions in the future.

Also known as the natural debt, the term “historical responsibility” was assigned by Smith (1991). From the trends of GHG emissions, Smith (1991) presents three important questions: "How much if anything should be done by when to change these trends?", "What projects should be undertaken and where?" and "Who should pay?" In order to answer these questions, the author argues that the responsibility of nations would be better indicated if historic emissions were taken into account. Thus, Smith (1991) attributes this historical responsibility as a natural debt, where such debt represents efforts to maintain high rates of economic growth by borrowing assimilative capacity of the environment.

As well addressing the issue of historical responsibility, on the one hand Shin (1998) argues that developed countries should take the leadership in combating greenhouse gas emissions, because these countries are responsible for 63% of total CO_2 emissions and considering the cumulative emissions they are responsible for more than 90% of the fossil fuel accumulated in the world. However, on the other hand Shin (1998) presents other important determinants of increased emissions, such as participation of the population, economic activity and energy consumption.

In addition to the authors mentioned above, Gupta and Bhandari (1999) argue that although the international negotiations are underway to control GHG emissions, little has been done in terms of commitments and implementation. The authors reason that absence of progress occurs by a lack of definition of the international sharing. Thus, in order to overcome this problem, Gupta and Bhandari (1999) explore the principle of equal rights per capita emissions.

However, Munksgaard and Pedersen (2001) argue that CO_2 emissions per unit of GDP *per capita* may lead to erroneous conclusions in a context with open economies. Therefore, in order to achieve more effective and fair policies, other approaches have been proposed in the literature, especially those that distinguish the responsibility between consumer and producer as an alternative to the principle of territorial responsibility (*e.g.* KONDO *et al.*, 1998; MUNKSGAARD and PEDERSEN, 2001; FERNG, 2003; BASTIANONI *et al.*, 2004; WIEBE *et al.*, 2012).

According to Munksgaard and Pedersen (2001) by the accounting principle of production, the producer is responsible for CO_2 emissions from the production of energy, goods and services. Moreover, it should be noted that this principle is the method used in the Kyoto Protocol. However, as presented by the authors, a disadvantage of this principle is a lack of distinction between export and domestic consumption.

Therefore, contrary to the principle used in the Kyoto Protocol, other concepts have been proposed to ensure the responsibility of the consumer of goods and services for emissions caused during the production process (MUNKSGAARD and PEDERSEN, 2001; WIEDMANN *et al.*, 2007).

Following the accounting principle of consumption, the consumer is responsible for CO_2 emissions from the production of energy, goods and services. Under these circumstances, CO_2 emissions are related with the use of final goods and services, even if they are imported from other countries (MUNKSGAARD and PEDERSEN, 2001).

Thus, we have seen that responsibilities of producers and consumers represent two opposing accounting principles. However, as exposed by Wiedmann *et al.* (2007) there are suggestions to quantify the responsibilities shared, *i.e.*, to allocate the environmental impact caused by emissions during the production of a particular product to all agents involved (*e.g.* BASTIANONI *et al.*, 2004).

In the context of globalization, national CO_2 emissions differs from the responsibility of national CO_2 emissions in terms of the principle of responsibility and resulting estimates (FERNG, 2003). Thus, according to the author to make a sharing of responsibility for anthropogenic CO_2 emissions between participating countries of agreements like the Kyoto Protocol (with respect to the principle of territorial responsibility), we may see a problem known as carbon leakage.

As discussed by Ferng (2003), the pollution problems are beyond political and national boundaries. Thus, to be self-sufficient in terms of resource utilization on a local and regional scale is not enough, because final goods and production inputs can generally be obtained through trade. Accordingly, it is important to keep in mind that trade cannot serve as a solution to global warming, because it may lead to a deficiency in global carbon sequestration capacity.

2.2. Emissions and international trade

Despite all the discussion regarding the responsibility for GHG emissions by different principles, it is important to take into consideration trade and all responsibility for GHG emissions involved. Furthermore, it is important to consider the literature around the liberalization of international trade and related environmental consequences.

The pollution embodied in trade flows becomes important due to the sudden expansion and globalization of world economies, where demand can be supplemented through international trade. Thus, the use of principles of responsibility that do not consider international trade capture only the direct national CO_2 emissions (FERNG, 2003; HOEKSTRA and JANSSEN, 2006). Thus recent studies have explored and demonstrated that a significant amount of pollution is embodied in international trade (*e.g.* WYCKOFF and ROOP, 1994; LENZEN, 1998; MACHADO *et al*., 2001; MURADIAN *et al*., 2002; AHMAD and WYCKOFF, 2003; LENZEN *et al*., 2004).

However, according to Wyckoff and Roop (1994) many controlling policies are based on reducing domestic emissions of greenhouse gases, which ignores, for example, CO_2 emissions embodied in international trade flows. In addition, as demonstrated by Ferng (2003), with increasing international trade and production migration beyond national borders, environmental issues related to responsibility for environmental degradation gain strength, and instead of focusing exclusively on domestic emissions one must take into account, for example, consumption.

The incorporation of CO_2 in international trade is very important for the discussion of the attribution of responsibility for CO_2 emissions. Furthermore, with the incorporation of CO_2 in international trade it is possible to discuss questions such as: Who is responsible for CO_2 emissions when we have the production of CO_2 intensive goods for export? The consumer or producer? (MUNKSGAARD and PEDERSEN, 2001).

Moreover, considering international trade, Antweiler (1996) introduces the concept of pollution in terms of trade and approaches another important question: “Do countries gain or lose environmentally from engaging in international trade?”

As mentioned previously, with the process of globalization, developed countries can achieve their targets for reducing emissions through international trade and/or shift their emissions-intensive production to other countries, *i.e.*, continuing with degradation of the environment (WYCKOFF and ROOP, 1994; KONDO *et al.* 1998; FERNG, 2003; WIEBE *et al.* 2012).

Therefore, there is a growing concern with the problem of carbon leakage and consequently many studies have taken into consideration the estimated emissions embodied in international trade through input-output analysis (*e.g.* WYCKOFF and ROOP, 1994; MUNKSGAARD and PEDERSEN, 2001; WIEBE *et al.* 2012).

Thus, within the context of the allocation of responsibilities, in recent years many studies have tried to develop a more comprehensive approach to measure resource use and pollution generation embodied in trade flows, including contributions that combine input-output analysis and ecological footprint (TURNER *et al.*, 2007).

However, beyond this discussion about responsibilities for GHG emissions and international trade, the debate behind environmental issues also involves discussion around trade liberalization and related environmental consequences.

The world economy is in continuous change over the years. The economic activity, population and per capita income, for example, showed significant changes. Moreover, the world economy has become more integrated, *e.g.* technological advances in communication and information, the reduction of trade barriers and foreign investment (NORDSTRÖM e SCOTT, 1999).

According Nordström and Scott (1999) with more integrated economies, the costs of international trade transactions substantially reduced, leading to an increase of 14 times in the trade since 1950.

However, the evolution and growth of the world economy may be accompanied by environmental degradation (*e.g.* global warming, air pollution). Given this, discussions around international trade, the effects of environmental policy and the environmental consequences of trade liberalization have been made by the environmental community, *e.g.* negotiations on NAFTA (NORDSTRÖM and SCOTT, 1999; COPELAND and TAYLOR, 2004).

Moreover, according to Copeland and Taylor (2004) the debate was intensified with the creation of the World Trade Organization (WTO) and proposals for future rounds of trade negotiations. However, the debate has often been unproductive because the involved agents value the environment differently.

Given this discussion around environmental issues, it has been possible to find in the literature many authors who address the environmental consequences of economic growth and international trade (*e.g.* COPELAND and TAYLOR, 1994; NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002; COPELAND and TAYLOR, 2004; BRUNNERMEIER and LEVINSON, 2004).

Copeland and Taylor (2004) approach theories and empirical works to answer three questions: "What do we know about the relationship between international trade, economic growth, and the environment? How can this evidence help us evaluate ongoing policy debates in this area? Where do we go from here?"

A first theory approached by Copeland and Taylor (2004) is known as the Environmental Kuznets Curve (EKC). According to the authors, the EKC literature postulates a simple relationship between per capita income and pollution. According Atweiler *et al.* (2001) the main issue behind this theory is as follows: "How does economic growth affect the environment?"

The EKC hypothesis is that we have a relationship in the form of inverted U between per capita income of a country (economic development) and their level of environmental quality (pollution levels), *i.e.*, increase in income is associated with an increase pollution in early stages of economic development and a decline in pollution in more advanced stages (NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002; COPELAND and TAYLOR, 2004).

However, Dasgupta *et al*. (2002) argue that the model of EKC provoked conflicting reactions of researchers and policymakers, and it has been possible to find at least four different approaches[6]. Besides the different approaches presented by Dasgupta *et al.* (2002), other authors present different results about the EKC, for example, Chimeli and Braden (2005) and Chimeli (2007).

However, despite the relevance and relationship between income growth and the environment, Copeland and Taylor (2004) discuss the fact that trade can change the environmental results through a variety of other ways, such as with the displacement of pollution-intensive industries from countries with stringent environmental policies for those with less stringent policies.

According Atweiler *et al.* (2001), this branch of literature seeks to examine the relationship between pollution abatement costs and trade flows and it seeks to answer the following question: "How do environmental regulations affect trade flows?"

However, according to Copeland and Taylor (2004), the literature has not always been clear about the hypothesis to be tested. However, the authors show that much of the attention has been directed to three hypotheses of the effect of pollution regulation on trade flows.

The first hypothesis is that strong regulation of pollution has effects on plant location decisions and trade flows - pollution haven effect (COPELAND and TAYLOR, 2004). On the other hand, the second hypothesis, known as pollution haven hypothesis, according to Copeland and Taylor (2004) and Taylor (2005) is a stronger version of the first, because according to this hypothesis, a reduction of trade barriers will lead to a shifting of intensive industry from countries with stringent pollution regulations for countries with weaker regulations, *i.e.*, a trade liberalization leads to a shifting of production of "dirty goods" from countries with stringent regulations (North) for countries with weaker regulation (South).

Thus, given the definitions it is important to note that the existence of a pollution haven effect is usually necessary, but not sufficient to ensure the pollution haven hypothesis, because an indirect evidence of pollution haven hypothesis can be provided from other sources (COPELAND and TAYLOR, 2004)

[6] For more details see Dasgupta *et al.* (2002).

Finally, a third hypothesis is that the direction of "dirty goods" trade is decided mainly by conventional determinants of comparative advantage and differences in technology. In terms of effect, Copeland and Taylor (2004) discuss that there is no reason to expect that trade has the same effect in all countries, because the effect of trade liberalization on the environment depends on the comparative advantage of a country. Furthermore, the effects of trade on the environment depend on environmental policy.

According to Antweiler *et al.* (2001), a critical approach involving environmental policy, it is that despite being successful in predicting patterns of trade in a world where politics is fixed, their findings may lead to erroneous conclusions in a world where environmental protection is endogenous.

However, the issue of environmental policy involves other considerations. Copeland and Taylor (2004) show two concerns, the first involving the use of environmental policy as a substitute for trade policy, and the second concern that involves the use of trade policy to achieve environmental goals.

However, Chichilnisky (1994) argues that to develop appropriate environmental policies is necessary to understand the connection between markets and the environment. In this context the author raises some questions: Why do developing countries tend to specialize in the production and the ex-port of goods which deplete environmental resources such as rain forests? Do they have a comparative advantage in "dirty industries", and if so, does efficiency dictate that this advantage should be exploited? Is it possible to protect resources without interfering with free markets? Are trade policies based on traditional comparative advantages compatible with environmental preservation?

Besides these issues, another point is approached by Chichilnisky (1994): "How do property rights affect trade?" According to the author, the differences in property rights regimes for environmental resources may be responsible for some aspects of the patterns of trade between North and South.

According to Chichilnisky (1994), the global environment has handled North-South issue, due a concern about the international issues related to the environment. Consequently, there has been a concern in linking environmental policy with economic issues of interest to the industrialized and developing countries (*e.g.* technology transfer).

Thus, the problems involving property rights, which arise when societies are in transition from an agricultural to an industrial economy trading with already industrialized societies.

2.3. Ecological footprint and input-output analysis

According to Wiedmann and Lenzen (2007), initially developed and described by Rees and Wackernagel, "the Ecological Footprint is an estimate of the proportion of the planetary biological productivity and assimilative capacity effectively appropriated by the consumption of a given population or activity over a specified time period". In addition, for Turner *et al.* (2007), ecological footprint measures human demand on bio-productivity, assessing the amount of biologically productive land and sea area needed to maintain consumption by a given human population.

Overall, the analysis of the ecological footprint estimates the resources that are used, *i.e.*, needed to sustain consumption, production, or other types of activity. Moreover, it expresses these requirements using area units (FERNG, 2003).

The assumption behind this corresponds to the fact that every individual, city or country affects the Earth, because they consume products and services of nature. Thus, Wackernagel *et al.* (1999) describe the ecological impact corresponding to the amount of nature that they occupy to live.

Denominated as natural capital, it corresponds the amount that individuals need and use of nature to sustain themselves, so when measurable it is called ecological footprints.

Moreover, according to Wiedmann and Lenzen (2007) the indicator of ecological footprint is a technique used to inform various audiences about sustainable development and it is often used as an educational tool. In addition, according to Wiedmann *et al.* (2007), the ecological footprint is an indicator that tries to capture humanity's demand for natural resources, following the principle known as consumer responsibility.

However, in spite of the footprint technique to take into account the consumer's responsibility, Turner *et al.* (2007) argue that the ecological footprint concept captures the impacts embodied in trade only in a rudimentary form. According to the authors, the technique is practical to calculate the resource consumption; however there are fundamental deficiencies in the methodology. More generally, Turner *et al.* (2007) argue that the production chains are not identified, *i.e.*, it is not possible to capture the intensity of the ecological footprint embodied directly and indirectly in the trade of goods and services.

Thus, as suggested by Wiedmann *et al.* (2007), the ecological footprint should be estimated based on a multi-regional input-output model (MRIO). Moreover, the authors argue that the method is more appropriate and accurate to allocate the total pollution and use resources embodied in traded commodities, given the principle of responsibility chosen.

The input-output analysis is based around a set of economic accounts disaggregated by sector, with the primary function to quantify the interdependence of different activities within the economy (MILLER and BLAIR, 2009). The input-output matrices are usually built in monetary units for national accounting. However, Leontief (1970) makes an initial environmental exposure using physical units.

Given the growing number of studies, Turner *et al.* (2007) describe the combination of the use of input-output technique and ecological footprint analysis, arguing that the adoption of a multi-regional input-output model is the most appropriate for calculating ecological footprints. However, this article is only the first part of a study prepared by the authors. In the second part, Wiedmann *et al.*, (2007) present a literature review of recent methodological and empirical developments, *i.e.*, they review the applications of input-output to estimate environmental impacts embodied in trade.

According to Ferng (2003) the method of input-output is appropriate to address the issues involving energy, because it has a structure and ability to incorporate the energy flows associated with the flow of goods. Thus, it is possible to observe that in recent years, more sophisticated models have been developed and used, based on environmental statistics incorporated in trade through the use of multi-regional input-output models. However, despite the emergence of more sophisticated models, according to Wiedmann *et al.* (2007) there is still debate regarding how to calculate the ecological footprint from the use of multi-regional input-output models.

Thus, in terms of discussions involving GHG emissions, the estimation of anthropogenic CO_2 emissions in the stages of production and consumption is increasingly highlighted and input-output analysis is shown as an important method (*e.g.* PROOPS, 1988; COMMON and SALMA, 1992; MUNKSGAARD and PEDERSEN, 2001).

3. DATABASE

The data structure used in this work comes from of the World Input-Output Database (WIOD)[7]. As approached by Timmer (2012), the database was developed to analyze the effects of globalization on trade patterns, environmental pressures and socioeconomic development through a wide range of countries.

Thus, as discussed by the authors, the database allows one to take into account issues related to socio-economic aspects (*e.g.* jobs or creating value added) as well as environmental aspects (*e.g.* energy use, emissions of greenhouse gases or use of water).

Therefore, the data structure of the present work consists of input-output tables for 40 countries[8] (27 EU countries and 13 other selected countries) over the “Rest of the World” for the period of 1995-2009[9]. It is important to note that these tables have 35 productive sectors.

Furthermore, this work also uses atmospheric emissions of CO_2 (in tons) for the same 40 countries selected and the same range of time and sectors.

Figures 1-4 bring CO_2 emissions for the 40 selected countries plus "Rest of the World" for 1995, 2000, 2005 and 2009, respectively.

It is possible to see an increase of the average over the years. For 1995, the average is equal to 462.11 million tons of CO_2. While for 2000 the average is equal to 498.08 million tons of CO_2. And for the other years, 2005 and 2009, it is equal to 557.67 and 606.59, respectively.

Through Figures 1-3, it is possible to see that the United States (USA), China (CHN) and Russia (RUS) are the countries with highest levels of CO_2 emissions for 1995, 2000 and 2005, respectively. It is important to note the increase in emissions of China (CHN), from 2804.93 billion tons of CO_2 in 2000 (Figure 2) to 4255.48 billion tons of CO_2 in 2005 (Figure 3).

For (Figure 4), the behavior observed in 2005 is repeated, except that India (IND) shall be included among the group of countries with highest levels of CO_2 emissions. And as a highlight, China (CHN) shows an increase in the level of CO_2 emissions, 6213.55 billion tons and with a level higher than the United States (USA).

Given the relevance and focus of this study, it is important to observe the behavior in terms of CO_2 emissions for some countries. Figures 5-8, show the temporal evolution of the emissions of CO_2 to the United States (USA), China (CHN), Brazil (BRA), India (IND) and Russia (RUS), respectively.

Through Figure 5, it is possible to observe that the United States (USA) present a behavior of increasing of CO_2 emissions levels until the year 2000 and from this year present a decrease, except in 2007.

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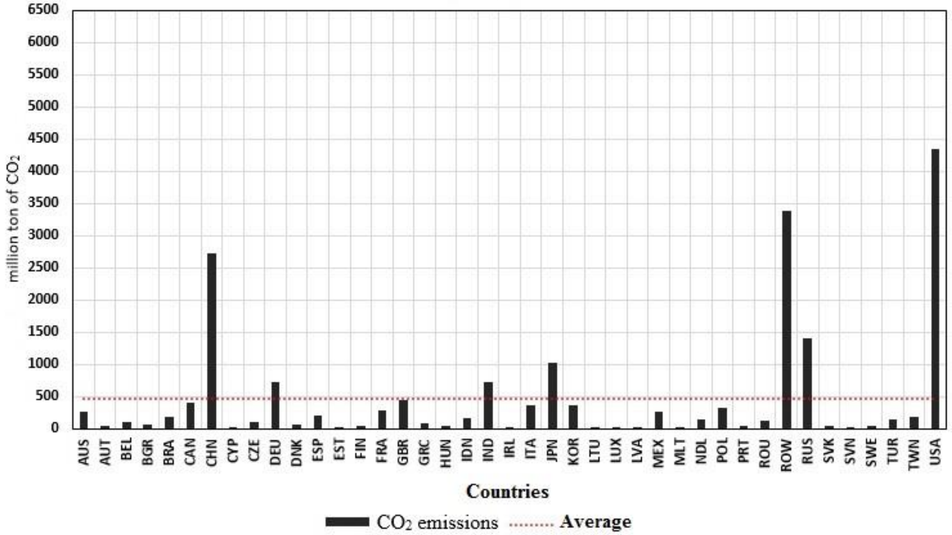
[7] For more details about the WIOD project see: DIETZENBACHER *et al.* (2013), ERUMBAN *et al*. (2012a, 2012b), GENTY and ARTO (2012), TIMMER (2012).

[8] Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy , Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Sweden, Slovakia, Slovenia, Spain, Taiwan, Turkey, United Kingdom e United States.

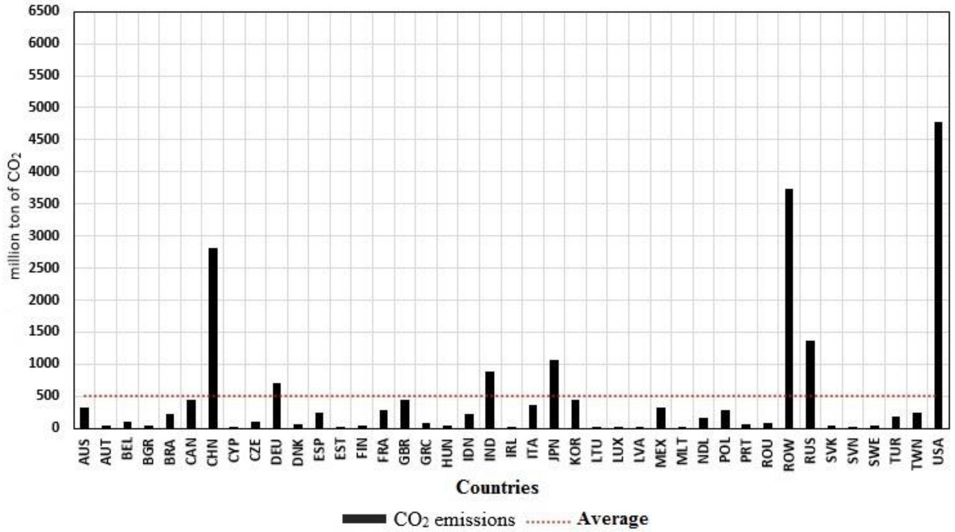
[9] These countries together account for about 85% of world GDP (DIETZENBACHER *et al.*, 2013).

Figure 1 – CO_2 emissions for selected countries – 1995



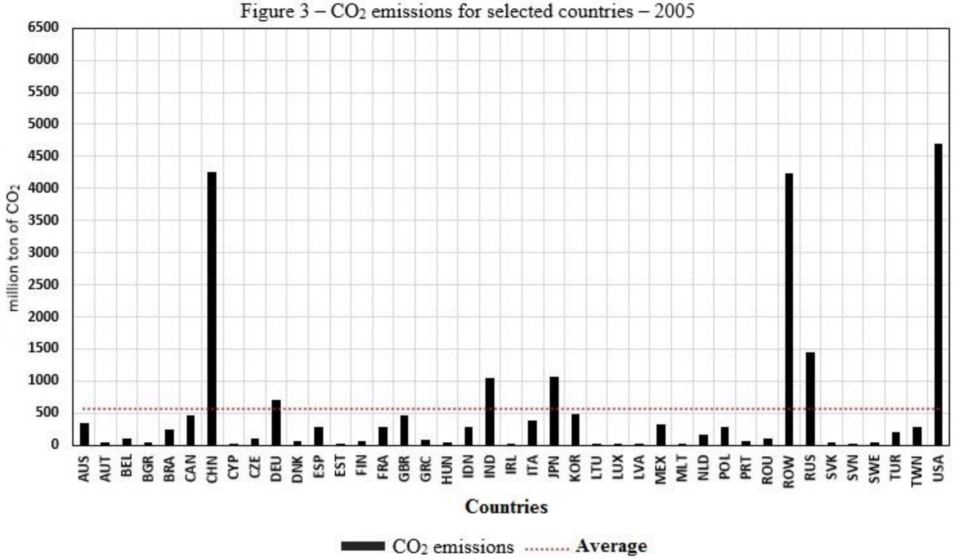
Source: Own elaboration from WIOD database.
Note: Average equal to 462.11 million tons of CO_2.

Figure 2 – CO_2 emissions for selected countries – 2000



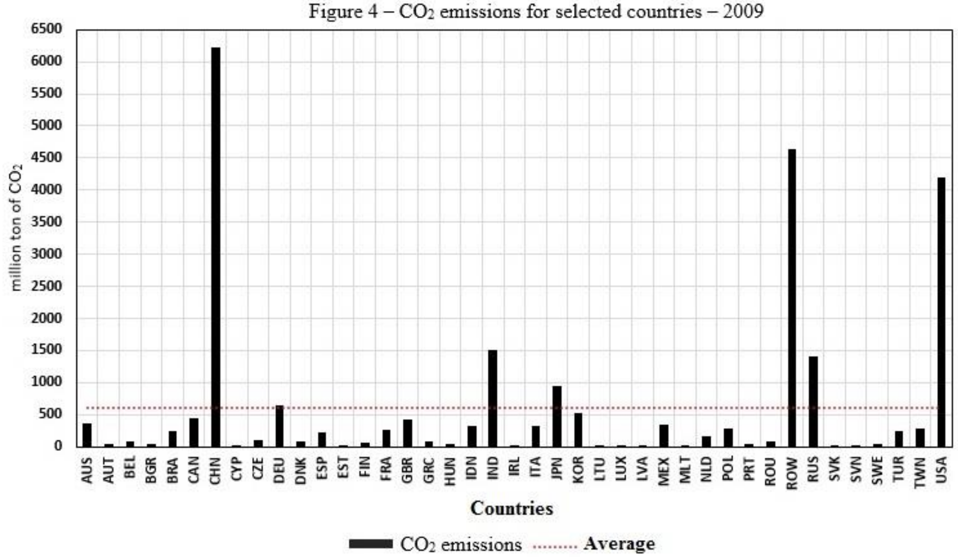
Source: Own elaboration from WIOD database.
Note: Average equal to 498.08 million tons of CO_2.

Figure 3 – CO_2 emissions for selected countries – 2005



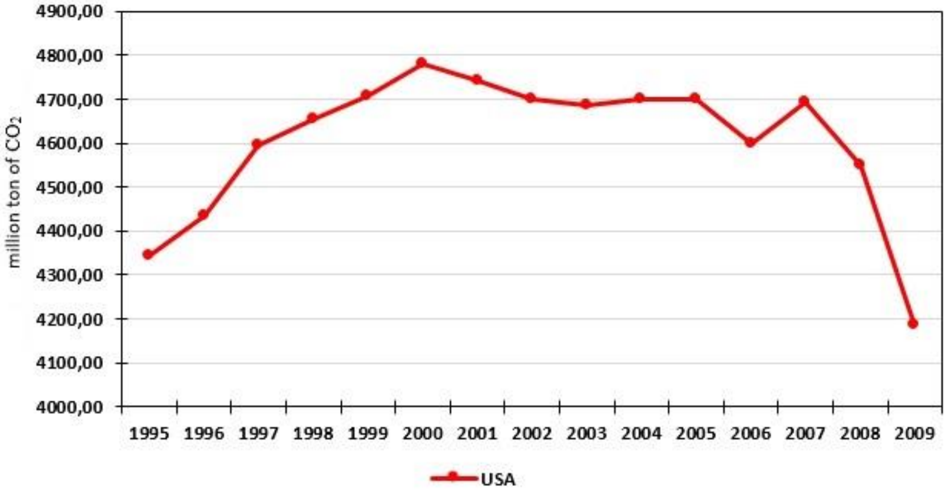
Source: Own elaboration from WIOD database.
Note: Average equal to 557.67 million tons of CO_2.

Figure 4 – CO_2 emissions for selected countries – 2009



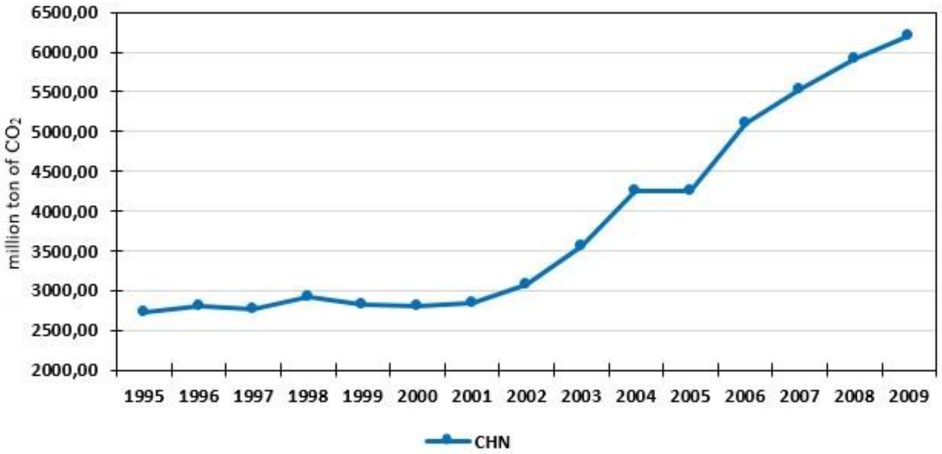
Source: Own elaboration from WIOD database.
Note: Average equal to 606.59 million tons of CO_2.

Figure 5 – CO_2 emissions of the United States (USA) – 1995-2009



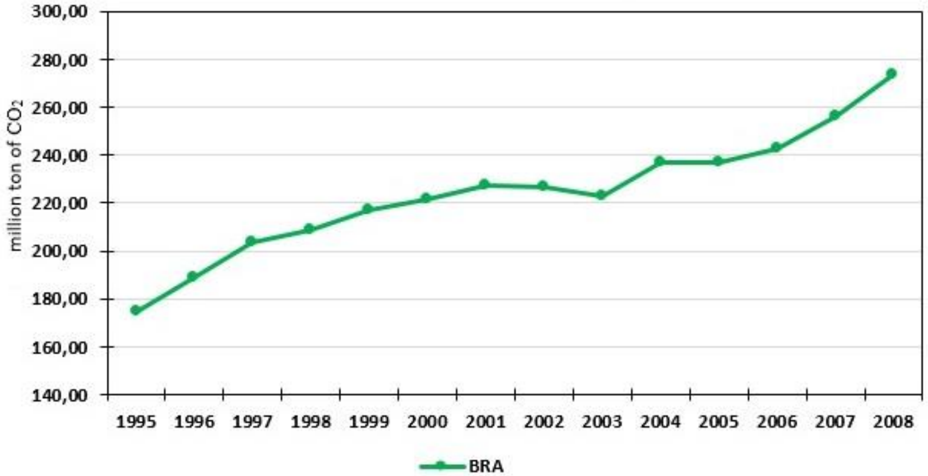
Source: Own elaboration from WIOD database.

Figure 6 – CO_2 emissions of China (CHN) – 1995-2009



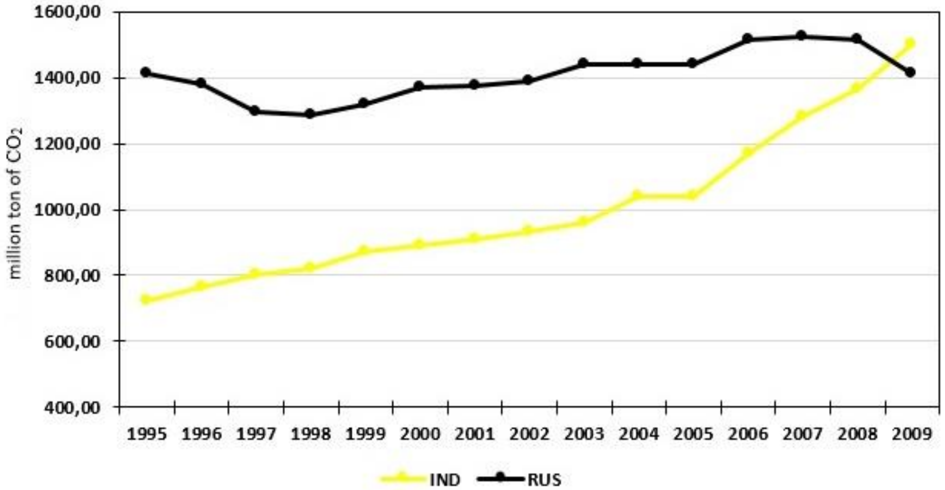
Source: Own elaboration from WIOD database.

Figure 7 – CO_2 emissions of Brazil (BRA) – 1995-2009



Source: Own elaboration from WIOD database.

Figure 8 – CO_2 emissions of India (IND) and Russia (RUS) – 1995-2009



Source: Own elaboration from WIOD database.

Figure 6 shows the results for China (CHN). It is possible to observe a behavior different than presented by the United States (USA), because China (CHN) presents small increases in emission levels for the early years (1995-2001) and from 2002 it presents the more significant additions.

For Brazil (BRA), Figure 7, it is possible to observe a behavior similar to observed for China (Figure 6), *i.e.* the country also presents a performance of increase for most of the years, however at lower levels.

Finally, for India, Figure 8, as well as for Brazil (BRA) and China (CHN), it is possible to observe the behavior of increase in CO_2 emissions over the years (1995-2009). On the other hand, to Russia (RUS), Figure 8, it is possible to observe a behavior with larger oscillations.

Thus, it is possible to observe a behavior different in terms of absolute CO_2 emissions between the United States (USA) and BRIC (Brazil, Russia, India and China), for example. Given that USA and BRIC represent countries with different stages of development, the first is considered developed and the second as developing, important issues presented in the literature review can be discussed, such as: theory of environmental kuznets curve (EKC), carbon leakage, the pollution haven effect, the pollution haven hypothesis. In addition, other issues can be addressed, such as differences in the composition of natural fuel reserves of the countries and institutional reforms adopted by them.

However, this result should be seen at first only as an indication and motivation to analyze and test such theories, because other factors may be involved. Furthermore, it is noteworthy that an analysis of these results in the context of these hypotheses and theories is made in a late section.

4. METHODOLOGY

4.1. Input-Output Models (Conceptual Model and Representation)[10]

An IP model for a given region or country describes the monetary flows of goods and services between local industries and segments of final demand. The analysis of IP has become one of the most used methods to evaluate the economy, due to its ability to aggregate information on the process of production, intermediate consumption, distribution of generated income, foreign trade, salary and tax (MILLER and BLAIR, 2009).

In order to generalize, the model shown below is described considering an economy with a generic number of *n* sectors. Thus, it is possible to mathematically represent the relationships, as follows:

$$X_i = \sum_{j=1}^{n} Z_{ij} + C_i + I_i + G_i + E_{Xi} \qquad i = 1, 2, 3 \dots n \qquad (1)$$

where: X_i = total demand for total output of sector *i*; Z_{ij} = production of sector *i*, sold as intermediate input to sector *j*; C_i = production of sector *i* sold to families; G_i = production of sector *i*, sold to the government; I_i = production of sector *i*, sold as fixed investment; and E_{Xi} = production of sector *i*, sold to abroad, *i.e.* export.

However, it is possible to imagine an inter-regional input-output model that describes the monetary flows of goods and services through the economy, considering different regions. Thus, given the fact that it is possible to have an inter-regional model with various regions, a version for the particular case of this work is presented, *i.e.*, an economy divided into 41 regions (27 EU countries, 13 other selected countries and the “Rest of the World”).

[10] This subsection is based on Miller and Blair (2009), and Guilhoto (2011).

The inter-regional input-output model can be represented mathematically in matrix notation as[11]:

$$Z^* i_{41n} + Y^* = X^* \tag{2}$$

where: Z^* = *41nx41n* matrix and it represents the interregional input-output table; i_{41n} = unit vector (all elements are equal to 1) with *41nx1* order; Y^* = *41nx1* vector and it represents the final demands of the regions, andX^* = 41nx1 vector and it represents the production sector of the regions.

Thus, the elements of equation (2) can be represented as follows:

$$Z^* = \begin{bmatrix} Z_{ij}^{1,1} & Z_{ij}^{1,2} & \cdots & Z_{ij}^{1,40} & Z_{ij}^{1,41} \\ Z_{ij}^{2,1} & Z_{ij}^{2,2} & & Z_{ij}^{2,40} & Z_{ij}^{2,41} \\ \vdots & & \ddots & \vdots & \\ Z_{ij}^{41,1} & Z_{ij}^{41,2} & \cdots & Z_{ij}^{41,40} & Z_{ij}^{41,41} \end{bmatrix} \quad Y^* = \begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ \vdots \\ Y^{41} \end{bmatrix} \quad X^* = \begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ \vdots \\ X^{41} \end{bmatrix} \tag{3}$$

Where the interregional input-output matrix is represented by Z^*, and the sub-matrices $Z_{ij}^{1,1}$, $Z_{ij}^{2,2}$..... $Z_{ij}^{40,40}$e $Z_{ij}^{41,41}$ are the sub-matrices with intra-regional flows and the other sub-matrices are related to inter-regional flows. The components Y^1, Y^2..... Y^{40}e Y^{41}; e X^1, X^2..... X^{40}e X^{41} are vectors *nx1* containing the final demands and product sectorial, respectively.

However, as shown by Guilhoto (2011), assuming that the intermediate flows per unit of final product are fixed, it is possible through the inter-sector flows (Z_{ij}) and the total output (X_i) to determine the technical coefficient[12].

And a more convenient way to write the equation (2) is to incorporate technical coefficients (A^*):

$$A^* = Z^*(\widehat{X}^*)^{-1} \tag{4}$$

Rewriting it:

$$A^* X^* + Y^* = X^* \tag{5}$$

The elements of A^* are divided into two types: intra-regional and inter-regional technical coefficients.

Manipulating algebraically equation (5):

$$X^* = B^* Y^* \tag{6}$$

where $B^* = (I - A^*)^{-1}$ corresponds to Leontief matrix for the IR-IP model.

Thus, we can write the interregional model as follows:

$$\begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^{40} \\ X^{41} \end{bmatrix} = \begin{bmatrix} B^{1,1} & B^{1,2} & \cdots & B^{1,40} & B^{1,41} \\ B^{2,1} & B^{2,2} & & B^{2,41} & B^{2,41} \\ \vdots & & \ddots & & \vdots \\ B^{40,1} & B^{40,2} & \cdots & B^{40,40} & B^{40,41} \\ B^{41,1} & B^{41,2} & & B^{41,40} & B^{41,41} \end{bmatrix} \begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ Y^{40} \\ Y^{41} \end{bmatrix} \tag{7}$$

[11] Each region (country) is represented by a number.
[12] The technical coefficient a_{ij} express direct requirement of input of sector *i* needed to produce a monetary unit of output of sector *j*.

4.2. Modeling CO_2 Emissions[13]

Wiebe *et al.* (2012) describes two forms of modeling of CO_2 emissions in such models. The first, suggested by Leontief (1970) uses the technique of adding a row in the matrix Leontief (pollution sector), providing pollution of all the other sections and having total pollution as the sum of the row (*e.g.* HETHERINGTON, 1996; LENZEN, 1998; LABANDEIRA and LABEAGA, 2002; HILGEMBERG, 2004; LENZEN *et al.*, 2004; MILLER and BLAIR, 2009; CARVALHO *et al.*, 2013). The second form of modeling, used by Peters and Hertwich and coauthors (*e.g.* PETERS and HERTWICH, 2004, 2006), it is to multiply the Leontief inverse by a matrix of coefficients pollution intensity. According to Wiebe *et al.* (2012) in terms of total emissions, the both methods give the same result.

Thus, given that the objective of this study is to model CO_2 emissions in terms of international trade, this paper uses the second method for modeling CO_2 emissions in the context of input-output tables.

In such modeling, it is necessary to keep in mind that emissions from one sector refer to the amount of pollution in terms of CO_2 that a sector, in particular, emits to enable its production. On the other hand, the intensity coefficient of CO_2 uses (CI's) corresponding to the ratio of CO_2 emission and the total output of sector *i*, *i.e.*:

$$CI_i^n = \frac{ECO2_i^n}{VBP_i^n} \tag{8}$$

where: CI_i^n is the intensity coefficient of use of CO_2 from industry *i* in the country *n*; $ECO2_i^n$ is the CO_2 emissions of the sector *i* of country *n*, and VBP_i^n is the total output of industry *i* in the country *n*.

Therefore, the CI enables us to classify the sector as intensive or not with respect to CO_2 emissions. Furthermore, the CI is the weighting factor of the input-output matrix, where in order to better capture the dependency and CO_2 emissions among countries, the coefficients of intensity are calculated and the following algebraic operations are made:

$$\hat{E} = \begin{bmatrix} CI_i^1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & CI_i^{41} \end{bmatrix} \tag{9}$$

Thus, the matrix $\hat{E}$ is used as follows:

$$B^{¤} = B\hat{E} \tag{10}$$

where $B^{¤}$ represents the Leontief inverse matrix weighted by the emission of CO_2.

Therefore, the input-output model which uses the coefficient matrix of intensity of pollution (CO_2 emission) can be written in matrix form as follows:

$$\pi = \hat{E}X = \hat{E}(I - A)^{-1}Y \tag{11}$$

[13] This subsection is based on Wiebe *et al.* (2012).

Substituting (10) into (11) we have:

$$\pi = B^{¤}Y \tag{12}$$

where π is the matrix of pollution.

4.3. Miyazawa Multipliers[14]

As explained by Fritz *et al.* (1998), it is important to make a distinction between polluting and non-polluting sectors of an economy. Thus, the notion of pollution generation, direct and indirect, becomes another factor to be observed. And according to the authors, such relationships can be explored through methodological framework originally proposed by Miyazawa (1966, 1968, 1971) and later extended by Sonis and Hewings (1993, 1995, 1997).

Miyazawa's work consists of an application of internal and external multipliers. Miyazawa internal and external multipliers are derived to partition the Leontief inverse matrix in propagation of internal activity and propagation of external activity, respectively (OKYAMA; SONIS; HEWINGS, 1999).

According to Sesso Filho *et al.* (2006), the methodology allows to classify the types of synergistic interactions between regions and enables us to examine, through internal and external interdependencies, the structure of trade between two regions.

First it is exposed the methodological framework behind Miyazawa multipliers. From this initial decomposition, proposed by Miyazawa and based on Fritz et al. (1998), issues involving pollution (CO_2) can be derived.

Therefore, consider the following input-output system with two regions[15]:

$$\left(\frac{X_{11}}{X_{21}}\middle|\frac{X_{12}}{X_{22}}\right) = \left(\frac{Z_{11}}{Z_{21}}\middle|\frac{Z_{12}}{Z_{22}}\right) + \left(\frac{Y_{11}}{Y_{21}}\middle|\frac{Y_{12}}{Y_{22}}\right) \tag{13}$$

where: Z represents trade flows (intermediate consumption), Y is the final demand. Thus, X equals the total output.

From the vector X and the trade flows matrix (Z), it is possible to obtain the matrix of technical coefficients (direct inputs)[16]:

$$A = \left(\frac{A_{11}}{A_{21}}\middle|\frac{A_{12}}{A_{22}}\right) \tag{14}$$

where $A_{11}$and A_{22} are matrices of direct inputs of the first and second region, respectively. A_{12} and A_{21} are matrices of direct inputs purchased by the first and second regions, respectively.

The matrix A can be presented in a separeted form: "*Pull-Decomposition*". Thus, the first region is decomposed to exert an influence on the second region by "pulling-input" (import) for production from this second region. The same decomposition and interpretation can be made to the second region.

[14] Based on Fritz, Sonis and Hewings (1998), Sonis and Hewings (1999b), and Okuyama, Sonis e Hewings (1999).

[15] Guilhoto *et al.* (2001) expanded and discussed the methodology proposed by Miyazawa for interregional model at the level of 5 macro regions of the Brazilian economy for the year 1995.

[16] For more details see Miller e Blair (2009).

Thus, depending on the used perspective, the off-diagonal entries in equation (14) can be seen as "push" or "pull" linkages with other region:

$$A = \left(\frac{A_{11}}{A_{21}}\middle|\frac{0}{0}\right) + \left(\frac{0}{0}\middle|\frac{A_{12}}{A_{22}}\right) = A_1 + A_2 \tag{15}$$

For purposes of this paper, a hierarchy and methodological framework[17], where the Leontief inverse matrix is given by

$$B = (I - A)^{-1} = \left(\frac{B_{11}}{B_{21}}\middle|\frac{B_{12}}{B_{22}}\right) \tag{16}$$

The matrices of internal multipliers Miyazawa for the two regions are given by:

$$B_1 = (I - A_{11})^{-1} \tag{17}$$

$$B_2 = (I - A_{22})^{-1} \tag{18}$$

where B_1 is a matrix multipliers internal for region 1 (country), and B_2 for the region 2.

However, Leontief inverse matrices can be defined as:

$$\Delta_1 = (I - A_{11} - A_{12}B_2A_{21})^{-1} \tag{19}$$

$$\Delta_2 = (I - A_{22} - A_{21}B_1A_{12})^{-1} \tag{20}$$

This matrix Δ_1 can be interpreted, according to Sonis and Hewings (1999b), as the external matrix multiplication of the first region revealing the influence of the second[18]. A similar interpretation can be made to Δ_2.

By equations (14), (17) e (18), the following equations can be obtained:

$$P_1 = A_{21}B_1 \tag{21}$$

$$P_2 = B_1A_{12} \tag{22}$$

$$S_1 = A_{12}B_2 \tag{23}$$

$$S_2 = B_2A_{21} \tag{24}$$

where P_1 is the matrix multiplier indicating input from Region 1 to Region 2 induced by internal propagation in Region 1. P_2 is the matrix multiplier for internal propagation in Region 1 induced by transactions from Regions 1 to 2. A similar interpretation can be made to $S_1$and S_2, respectively.

Thus, the external matrix multipliers for the regions can be derived as follows:

$$\Delta_{11} = (I - P_2S_2)^{-1} = (I - B_1A_{12}B_2A_{21})^{-1} \tag{25}$$

$$\Delta_{22} = (I - S_2P_2)^{-1} = (I - B_2A_{21}B_1A_{12})^{-1} \tag{26}$$

Δ_{11} includes direct, indirect and induced effects of sectors of the first region from the input demand effects of the second region. A similar relationship can be established for Δ_{22}.

---

[17] Based on (HEWINGS; OKUYAMA; SONIS, 2001).
[18] Such terminology and interpretation are different from the original definition of the Miyazawa's work as described by Sonis and Hewings (1999b).

Having specified and derived the methodology in terms of Miyazawa multipliers, it may extend to the environmental issue, *i.e.* CO_2 emissions.

Thus, for purposes of decomposition of the methodology in terms of pollution (CO_2), the multipliers of equations (19) and (20) are rewritten respectively as follows:

$$\Delta_1 = \Delta_{11} B_1 \tag{27}$$

$$\Delta_2 = \Delta_{22} B_2 \tag{28}$$

As showed by Fritz et al. (1998), the following decomposition of the Leontief inverse matrix, equation (23), can be obtained:

$$(I - A)^{-1} = \begin{pmatrix} \Delta_1 & B_1 A_{12} \Delta_2 \\ \Delta_2 A_{21} B_1 & \Delta_2 \end{pmatrix} \tag{29}$$

The first matrix multiplier of interest in the decomposed Leontief inverse of Eq. (29), , $\Delta_2 A_{21} B_1$, reveals the influence of the internal propagation of sectors in Region 1in the level of product of the sectors in the region 2.

In order to evaluate the Region 1 sectors' impact in terms of pollution, the matrix multiplier is premultiplied by a diagonal matrix of pollution coefficients, $\hat{R}$, whose off-diagonal elements are all zero, and thus becomes a pollution matrix multiplier:

Then, the matrix of pollution can be obtained:

$$Pol_1 = \hat{R}[\Delta_2 A_{21} B_1] \tag{30}$$

where Pol_1 is matrix of pollution multipliers whose elements, $p_{i_2 j_1}$, represent the increase in pollution generated by industry i_2 (region 2) as a result of a unit increase in final demand in industry, i_1 (region 1).

In order to evaluate the total amount of pollution generated by a unit increase in a Region 1 industry's output level, the appropriate column multipliers are calculated:

$$m_{j_1} = \sum_{i_2} p_{i_2 j_1} \tag{31}$$

where m_{j_1} is industry j_1's column multiplier with respect to all the region 2' industries.

The multipliers of the matrix Pol_1 result from the interaction of three multiplier matrices, Δ_{22}, B_2 and B_1, with A_{21}. The sources of pollution induced by the region 1 sectors' production activities can be unveiled by looking at the column sums of these matrices with respect to the region 2 sectors:

i) $\hat{R}A_{21}$ = pollution generated by direct input requirements of Region 1;

ii) $\hat{R}A_{21}B_1$ = pollution caused by direct and indirect input requirements of Region 1;

iii) $\hat{R}B_2A_{21}B_1$ = pollution caused by internal propagation of Region 1 and the induced direct and indirect production of Region 2;

iv) $\hat{R}\Delta_{22}B_2A_{21}B_1$ = total pollution multiplier of Region 1 with pollution caused by the internal propagation of Region 1 and the induced internal and external propagation of Region 2.

The sum of the column industries j_1 in *i, ii, iii* e *iv* are termed as: $m_{j_1}^1$, $m_{j_1}^2$, $m_{j_1}^3$ e m_{j_1}, respectively. Thus, the following definitions may be employed in the empirical analysis:

i) $m_{j_1}^1$ = direct input requirements in the total multiplier;

ii) $m_{j_1}^2 - m_{j_1}^1$ = indirect input requirements in the total multiplier;

iii) $m_{j_1}^3 - m_{j_1}^2$ = internal propagation of Region 2 in the total multiplier;

iv) $m_{j_1} - m_{j_1}^3$ = external propagation of Region 2 in the total multiplier.

Similarly, we can derive and investigate the influence of region 2 in the product of region 1.

5. RESULTS

This section aims to present the results of this work. The section is divided into four subsections. The first section presents the intensity coefficients of CO_2 emissions. The second section (global trade balances of CO_2) presents the results involving international trade and CO_2 emissions. The third section presents the results about the Miyazawa multipliers. Finally, the fourth and final brings a summary and discussion of results jointly and in parallel with the presented literature review.

5.1. Intensity Coefficients of CO_2 Emissions

From the input-output model and the availability of CO_2, it is possible to obtain aggregated indicators for different countries. The intensity coefficients of CO_2 emissions enable us to classify the country as intensive or not with respect to CO_2 emissions, *i.e.*, to observe the behavior of each of the 40 countries plus the *"*Rest of the World*"*. Moreover, these coefficients enable us to incorporate CO_2 emissions in the input-output model by matrix $\hat{E}$ (Equation 9).

It is important to note that the intensity coefficients of emission were calculated for the 40 countries plus the "Rest of the World". However, for this paper Figures 9 and 10 show the results for the United States (USA), Germany (DEU), France (FRA), United Kingdom (GBR) and Japan (JPN), and China (CHN), Brazil (BRA), India (IND) and Russia (RUS), respectively[19].

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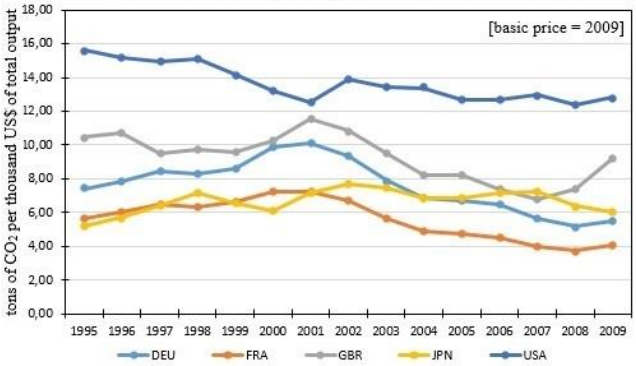
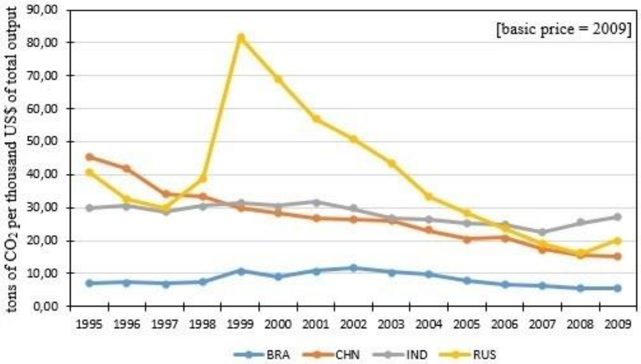
[19] This selection has the intention to motivate through these preliminary results, discussions of hypotheses and theories discussed in the literature review.

Figure 9 – Intensity Coefficients of CO_2 emissions (Principal Economies)



Source: Own elaboration from WIOD database.

Figure 10 – Intensity Coefficients of CO_2 emissions (BRIC)



Source: Own elaboration from WIOD database.

From Figure 9, it is possible to observe, in general, a decrease with respect to the magnitude of the intensity coefficient of CO_2 emissions for selected countries (Germany, France, UK, Japan and the United States), representing a scenario of production with lower CO_2 emission intensity. However, it is important to keep in mind that this does not necessarily reflect a decrease in the absolute amount of CO_2 emissions.

This point of discussion becomes even more relevant when it is observed the intensity coefficients in developing countries, for example. Through Figure 10, we can observe that the intensity coefficients of CO_2 emissions for developing countries (Brazil, Russia, India and China) exhibit a behavior of decrease. However, as shown below, such countries have for the same period a behavior of increase in terms of absolute emissions of CO_2.

Given the results presented in Figures 9 and 10 it is possible to think about the issues around the Kyoto Protocol, for example, differences in behavior between the signatory and non-signatory countries, or between countries belonging to Annex I and Non-Annex I.

However, for this study, the coefficients of intensity of CO_2 emissions are more important in methodological terms than in terms of the result itself, since they are used to incorporate CO_2 emissions in international trade, this allow us to obtain results and discussions with regard to CO_2 emissions and international trade.

Thus, the results and discussions involving emissions and international trade are presented in the next two sections (5.2 Trade balances of Global CO_2 Emissions and 5.3 Miyazawa Multipliers).

5.2. Trade balances of Global CO_2 Emissions

Furthermore, input-output models, as discussed by Wiebe *et al.* (2012), allow us to obtain indicators of production and consumption of CO_2 emissions to countries and regions, for example, taking into account the emissions embodied in international trade.

Thus, for this study, the trade balance of CO_2 emissions embodied in international trade are calculated for the 40 countries and the major net exporters and net importers of CO_2 emissions can be identified. And thus, as shown by Wiebe *et al.* (2012), the results are able to show the responsibility of a country for emissions abroad.

The carbon trade balances are calculated from matrix π (equation 12) for all countries[20] for the years 1995, 2000, 2005 and 2009, respectively. However, it is noteworthy, as the strategy used by Wiebe et al. (2012) and adapted to the database of this study, for purposes of calculating the trade balance of CO_2 emissions, the π matrix is aggregated in a 41x41 trade matrix (number of spatial units,

[20] Complete results are available from the authors.

i.e. 40 countries plus the "rest the world", WIOD project), showing the sales in terms of CO_2 for each country in the rows and the purchases in terms of CO_2 in the columns. Thus, from this matrix is done the calculus of the carbon trade balances for each country. Imports are derived from the sums of the rows, except the diagonal elements, and exports come from the column sums, again, unless the element of the main diagonal[21].

Thus, overall emissions embodied in the production and consumption are associated with the intermediate flows between 40 countries plus the "Rest of the World". Pollution embodied in production is the CO_2 emissions associated with the sale of inputs by a spatial unit (one country to the other 39 countries plus the "Rest of the World"). And similarly, pollution embodied in consumption corresponds to the emissions associated with the acquisition of inputs.

For comparison, Figure 11 shows the evolution of global trade balances of CO_2 emissions embodied in international trade[22], *i.e.*, emissions embodied in consumption (dotted lines) and production (solid lines) for five countries: China (CHN) , Germany (DEU), United Kingdom (GBR), United States (USA), and Japan (JPN).

Thus, with the Figure 11 we can see that for the USA the dotted line is above the solid line, *i.e.*, CO_2 emissions embodied in consumption are higher than the emissions embodied in production for the years 1995-2009.

On the other hand, for GBR the line solid (production) is above the dotted line (consumption) until the year 2004, exhibiting similar behavior to USA only from 2005. For DEU, it is possible to observe a behavior with oscillations between the years 1995 to 2003 and from 2004 presented in conduct contrary to the USA, with CO_2 emissions embodied in production larger than emissions embodied in consumption.

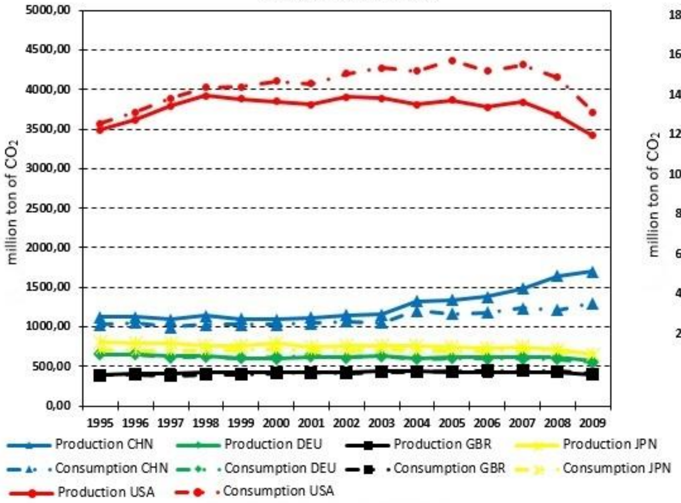
Finally, for JPN and CHN, it is possible to see that the solid line is above the dotted line, *i.e.*, contrary to the behavior exhibited by the USA, for these two countries CO_2 emissions embodied in production are higher than emissions embodied in consumption for the years 1995 to 2009.

Similarly, Figure 12 shows the evolution of global trade balances of CO_2 emissions embodied in international trade, *i.e.*, emissions embodied in consumption (dotted lines) and output (solid lines), for a range of different countries: Brazil (BRA), Russia (RUS), India (IND) and China (CHN).

On the one hand, RUS exhibits similar behavior to that presented by CHN with the solid line above the dotted line, *i.e.*, CO_2 emission embodied in the production being higher than the emission embodied in the consumption for the years 1995-2009. BRA, also, presents a solid line above the dotted line, for most years, except 1999-2001.

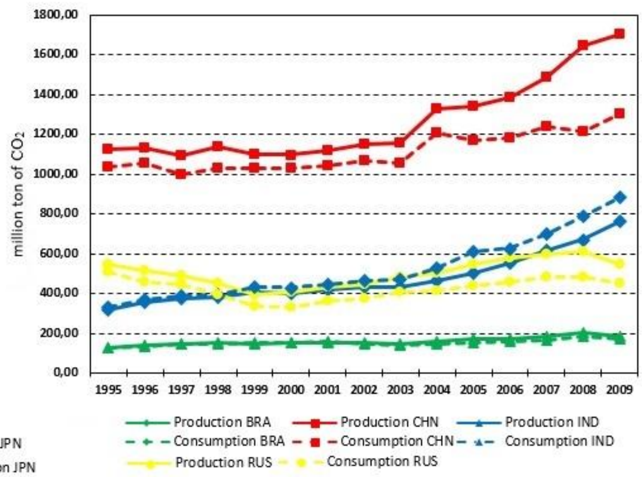
[21] The main diagonal are the emissions that are produced and consumed within the same country.
[22] Note that emissions embodied in international trade correspond to the emissions associated with intermediate flows of input-output tables.

Figure 11 – CO_2 emissions embodied in consumption and production (Principal Economies)



Source: Own elaboration from WIOD database.

Figure 12 – CO_2 emissions embodied in consumption and production (BRIC)

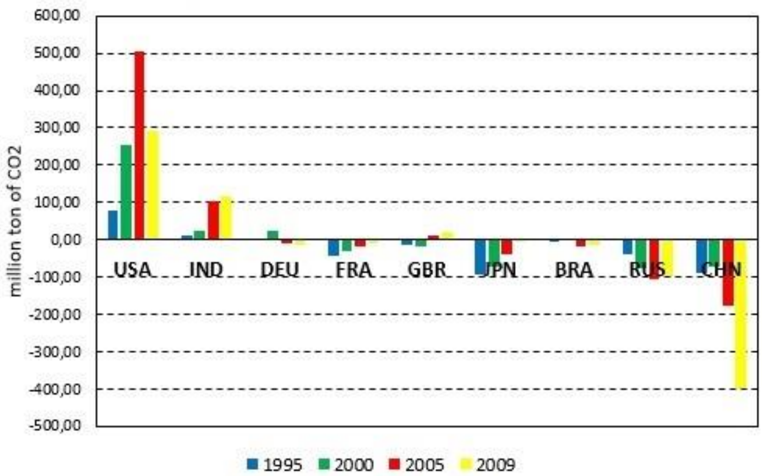


Source: Own elaboration from WIOD database.

However, on the other hand, IND shows a different behavior, with the CO_2 emissions embodied in the consumption higher than CO_2 emissions embodied in production, for the years 1995 to 2009.

Figure 13 shows, for comparison purposes, results of trade balances of some economies such as the United States (USA), Germany (DEU), France (FRA), United Kingdom (GBR), Japan (JPN), Russia (RUS), China (CHN), Brazil (BRA) and India (IND). Thus, through this figure we can see which of these countries are classified as net importers of CO_2, and which are classified as net exporters of CO_2[23] for the years 1995, 2000, 2005 and 2009.

Figure 13 – Net Imports and Net Exports of CO_2 emissions



Source: Own elaboration from WIOD database.
Note: Positive values indicate net importers of CO_2 and negative values indicate net exporters of CO_2.

The USA was the country with the highest net imports of CO_2 for the four years in question, with a growth until 2005, more than tripling its net imports of CO_2, and a decrease in 2009. On the other hand, the country with the highest net export of CO_2 for the year 1995 was JPN, for the year

[23] It is noteworthy that net importer and net exporter terms refer to the balance of CO_2 emissions embodied in international trade.

2000 RUS, and for the years 2005 and 2009 CHN. Moreover, it is important to emphasize the growth evidenced by CHN, where the net export of CO_2 quadruples when comparing 1995 with 2009.

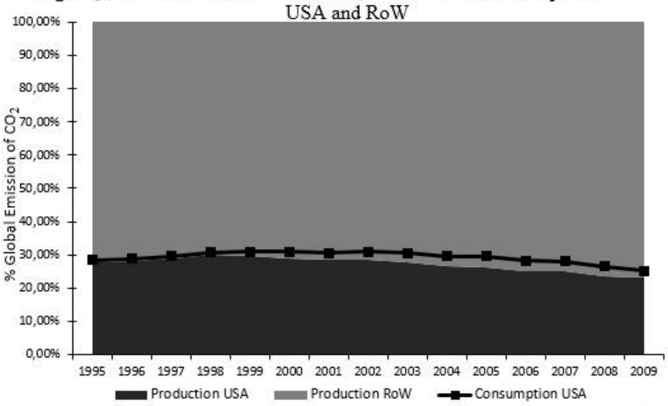
Regarding the classification of countries as exporters or importers of CO_2, it is possible to observe USA and IND as net importers in the four years (1995, 2000, 2005, and 2005). On the contrary, FRA, JPN, CHN and RUS are classified as net exporters in these four years.

However, some countries such as BRA, DEU and GBR have different behavior over the years. DEU, for example, in the first two years, 1995 and 2000, is classified as a net importer of CO_2; however, in 2005 and 2009 it reverses and goes on to present a profile of a net exporter of CO_2. Regarding GBR, the pattern is given contrary to DEU; it is possible to observe a profile of net exporter in the first two years and a net importer in the last two years. Finally, BRA is classified as a net exporter in 1995, 2005, and 2009, and classified as a net importer only the year 2000.

For comparison purposes, Figures 14 and 15 bring the evolution of emissions embodied in consumption and production for the United States (USA), and China (CHN), respectively, compared with the emissions embodied in the rest of the world's production.

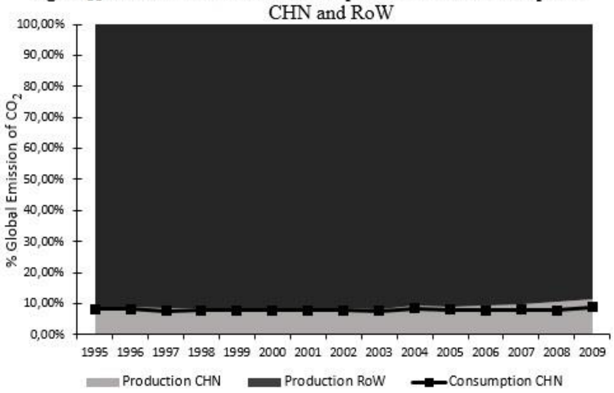
Through Figure 14, you can see that CO_2 emissions embodied in the production of the USA in 1995 account for approximately 28% of emissions embodied in production worldwide. Moreover, it is possible to observe an increase by the year 2002, with a share of approximately 30%. However, after this year (2002), one can see a decrease of such participation. An important result is the fact that the USA has a line of CO_2 emissions embodied in consumption that is above the production line of their own country, which means that the country is classified as a net importer of CO_2 emissions for the period of analysis (1995-2009).

Figure 14 - CO_2 emissions embodied in production and consumption - USA and RoW



Source: Own elaboration from WIOD database.

Figure 15 - CO_2 emissions embodied in production and consumption - CHN and RoW



Source: Own elaboration from WIOD database.

Similarly, by Figure 15, it can be observed that the emissions of CO_2 embodied in the production of CHN in the year 1995 correspond to approximately 8% of the emissions embodied in production worldwide. Moreover, it is possible to observe a movement of growth over time, with a share of approximately 11% in 2009.

However, contrary to the USA (Figure 14), CHN has a line of CO_2 emissions embodied in consumption below the line production of the country itself, *i.e.*, confirming the behavior of a net exporter of CO_2 shown in the figures above.

It is important to note that these results have similarities and differences with respect to other studies involving the same subject. The work of Wiebe *et al.* (2012), the basis for the methodology developed in this section shows, for example, similar results for the United States (USA), Germany (DEU), Russia (RUS), China (CHN), *i.e.* these countries have the same behavior in terms of classification (net exporter or net importer of CO_2 emissions), with differences in the magnitude, which is justified by the use of different databases. However, it is also possible to observe different results for India (IND), France (FRA) and United Kingdom (GBR).

Given the results of this section, and according to the purpose of this study, it is important to analyze the structure of trade among the countries. In order to contribute to the literature on international trade and emissions, the next section presents the results for the Miyazawa multipliers.

5.3. Miyazawa Multipliers[24]

As described above and demonstrated by Hewings *et al*. (2001), the Miyazawa multiplier, external and internal, feature the degree of economic interaction between the two regions through the activities propagation of external and internal, respectively. However, for this study the Miyazawa multipliers able us to classify the structure of trade between two regions in terms of CO_2 emissions, such as the application made by Fritz *et al*. (1998).

Furthermore, it is noteworthy that as presented by Hewings *et al.* (2001), Miyazawa multipliers can be derived by an interregional system with more than two regions, however, the calculation of these multipliers requires the specification of the hierarchy (order) of propagation. So with a system with n-regions, it is possible to construct (n+1)!/2 combinations of "routes" of propagation[25].

The strategy used in this work is the pre-set pairs from the results found in previous sections, according to the literature and importance of the countries in the global context, and regarding the discussions about international trade and CO_2 emissions. Thus, the Miyazawa multipliers for this paper are calculated by taking pairs, the countries adopted as internal region (specified as R1 in the figures) at first are considered as external region later (specified in the figures as R2), such as example in Figure 16, where China (CHN) is considered the internal region and the United States (USA) the external region, however, in Figure 17, such specification is reversed.

Thus, Figures 16-23 show the results of Miyazawa multipliers in terms of pollution for some pairs of countries. Note that the results represent the average of the Miyazawa multipliers, *i.e.*, the values of the figures are the average of 35 productive sectors for each of the respective countries and years.

The results represent the increase of pollution generated by the external region (R2) industries as a result of the increase of US$1.00 in the final demand of the internal region (R1). Thus, it is possible to observe the pollution generated by the direct requirement of inputs for the internal region, pollution caused by the indirect requirement of inputs for the internal region, internal propagation of external region (pollution induced by direct and indirect production of the external region) and external propagation from the external region[26]. Furthermore, the figures show the values for four specific years, 1995, 2000, 2005 and 2009.

The first figure (Figure 16) shows the results for economic interaction in terms of pollution (CO_2 emissions) to China (CHN) and the United States (USA), *i.e.*, the influence of internal propagation of China (CHN) in the level of pollution in the United States (USA).

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[24]For details on application and derivation of the methodology see: FRITZ *et al* (1998); HEWINGS *et al.* (2001); OKUYAMA *et al.* (1999); SONIS and HEWINGS (1993, 1995, 1999a, 1999b); SONIS, M. *et al.* (1997); MIYAZAWA (1966, 1968, 1971).

[25] For an extension of this approach, see Guilhoto *et al.* (2001).

[26] The results for the external propagation are not shown in the figures, because they are characterized by low values due to their own methodological character.

Through the Figure 16 it is possible to observe that the pollution generated by the direct and indirect requirement of inputs of China (CHN) in the United States (USA), blue and red line, respectively, exhibit a similar behavior over the years, falling at first (1995 to 2000), and increasing thereafter (2005 to 2009).

However, the highlights are the results found for the pollution caused by the internal propagation of own United States (USA), black line, because it is possible to observe a decreasing trend, which represent an internal production process less polluter.

The result becomes even more relevant when it is considering the multiplier of the second figure (Figure 17), which shows the results for economic interaction in terms of pollution (CO_2) of the United States (CHN) and China (CHN), *i.e.* the influence of the internal propagation of the United States (USA) at the level of pollution in China (CHN).

From Figure 17 it is possible to observe an opposing behavior when the pollution caused by China's own internal propagation (CHN), given a monetary increase of one unit (US$) in final demand of United States (USA), is analyzed. Differently what it is observed for the United States (USA), China (CHN) exhibits a behavior increased over the years, which represent a more polluter internal process.

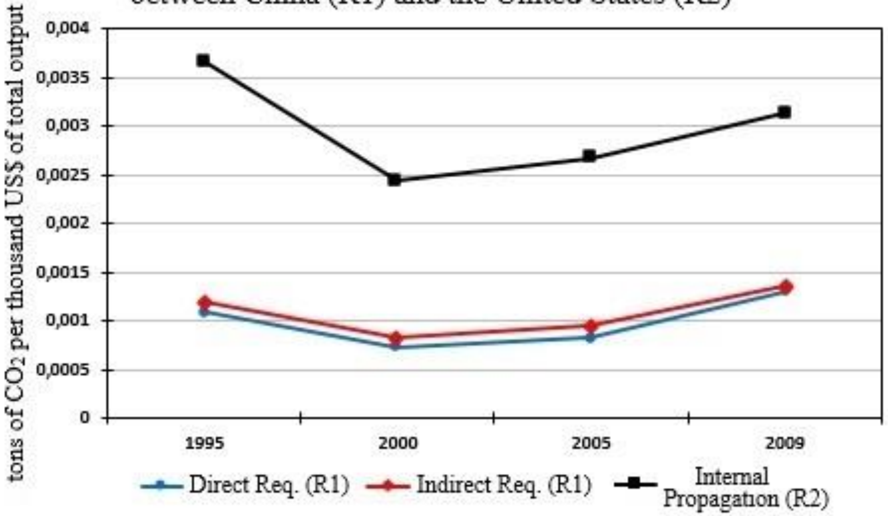
Moreover, in terms of pollution generated by the direct and indirect requirement of inputs of the United States (USA) in China (CHN), the behavior is similar over the years, with a tendency to increase (Figure 17).

On the other hand, Figure 18 shows the results for economic interaction in terms of CO_2 emissions for Brazil (BRA) and China (CHN). In other words, it brings the influence of internal propagation of Brazil (BRA) in the level of pollution of China (CHN).

Thus, by Figure 18, it is possible to observe that the pollution generated by the direct and indirect requirement of inputs from Brazil (BRA) in China (CHN), blue and red line, respectively, show a similar behavior of increase over the years. However, as it is observed for the United States (USA) and China (CHN), the highlights are the results found for the pollution caused by own internal propagation of China (CHN), black line, because it is possible observe a clear trend of increase, which is, as mentioned earlier, an internal production process more polluter.

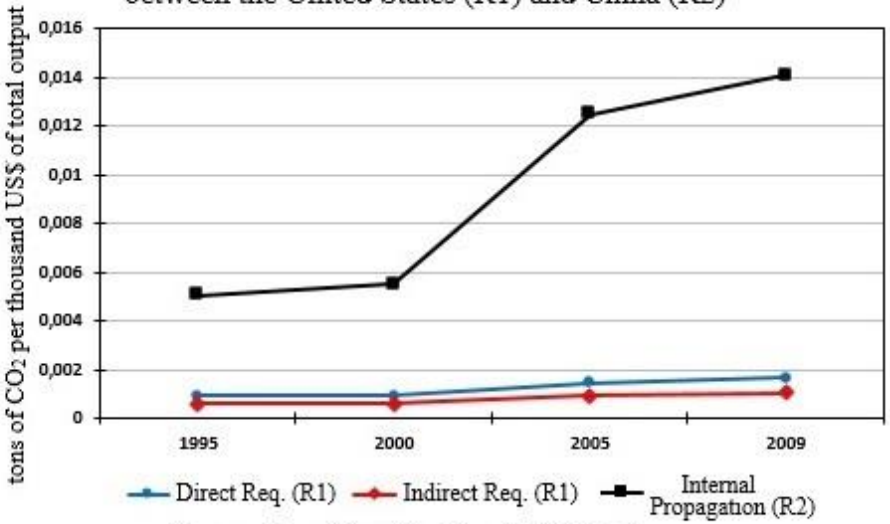
When the analysis is inverted, the pollution generated by the direct and indirect requirement of inputs of China (CHN) in Brazil (BRA), Figure 19, it is possible to observe a behavior of increase, however, with different magnitudes. Moreover, in terms of results for the pollution caused by internal propagation of Brazil (BRA), black line, it is possible to observe a similar behavior presented by China (CHN), *i.e.*, a tendency to increase, representing an internal process productive more polluter. However, for Brazil, Figure 19, between 2005 and 2009 it is possible to see a decrease.

Figure 16 – Average of Miyazawa Multipliers of Pollution due interaction between China (R1) and the United States (R2)



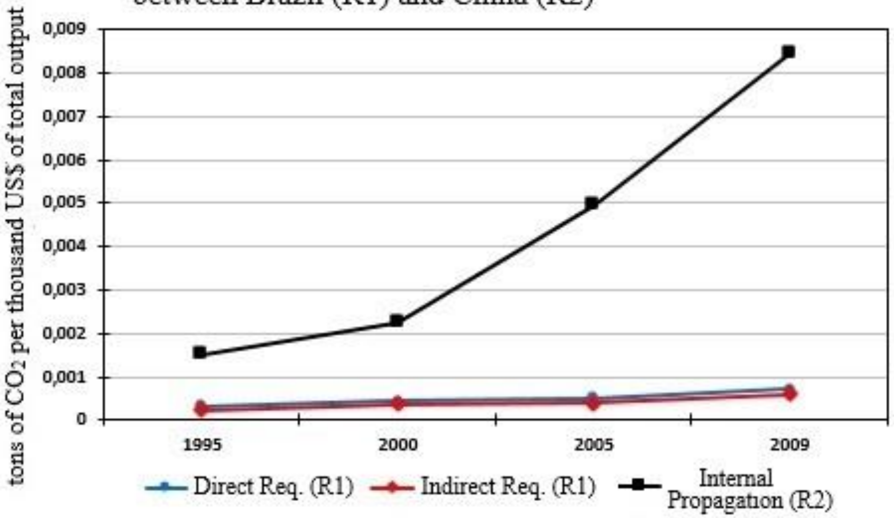
Source: Own elaboration from WIOD database.

Figure 17 – Average of Miyazawa Multipliers of Pollution due interaction between the United States (R1) and China (R2)



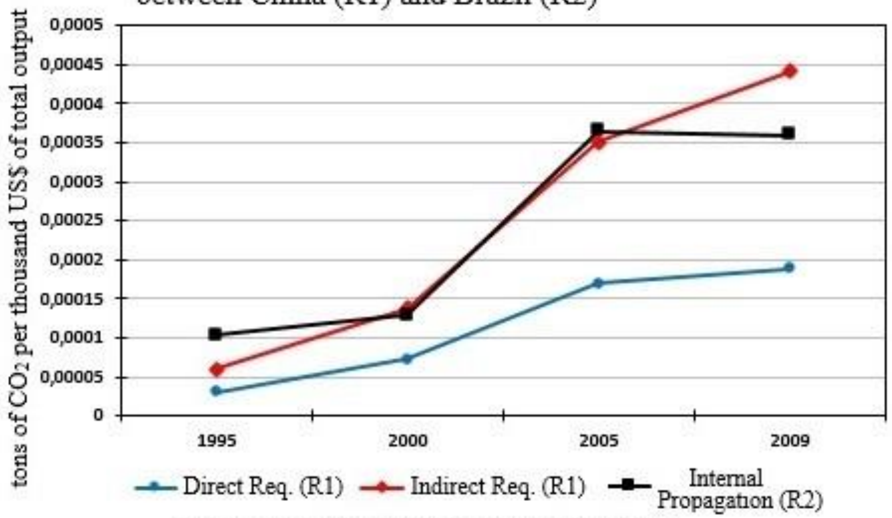
Source: Own elaboration from WIOD database.

Figure 18 – Average of Miyazawa Multipliers of Pollution due interaction between Brazil (R1) and China (R2)



Source: Own elaboration from WIOD database.

Figure 19 – Average of Miyazawa Multipliers of Pollution due interaction between China (R1) and Brazil (R2)



Source: Own elaboration from WIOD database.

Figures 20 and 21 bring the results to the economic interaction in terms of pollution (CO_2) for the United States (USA) and the BRIC. From Figure 20, it is possible to observe that the pollution generated by the direct and indirect requirement of inputs by United States (USA) in BRIC, blue and red line, respectively, exhibit a similar behavior over the years, an increase from 1995 to 2005 , and from this an behavior of decrease.

However, the highlights are the results found for the pollution caused by the internal propagation of BRIC, black line, because it is possible to observe a tendency to increase until 2005, which represent an internal productive process more polluter, and from 2005 to 2009 an inverse behavior (decrease).

In terms of results for the influence of the internal propagation of BRIC in the level of pollution in the United States (USA), Figure 21, it is possible to observe an opposing behavior for pollution caused by internal propagation of the United States (USA) in comparison with what is seen to BRIC (Figure 20), *i.e.* internal production process less polluter.

Finally, Figures 22 and 23 bring the results to the economic interaction in terms of pollution to the European Union (EU) and the BRIC.

Through Figure 22 it is possible to observe the influence of internal propagation of the European Union (EU) in the level of pollution of BRIC, where the pollution generated by the direct and indirect requirement of inputs of the European Union (EU) in BRIC, blue and red line , respectively, show a similar behavior to decrease.

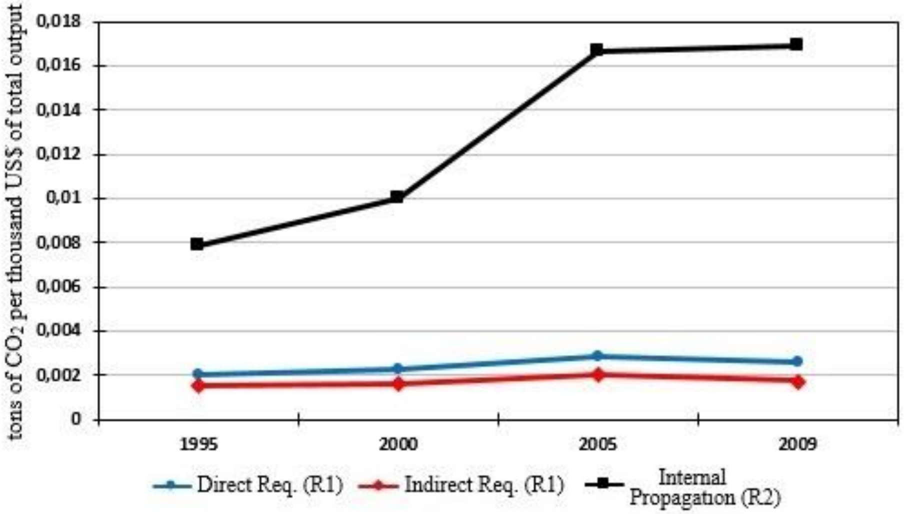
Moreover, with respect to pollution caused by internal propagation BRIC, black line, it is possible to see a tendency of increase, which represents an internal production process more polluter until the year 2005 and contrary a behavior of decrease from 2005 to 2009.

When the analysis is reversed, *i.e.*, the pollution generated by the direct and indirect requirement of inputs of BRIC in the European Union (EU), Figure 23, it is possible to see that they also show a similar behavior, *i.e.*, both exhibit a behavior of increase between 1995 and 2000 and from that, a decrease behavior (*i.e.* 2000 to 2005, 2005 to 2009).

In terms of pollution caused by internal propagation of the European Union (EU) two different scenarios are observed, first representing a more polluter production process (1995-2000) and then a reverse production process, less polluter (2000-2009).

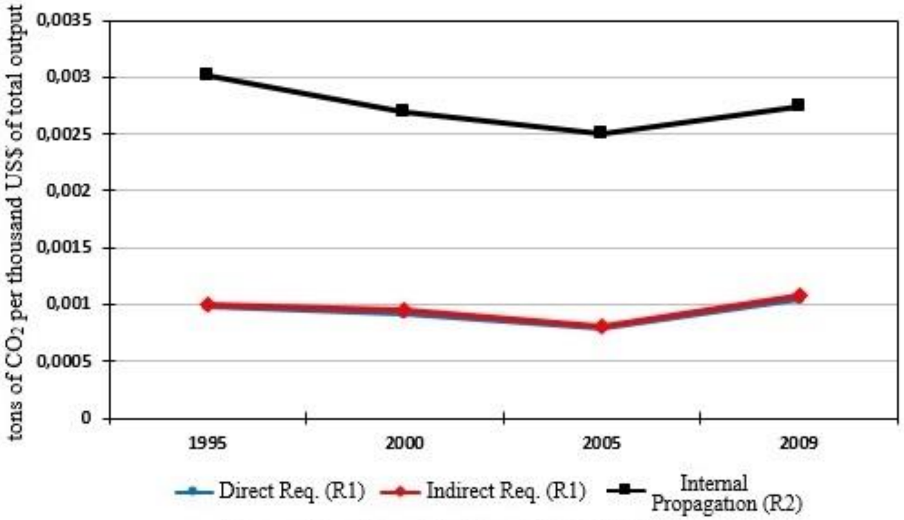
The results of this section allowed us to analyze the structure of trade relations among the countries in terms of pollution (CO_2 emissions). Thus, in the next section we will make a discussion and analysis of all the results of this work.

Figure 20 – Average of Miyazawa Multipliers of Pollution due interaction between the United States (R1) and BRIC (R2)



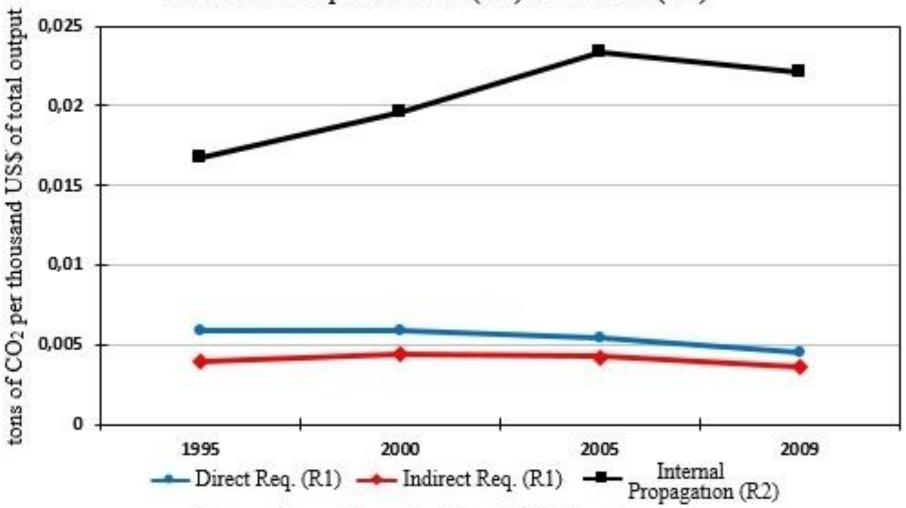
Source: Own elaboration from WIOD database.

Figure 21 – Average of Miyazawa Multipliers of Pollution due interaction between BRIC (R1) and the United States (R2)



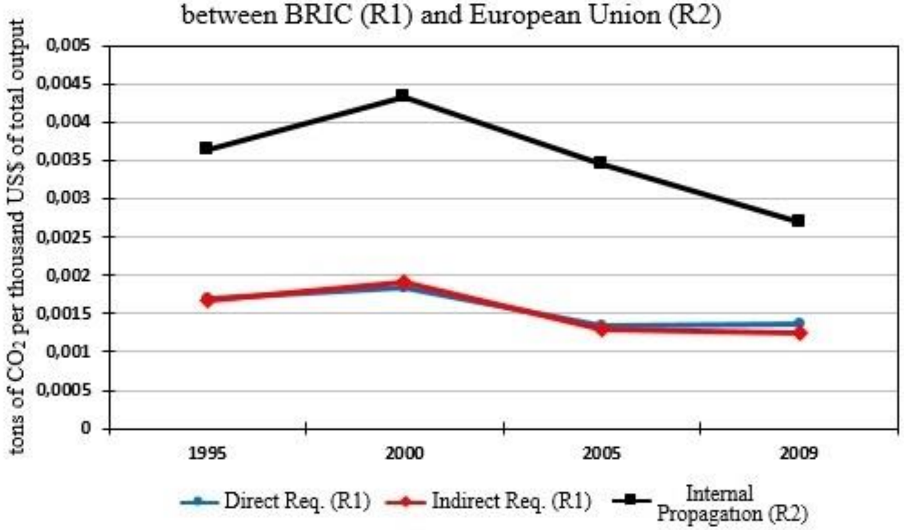
Source: Own elaboration from WIOD database.

Figure 22 – Average of Miyazawa Multipliers of Pollution due interaction between European Union (R1) and BRIC (R2)



Source: Own elaboration from WIOD database.

Figure 23 – Average of Miyazawa Multipliers of Pollution due interaction between BRIC (R1) and European Union (R2)



Source: Own elaboration from WIOD database.

5.4. DISCUSSION

Given the different results presented, this section has the intention of to present a discussion of the results in light of the theories presented in the literature review.

Through the analysis of the levels of CO_2 emissions for countries such as, United States (USA), China (CHN) and Russia (RUS), it is possible to observe a behavior of high CO_2 emission over time (Figure 1-4). Moreover, the rise of China (CHN) makes the discussion more attractive, because the increase is significantly.

Given these results and discussions described in the literature review, an analysis in terms of developed and developing countries seem to be relevant. Through Figures 5-8, we can think about such discussion, because there is an evidence, on the one hand, of increase in emissions from the United States (USA), developed country, in the first instance and subsequently a high decrease. Moreover, there is a contrary evidence to China (CHN), Brazil (BRA), India (IND) and Russia (RUS), developing countries.

In terms, for example, the theory of EKC, it is possible to imagine that such examples of results follow the hypothesis behind this theory, *i.e.* inverted U-shape between the per capita income (development economic) and level of environmental quality (pollution levels). The United States (USA), on one hand, being in a more advanced stage of economic development is responding with a decline of pollution. On the other hand, countries like China (CHN), Brazil (BRA), India (IND) and Russia (RUS), being in a lower stage of economic development, are presenting a pollution increased.

As approached by Nordstrom and Scott (1999), Dasgupta *et al.* (2002), Copeland and Taylor (2004), this result may be an evidence that the increase in income is associated with an increase in pollution in early stages of economic development and a decline in pollution in more advanced stages. However this is not the main focus of this work, so it is not done any empirical test to evaluate this hypothesis.

However, other hypotheses can be discussed, such as carbon leakage. These results can be linked in some way to a carbon leakage from developed to developing countries. Even more specifically, it can be represented, for example, the use of international trade to reduce CO_2 emissions.

Another hypothesis that can be evaluated is the pollution haven effect, *i.e.* a pollution regulations taking effect on plant location decisions and trade flows. Or even more strongly, that a reduction in trade barriers is leading to a shift of pollution-intensive industry in countries with stringent rules for countries with weaker regulations (pollution haven hypothesis).

However, despite the results of the absolute emissions presented evidence that they can apply and discuss some of the theories, before drawing conclusions, it is necessary to look at the results around the international trade, which for this study consists of the results extracted from of input-output tables: (a) Trade Balance of Global CO_2 Emissions; and (b) Miyazawa Multipliers.

Through the first results (Trade Balance of Global CO_2 Emissions), it is possible to present a discussion of responsibility for emissions by different principles and consider the different behaviors in terms of developed and developing countries, for example.

Given the results presented in Figures 4-8 (absolute emissions) it is observed that developing countries present behavior of increase in CO_2 emissions. However, such results may lead to erroneous conclusions and attributions of responsibility for emissions, because they consider only the territorial emissions.

When we observe, for example, the evolution of the global balances of CO_2 emissions embodied in international trade, *i.e.*, emissions embodied in consumption and production, different evidence and conclusions can be made.

Taking as exercise the global balances of CO_2 emissions to the United States (USA) and the BRIC (Brazil, Russia, India and China), for example, Figures 11 and 12, it is possible to observe different results compared to those presented for emissions absolute CO_2.

On the one hand, the United States (USA) have CO_2 emissions embodied in consumption higher than emissions embodied in production for the years 1995-2009. On the other hand, China (CHN) and Russia (RUS) have emissions CO_2 embodied in production higher than emissions embodied in consumption for the years 1995 to 2009. Brazil (BRA), shows a similar behavior of Russia (RUS) and China (CHN) with except from 1999 to 2001. Finally, India (IND) have a differently behavior, CO_2 emissions embodied in consumption higher than CO_2 emissions embodied in production for the years 1995-2009.

Thus, it is possible to affirm that the United States (USA) and India (IND) are classified as net importers of CO_2, and China (CHN), Brazil (BRA) and Russia (RUS) are net exporters of CO_2. These results are important, because they allow us to obtain different perspectives and discussions by different principles of responsibility.

These exercises show interesting results around international trade, however, as described in the previous section, the results concerning the trade structures among countries, Miyazawa multipliers, can contribute further in terms of the relationship between international trade and CO_2 emissions.

Given the results described in the previous section, it is possible to observe, for example, that when you have the pairing between the United States (USA) and European Union (EU), developed countries, with China (CHN), developing country, the result is similar. An increase of a US$1.00 in the final demand in China (CHN) in terms of pollution in the United States (USA) is lower over the year, *i.e.*, evidence that the internal production process of the USA is increasingly less polluter.

The result of the pairing becomes more attractive when it reverses the analysis and the shock of final demand, *i.e.*, an increase of a US$1.00 in the final demand is given in the United States (USA) in relation to China (CHN). It is observed that the internal production process of China (CHN) is more polluter, given the interaction.

Consider other pairings between developed and developing countries, it is possible to see similar results. The pairing between USA and BRA, or between the United States (USA) and European Union (EU) with the BRIC, it is possible, on the one hand, observe an internal production process more polluter to developing countries and blocks (Brazil and BRIC) and, on the other hand, a production process less polluter for developed countries and blocks (EU and USA).

When the analysis is done in terms of interaction between two developing countries (South-South) as Brazil (BRA) and China (CHN), it is possible to observe a more polluter domestic production process.

Given these results for the pre-defined pairings and thinking about the discussions described in the literature review is plausible discuss and raise questions about the theories behind the carbon leakage, the pollution haven effect, the pollution haven hypothesis, the use of environmental policy as a substitute for trade policy, the use of trade policy to achieve environmental goals, and patterns of trade between North and South, for example.

The results for China (CHN), for example, always have a more polluter production process, which can be interpreted as a carbon leakage, where countries that have a trade relationship with China (CHN) may be taking advantage of international trade to reduce their emissions. Looking at these results plus global trade balances of CO_2 there is further evidence that international trade is being used to reduce emissions.

Given these results, as was discussed for absolute emissions it is possible to think about to the pollution haven effect. Although the present study does not provide evidence for the regulation by countries, it is possible to present a simple discussion, because the literature points to a situation where Northern countries have strong regulations and Southern countries a weak regulations (*e.g.* Copeland and Taylor 2004 and Taylor, 2005)

Given that we have examples of North-South pairings (*e.g.* the United States and China, the United States and BRIC) in the production process in the South is increasingly polluter and North less polluter, *i.e.* regulation is affecting the location decisions of plants, for example. Or even more strongly, that a reduction in trade barriers is leading the shift of pollution-intensive industry in countries with stringent regulations (North) to countries with weaker regulations (South), a hypothesis known as the pollution haven hypothesis.

Although the results present evidence that such theories may be occurring, it is necessary to interpret the results with caution, because these results represent only an exercise.

6. CONCLUSIONS

As shown in this work, the problem of greenhouse gas (GHG) and related climate change is an important debate in international economies, where research efforts have increasingly taken into account sustainable consumption. Discussions began to gain the attention of the world with the Kyoto Protocol

However, although it has been possible to observe some progress, real initiatives for more sustainable consumption have not materialized. Thus, efforts to develop more efficient and effective consumption systems are still unknown, with little practical advance (Tukker *et al.,* 2006).

As discussed by Wyckoff and Roop (1994), in the context of mitigation, many controlling policies are based on reducing domestic GHG emissions, ignoring the emissions of CO_2 embodied in international trade flows. Thus, international agreements for reducing GHG emissions are calculated based on the emissions produced within the geographical boundaries of the country, however disregarding the fact, for example, that increases in emissions in emerging economy and less developed countries may be due to production of goods for export (WIEBE *et al.*, 2012).

Thus, to investigate the location of such emissions and the involved countries are important steps to ensure the reduction of GHG emissions. Given the rapid expansion and globalization of world economies, pollution embodied in trade flows becomes another factor to take into consideration.

In terms of contribution to the work of Wiebe et al. (2012), for example, the present study sought through multipliers Miyazawa address the issues of feedback loop among countries.

Furthermore, this study used a solid database (WIOD project) in terms of compatibility of Input-Output Tables and atmospheric CO_2, the same range of time and sectoral disaggregation.

The following results can be highlighted: i) the increase of CO_2 emissions in developing countries (*e.g.* Brazil , Russia, India and China); ii) the opposing behavior of the USA and BRIC (Brazil , Russia, India and China), with the exception of India, in terms of net balances of emissions embodied in international trade; iii) evidence that the decrease of CO_2 emissions in some countries comes from greater interaction in terms of trade with other countries; iv) the developed countries have an internal production process increasingly less polluting, and contrary to, developing countries have an internal production process more polluting, given the pairing between them.

Furthermore, this study, through the different results, makes a discussion on the theory of environmental Kuznets curve, the pollution haven effect, the pollution haven hypothesis, trade's patterns between North and South, and others.

Although the results present evidence that such theories may be occurring, it is necessary to interpret the results with caution, as these results represent an exercise. Although it is possible to observe a pattern, it is important to observe other interactions, because countries interact differently. In general the relation of cause and effect relationship between emissions and international trade has other components, *e.g.* cost, capital mobility and hand labor, which are not addressed in the scope of this work.

Furthermore, it is noteworthy that it is not the scope of this paper to discuss and present all pairings that can be performed using as a basis the 41 spatial units (*i.e.* 40 countries plus the "Rest of the World"). The pairings chosen sought to highlight the issues related to the integration process among countries and the impact on emissions. The choice of pairings can also take into consideration components sociological and political-economy, for example. This may be a possible extension of this work.

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APPENDIX

Appendix I – CO_2 Balance of the 40 selected countries – 1995 in millions of tons

Country	**AUS**	**AUT**	**BEL**	**BGR**	**BRA**	**CAN**	**CHN**	**CYP**	**CZE**	**DEU**
Domestic CO_2 Production	171.52	41.54	78.13	30.03	128.21	274.00	1121.56	3.17	63.24	653.47
Domestic CO_2 Consumption	166.97	40.08	69.76	29.80	125.47	264.46	1032.82	5.06	65.16	655.84
Exports	39.45	20.95	44.42	9.70	20.95	75.27	199.53	0.45	14.89	167.40
Imports	34.90	19.49	36.04	9.47	18.21	65.73	110.80	2.33	16.81	169.77
Imports - Exports	-4.55	-1.46	-8.38	-0.23	-2.74	-9.54	-88.74	1.88	1.92	2.37
(I) or (E)*	**E**	**E**	**E**	**E**	**E**	**E**	**E**	**I**	**I**	**I**

Country	**DNK**	**ESP**	**EST**	**FIN**	**FRA**	**GBR**	**GRC**	**HUN**	**IDN**	**IND**
Domestic CO_2 Production	51.32	123.78	7.97	35.30	298.41	399.04	35.05	33.02	115.11	316.37
Domestic CO_2 Consumption	43.72	126.07	10.29	27.63	256.66	387.10	38.56	37.17	114.66	330.11
Exports	22.83	33.47	1.26	17.83	118.42	111.06	5.22	7.94	25.96	23.12
Imports	15.24	35.76	3.59	10.16	76.68	99.12	8.73	12.09	25.51	36.86
Imports - Exports	-7.60	2.29	2.33	-7.67	-41.74	-11.93	3.50	4.15	-0.45	13.73
(I) or (E)*	**E**	**I**	**I**	**E**	**E**	**E**	**I**	**I**	**E**	**I**

Country	**IRL**	**ITA**	**JPN**	**KOR**	**LTU**	**LUX**	**LVA**	**MEX**	**MLT**	**NDL**
Domestic CO_2 Production	19.38	286.79	804.12	229.61	7.70	4.85	6.24	213.53	1.30	132.05
Domestic CO_2 Consumption	18.22	275.47	712.59	205.22	10.21	3.76	7.55	212.10	1.76	106.01
Exports	9.19	89.39	228.48	68.39	2.01	3.86	1.45	35.23	0.38	70.48
Imports	8.03	78.07	136.96	44.00	4.52	2.77	2.76	33.80	0.83	44.43
Imports - Exports	-1.16	-11.32	-91.52	-24.39	2.51	-1.09	1.31	-1.43	0.46	-26.05
(I) or (E)*	**E**	**E**	**E**	**E**	**I**	**E**	**I**	**E**	**I**	**E**

Country	**POL**	**PRT**	**ROM**	**RUS**	**SVK**	**SVN**	**SWE**	**TUR**	**TWN**	**USA**
Domestic CO_2 Production	181.27	30.19	63.87	544.64	19.96	8.72	47.00	102.21	120.36	3491.43
Domestic CO_2 Consumption	181.96	30.83	72.08	508.32	18.72	9.13	34.71	109.84	98.63	3569.08
Exports	27.91	8.32	7.64	92.65	7.71	2.92	28.25	9.62	54.30	354.72
Imports	28.60	8.95	15.85	56.33	6.46	3.34	15.96	17.25	32.57	432.37
Imports - Exports	0.69	0.64	8.21	-36.32	-1.24	0.41	-12.30	7.63	-21.73	77.66
(I) or (E)*	**I**	**I**	**I**	**E**	**E**	**I**	**E**	**I**	**E**	**I**

Source: Own elaboration from WIOD database.

Note: * Net Import (I) or Net Export (E) in terms of CO_2 emissions.

Appendix II – CO_2 Balance of the 40 selected countries – 2000 in millions of tons

Country	AUS	AUT	BEL	BGR	BRA	CAN	CHN	CYP	CZE	DEU
Domestic CO_2 Production	231.09	41.39	77.67	21.04	151.64	320.78	1095.90	4.74	71.46	595.41
Domestic CO_2 Consumption	232.42	40.16	66.41	21.24	154.07	288.48	1026.13	7.57	81.31	618.32
Exports	48.80	21.67	47.73	7.37	22.26	110.29	187.78	0.79	15.29	174.79
Imports	50.13	20.45	36.47	7.57	24.68	77.99	118.01	3.62	25.15	197.71
Imports - Exports	1.33	-1.22	-11.26	0.20	2.42	-32.31	-69.77	2.83	9.86	22.91
(I) or (E)*	**I**	**E**	**E**	**I**	**I**	**E**	**E**	**I**	**I**	**I**
Country	**DNK**	**ESP**	**EST**	**FIN**	**FRA**	**GBR**	**GRC**	**HUN**	**IDN**	**IND**
Domestic CO_2 Production	51.37	138.17	9.33	33.43	298.68	427.98	51.30	32.80	136.34	403.29
Domestic CO_2 Consumption	37.35	150.94	11.72	28.12	268.68	410.17	59.93	39.98	133.88	429.09
Exports	28.07	42.44	1.81	17.06	121.22	140.92	8.87	8.37	35.52	36.81
Imports	14.05	55.21	4.20	11.75	91.21	123.11	17.50	15.55	33.06	62.61
Imports - Exports	-14.02	12.77	2.39	-5.31	-30.01	-17.80	8.63	7.18	-2.46	25.80
(I) or (E)*	**E**	**I**	**I**	**E**	**E**	**E**	**I**	**I**	**E**	**I**
Country	**IRL**	**ITA**	**JPN**	**KOR**	**LTU**	**LUX**	**LVA**	**MEX**	**MLT**	**NDL**
Domestic CO_2 Production	29.01	293.69	790.18	253.96	7.20	5.83	5.58	270.55	1.51	137.17
Domestic CO_2 Consumption	24.15	299.34	719.90	231.95	9.74	3.15	6.17	273.87	2.13	112.46
Exports	16.30	92.93	210.53	82.52	2.26	5.16	1.78	53.61	0.54	75.21
Imports	11.44	98.58	140.25	60.51	4.79	2.48	2.37	56.93	1.17	50.50
Imports - Exports	-4.85	5.65	-70.28	-22.01	2.54	-2.68	0.59	3.32	0.62	-24.71
(I) or (E)*	**E**	**I**	**E**	**E**	**I**	**E**	**I**	**I**	**I**	**E**
Country	**POL**	**PRT**	**ROM**	**RUS**	**SVK**	**SVN**	**SWE**	**TUR**	**TWN**	**USA**
Domestic CO_2 Production	144.50	37.98	43.60	404.03	22.12	8.30	48.14	126.00	146.74	3846.81
Domestic CO_2 Consumption	157.30	41.56	49.80	330.27	20.55	9.20	35.90	137.94	134.24	4101.46
Exports	25.24	9.76	8.09	119.50	8.35	2.95	31.32	16.60	61.09	390.96
Imports	38.04	13.34	14.29	45.73	6.78	3.86	19.09	28.54	48.60	645.60
Imports - Exports	12.80	3.58	6.20	-73.76	-1.57	0.90	-12.23	11.94	-12.50	254.65
(I) or (E)*	**I**	**I**	**I**	**E**	**E**	**I**	**E**	**I**	**E**	**I**

Source: Own elaboration from WIOD database.

Note: * Net Import (I) or Net Export (E) in terms of CO_2 emissions.

Appendix III – CO_2 Balance of the 40 selected countries – 2005 in millions of tons

Country	AUS	AUT	BEL	BGR	BRA	CAN	CHN	CYP	CZE	DEU
Domestic CO_2 Production	281.02	50.56	84.55	25.63	169.41	359.01	1342.38	4.36	78.49	612.11
Domestic CO_2 Consumption	287.14	47.30	75.34	27.82	152.22	310.64	1167.35	6.74	85.37	603.53
Exports	64.22	29.66	55.95	6.44	40.57	131.32	354.11	1.06	22.07	224.77
Imports	70.34	26.40	46.73	8.64	23.38	82.95	179.08	3.43	28.95	216.18
Imports - Exports	6.12	-3.26	-9.21	2.19	-17.19	-48.37	-175.03	2.37	6.89	-8.59
(I) or (E)*	**I**	**E**	**E**	**I**	**E**	**E**	**E**	**I**	**I**	**E**
Country	**DNK**	**ESP**	**EST**	**FIN**	**FRA**	**GBR**	**GRC**	**HUN**	**IDN**	**IND**
Domestic CO_2 Production	58.16	168.20	11.81	35.09	307.08	422.18	57.05	39.07	184.78	505.12
Domestic CO_2 Consumption	37.89	182.19	17.12	29.37	290.95	435.34	72.96	44.58	190.37	608.52
Exports	36.70	58.33	0.14	18.75	126.31	149.99	3.82	13.22	43.07	51.99
Imports	16.44	72.32	5.46	13.03	110.18	163.14	19.73	18.74	48.66	155.39
Imports - Exports	-20.26	13.99	5.32	-5.71	-16.13	13.15	15.91	5.52	5.59	103.40
(I) or (E)*	**E**	**I**	**I**	**E**	**E**	**I**	**I**	**I**	**I**	**I**
Country	**IRL**	**ITA**	**JPN**	**KOR**	**LTU**	**LUX**	**LVA**	**MEX**	**MLT**	**NDL**
Domestic CO_2 Production	40.18	321.73	741.27	275.04	9.79	16.75	6.06	303.82	1.36	147.18
Domestic CO_2 Consumption	28.07	323.98	701.27	245.63	11.98	4.07	6.85	304.36	2.12	119.98
Exports	26.30	108.14	198.74	100.47	3.96	15.36	2.14	65.30	0.55	81.02
Imports	14.19	110.39	158.74	71.06	6.15	2.67	2.93	65.84	1.31	53.82
Imports - Exports	-12.11	2.25	-40.00	-29.41	2.19	-12.68	0.78	0.54	0.76	-27.21
(I) or (E)*	**E**	**I**	**E**	**E**	**I**	**E**	**I**	**I**	**I**	**E**
Country	**POL**	**PRT**	**ROM**	**RUS**	**SVK**	**SVN**	**SWE**	**TUR**	**TWN**	**USA**
Domestic CO_2 Production	173.34	42.38	54.67	544.06	22.60	9.68	54.49	134.51	155.98	3860.50
Domestic CO_2 Consumption	181.76	47.15	66.59	439.44	23.09	10.07	39.82	151.95	149.91	4366.48
Exports	37.50	11.38	10.11	163.58	9.58	4.44	36.71	21.68	64.68	349.79
Imports	45.92	16.15	22.03	58.96	10.06	4.83	22.04	39.12	58.61	855.77
Imports - Exports	8.42	4.77	11.92	-104.62	0.48	0.38	-14.67	17.44	-6.07	505.98
(I) or (E)*	**I**	**I**	**I**	**E**	**I**	**I**	**E**	**I**	**E**	**I**

Source: Own elaboration from WIOD database.

Note: * Net Import (I) or Net Export (E) in terms of CO_2 emissions.

Appendix IV – CO_2 Balance of the 40 selected countries – 2009 in millions of tons

Country	AUS	AUT	BEL	BGR	BRA	CAN	CHN	CYP	CZE	DEU
Domestic CO_2 Production	280.45	45.35	78.95	23.80	182.36	333.73	1699.83	3.93	73.48	563.59
Domestic CO_2 Consumption	300.87	41.37	66.89	22.93	168.88	314.67	1303.58	6.03	70.12	552.03
Exports	56.79	28.09	51.03	8.66	41.62	98.84	606.63	1.09	24.69	210.15
Imports	77.21	24.12	38.97	7.79	28.14	79.78	210.38	3.19	21.33	198.59
Imports - Exports	20.42	-3.98	-12.06	-0.87	-13.49	-19.06	-396.25	2.10	-3.36	-11.56
(I) or (E)*	**I**	**E**	**E**	**E**	**E**	**E**	**E**	**I**	**E**	**E**
Country	**DNK**	**ESP**	**EST**	**FIN**	**FRA**	**GBR**	**GRC**	**HUN**	**IDN**	**IND**
Domestic CO_2 Production	54.88	152.41	9.27	37.29	285.21	386.37	52.52	34.31	208.90	763.22
Domestic CO_2 Consumption	35.90	156.35	8.99	31.83	277.64	407.37	61.09	37.05	206.49	880.70
Exports	34.27	59.65	3.49	18.07	114.12	124.40	11.42	13.55	45.71	58.47
Imports	15.30	63.60	3.22	12.61	106.55	145.40	20.00	16.29	43.29	175.95
Imports - Exports	-18.97	3.95	-0.27	-5.46	-7.57	21.00	8.57	2.74	-2.41	117.48
(I) or (E)*	**E**	**I**	**E**	**E**	**E**	**I**	**I**	**I**	**E**	**I**
Country	**IRL**	**ITA**	**JPN**	**KOR**	**LTU**	**LUX**	**LVA**	**MEX**	**MLT**	**NDL**
Domestic CO_2 Production	36.86	266.74	653.50	255.78	9.16	15.29	6.35	287.05	1.52	139.51
Domestic CO_2 Consumption	27.56	285.82	651.48	233.70	12.09	3.17	6.52	302.29	2.12	112.26
Exports	25.12	88.41	149.94	97.87	4.13	14.32	2.53	49.58	0.70	80.06
Imports	15.81	107.50	147.92	75.79	7.06	2.19	2.70	64.82	1.29	52.80
Imports - Exports	-9.31	19.08	-2.02	-22.07	2.93	-12.12	0.17	15.24	0.59	-27.25
(I) or (E)*	**E**	**I**	**E**	**E**	**I**	**E**	**I**	**I**	**I**	**E**
Country	**POL**	**PRT**	**ROM**	**RUS**	**SVK**	**SVN**	**SWE**	**TUR**	**TWN**	**USA**
Domestic CO_2 Production	174.03	37.80	48.86	545.15	22.76	9.28	47.83	151.76	146.18	3419.15
Domestic CO_2 Consumption	186.49	40.14	55.84	449.98	22.76	10.25	38.20	171.47	140.52	3709.57
Exports	37.14	11.67	9.39	153.46	10.39	4.11	31.58	24.86	60.08	332.24
Imports	49.60	14.01	16.37	58.29	10.38	5.08	21.95	44.57	54.42	622.66
Imports - Exports	12.46	2.34	6.98	-95.17	0.00	0.97	-9.63	19.71	-5.66	290.41
(I) or (E)*	**I**	**I**	**I**	**E**	**E**	**I**	**E**	**I**	**E**	**I**

Source: Own elaboration from WIOD database.

Note: * Net Import (I) or Net Export (E) in terms of CO_2 emissions.