Energy Economics 40 (2013) 383–395

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

International trade and emissions: The case of the Minas Gerais state — 2005

Terciane Sabadini Carvalho [a], Flaviane Souza Santiago [a], Fernando Salgueiro Perobelli [b,*]

[a] Department of Economics, Federal University of Minas Gerais, 31270-901, Av. Antônio Carlos, 6627 Belo Horizonte, MG, Brazil
[b] Department of Economics, Federal University of Juiz de Fora, 36036-330, Campus Universitário, Juiz de Fora, MG, Brazil

ARTICLE INFO

Article history:
Received 1 June 2012
Received in revised form 1 July 2013
Accepted 6 July 2013
Available online 24 July 2013

JEL classification:
D57
R15
Q56

Keywords:
Input–output
CO_2 emissions
Key sectors
Trade
Minas Gerais

ABSTRACT

In this paper, we present a hybrid regional input–output model that enables us to compute the intensity measures of CO_2 emissions in the state of Minas Gerais. The analysis uses a 2005 input–output matrix and presents the disaggregated data for 35 sectors. The results suggest that the sectors of Agriculture, Mining, and Metallurgy are key sectors for emissions, and that Petroleum and Alcohol, Nonmetallic Minerals, and Mining are the activities that consume more carbon per US$ million sold. We also analyze the trading partners of the European Union, the United States, China, and Argentina. The findings indicate that they are net importers of the carbon generated by Minas Gerais.

1. Introduction

The reduction of CO_2 emissions is a goal that has gained world-wide consensus as part of the mitigation of global warming. Despite this goal, the overall emissions of greenhouse gases (GHGs) have increased in recent years, especially in developing countries where international trade relations seem to be causing carbon leakages.

The Pollution Haven Hypothesis is an economic system with less environmental regulation. The system experiences a gain in competitiveness in the production of pollution-intensive goods that leads to increased exports to countries with more regulations (Mongelli et al., 2006). In this context, many studies have examined the separation of the responsibility of the producer from the consumer of the carbon embedded into trade (Peters and Hertwich, 2008). Thus, policy makers should consider the environmental implications of trade because without the full cost of externalities, the production of goods with large amounts of embedded CO_2 can occur in regions with weak environmental laws.

International trade causes a geographical separation between consumers and the pollution emitted from the production of many types of goods. If a country or region has a large share of its exports in the production of pollution-intensive goods, then a country might have large economic costs (real or perceived) associated with the participation in mitigation policies for climate change. If countries are insufficiently involved in these policies, then there is a risk that their production will move to nonparticipating countries (Peters and Hertwich, 2008).

According to Machado (2002), except for those impacts caused by the transport of goods, the environmental impacts that might be linked to foreign trade are not intrinsically related to the nature of marketing itself. Rather, they are especially related to the production and consumption of goods and services. In this sense, the final destination of the product (domestic or external) and where the consumption occurs (in the producer country or abroad) do not alter the a priori nature and magnitude of the environmental impact.

A serious limitation in the analysis of environmental impacts is the tendency to deal separately with each sector or industry without the recognition of the importance of intersectoral linkages. Modern agriculture uses large amounts of energy produced commercially and also uses industrial products. The link between energy and industry is changing because there is a strong tendency to less intensive use of energy in industrial production in some countries (WCED, 1987). Thus, an input–output analysis becomes an appropriate tool to investigate the environmental impacts that take into account the links between the various sectors of an economy.

In 2005, total Brazilian exports were US$ 118,529 million. The state of Minas Gerais accounted for 9% of the Brazilian GDP in that year and

* Corresponding author. Tel.: +55 3232371429.
E-mail addresses: tersabadini@gmail.com (T.S. Carvalho), santiago.flaviane@gmail.com (F.S. Santiago), fernando.perobelli@ufjf.edu.br (F.S. Perobelli).

0140-9883/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.eneco.2013.07.002

also figured as the second largest exporter, accounting for 11.4% of the total exports of Brazil.[1] Minas Gerais's exports are similar to Brazilian exports as a whole. The main exportable sectors of Minas Gerais in 2005 were Metallurgy[2] that accounted for more than 32% of the exports, Mining at 22%, and Food products[3] at 6%. The main imports were Petroleum and Alcohol (27.3%), Metallurgy (12.2%), and Automotive vehicles (8.8%). However, the products exported in large amounts from Brazil, such as petroleum and natural gas, sugar cane, and aircrafts, do not have the same importance for Minas Gerais. But the participation of Mining is higher in this state than in Brazil. Minas Gerais has the second largest industrial park in the country[4] with sectors such as Mining, Metallurgy, Automotive vehicles, Food products, Textile, Construction, Chemistry, and Nonmetallic Minerals. Its industrial production and exports increased between 2002 and 2011 more than the national average for that period, with an emphasis on Mining and Iron Ore.[5] Furthermore, the Energy Balance of Minas Gerais is more disaggregated by sector. These data reinforce the importance of analyzing the amount of carbon embedded in the trade structure of the state.

The national energy matrix considers the participation of different energy inputs. Among these inputs, petroleum and its derivatives and natural gas provided the largest share of energy consumption in 2005, representing approximately 42%. The petroleum-derived fuels (especially diesel oil, fuel oil, and gasoline) were used mainly in the sectors of transport and the thermal generation of electricity. In many developed countries, the consumption of fuels in transportation and electricity is balanced, but in Brazil because of the strong participation of hydropower in the energy matrix, the transportation sector is the main consumer of fuel. According to the 2005 National Energy Balance (BEN) (MME, 2006), about 137 million *toe* (tons of oil equivalent) of secondary energy was consumed by the economy, fuel consumption was responsible for 55.7% or 76.4 million *toe* of the total.

In Minas Gerais, the final energy consumption in 2005 reached 25.5 million toe. In that year, this amount was equivalent to 14.7% of the energy consumption in Brazil. Similar to what occurs nationally, the petroleum and its derivatives and natural gas had a higher share of the final consumption of energy in the state, about 40% of the total. The industrial sector had the highest demand for secondary energy, corresponding to 11.19 million toe(55.23%) and the transport sector was second in the state with consumption of 28.6% of the total. In the transport sector, petroleum and its derivatives and natural gas accounted for 89% of the total consumption of nonrenewable resources (CEMIG, 2007).

In this context, this paper intends to make a quantitative comparison of the emissions embodied in the international trade of Minas Gerais with the carbon profile of the state through a hybrid input–output model. The model evaluates the emission intensity from the combustion of fossil fuels in 35 sectors of the state in 2005. Hybrid models allow researchers to consider sectoral emissions of pollutants together with the monetary transactions of input–output with the aim of capturing the interrelationships between the production of goods by sectors and the emissions of pollutants (Hilgemberg, 2004). Thus, an analysis with a hybrid input–output model can compute the measures of intensity inCO_2 emissions, for example, to quantify the additional emissions caused directly and indirectly when the sectors increase their output. Furthermore, while economic and detailed trade data are available, the availability of sectoral CO_2 emission data that are equivalent are often restricted. Thus, to enable the analysis of all of the sectors in the matrix, we make the energy matrix compatible with the input–output matrix (Su et al., 2010).

Specifically, this paper aims to calculate the elasticity of CO_2 emissions in relation to changes in final demand and key sectors. The paper also analyzes the international trade structure to verify whether Minas Gerais is a net exporter of carbon and verifies that the trading partners of the state are considered importers of the carbon intensive products. Further, we analyze the results of international trade from the perspective of the consumers' and the producers' responsibilities. To achieve the proposed objectives, Section 2 presents some evidence from the literature on input–output models with CO_2 emissions that address the topic of international trade. Section 3 presents the equations of the input–output model and some indicators used in its construction. Section 4 describes the database. Section 5 presents and discusses the empirical results of the model and, Section 6 presents the conclusions.

2. Carbon emissions and international trade

The international literature presents many studies, especially in the area of regional economics, about the intensity of CO_2 emissions in economic activities and its incorporation into international trade. The studies by Hawdon and Pearson (1995) and Hetherington (1996) for the United Kingdom, Lenzen (1998) for Australia, and Tarancón Morán and del Río González (2007) for Spain identify emission coefficients for these countries by using an input–output (IO) analysis. Other studies such as Peters and Hertwich (2008), Machado (2002),and Nakano et al. (2009) seek to identify the emission coefficients in trade between different countries.

In this context, Peters and Hertwich (2008) evaluate the CO_2 emissions embedded in international trade in 87 countries and 57 sectors for the year 2001 by using an IO model and the multi-regional database from the Global Trade Analysis Project — GTAP. The main focus of their article is a quantitative comparison of how the emissions embedded in international trade form the environmental profile of a country, and they also discuss the implications for global climate policy. The results show that there are around 53Gt CO_2 embedded in global trade, and that Annex I countries are net importers of carbon.[6] Further, the authors argue the importance of studies in this area because the emissions embedded in trade might have a significant impact on the participation and the effectiveness of global climate policies such as the Kyoto Protocol.

Nakano et al. (2009) examine the incorporation of carbon in trade by using an internationally comparable OECD database (IO, bilateral trade of goods, and CO_2 emissions) for 41 countries comprising 17 industries. Their results suggest that in the mid-1990s and the early 2000s, there were “trade deficits” inCO_2 emissions for 21 OECD countries and the magnitude of this “trade deficit” rose in the late 1990s. While a third part of the overall increase in emissions took place within the non-OECD economies in the late 1990s, more than half of the emissions based on consumption were attributed to the OECD economies. The simulations show that the increase in the intensity of global trade has an increasing impact on the embedded emissions, while the transfer of technology from the low carbon countries to the high carbon countries reduces the global emissions and carbon trading gaps. The results also suggest that the future policy discussions on global GHGs need to consider the interrelationships between countries rather than just set goals for individual countries.

In the Brazilian context, Schaeffer and Sá (1996) study the carbon embedded in imports and exports from 1970 to 1993 and express concern that developed countries were transferring their CO_2 emissions to developing countries through their imports. The work estimates the amount of energy and carbon embedded in exports and imports of non-energy goods by means of an IO model to determine whether

[1] IBGE data — Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*). Available online at: http://www.ibge.gov.br. Last accessed January 31, 2009 and of João Pinheiro Foundation (*Fundação João Pinheiro*). Available online at: http://www.fjp.gov.br. Last accessed January 31, 2009.

[2] In the matrix of 2005, the Steel sector was added to the Metallurgy sector.

[3] In the matrix of 2005, the Coffee sector was added to the Food products sector.

[4] The largest industrial park is located in Sao Paulo.

[5] Data are from the Brazilian Institute of Geography and Statistics (IBGE).

[6] The Annex I countries: Germany, Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Denmark, Slovakia, Slovenia, Spain, the United States, Estonia, Finland, France, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Norway, New Zealand, the Netherlands, Poland, Portugal, the United Kingdom, the Czech Republic, Romania, Russia, Sweden, Switzerland, and the Ukraine.

these carbon-rich products are a problem that is worth being treated in the Brazilian case. Because of the lack of data, the composition used the same goods exported and imported by Brazil to those used for household products in the United States in other studies. The authors calculate the use of energy embedded in imports for the period of 1970 to 1980 and the period 1981 to 1993 by using the USIO matrices for 1967 and 1977 respectively. Thus, the data had to be adjusted based on studies of Brazil's energy. Their estimates show that the carbon content of exports was considerably higher than imports since 1980. In 1990, the difference expressed as a fraction of the total carbon emissions in Brazil was 11.4% or about 8.3 million tons of carbon.

Machado (2002) uses an IO model in hybrid units for the years of 1985, 1990, and 1995 with the objective of evaluating the impacts of trade on energy use and CO_2 emissions. The results show that Brazil is a net exporter of energy and carbon embedded in non-energy products, and that every dollar earned with exports embodies considerably more energy and carbon than each dollar dispensed with imports. The most carbon-intensive sectors were Iron and Steel, Transport, Nonmetallic Minerals, Cellulose and Paper, and Other Metallurgy.

Carvalho and Perobelli (2009) develop a hybrid interregional IO model for São Paulo and the rest of Brazil to quantify the CO_2 emissions associated with the consumption of energy fuels, that is, to analyze the sectors that incorporate carbon in their production, as well as the amount of carbon embedded in exports. The CO_2 emissions considered are caused by energy fuels such as diesel, fuel oil, gasoline, LPG, naphtha, kerosene, city gas, coke, charcoal, ethanol, and other energy sources from oil. The results show that Agriculture, Steel, Food and Beverage, Other Industries, and Transport are highlighted as key sectors in CO_2-emissions in the two regions. Regarding the amount of CO_2embedded in exports, the results indicate that the Brazilian export basket is largely pollution intensive.

3. Methodology

Researchers often use the IO analysis to study the interactions and interdependencies between the sectors of the economy in a region or a country. The degree of interdependence can be assessed by measures known as intersectoral coefficient requirements. These coefficients allow researchers to evaluate, for example, the impact of changes on final demand from one sector in other sectors of the economy.

There are several possible extensions of an IO analysis; among which of particular relevance to this work is the use of an energy sector to study the intensity of CO_2 emitted in Minas Gerais and the identification of carbon embedded in international trade. The approach used in this work is based on building a hybrid IO table. Several authors have used this approach, such as Gowdy and Miller (1987), Hetherington (1996), Hilgemberg (2004), Labandeira and Labeaga (2002), Lenzen (1998), Machado (2002), and Miller and Blair (2009). According to Miller and Blair (2009), the IO model in hybrid units is the most consistent formulation for the application of IO models to environmental questions involving the physical and economic use of energy.

The approach of hybrid units consists of one row and one column for the sector of energy fuels in the IO table. The new line describes in physical units (Gg/1000 toe)[7] the sales in the fuel sector to the other sectors of the economy, and its column describes in monetary units (US$) the total purchases made by the fuel sector. The recalculation of the IO matrix A and the Leontief inverse flows $(I-A)^{-1}$ is necessary because of the new flows in the matrix (Perobelli et al., 2007). Then, we do a necessary calculation of the direct requirements that are the immediate effects of a change in the final demand and the total and indirect requirements that capture the secondary effects of a change in the final demand between sectors. This work shows the dependencies among all sectors (generation of emissions) that are represented by the fuel industry. Appendix A presents the formalization of these indicators.

3.1. Sector impacts and key sectors in CO_2 emissions

This subsection follows the presentation of the concept of elasticity and the method for the identification of key sectors of energy consumption made in Alcántara and Padilla (2003), Carvalho and Perobelli (2009),and Hilgemberg (2004).

To calculate the key sectors with regard to emissions, we construct a matrix of intersectoral emission demands with respect to final consumption. For this matrix, consider Γ a scalar denoting the generation of total emissions by the production system and τ' a row vector of emissions per unit of product sector. From the Leontief model, we can write:

$$\Gamma = \tau' X^* = \tau' (I - A^*)^{-1} Y^* \tag{1}$$

where X^* is a hybrid[8] vector of the total production, $(I - A^*)^{-1}$ is the hybrid inverse Leontief (and A^* is the hybrid IO matrix), and Y^* is the hybrid demand final vector.

If the CO_2 emissions depend on the final demand of the economy, we can write:

$$\Delta\Gamma = \tau' \Delta X^* = \tau' (I - A^*)^{-1} Y^* \gamma \tag{2}$$

where γ is a scalar that represents the proportional increase in final demand.

If s is a vector of final demands for participation of an industry in their respective effective productions, then:

$$s = \left(\widehat{X}^*\right)^{-1} Y^* \ \ or \ \ Y^* = s\widehat{X}^* \tag{3}$$

where $\hat{X}^*$ is a diagonal hybrid vector of the final demand. Substituting Eq. (1) into Eq. (2), we have:

$$\Delta\Gamma = \tau' (I - A^*)^{-1} \widehat{X}^* s\gamma. \tag{4}$$

Dividing by Γ generates:

$$\Gamma^{-1}\Delta\Gamma = \Gamma^{-1}\tau' (I - A^*)^{-1} \widehat{X}^* s\gamma \tag{5}$$

where $\Gamma^{-1}\Delta\Gamma$ shows the overall increase of emissions relative to an increase in the final demand. However, this term does not bring any additional information given the linear nature of the model, then $\Gamma^{-1}\Delta\Gamma = \gamma$. Thus, we need to breakdown the matrix. The first step is to transform Eq. (5). Thus, d' is a vector of the distribution of the final emission between the n productive sectors of the economy such that $\sum_{i=1}^{n} d_i = 1$. Therefore, the vector of the sectoral consumption coefficients, τ',can be written as

$$\tau' = \Gamma d' \left(\widehat{X}^*\right)^{-1}. \tag{6}$$

Substituting Eq. (6) into Eq. (5) generates

$$\Gamma^{-1}\Delta\Gamma = d' \left(\widehat{X}^*\right)^{-1} (I - A^*)^{-1} \widehat{X}^* s\gamma, \tag{7}$$

and considering that

$$(I - D)^{-1} = \left(\widehat{X}^*\right)^{-1} (I - A^*)^{-1} \widehat{X}^*. \tag{8}$$

[7] Each Gigagram (Gg) represents a thousand tons of CO_2. So the unit, Gg/1000 toe, represents the amount of CO_2 (one thousand ton) per one thousand ton of oil equivalent (toe) consumed.

[8] The hybrid vector incorporates a line for the energy sector in physical units.

According to Miller and Blair (2009), when any two matrices P and Q are connected by the relation $P = MQM^{-1}$, they are said to be similar and are expressed by $P \approx Q$. Therefore, the product of the right-hand side of Eq. (8) becomes or can be understood to be the approximate value of the total requirements (direct and indirect) for the production of goods and services in the economy, which are usually obtained from the matrix $(I - A^*)^{-1}$.

Diagonalizing the vector s, we can obtain from Eqs. (7) and (8)

$$\varepsilon' = d'(I{-}D)^{-1}\hat{s}\gamma. \quad (9)$$

That provides a proportional variation of the sectoral emissions in relation to a proportional change in the final demand.

Omitting γ and diagonalizing the vector d', we obtain:

$$\Gamma^y = \hat{d}(I{-}D)^{-1}\hat{s} \quad (10)$$

where τ_{ij}^y is the characteristic element of the matrix Γ^y and expresses the increase in the emissions of sector **i** in response to an increase of US$ 1 million in the final demand in sector **j**. Thus, the sum of the industry **j** column expresses the increase of emissions throughout the economy in response to a change of US$ 1 million in the final demand sector **j**.

If τ_{ij}^y is an element of the matrix Γ^y. Thus, we can define

$$P_{\bullet j} = \sum_{i=1}^{n} \tau_{ij}^y \qquad (i = 1, 2, \ldots, n) \quad (11)$$

and

$$P_{i\bullet} = \sum_{j=1}^{n} \tau_{ij}^y \qquad (j = 1, 2, \ldots, n). \quad (12)$$

Alcántara and Padilla (2003) call the total impact the sum of columns that show the increase in emissions caused by a US$ 1 million increase in the final demand of sector j as given by Eq. (11). And call the distributive impact, the sum of the lines that shows the increase in the emissions of sector i that results from a US$ 1 million increase in the final demand experienced by all sectors of the economy as given by Eq. (12).

The definitions of Γ_T and Γ_D become the median values of the total and the distributive impacts respectively.[9] Alcántara and Padilla (2003) adopt the classification set out in Table 1.

The sectors in quadrant I have their emissions determined, in part, by the demand from other sectors because the distributive impact is greater than the median of the economy. The sectors in quadrant II are the key sectors because they have a total and a distributive effect greater than the median values of the economy, namely, they are induced to emit by increased demand from the other sectors; and at the same time, they push for the emissions from the other sectors by increasing their own demand. The sectors in quadrant III are the least relevant with regard to emissions, and quadrant IV contains the sectors with a high content of emissions.

3.2. Analysis of CO_2 emissions embedded in exports and imports

Considering a closed economy, we can apply a consistency check by the equation $\mathbf{F} = \boldsymbol{\alpha}^* \boldsymbol{y}$ where the vectors of the total carbon intensity coefficients ($\boldsymbol{\alpha}^*$) and of the final demand ($\mathbf{Y}$) are expressed in hybrid units and the vector of the supply/use of the fuel ($\mathbf{F}$) is expressed in physical units. The vector product $\boldsymbol{\alpha}^*\boldsymbol{Y}$ must be equal to the energy product vector (F) that in turn is input data in the hybrid units model.

Table 1
Sectors classification.
Source: Alcántara and Padilla (2003).

	$\sum_i \tau_{ij}^y < \Gamma_T$	$\sum_i \tau_{ij}^y > \Gamma_T$
$\sum_j \tau_{ij}^y > \Gamma_D$	Relevant sectors in terms of demand from other sectors	Key sectors: press the energy consumption and are pressure to consume energy
$\sum_j \tau_{ij}^y < \Gamma_D$	Non-relevant sectors	Relevant sectors from the standpoint of its demand

Once the consistency of the model is verified, we can use these coefficients to estimate the emissions embedded in international trade (Machado, 2002).

The measuring of emissions embedded in exports is needed because the export (E) is one of the total final demand components (Y). In this way, the carbon incorporated in the export can be estimated as follows:

$$F_E = \hat{\alpha}^* E \quad (13)$$

where $\mathbf{F_E}$ corresponds to the carbon embedded in exports, $\boldsymbol{\alpha}^*$ is a vector of the total emission coefficients, and **E** are the exports.

The same is done for the import vector because the analysis aims to determine the net balance of CO_2 in Minas Gerais's international trade. We submit the hypothesis that if imports are produced within the state, there will be carbon leakage to the other countries. Thus, the carbon that is embedded in imports follows:

$$I_E = \hat{\alpha}^* I \quad (14)$$

where I are the imports, and I_E are the emissions embedded in the imports.

4. Database

For the construction of the IO model with hybrid units, we use data from the 2005 IO matrix for Minas Gerais released by the João Pinheiro Foundation (FJP) and by the Energy Balance of Minas Gerais (BEEMG) that is published by CEMIG (2007). The IO matrix has 35 sectors and 55 product groups. From this set, procedures exist to obtain the IO matrix with hybrid units (35 × 35 industries).

The next step is the construction of the hybrid units. This process involves reconciling the information derived from the IO matrix with 35 sectors from FJP and with the BEEMG data. Only 12 sectors have the required data. As the two bases comprise a different number of sectors, a breakdown of the BEEMG data is necessary to establish a similar sector aggregation to that encountered in the IO matrix. The breakdown applied is based on the total production of each sector (assuming that the amount of energy used in each sector is linear to its production) and aims to preserve the information provided by the use of energy and the BEEMG matrix as much as possible.

Next, the coefficients for energy need to be converted into CO_2 emissions caused by fuel consumption[10] by various sectors of the economy. To implement this conversion, the conversion coefficients in the matrix of energy and emissions, which represent the total amount of carbon dioxide, are converted into Gg/1000 toe released into the atmosphere. Table 2 presents these coefficients.[11]

[9] The authors chose to use the median in place of the mean, as the mean is a measure of central tendency indicated in cases where the distribution of values is symmetrical. When an asymmetric distribution such as pollution exists, the median is most suitable as a measure of central tendency.

[10] The CO_2 emissions considered in this article are caused by fossil fuels (natural gas, diesel oil, fuel oil, gasoline, liquefied petroleum gas, kerosene and other derivatives of petroleum). One limitation of this study is that the emissions caused by changes in land use are not considered, which underestimates emissions for agriculture and livestock.

[11] Because data are available for only12 sectors, the same disaggregation procedure is adopted.

Table 2
Conversion coefficients (Gg/1000 toe) of CO_2 consumption.
Source: Energy and Emissions Matrix (Economia and Energia, 2000).

Sectors	Diesel oil	Fuel oil	Gasoline	LPG	Kerosene	Mineral coal	Ethyl alcohol	Other secondary oil
Agriculture and Livestock	3.07	3.21	2.87	2.61	2.98	3.78	2.39	3.07
Mining	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Non-metalic Minerals	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Non-ferrous and Metallurgy	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Cellulose and Paper	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Chemistry	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Food and Beverage	3.07	3.21	2.87	2.61	2.98	3.81	3.03	3.07
Textiles and Clothing	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Other Industries	3.07	3.21	2.87	2.62	2.98	3.93	2.8	3.07
Trade and Services	3.07	3.21	2.87	2.61	2.98	3.81	2.71	3.07
Transport	3.07	3.21	2.87	2.61	2.97	3.95	2.76	3.07
Public Services	3.07	3.21	2.87	2.61	2.98	3.93	2.8	3.07
Energy Sector	3.07	3.21	2.87	2.61	2.98	3.94	3	3.07

The last step is the replacement of the flow lines of the energy sector from monetary units into physical units. This process involves three steps. The first step is the computation of the physical values of the regional carbon flows under the assumption that the amount of energy used is linearly related to production. The second step is to build a ratio of the intersectoral production to the total intermediate consumption that excludes the energy sector and to multiply this share by the total intermediate consumption to balance the matrix without the energy sector line in monetary units. The third step is the allocation between the sectors of the values in the first step of this procedure.[12]

5. Analysis of results and discussion

5.1. Emissions demand and key sectors

The intersectoral demand for emissions provides information in a matrix format in which each element in a column shows the contribution of the direct and indirect effects resulting from a US$ 1 million increase in the final demand of a specific sector. Then the sum of the elements in a column shows the total impact on emissions from all sectors in Minas Gerais because of a US$ 1 million increase in the final demand of a sector. Similarly, the sum of each row represents the distributive impact, that is, the emission that could be generated in an industry if the final demand of the other sectors grows by US$ 1 million.

The results show that the sectors with the greatest impact are those that push the total emissions from other sectors above the economy's median because of an increase of US$ 1 million in its own final demand. In Minas Gerais, the median is 0.032G g/1000 toe additional carbon in response to increased demand. The major distributive impact occurs when activities emit CO_2 up to 0.019 Gg/1000 toe of carbon in response to the additional US$ 1 million in the final demand from all sectors. Thus, the key sectors are those with full and distributive impacts above the median.

Fig. 1 shows the specifications for the key sectors. Quadrant II contains these sectors: Agriculture, Livestock and Fisheries, Mining, Food products, Cellulose and Paper, Petroleum and Alcohol, Chemistry; Nonmetallic Minerals, Metallurgy, Automotive vehicles, Construction, and Transports. Quadrant I contains the sectors that have emissions determined in part by demand from other sectors. Quadrant III has the sectors less relevant with regard to emissions. And quadrant IV shows the sectors that have a high content of emissions.

In Fig. 2, Petroleum and Alcohol, and Transports have the greatest distributive impact. This impact is an expected result because in general the first is the largest producer of fossil fuels and the second uses fossil fuels as a basic input. Food products, Mining, Metallurgy, Automotive Vehicles, and Construction have greater overall impact that discloses that the increase in their individual demand pushes the emissions from other sectors.

5.2. Analysis of carbon content in international trade in Minas Gerais

An important question to consider when analyzing the emissions of a region is how to account for CO_2 emissions in open economies in relation to international trade. Munksgaard and Pedersen (2001) discuss the production and consumer accounting principle in their work. According to the production accounting principle the producer is responsible for the CO_2 emissions from the energy, goods, and services. This responsibility means that the CO_2 emissions are all located in the processes actually emitting CO_2 into the atmosphere. The production principle does not distinguish between export and domestic consumption. According to the consumer principle, the consumer is responsible for CO_2 emissions from the production of energy, goods, and services. In this case, the CO_2 emissions are related to the final use of the goods and services even if they are imported from others countries (Munksgaardand Pedersen, 2001).

The emission intensity present in the export structure is based on the exported volume and is calculated according to formula (13). According to the information in the 2005 IO matrix, the largest exporters of the state were the sectors of Metallurgy, Mining, Agriculture, Food products, and Automotive vehicles. The largest importers were Petroleum and Alcohol, Metallurgy, Chemistry, and Automotive vehicles. Fig. 3 presents the group of sectors with greater participation in the trade of Minas Gerais.

A calculation of the carbon content in Minas Gerais's international trade in the various sectors discloses that Nonmetallic minerals, Mining, Rubber and Plastic, Leather goods and Footwear, Livestock and Fishery, and Food products are the activities that have the highest amount of carbon incorporated per million US$ sold.[13] Table 3 presents the carbon coefficients in the sectors involved in international trade.

Table 3 shows that the sectors that have carbon content above the median of 0.1768 Gg/1000 toe are Nonmetallic minerals, Mining, Rubber and Plastic, Leather goods and Footwear, Livestock and Fishery, Food products, Textiles, Clothing and Accessories, and Paper, Petroleum and Alcohol, Pharmaceuticals, Hygiene and Cleaning, and Chemistry. From the perspective of the production accounting principle, Food products and Mining suggest that the production sector of Minas Gerais's trade structure has high carbon content. Moreover, Fig. 3 shows that seven of the sectors in the state that trade the most are listed as key sectors: Agriculture, Mining, Food products, Cellulose and Paper, Chemistry, Metallurgy, and Automotive vehicles. These sectors indicate that Minas Gerais's trade is intensive in emissions.

12 For the analysis of international trade the data are also collected from the SECEX data.

13 The average exchange rate in 2005 was 2.44 reais (R$) to the US dollar.

	Total impact smaller than the median	Total impact greater than the median
Distributive impact greater than the median	1) Textile Products; 2)Leather goods and footwear; 3) Clothing and accessories; 4) Rubber and plastic; e 5) Electricity, gas, water and urban sanitation.	1) Agriculture, forestry and logging; 2) Livestock and fishing; 3) Mining; 4) Food Products; 5) Cellulose and paper; 6) Petroleum derivatives and alcohol; 7) Chemistry; 8)Non-metallic minerals; 9) Metallurgy; 10) Automotive vehicles; 11) Building e 12) Transport; storage and mailing.
Distributive impact smaller than the median	1) Beverage products; 2) Tobacco products; 3) Pharmaceuticals, perfumery, hygiene and cleaning; 4) Metal (except machinery and equipment); 5) Machinery and Equipment; 6) Parts and accessories for vehicles; 7) Other transport equipment; 8) Furniture, wood and sundries; 9) Information services; 10) Financial intermediation and insurance; 11) Real estate and rental; 12) Accommodation and food services; e 13) Business services.	1) Eletrical materials, appliances and equipment; 2) Trade; 3) Education and health market; 4) Public administration; e 5) Other services.

Fig. 1. Sectors classification of Minas Gerais according to the results for 2005 based on Table 1.
Source: Elaborated by the authors based on the research results.

5.3. Emission intensity in the trade structure

According to the data from *Secretaria de Comercio Exterior* (Secretary of Foreign Trade— SECEX), in 2005 the main trading partner of Minas Gerais was the European Union with a total of 29% of exports and almost 18% of imports from the region. The second largest was the United States with 18% of exports and 18% of imports, followed by China with 11% and 5% and Argentina with 7% and 9%. The rest of the world amounted to 36% of the exports and 49% of the imports. The analysis in this subsection seeks to identify the most tradable sectors that have a high carbon content and what the net result of international trade is in relation to CO_2 emissions.

Table 4 presents the amount of carbon incorporated into trade between Minas Gerais and the European Union. According to the data, the sectors that export the most are Agriculture, Metallurgy, Mining, Food products, and Chemistry, which also has the highest total amount of carbon embedded. Among these, Mining, Food products, and Chemistry have a median of carbon per million US$ above the median of the economy. Imported activities with more carbon incorporated are Automotive vehicles; Chemistry; Petroleum and Alcohol; Electrical machinery, equipment and supplies; and Mining. Automotive vehicles and Electrical machinery, equipment and supplies are the only activities that have a median carbon per million US$ below the regional median. Accounting for the net result of trade related to the embedded carbon, Minas Gerais in 2005 was a net exporter of carbon by selling products that embedded about 431.29 Gg/1000 toe of carbon more than bought.

Trade between Minas Gerais and the United States, according to Table 5, shows Mining, Agriculture, Metallurgy, Chemistry, and

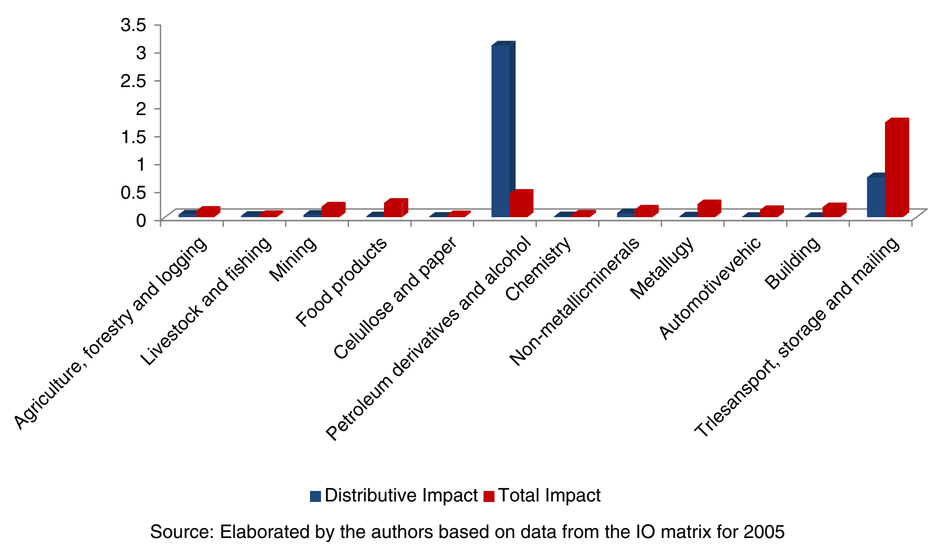

Fig. 2. Total and distributive impacts for the sectors located in Minas Gerais in 2005.
Source: Elaborated by the authors based on the research results.

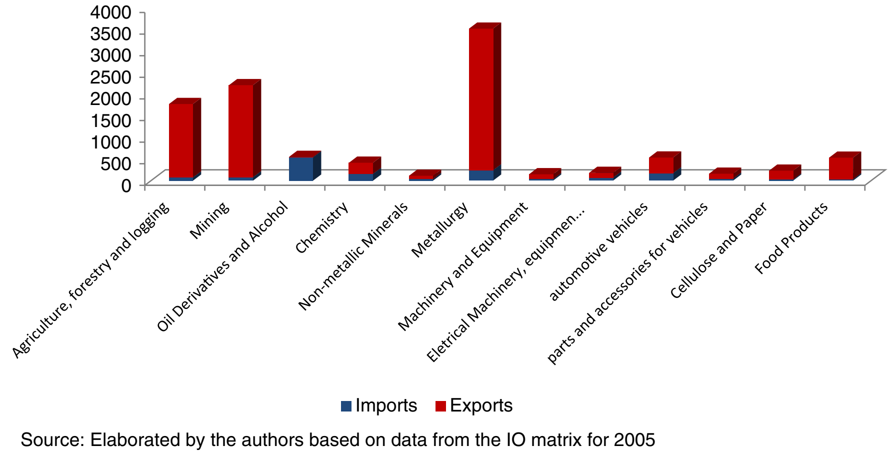

Fig. 3. Exports and imports (in millions of US$) in 2005.
Source: Elaborated by the authors based on data from the IO matrix for 2005.

Nonmetallic minerals as those responsible for the majority of exports and higher carbon content. Among the five sectors, only Agriculture and Metallurgy have a median carbon per million US$ below the median of the economy. The net result is a leak of carbon to the United States of 7.41 Gg/1000 toe carbon, which is well below what occurs with the EU.

Table 6 shows the emission intensity arising from the trade between China and Minas Gerais. Of the five sectors that export the most to China, four have the highest carbon content in total: Metallurgy, Agriculture, Mining and Leather goods and footwear. The latter two are on the list of sectors with higher carbon content per million US$ traded. The most carbon embedded sectors for imports are Petroleum and Alcohol, Mining, Chemistry, and Metallurgy. Petroleum and alcohol is the sector that has the highest carbon content (1.92 Gg/1000 toe/million US$). The result is net exports of 149.93 Gg/1000 toe carbon to China.

Table 7 presents the data on the carbon content of the trade between Minas Gerais and Argentina. The sectors that export the most to Argentina are: Automotive vehicles; Mining; Cellulose and Paper; Metallurgy; and Electrical machinery, equipment and supplies; and of these, only the latter is not on the list of activities with the highest total carbon content. Of those, Cellulose and Paper, Mining, and Chemistry have embedded carbon per US$ 1 million above the median. Concerning imports, the five sectors with the most imports and higher carbon content are Automotive vehicles, Agriculture, Food products, Parts and accessories for vehicles, and Livestock and Fishery. The result is that Minas Gerais is a net exporter of carbon to Argentina with 69.61 Gg/1000 toe.

Regarding other countries, Table 8 shows the sectors that export the most from Minas Gerais: Metallurgy, Mining, Food products, Agriculture, and Cellulose and Paper. Those sectors are also responsible for most of the carbon embedded into the total. In imports, the sectors that stand out most are Petroleum and Alcohol, Metallurgy, Mining, Chemistry, and Automotive vehicles. The net result is a deficit of 49.90 Gg/1000 toe for Minas Gerais because it imports more carbon.

The final balance is that Minas Gerais is a net exporter of carbon, with a surplus of 608.34 Gg/1000 toe. Of this total, the EU and China are the main consumers. And this positive net export indicates that Minas Gerais production causes more CO_2 emissions as compared to consumption of its imported goods.

The government believes that Brazil, as a developing country, should not take disproportionate responsibility for the increased concentrations of GHGs in the atmosphere, according to the principle of "common but differentiated responsibilities." The Manufactured Industrial goods are responsible for much of the trade in Minas Gerais. These goods are almost all internationally tradable and increase the internal cost of reducing carbon embedded in those sectors, which implies a loss of competitiveness and the risk for the substitution of domestic production by imports (MDIC, 2012). The competitiveness reduction could also provoke a decrease in the Brazilian industrial production of exports. Therefore, industrial export production probably would be replaced by purchases from other countries. Besides being highly undesirable for a developing country, this effect does not guarantee the net reduction of CO_2 emissions because the product that is subject to similar technical characteristics anywhere in the world replaces the local reduction of emissions by expanding the GHGs in another region. This effect is called carbon leakage.

Furthermore, the high intensity of GHGs in some sectors is largely the intrinsic characteristics of the large-scale consumption of fuels fossils (particularly in the generation of heat). There are opportunities for incremental gains; but for the foreseeable future, the development of alternative technologies capable of producing industrial products without a large amount of GHGs will be very difficult.

Thus, even Brazil has various sectoral mitigation targets, Minas Gerais and the sectors that stand out in terms of carbon content in international trade, such as Mining and Metallurgy, are not much affected by the inability to develop alternative technologies in the short run. Still, many other industrial sectors, such as Transports, Cellulose and Paper, Agriculture, and Food are within the emission reduction plan coupled with the goal of maintaining their competitiveness.

Table 3
Carbon embedded (in Gg/1000 toe) per million of US$ sold in 2005.
Source: Elaborated by the authors based on the research results.

Sectors	Carbon embedded/ million of US$	Sectors	Carbon embedded/ million of US$
Agriculture	0.1731	Rubber and Plastic	0.2266
Livestock and Fishery	0.2169	Chemistry	0.1805
Mining	0.2811	Nonmetallic Minerals	0.9136
Food Products	0.2093	Metallurgy	0.1703
Beverage Products	0.1692	Metal — except Machinery and Equipment	0.1314
Tobacco Products	0.1485	Machinery and Equipment	0.1375
Textile	0.2004	Electrical Materials, Appliances and Equipments	0.1373
Leather Goods and Footwear	0.2203	Automotive Vehicles	0.1386
Clothing and Accessories	0.1823	Parts and Accessories for Vehicles	0.1346
Cellulose and Paper	0.2028	Other Transport Equipment	0.1058
Petroleum and Alcohol	1.9190	Furniture	0.1050
Pharmaceuticals, Hygiene and Cleaning	0.2051		

Table 4
Emission intensity in the trade structure between Minas Gerais and EU in 2005.
Source: Elaborated based on the SECEX database and the research results.

Sectors	Exports (in millions of US$)	Total Embedded Carbon	Sectors	Imports (in millions of US$)	Total Embedded Carbon	Balance
Agriculture	1026.96	177.79	Agriculture	5.49	0.95	176.84
Livestock and Fishery	0.95	0.21	Livestock and Fishery	2.43	0.53	−0.32
Mining	306.71	86.23	Mining	23.26	6.54	79.69
Food Products	133.78	28.00	Food Products	4.21	0.88	27.11
Beverage Products	0.07	0.01	Beverage Products	1.44	0.24	−0.23
Tobacco Products	0.01	0.00	Tobacco Products	0.00	0.00	0.00
Textile	3.75	0.75	Textile	1.16	0.23	0.52
Leather goods and footwear	5.51	1.21	Leather goods and footwear	0.60	0.13	1.08
Clothing and accessories	0.57	0.10	Clothing and accessories	0.83	0.15	−0.05
Celullose and Paper	22.02	4.47	Celullose and Paper	9.10	1.84	2.62
Petroleum and Alcohol	4.39	8.42	Petroleum and Alcohol	33.67	64.61	−56.19
Pharmaceuticals, hygiene and cleaning	0.36	0.07	Pharmaceuticals, hygiene and cleaning	2.94	0.60	−0.53
Rubber and Paper	1.24	0.28	Rubber and Paper	15.82	3.59	−3.30
Chemistry	104.58	18.87	Chemistry	43.27	7.81	11.06
Nonmetallic Minerals	17.39	15.89	Nonmetallic Minerals	4.08	3.72	12.17
Metallurgy	1072.88	182.69	Metallurgy	4.27	0.73	181.96
Metal - except machinery and equipment	1.51	0.20	Metal - except machinery and equipment	17.69	2.32	−2.13
Machinery and Equipment	28.18	3.88	Machinery and Equipment	17.40	2.39	1.48
Eletrical Machinery, equipment and supplies	12.46	1.71	Eletrical Machinery, equipment and supplies	27.80	3.82	−2.11
Automotive vehicles	69.36	9.61	Automotive vehicles	50.98	7.06	2.55
Parts and accessories for vehicles	10.62	1.43	Parts and accessories for vehicles	16.47	2.22	−0.79
Other transport equipment	0.15	0.02	Other transport equipment	2.60	0.27	−0.26
Furniture	8.74	0.92	Furniture	7.72	0.81	0.11
Total	2832.20	542.76	Total	293.23	111.46	431.29

The results cannot say whether carbon is leaked to Brazil, and more specifically, to the state of Minas Gerais. For example, we cannot affirm if the European Union, which has 15 countries that are part of the Kyoto Protocol agreement, or even the United States, is reducing their production of carbon-intensive products to meet their goals of emissions. Meanwhile, they continue to buy these products from countries that are not part of the agreement. For this affirmation, we need to analyze the historical data on EU and US trade and analyze the changes in their imports over time. Still, the European Union, among its responses to climate change, has an official list of sectors that are exposed to significant risks of carbon leakage called the EU Emissions Trading System (EU ETS). This list covers five years and works on the 'cap and trade' principle. The overall volume of GHGs that can be emitted each year by the power plants, factories, and other companies covered by the system is subject to a cap set at the EU level. Within this Europe-wide cap, companies receive or buy emission allowances that they can trade if they wish. The allowances given to the manufacturing industry for free are distributed to companies on the basis of harmonized rules. These rules ensure that installations of a given type are treated equally across the European Union. Underpinning these rules are ambitious benchmarks of emission performance that have been drawn up in consultation with industry. By rewarding the most efficient installations, the benchmarks strengthen the incentive for businesses to reduce their emissions (EU, 2012).

The European Council that met in Brussels on March 13 and 14, 2008, recognized that in the global context of competitive markets, the risk of carbon leakage is a concern that needs to be analyzed and addressed urgently in the new Emissions Trading System Directive. An international agreement remains the best way of addressing this issue (EU, 2008). As in the European Union, the United States conducted in 2009 a study to analyze the most vulnerable sectors to possible emission reductions that could lead to a loss of competitiveness and carbon leakage. This study points to the industries of Chemistry, Non-metallic Minerals, and Mining as the most vulnerable. Although these sectors account for only a small part of the total industrial production in the United States, they are responsible for almost half of the total of GHGs. The American Clean Energy and Security Act of 2009 (ACES) establishes a variant emission trading plan similar to the European Union Emission Trading Scheme. The models predict that the vast majority of emission reductions achieved by these industries will be from reductions in the emission-intensity of their production (e.g., increased energy efficiency, or shifts to lower emission production methods), rather than from declines in production associated with increased imports from unregulated countries. Thus, this policy prevents carbon leakage through the export of these products to developing countries with lower environmental regulations.

But if a reduction in the demand occurs for the sectors of Mining, Food, Chemistry, and Metallurgy in Minas Gerais because of mitigation policies in the European Union or the United States, the reduction will represent an economic loss to the state because the participation of the European Union and the United States in Minas Gerais's total exports of these sectors represents 40%, 29%, 71% and 36% respectively. However, so that does not happen, and in accordance with the "common but differentiated responsibility", Minas Gerais needs to actually follow the plan for a path of low-carbon development in its industry according to the goals set by the Sectoral Plan for Reducing Emissions of Industry (Industry Plan).[14]

[14] The Sectoral Plan for Reducing Emissions of Industry (Industry Plan) represents a commitment of the Brazilian society, the public and private sector, to promote a path of low-carbon development. The purpose of the Plan is to prepare the domestic industry for the new scenario on that productivity-carbon, equivalent to emission intensity of greenhouse gas emissions per unit of output is as important as labor productivity and other factors to determine the international competitiveness of the economy. For that, it is necessary to establish management systems emissions of greenhouse gases from industrial activity as a tool for improving competitiveness, in a process similar to what happened with the implementation of environmental management systems in the past.

Table 5
Emission intensity in the trade structure between Minas Gerais and US in 2005.
Source: Elaborated based on the SECEX database and research results.

Sectors	Exports (in millions of US$)	Total Embedded Carbon	Sectors	Imports (in millions of US$)	Total Embedded Carbon	Balance
Agriculture	240.07	41.56	Agriculture	1.56	0.27	41.29
Livestock and Fishery	0.10	0.02	Livestock and Fishery	2.82	0.61	−0.59
Mining	559.27	157.23	Mining	6.01	1.69	155.54
Food Products	10.95	2.29	Food Products	1.37	0.29	2.01
Beverage Products	0.02	0.00	Beverage Products	0.00	0.00	0.00
Tobacco Products	0.05	0.01	Tobacco Products	0.00	0.00	0.01
Textile	35.12	7.04	Textile	0.96	0.19	6.84
Leather goods and footwear	1.52	0.33	Leather goods and footwear	0.35	0.08	0.26
Clothing and accessories	1.02	0.19	Clothing and accessories	0.86	0.16	0.03
Celullose and Paper	3.87	0.78	Celullose and Paper	3.32	0.67	0.11
Petroleum and Alcohol	1.06	2.03	Petroleum and Alcohol	135.45	259.93	−257.90
Pharmaceutical, hygiene and cleaning	0.26	0.05	Pharmaceutical, hygiene and cleaning	1.47	0.30	−0.25
Rubber and Paper	1.08	0.24	Rubber and Paper	4.47	1.01	−0.77
Chemistry	80.24	14.48	Chemistry	64.82	11.70	2.78
Nonmetallic Minerals	43.54	39.78	Nonmetallic Minerals	3.77	3.45	36.33
Metallurgy	95.65	16.29	Metallurgy	1.62	0.28	16.01
Metal - except machinery and equipment	0.45	0.06	Metal - except machinery and equipment	2.61	0.34	−0.28
Machinery and Equipment	29.40	4.04	Machinery and Equipment	6.84	0.94	3.10
Eletrical Machinery, equipment and supplies	32.38	4.44	Eletrical Machinery, equipment and supplies	9.55	1.31	3.13
Automotive vehicles	29.27	4.06	Automotive vehicles	38.13	5.28	−1.23
Parts and accessories for vehicles	12.77	1.72	Parts and accessories for vehicles	1.05	0.14	1.58
Other transport equipment	0.12	0.01	Other transport equipment	3.81	0.40	−0.39
Furniture	2.29	0.24	Furniture	4.24	0.45	−0.20
Total	1180.50	296.91	Total	295.09	289.50	7.41

6. Final considerations

This article seeks to analyze the intensity and the embedded nature of carbon dioxide emissions in the international trade of Minas Gerais in 2005. The model uses 35 sectors in Minas Gerais in a hybrid regional IO table. In the table, sales information from the energy sector to other sectors is recorded as physical units of emissions (Gg/1000 toe), which follows similar approaches in the literature. To achieve the goals of the study, we estimate the elasticity of emissions because of changes in final demand to find the key sectors (those who are pushed by and push emissions) and also analyze the carbon content of international trade.

The results show that some of the key sectors such as Mining, Food products, Cellulose and Paper, Chemistry, and Automotive vehicles are also those with greater embedded carbon for every US$ million traded, which suggests that the main trade activities in the

Table 6
Emission intensity of the trade structure between Minas Gerais and China in 2005.
Source: Elaborated based on the SECEX database and research results.

Sectors	Exports (in millions of US$)	Total Embedded Carbon	Sectors	Imports (in millions of US$)	Total Embedded Carbon	Balance
Agriculture	108.97	18.86	Agriculture	1.74	0.30	18.56
Livestock and Fishery	0.07	0.02	Livestock and Fishery	0.00	0.00	0.02
Mining	127.98	35.98	Mining	5.80	1.63	34.35
Food Products	0.13	0.03	Food Products	0.49	0.10	−0.07
Beverage Products	0.00	0.00	Beverage Products	0.00	0.00	0.00
Tobacco Products	0.00	0.00	Tobacco Products	0.00	0.00	0.00
Textile	0.31	0.06	Textile	1.14	0.23	−0.17
Leather goods and footwear	5.35	1.18	Leather goods and footwear	3.45	0.76	0.42
Clothing and accessories	0.00	0.00	Clothing and accessories	0.89	0.16	−0.16
Celullose and Paper	0.03	0.01	Celullose and Paper	0.10	0.02	−0.02
Petroleum and Alcohol	0.00	0.00	Petroleum and Alcohol	44.59	85.56	−85.56
Pharmaceuticals, hygiene and cleaning	0.05	0.01	Pharmaceuticals, hygiene and cleaning	0.03	0.01	0.00
Rubber and Paper	0.18	0.04	Rubber and Paper	1.06	0.24	−0.20
Chemistry	4.36	0.79	Chemistry	9.12	1.65	−0.86
Nonmetallic Minerals	2.04	1.86	Nonmetallic Minerals	2.81	2.57	−0.71
Metallurgy	1089.35	185.49	Metallurgy	7.91	1.35	184.15
Metal - except machinery and equipment	3.12	0.41	Metal - except machinery and equipment	1.86	0.24	0.17
Machinery and Equipment	1.32	0.18	Machinery and Equipment	2.33	0.32	−0.14
Eletrical Machinery, equipment and supplies	6.88	0.94	Eletrical Machinery, equipment and supplies	7.45	1.02	−0.08
Automotive vehicles	0.00	0.00	Automotive vehicles	0.04	0.00	0.00
Parts and accessories for vehicles	1.94	0.26	Parts and accessories for vehicles	0.99	0.13	0.13
Other transport equipment	0.00	0.00	Other transport equipment	0.01	0.00	0.00
Furniture	2.92	0.31	Furniture	1.92	0.20	0.11
Total	1355.03	246.43	Total	93.72	96.51	149.93

Table 7
Emission intensity of the trade structure between Minas Gerais and Argentina in 2005.
Source: Elaborated based on the SECEX database and research results.

Sectors	Exports (in millions of US$)	Total Embedded Carbon	Sectors	Imports (in millions of US$)	Total Embedded Carbon	Balance
Agriculture	16.09	2.78	Agriculture	32.58	5.64	−2.86
Livestock and Fishery	0.01	0.00	Livestock and Fishery	5.72	1.24	−1.24
Mining	84.85	23.86	Mining	3.11	0.88	22.98
Food Products	8.93	1.87	Food Products	19.23	4.02	−2.16
Beverage Products	0.00	0.00	Beverage Products	0.00	0.00	0.00
Tobacco Products	0.00	0.00	Tobacco Products	0.00	0.00	0.00
Textile	12.68	2.54	Textile	1.28	0.26	2.28
Leather goods and footwear	1.29	0.29	Leather goods and footwear	0.00	0.00	0.29
Clothing and accessories	0.38	0.07	Clothing and accessories	0.00	0.00	0.07
Celullose and Paper	57.66	11.69	Celullose and Paper	1.86	0.38	11.32
Petroleum and Alcohol	0.35	0.67	Petroleum and Alcohol	0.42	0.81	−0.13
Pharmaceuticals, hygiene and cleaning	0.04	0.01	Pharmaceuticals, hygiene and cleaning	0.23	0.05	−0.04
Rubber and Paper	6.66	1.51	Rubber and Paper	3.28	0.74	0.77
Chemistry	17.13	3.09	Chemistry	5.11	0.92	2.17
Nonmetallic Minerals	1.03	0.94	Nonmetallic Minerals	0.41	0.38	0.57
Metallurgy	35.24	6.00	Metallurgy	0.00	0.00	6.00
Metal - except machinery and equipment	15.27	2.01	Metal - except machinery and equipment	3.58	0.47	1.54
Machinery and Equipment	18.28	2.51	Machinery and Equipment	2.41	0.33	2.18
Eletrical Machinery, equipment and supplies	16.00	2.20	Eletrical Machinery, equipment and supplies	1.05	0.14	2.05
Automotive vehicles	237.21	32.87	Automotive vehicles	54.15	7.50	25.37
Parts and accessories for vehicles	4.40	0.59	Parts and accessories for vehicles	13.83	1.86	−1.27
Other transport equipment	0.10	0.01	Other transport equipment	0.00	0.00	0.01
Furniture	0.13	0.01	Furniture	2.80	0.29	−0.28
Total	533.73	95.53	Total	151.05	25.92	69.61

Table 8
Emission intensity of the trade structure between Minas Gerais the rest of the world in 2005.
Source: Elaborated based on the SECEX database and research results.

Sectors	Exports (in millions of US$)	Total Embedded Carbon	Sectors	Imports (in millions of US$)	Total Embedded Carbon	Balance
Agriculture	306.54	53.07	Agriculture	33.78	5.85	47.22
Livestock and Fishery	3.61	0.78	Livestock and Fishery	4.96	1.08	−0.29
Mining	1052.09	295.78	Mining	41.18	11.58	284.20
Food Products	346.21	72.45	Food Products	6.97	1.46	70.99
Beverage Products	0.22	0.04	Beverage Products	2.73	0.46	−0.43
Tobacco Products	0.06	0.01	Tobacco Products	0.00	0.00	0.01
Textile	17.18	3.44	Textile	13.38	2.68	0.76
Leather goods and footwear	7.16	1.58	Leather goods and footwear	1.60	0.35	1.22
Clothing and accessories	1.39	0.25	Clothing and accessories	2.45	0.45	−0.19
Celullose and Paper	123.62	25.07	Celullose and Paper	10.01	2.03	23.04
Petroleum and Alcohol	5.14	9.86	Petroleum and Alcohol	325.27	624.18	−614.32
Pharmaceuticals, hygiene and cleaning	1.73	0.35	Pharmaceuticals, hygiene and cleaning	8.12	1.67	−1.31
Rubber and Paper	4.26	0.96	Rubber and Paper	7.93	1.80	−0.83
Chemistry	51.05	9.21	Chemistry	35.89	6.48	2.74
Nonmetallic Minerals	11.48	10.48	Nonmetallic Minerals	27.16	24.81	−14.33
Metallurgy	984.52	167.64	Metallurgy	226.61	38.59	129.06
Metal - except machinery and equipment	44.73	5.88	Metal - except machinery and equipment	6.72	0.88	4.99
Machinery and Equipment	37.06	5.10	Machinery and Equipment	5.02	0.69	4.41
Eletrical Machinery, equipment and supplies	43.97	6.04	Eletrical Machinery, equipment and supplies	22.79	3.13	2.91
Automotive vehicles	26.07	3.61	Automotive vehicles	29.71	4.12	−0.51
Parts and accessories for vehicles	86.06	11.58	Parts and accessories for vehicles	12.54	1.69	9.90
Other transport equipment	0.07	0.01	Other transport equipment	0.00	0.00	0.01
Furniture	8.14	0.86	Furniture	0.06	0.01	0.85
Total	3162.33	684.06	Total	824.87	733.96	−49.90

state are carbon intensive. Furthermore, based on the discussion of the responsibility of the consumer, we observe that the major trading partners of Minas Gerais are net importers of these carbon intensive sectors.

The United States is the only country with a small net result. However, what trade exists between the United States and Minas Gerais is with high carbon content sectors such as Petroleum and Alcohol, Mining, and Non-metallic minerals. Therefore, in general, all countries import more carbon intensive activities than export. But these results do not affirm if any carbon leakage is directed at Minas Gerais. Our conclusion is that the most appropriate way of dealing with the problem of carbon leakage is continuing negotiations and international agreements that establish goals for reducing CO_2 emissions in both developed and developing countries.

In the short term, according to the assumptions in this paper, there is evidence of a trade-off between emission restrictions and the activity's level because the only way to reduce the amount of CO_2 in the economy is to restrict the production in those sectors. This paper avers that the emissions depend on the interrelations between the various productive activities. Thus, its methodology provides relevant information to support management and policy formulation regarding the best strategy for controlling emissions in Minas Gerais.

Brazil announced in 2007 the National Plan on Climate Change. The mitigation technologies and practices by sector, based on IPCC (2007), are considered the most relevant to Brazilian conditions. In the energy sector, improved efficiency of the energy supply and distribution was discussed: switching from carbon-intensive fuels to those with lower carbon content, renewable sources, and carbon capture and storage. In the transport sector, the plan calls for the use of efficient vehicles, rail systems, public transportation, and the design of the transport system. In the industrial sector, measures such as the use of efficient equipment, adopting recycling practices and replacement of materials, control of greenhouse gas emissions, carbon capture, and storage were examined (PNMC, 2008).

Minas Gerais is part of that plan and already has the following initiatives: implementing the Program of Technology Development of Biodiesel Production, SOLDIESEL, and the proposal for the Innovation Centre for Bioenergy, *Bioerg*, both of which aim to increase the competitiveness of the state in bioenergy.

Appendix A

Formalization of the regional input–output model with an emission sector.

We use the regional IO model from Miller and Blair (2009) to represent the interactions between the various sectors of an economy. The model's main function is to assess the sectoral production requirements necessary to meet the final demand for goods and services of a given sector structure. The representation of intersectoral relations is done as follows:

$$X = (I - A)^{-1} Y. \tag{A.1}$$

An extension of the IO model is the emission analysis that determines the total emissions generated to deliver a product to final demand, the direct emissions generated by the production process, and the indirect emissions embedded in the input industry.

In IO models with embedded emissions, we work with a set of matrices similar to the traditional model (Eq. 1): a transaction matrix in emissions or a flow matrix, a matrix of CO_2 direct generation, and a matrix of total generation of CO_2. With only a small change in the representation of the intersectoral transactions in the conventional IO system, we can build these IO matrices.

The approach using hybrid units incorporates one row and one column for the energy fuel sector in the IO table. The new line describes in physical units (Gg/1000 toe) the sales of the fuel sector compared to other sectors of the economy. The column describes in monetary units ($) the total purchases made by the fuel sector. After this merger, a new calculation of the Leontief inverse is necessary because of the new line in physical units.

To begin we need to build an emission-flow matrix in physical units considering an economy with (nxk) sectors where k represents the fuel sectors. Thus, the emission-flow vector E has the dimension $kx(nxk)$. Assuming that the emissions consumed by the final demand (in physical units) are given by E_y and the total emission consumption is determined by F (E_y and $F$are column vectors with k elements) the emission flow can be represented as:

$$E_i + E_y = F \tag{A.2}$$

where i is a column vector $(nx1)$ whose elements number one. This equation shows that the total emissions consumed (and produced) in the economy are given by the sum of the consumed emissions by sector (described in the line of E) plus the emissions consumed by the final demand.

From the matrix E, the intersectoral transaction matrix in hybrid units can be constructed. To do this, we substitute into the intersectoral transactions matrix the lines representing the emission flows in monetary units with the lines that represent the emission flows in physical units (Gg/1000 toe). We also set the corresponding total output, X^*, and the final demand, Y^*, so that the vectors for the fuel sector and the other sectors are similarly measured in physical and monetary units respectively.

Considering a regional model for Minas Gerais with n sectors of activity plus a fuel sector, we have schematically an IO table in monetary values and one emission vector:

$$\underset{nxn}{Z} = \begin{bmatrix} \$ & \$ \\ \vdots & \vdots \\ \$ & \$ \end{bmatrix} \tag{A.3}$$

and

$$\underset{1xn}{E} = [Gg/toe \quad \cdots \quad Gg/toe]. \tag{A.4}$$

Now, the new IO table is Z^* in which the flows of fuel sales are measured in physical units and the other flows in monetary units (Hilgemberg, 2004):

$$\underset{(n+1)\times(n+1)}{Z} = \begin{bmatrix} \$ & \$ & \cdots & \$ \\ \vdots & \vdots & \cdots & \vdots \\ \$ & \$ & \cdots & \$ \\ Gg/toe & \cdots & \cdots & Gg/toe \end{bmatrix}. \tag{A.5}$$

Adopting the same procedure for the total output (X) and final demand (Y) by sector, it is possible to obtain the following vectors:

$$X^* = \begin{bmatrix} \$ \\ \vdots \\ \$ \\ Gg/toe \end{bmatrix} \tag{A.6}$$

and

$$Y^* = \begin{bmatrix} \$ \\ \vdots \\ \$ \\ Gg/tep \end{bmatrix}. \tag{A.7}$$

Defining $\widehat{X} = diag(X^*)$, the possibility exists to construct a hybrid matrix of direct requirement coefficients as:

$$A^* = Z^* \left(\widehat{X}^*\right). \tag{A.8}$$

Each element of A^* corresponds to the proportion of inputs in the sector *i* needed for \$1.00 of production in the sector *j*. Thus, the elements of A^* are called direct requirement coefficients.

In matrix form, we have:

$$A^* = \begin{bmatrix} \frac{\$}{\$} & \cdots & \frac{\$}{Gg/toe} \\ \vdots & \ddots & \vdots \\ \frac{Gg/toe}{\$} & \cdots & \frac{Gg/toe}{Gg/toe} \end{bmatrix}. \tag{A.9}$$

The IO model in hybrid units can be defined similarly to the expression (A.1) and can be written as follows:

$$X^* = B^* Y^* \tag{A.10}$$

where $B^* = (I - A^*)^{-1}$ is the version of the Leontief inverse matrix with elements in hybrid units.

The hybrid matrix of the total net requirement for the coefficients for emissions can be defined as follows:

$$R^* = B^* - I^* \tag{A.11}$$

where I^* is the identity matrix $(n + 1)x(n + 1)$.

To calculate the matrix for indirect requirements, Q^*, we use the matrices R^* and A^* and thus have:

$$Q^* = R^* - A^*. \tag{A.12}$$

The matrices A^*, R^*, and Q^* provide information about the degree of direct (that are the immediate effects from a variation in the final demand), total, and indirect dependencies (captures the secondary effects from a change in final demand) between sectors respectively. In this work, we show the dependencies among all sectors (emission generation) that are represented by the fuel sector.

The matrix of direct and total requirements of emissions is obtained by extracting the lines of the emission flows of A^* and $(I - A^*)^{-1}$ respectively. Because this paper is concerned only with the information from the fuel sector, we need to extract the matrices described for just the information on the intersectoral emission requirements of the fuel sector. For this extraction, we create a matrix F^* (nxn) in which the elements that represent emission flows (in Gg/1000 toe) are distributed along the main diagonal and other elements are represented by zero.

$$F^* = \begin{bmatrix} Gg/toe & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & Gg/toe & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{A.13}$$

If we calculate $F^* \left(\widehat{X}^*\right)^{-1}$, we have a matrix of zeros that relate to the sectors that are not fuel, and ones that denote the location of the fuel sector. Thus, when we multiply the matrices of direct and total requirements of emissions by $F^* \left(\widehat{X}^*\right)^{-1}$, we retrieve only the emission coefficients, that is, the amount of CO_2.

Therefore, δ represents the direct requirements and a the total requirements:

$$\delta = F^* \left(\widehat{X}^*\right)^{-1} A^* \tag{A.14}$$

and

$$a = \widehat{F}^* \left(\widehat{X}^*\right)^{-1} (I - A^*)^{-1}. \tag{A.15}$$

Because the indirect requirements, λ, are obtained from the difference between the total requirements (Eq. (A.16)) and the direct requirements (Eq. (A.15)) of emissions:

$$\lambda = \widehat{F}^* \left(\widehat{X}^*\right)^{-1} [(I - A^*) - A^*]. \tag{A.16}$$

Thus, assuming that the emissions are linearly related to the emission requirements provided by Eqs. (A.14), (A.15), and (A.16), then obtaining the direct, indirect, and total emission requirements respectively is possible.

Appendix B

Sectors disaggregation of the energy balances of Minas Gerais.

Appendix Table B

2005 Matrix Sectors	Energy Balance of Minas Gerais (Sectors)
Agriculture, Silviculture and Forestry	Agricultural
Livestock and Fisheries	
Mining	Mining and Pelletizing
Food	Food and Beverage
Beverage	
Tobacco Products	
Textiles	Textile
Leather Goods and Foorwear	
Clothing and Accessories	
Cellulose and Paper	Paper and Cellulose
Rubber and Plastic	
Oil Derivatives and Alcohol	
Pharmaceuticals, Cosmetics, Hygiene and Cleaning	Chemistry
Chemistry	
Non-metallic Minerals	Cement
	Lime
Metallurgy Metal - except machinery and equipment	Non-ferrous Metallurgical and Others
	Iron and Steel Integrated
	Steel Integrated
	Steel non-Integrated
	Iron
	Other from Steel
Machinery and Equipment	Other Industries
Machinery, Appliances and Equipment	
Automotive Vehicles	
Parts and Accessories for Vehicles	
Other Equipment of Transport	
Furniture, Wood and Sundries	
Electricity, Gas, Water and Urban Sanitation	Services
Construction	
Trade	Trade
Information Services	Services
Financial Intermediation and Insurance	
Real Estate and Rental	
Accommodation and Food Services	
Business Services	
Education and Private Health	
Other Services	
Transport, Storage and Mailing	Transport
Public Administration	Public

Appendix C. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2013.07.002.

References

Alcántara, V., Padilla, E., 2003. "Key" sectors in final energy consumption: an input–output application to the Spanish case. Energy Econ. 31, 1676–1678.
Carvalho, T.S., Perobelli, F.S., 2009. Avaliação da intensidade de emissões de CO_2 setoriais e na estrutura de exportações: um modelo inter-regional de insumo-produto São Paulo/restante do Brasil. Econ. Apl. 13, 99–124.
Companhia Energética de Minas Gerais — CEMIG, 2007. 23º Balanço Energético do Estado de Minas Gerais — BEEMG, ano base 2007. Available online at: http://www.cemig.com.br (Last accessed December 20, 2009).
Economia and Energia, 2000. Matriz Energética e de Emissões. Available online at: http://www.ecen.com/matriz/ (Last accessed January 20, 2010).
European Comission (EU), 2008. Directive 2008/101/Ec of the European Parliament and of the Council of 19 November 2008. Off. J. Eur. Union 1, 1–19 (Available online at: http://ec.europa.eu/clima/policies/ets/index_en.htm. Last accessed January 15, 2013).
European Comission (EU), 2012. The EU Emissions Trading Systems (EU ETS). Climate Action. Available online at: http://ec.europa.eu/clima/policies/ets/index_en.htm Last accessed January 15, 2013.
Gowdy, J.M., Miller, J.L., 1987. Technological and demand change in energy use: an input–output analysis. Environ. Plan. 19, 1387–1398.
Hawdon, D., Pearson, P., 1995. Input–output simulations of energy, environment, economy interactions in the UK. Energy Econ. 17, 73–86.
Hetherington, R., 1996. An input–output analysis of carbon dioxide emissions for the UK. Energy Convers. Manag. 37, 979–984.
Hilgemberg, E.M., 2004. Quantificação e Efeitos Econômicos do Controle de Emissões de CO2 Decorrentes do Uso de Gás Natural, Álcool e Derivados de Petróleo no Brasil: Um Modelo Interregional de Insumo-Produto. (Tese de Doutorado) School of Agriculture "Luiz de Queiroz", Federal University of São Paulo, São Paulo.
IPCC, 2007. Summary for policymakers. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Labandeira, X., Labeaga, J.M., 2002. Estimation and control of Spanish energy-related CO2 emissions: an input–output approach. Energy Pol. 30, 597–611.
Lenzen, M., 1998. Primary energy and greenhouse gases embodied in Australian final consumption: an input–output analysis. Energy Policy 26, 495–506.
Machado, G.V., 2002. Meio Ambiente e Comércio Exterior: Impactos da Especialização Comercial Brasileira sobre o Uso de Energia e as Emissões de Carbono do País. (Tese de Doutorado) Faculty of Engineering, Federal University of Rio de Janeiro, Rio de Janeiro.
Miller, R., Blair, P., 2009. Input–Output Analysis: Foundations and Extensions. Prentice-Hall, New Jersey.
Ministério de Minas e Energia — MME, 2006. Balanço Energético Nacional. Available online at: http://www.mme.gov.br (Last accessed March 15, 2011).
Ministério do Desenvolvimento, Indústria e Comércio Exterior — MDIC, 2012. Plano Setorial de Mitigação da Mudanca Climática para a Consolidação de uma Economia de Baixa Emissão de Carbono na Indústria de Transformação (25 pp.).
Mongelli, I., Tassielli, G., Notarnicola, B., 2006. Global warming agreements, international trade and energy/carbon embodiments: an input–output approach to the Italian case. Energy Policy 34, 88–100.
Munksgaard, J., Pedersen, K.A., 2001. CO2 accounts for open economies: producer or consumer responsibility? Energy Policy 29, 327–334.
Nakano, S., Okamura, A., Sakurai, N., Suzuki, M., Tojo, Y., Yamano, N., 2009. The measurement of CO2 embodiments in international trade: evidence from the harmonised input–output and bilateral trade database. OECD Science, Technology and Industry Working Papers, 2009/03. OECD Publishing (Available online at: http://dx.doi.org/10.1787/227026518048. Last accessed March 18, 2011).
Perobelli, F.S., Mattos, R.S., Faria, W.R., 2007. Interações energéticas entre o Estado de Minas Gerais e o restante do Brasil: uma análise inter-regional de insumo-produto. Econ. Apl. 11, 113–130.
Peters, G.P., Hertwich, E.G., 2008. CO_2 embodied in international trade with implications for global climate policy. Policy Anal. 42, 1401–1407.
PNMC, 2008. Plano Nacional sobre Mudança do Clima. Governo Federal, Comitê Interministerial sobre mudança do clima. (154 pp.).
Schaeffer, R., de Sá, A., 1996. The embodiment of carbon associated with Brazilian imports and exports. Energy Convers. Manag. 37, 955–960.
Su, B., Huang, H.C., Ang, B.W., Zhou, P., 2010. Input–output analysis of CO_2 emissions embodied in trade: the effects of sector aggregation. Energy Econ. 32, 166–175.
Tarancón Morán, M.A., del Río González, P., 2007. A combined input-output and sensitivity analysis approach to analyse sector linkages and CO_2 emissions. Energy Economics. 29, 578–597.
WCED, 1987. Nosso Futuro Comum, 1st ed. FGV, Rio de Janeiro.