Tracing Brazilian regions' CO2 emissions in domestic and global trade

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The current Brazilian position on climate change has been formalized with the law of National Climate Change Policy, which provides a legal framework for national actions aimed at mitigation and adaptation. Within PNMC, the country has defined its national voluntary reduction targets for greenhouse gases emissions, with reductions between 36.1% and 38.9% of projected emissions by 2020. The distribution of the corresponding mitigation efforts by regions is of great concern in a large country like Brazil. In fact, most of Brazilian states have established public policies on climate change. In this context, questions raised in the literature on global climate change, such as the environmental responsibility for emissions embodied in trade, also apply at the regional level, and perhaps even to a larger extent. In order to analyze at regional level the current relationship between Brazil's CO2 emissions and domestic and global value chains, in this study we adopt a new framework that combines a world input-output table with an inter-regional input-output table. Also, a new database is compiled on Brazilian states' energy use (by fuel) and related CO2 emissions at sectoral level, based on states' official energy balances. We are able to evaluate the CO2 emissions in each of the 27 Brazilian states, considering their respective productive structure, energy use, as well as their trade with other states or foreign countries. We find that, in 2008, emissions from the production of inter-regionally traded goods and services corresponded to 36% of Brazilian CO2 emissions. There is great variation among states concerning their emissions intensities and carbon content of their trade relationships with their states and foreign countries.

A atual posição do Brasil em relação às mudanças climáticas foi formalizada com a Lei da Política Nacional sobre Mudança do Clima, que estabeleceu o quadro legal para as ações nacionais voltadas à mitigação e à adaptação. O país também definiu suas metas voluntárias para redução das emissões de gases do efeito estufa, entre 36,1% e 38,9% das emissões projetadas para 2020. A distribuição geográfica dos esforços de mitigação é de grande interesse em um país heterogêneo como o Brasil. De fato, a maioria dos estados brasileiros estabeleceram políticas oficiais sobre mudanças climáticas. Nesse contexto, questões levantadas pela literatura sobre mudanças climáticas globais, tais como a responsabilidade ambiental por emissões incorporadas no comércio internacional, aplicam-se também em nível regional, possivelmente em ainda maior grau. A fim de analisar em nível regional a relação entre emissões de CO2 e as cadeias de valor domésticas e globais, nesse estudo adota-se uma nova abordagem que integra uma matriz de insumo-produto global e uma inter-regional. Adicionalmente, construiu-se uma nova base de dados para o uso de energia (por tipo de combustível) e respectiva emissão de CO2 por setor de atividade econômica em cada estado do Brasil, baseada nos balanços energéticos oficiais. Com isso, torna-se possível avaliar as emissões de CO2 nos estados, considerando as respectivas estruturas produtivas, de uso de energia, bem como suas relações comerciais com outros estados e países. Observou-se que as emissões provindas da produção de bens e serviços comercializados entre os estados corresponderam a 36% das emissões totais do Brasil, em 2008. Há grande variação entre os estados quanto suas intensidades de emissões, bem como o conteúdo de carbono de suas relações comerciais com outros estados e países.

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1. Introduction

The Brazilian position on climate change has been formalized with the law of National Climate Change Policy (PNMC, in Portuguese – Law nº 12 187, dated December 29th, 2009) which provides a legal framework for national actions aimed at mitigation and adaptation. Within PNMC, the country has defined its national voluntary reduction targets for greenhouse gases (GHGs) emissions, advancing from a merely programmatic policy (LUCON; GOLDEMBERG, 2010) to a legal commitment with clear environmental objectives that should guide subsequent policymaking. The reductions were defined between 36.1% and 38.9% of projected emissions by 2020. As indicated by Seroa da Motta (2011), sectoral mitigation percentages were adopted in the correspondence from Brazil for the Copenhagen Accord in 2010: out of the 38.9% national target, deforestation would be reduced by 24.7%, and the remaining 15.2% would be divided between energy use (7.7%), agriculture and cattle raising (6.1%), and other sectors (0.4%).

The distribution of the corresponding mitigation efforts by regions is of great concern in a large country like Brazil, with substantial regional variation in economic development, physical geography, production system, and energy consumption. In fact, Brazil's 1988 Constitution divides responsibilities for environmental policies and legislation among the three levels of government (PUPPIM DE OLIVEIRA, 2009), and most of Brazilian states have established public policies on climate change. According to NESA-USP, as of June 2015, out of the 27 states 16 have established policies and four are underway, having initiated draft legislation; three others have implemented local forums to dialogue about climate change at state level. Only Roraima, in the North region, Alagoas, Rio Grande do Norte, and Sergipe, in the Northeast region, do not even have climate change forums.

Four states have mandatory targets for reducing greenhouse gas emissions: São Paulo and Rio de Janeiro, in the most developed Southeast region; Mato Grosso do Sul, in the Central-West region; as well as Paraíba, in the Northeast region. There are also advancements in municipal climate change policies, the two most populous cities, São Paulo and Rio de Janeiro, have established mandatory targets. However, the mitigation targets are quite different from each other in Brazil's subnational climate change policies. This is not a problem in itself and can be echoing the principle of "common but differentiated responsibilities" professed by PNMC at international level. However, there is no coordination concerning the different basis of measurement (absolute values or intensities in the case of Rio de Janeiro) and incompatibilities in the baselines (different years of reference, based on inventories or projected emissions). At sectoral level, only Rio de Janeiro has stated specific targets. These characteristics reflect that the elaboration process of these subnational policies, which have autonomously emerged, detached from each other. The incongruity between the targets is problematic for economic agents, since it is not clear what the sum of national, state, and municipal targets means to their activities (FÓRUM CLIMA, 2012).

Thus, although the subnational policies indicate advances toward a less intensive effect on climate change, there is room for improvement in the regulatory aspects. As stated by Romeiro and Parente (2011) the main obstacles include the lack of convergence of actions implemented in the various states in Brazil. There are distinct targets and strategies in the three spheres of the country – federal, state and municipal – which makes the standardization of mitigation measures and its respective monitoring more difficult and less effective.

This criticism is not exclusive to Brazil, but also applied to other countries where subnational climate policies have emerged. Literature concerning these policies have flourished in the last years, when subnational governments have taken the lead to tackle climate change in many countries, such as the United States (LUTSEY; SPERLING, 2008; SCHREURS, 2008). Although there are advantages for engagement of subnational governments in climate change policies – such as greater flexibility to implement new policies (PUPPIM DE OLIVEIRA, 2009), and the attaining of efficiency gains from exploitation of local heterogeneities (SOMANATHAN *et al*, 2014) – most of literature agrees about the possibility of problems of coordination and complementarity, besides questioning their institutional capacity to take action in such policies. The Intergovernmental Panel on Climate Change's Fifth Assessment Report states that, since there are several limiting factors to a widespread reliance on subnational levels of government, "a federal structure that provides coordination and enables an easier transmission of climate policies throughout the agents of the economy is likely to increase the effectiveness of actions against climate change" (SOMANATHAN *et al*, 2014, p. 1183).

The coordination from top-down policies is also fundamental for dealing with an important aspect of the climate issue that has been overlooked by policy settings within all levels, which is the relationship between trade and greenhouse gases emissions. It is fundamental to consider the connections between economies, as trade links production and consumption in different regions. As stated by Peters et al (2011), ignoring these connections might result in a misleading analysis of underlying driving forces of emission trends and mitigation policies. Questions raised in the literature on global climate change, such as the environmental responsibility for emissions embodied in trade (e.g. VALE *et al* (2015); DOUGLAS; NISHIOKA (2012); WIEBE *et al* (2012); PETERS *et al* (2011); DAVIS; CALDEIRA (2010); NAKANO *et al* (2010); SERRANO; DIETZENBACHER (2010); HERTWICH; PETERS (2008)), also apply at the regional level, and perhaps even to a larger extent.

This paper analyzes the relationship between Brazilian states' CO2 emissions and inter-regional and international trade. In doing so, we aim to contribute to policies that account for such inter-relationships among regions. In this paper, we adopt a forward perspective (MENG *et al*, 2015) in analyzing the relationship between CO2 emissions and trade. That is, we aim to understand the responsibility of consumers for emissions embodied in trade, evaluating what amount of emission generated by a state is for its own final consumption or for other states and foreign countries.

A major difficulty for subnational climate change policies in Brazil is that there are very few published official inventories (even though, in general, all state policies indicate their formulation). At state level, to the best of our knowledge, only Espírito Santo, Minas Gerais, Paraná, Rio de Janeiro, and São Paulo have published comprehensive GHGs inventories[1]. Yet their periodicity differs, and the adopted methodologies are not entirely consistent to each other. For example, how each inventory proposes accounting for emissions due to freight originating in the state with destination to other state (FÓRUM CLIMA, 2012). In other to deal to some extent with this problem, in this study we quantify CO2 emissions in each of the 27 states of Brazil, in the year 2008. However, we share a limitation with most of literature[2] that analyzes the relationship between international trade and GHGs emissions: we account here for CO2 emissions due only to energy use (combustion of fossil fuels).

According to the Ministry of Science, Technology and Innovation (MCTI) (2014), in 2008 energy use accounted for about 18% of total GHGs emissions in Brazil. However, the

[1] Other states have published official inventories that comprehend only some emission sectors: Amazonas (electric power sector), Bahia (energy sector and industrial processes). Although comprehensive, the inventory of Acre covers only electric power generation and emissions from automobiles in the energy sector.

[2] For example, Douglas and Nishoka (2012), Wiebe et al (2012), Davis and Caldeira (2010), and Nakano et al (2010) account only for CO2 emissions due to combustion of fossil fuels, as we do in this study. Peters et al (2011) also consider CO2 emissions from cement production .and gas flaring. Hertwich and Peters (2009) consider GHGs, not including the sources and sinks of land-use change, which is the same as in the WIOD project. Besides the absence of data on land-use change and other GHGs with the necessary detail, the authors indicate that other sources present difficulties for allocation to economic activities.

climate impact of the energy sector is foreseen to grow in the next years. Decree nº 7 390, dated December 9th, 2010, which regulates PNMC, presents official projections for GHGs emissions in Brazil, for the year 2020. According to them, the GHGs emissions due to energy use are estimated to be 868,000 Gg in 2020 (about 140% larger than in 2008), amounting in 27% of total projected GHGs emissions. In fact, data of recent years show an even more relevant participation of emissions due to energy use. In 2012, it accounted for about 37% of total GHGs emissions (MCTI, 2014), given the sharp decline of emissions due to land-use change especially in Amazon region, from 2009. Given the increasing importance of energy use for the Brazilian GHGs scenario and its central role in global emissions, its climate impact and their relationship with the economic activities must be studied.

Besides this Introduction, this paper is organized as follows: section 2 presents the methodology used in the empirical analysis, as well as the newly compiled database. Results are then analyzed in section 3. Then, the last section presents some our concluding remarks.

2. Methodology

2.1. Estimating the country-state input-output table

In order to analyze at regional level the current relationship between Brazil's CO2 emissions and domestic and global value chains, in this study we adopt the framework proposed by Dietzenbacher *et al* (2013) for combining a world input-output table (WIOT) with an inter-regional input-output table (IRIOT), thus estimating a country-state input-output table for Brazil. In this approach, we do not to take one of the datasets (say the WIOT) as a starting point and adapt the other dataset (i.e. the IRIOT) accordingly, instead we construct input coefficients for which both datasets are used.

For the empirical application, we will use the WIOT for 2008 that was constructed in the WIOD project (see Dietzenbacher *et al*, 2013b).[3] It is a full inter-country input-output table covering 40 countries and the rest of the world as a 41st "country".[4] One of the countries included is Brazil. The IRIOT for 2008 is for Brazil and covers the 27 Brazilian states (GUILHOTO *et al*, 2010). Both the WIOT and the IRIOT were aggregated to 28 compatible industries.

2.2. CO2 emissions data for Brazilian states

In this paper, we account for CO2 emissions due to fossil fuels[5] in the economic sectors. It also embodies the CO2 emissions that are generated in thermal power plants, as well as that from the use of coke in iron and steel mills. Adopting a bottom-up approach, we were able to obtaining the levels of CO2 emissions by industry at the state level in Brazil. For the other countries in our model, we have considered the data on CO2 emission from the WIOD project.

First, we have departed from the Brazilian Energy Balance (EPE, 2009) and reconciled the data from state energy balances accordingly. For the year 2008, official energy balances are available for the following states: Alagoas, Bahia, Goiás, Minas Gerais, Rio de Janeiro, São

[3] The full database from the WIOD project (including a time series of WIOTs) is publicly and free of charge available at: http://www.wiod.org/database/index.htm.

[4] The countries in the WIOD's world input-output tables are: 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, Slovak Republic, Slovenia, Spain, Sweden, Taiwan, Turkey, United Kingdom, and USA (Dietzenbacher *et al*, 2013).

[5] The following fuels were taken into account: natural gas, steam coal, metallurgical coal, diesel oil, fuel oil, gasoline, LPG, kerosene, gas coke, coal coke, other oil by-products, and coal tar.

Paulo, Paraná, and Rio Grande do Sul. For Ceará and Espírito Santo, we have considered the participation in the national energy use and sectors' fuel structure from the energy balances of 2007 and 2010, respectively.

Following Montoya *et al* (2014), the data on fossil fuel use (in tOE) from the energy balances was then reconciled with the industry classification of Brazil's IRIOT. Next, we have estimated the corresponding CO2 emissions by adopting the carbon emission factors and oxidation fractions from the Brazilian Inventory of Anthropogenic Emissions and Removals of Greenhouse Gases (MCTI, 2010).

By adopting this approach, about 75% of Brazil's CO2 emissions due to energy use in 2008 were attributed to the ten aforementioned states that publish official energy balances. The differences from the national total by sector were allocated to the other states according to their respective gross output.

In our application, the CO2 emissions due to households' direct use of fossil fuels are disregarded (approximately 9% of the national emissions). Instead, we focus on the emissions that are generated by the various economic industries in their productive activities.

2.3. Trade in CO2 emissions (TiCE)

To investigate the inter-regional (and international) spillover of CO2 emissions, we adapt and apply the concept of trade in value added (TiVA) for our country-state input-output system.

From the basic Leontief model, the total output of an economy can be expressed as the sum of intermediate consumption and final consumption (MILLER; BLAIR (2009)) as

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \tag{1}$$

$$(\mathbf{I} - \mathbf{A})^{-\mathbf{1}} = \mathbf{B} \tag{2}$$

$$\mathbf{x} = \mathbf{B}\mathbf{y} \tag{3}$$

where $\mathbf{x}$ is the n×1 total output vector (n is the number of industries in the system), $\mathbf{A}$ is the n×n direct input coefficients matrix, $\mathbf{y}$ is the n×1 final demand vector, and $\mathbf{B}$ is the Leontief inverse matrix.

Considering $\mathbf{C}$ as the n×n diagonal matrix of CO2 emissions coefficients, we can describe the CO2 emissions related input-output model as:

$$\mathbf{v} = \mathbf{C}\mathbf{x} \tag{4}$$

from (3):

$$\mathbf{v} = \mathbf{C}\mathbf{B}\mathbf{y} \tag{5}$$

$$\mathbf{C}\mathbf{B} = \mathbf{G} \tag{6}$$

$$\mathbf{v} = \mathbf{G}\mathbf{y} \tag{7}$$

where $\mathbf{v}$ is the n×1 CO2 emissions vector, and $\mathbf{G}$ is the CO2 emissions related Leontief inverse.

In our empirical analysis, we applied a state-country input-output model. In this case, the above system can be expanded, considering r states / countries, in such a way that it is possible to estimate the contribution of the final demand in each state / country to the total CO2 emission of a given state / country. In this way, the dimensions of the above matrices and vectors become: a) $\mathbf{X}$, $\mathbf{Y}$, and $\mathbf{V}$, size [$(r.n) \times r$]; b) $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{G}$, size $(r.n) \times (r.n)$.

With the aim of analyzing the state / country interdependence in terms of CO2 emission, the matrix $\mathbf{G}$ above can be decomposed as follows:

$$\begin{bmatrix} \mathbf{G}^{11} & \dots & \mathbf{G}^{1r} \\ \vdots & \ddots & \vdots \\ \mathbf{G}^{r1} & \dots & \mathbf{G}^{rr} \end{bmatrix} = \begin{bmatrix} \mathbf{G}^{11} & \dots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \dots & \mathbf{G}^{rr} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \dots & \mathbf{G}^{1r} \\ \vdots & \ddots & \vdots \\ \mathbf{G}^{r1} & \dots & \mathbf{0} \end{bmatrix} \tag{8}$$

In equation (8), the elements of the first term of the sum can be regarded as intra-regional effects, representing impacts on the CO2 emissions of sectors of a region due to exogenous changes in final demand of the same region. On the other hand, the elements of the second term of the sum can be regarded as spillover effects, representing impacts on the CO2 emissions of sectors of a region due to exogenous changes in final demand of the other region.

In a state-country input-output framework, equation (7) can be represented as:

$$[\mathbf{v}^{\cdot 1} \quad \ldots \quad \mathbf{v}^{\cdot r}] = \begin{bmatrix} \mathbf{G}^{11} & \ldots & \mathbf{G}^{1r} \\ \vdots & \ddots & \vdots \\ \mathbf{G}^{r1} & \ldots & \mathbf{G}^{rr} \end{bmatrix} [\mathbf{y}^{\cdot 1} \quad \ldots \quad \mathbf{y}^{\cdot r}] \tag{9}$$

In the above equation, considering for example region *1*, the vector $\mathbf{v}^{\cdot 1}$ $[(r.n) \times 1]$ represents the contribution of region *1* to the total CO2 emissions in each one of the *r* states / countries and *n* sectors considered in the model, given the final demand $\mathbf{y}^{\cdot 1}$ of this region.

The vector $\mathbf{v}^{\cdot 1}$ in equation (9) comprehends the inflows / imports[6] of CO2 emissions of region *1* from other states / countries (besides its own contribution for its own value added, given by the elements from *1* to *n*). For example, the elements from $n+1$ to $2n$ correspond to its inflows / imports of CO2 emissions from each of the *n* sectors of region *2* (accordingly, the outflows / exports of CO2 emissions from region *2* to region *1*). Thus equation (9) represents the consumption-based accounting principle with the multiregional input-output method (see PEI *et al* (2015); PETERS *et al* (2011); DAVIS; CALDEIRA (2010)).

3. Main results

3.1. Traded components of global CO2 emissions

As can be expected for a country as heterogeneous as Brazil, the values of traded components of CO2 emissions vary greatly among the Brazilian states, as Table 1[7] presents. The states in the Southeast region (Espírito Santo, Minas Gerais, Rio de Janeiro, and São Paulo) presented the greatest sums of domestically consumed, inter-regionally and internationally traded CO2 emissions. They amounted in respectively 54%, 52% and 59% of the country's total. São Paulo's shares were the largest, except concerning the exports of CO2 emissions to foreign countries, in which Minas Gerais took the lead.

Considering the results for TiCE in Brazil in relation to those of other countries globe, its figures are quite small. Concerning the relationship of Brazilian states and foreign countries, as seen in the second and third columns of Table 1, the largest amounts of exports to and imports from Brazilian states corresponded to countries that are not individually treated in our model (i.e. the "rest of the world" region). However, it is notable that China's exports of CO2 to Brazilian states represented almost 30% of this component.

From the TiCE results, as highlighted in Chart 1, we have quantified the importance of international trade in global CO2 emissions. In 2008, 28% of global CO2 emissions, or 6.6 Gt CO2, were attributed to international trade. This is close to the findings of other authors (PETERS *et al* (2011): 26%; DAVIS; CALDEIRA (2010): 23%). China's exports of CO2 emissions alone represented 31% of the internationally traded emissions, or 9% of global emissions.

Emissions from the production of inter-regionally traded goods and services in Brazil amounted in 36% of the country's territorial (or production-based) CO2 emissions. International trade was slightly less relevant to Brazilian emissions than the world average, as 25% of its territorial CO2 emissions were attributed to its exports to foreign countries.

[6] In this paper, we distinguish between "inflows" / "outflows", regarding trade among domestic states, and "imports" / "exports", regarding trade between states and foreign countries, or between foreign countries.

[7] In this section, for better presentation, we have aggregated some of the countries in our model as "Other EU27" (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden) and as "Other countries + RoW" (Australia, Indonesia, Turkey, and ROW).

Table 1 – Allocation of global CO2 emissions separated into domestic, inter-regionally and internationally traded components (in thousand tons)

	Domestic	Exports (outflows) to Brazilian regions	Imports (inflows) from Brazilian regions	Exports to foreign countries	Imports from foreign countries
Acre	236	135	384	31	160
Amapá	240	72	430	123	226
Amazonas	1,956	4,238	1,800	864	3,580
Pará	2,430	1,956	4,194	5,325	2,111
Rondônia	744	713	1,145	224	611
Roraima	146	83	212	16	95
Tocantins	542	479	769	142	419
Alagoas	773	576	1,114	219	521
Bahia	8,488	6,296	7,050	4,946	5,493
Ceará	2,527	1,069	3,330	317	2,093
Maranhão	1,902	2,613	2,027	2,030	1,819
Paraíba	1,255	820	1,884	137	1,074
Pernambuco	4,372	3,274	3,794	857	2,827
Piauí	908	383	1,410	105	656
Sergipe	968	1,344	1,034	308	579
Rio Grande do Norte	1,070	873	1,726	278	777
Distrito Federal	3,842	1,402	5,012	205	2,669
Goiás	4,369	2,879	3,778	1,444	2,786
Mato Grosso	1,900	3,337	2,005	2,197	1,043
Mato Grosso do Sul	1,651	1,886	1,550	852	1,302
Espírito Santo	1,920	7,826	2,796	9,241	2,134
Minas Gerais	16,478	14,585	11,500	14,110	9,301
Rio de Janeiro	18,909	12,718	16,075	7,590	10,833
São Paulo	34,522	26,581	24,635	13,209	33,255
Paraná	7,867	8,986	6,463	3,586	7,308
Santa Catarina	6,023	7,265	4,995	2,957	5,116
Rio Grande do Sul	7,722	6,212	7,490	3,567	7,194
Brazil	133,759	118,602	118,602	74,880	105,982
China	3,423,810	29,829	6,502	2,037,241	438,670
India	1,021,366	3,279	778	240,880	186,831
Russia	859,049	5,378	1,274	468,338	137,248
USA	3,873,706	9,141	13,725	474,513	1,183,184
Mexico	262,729	630	1,798	60,796	118,411
Canada	243,070	2,861	1,542	150,580	186,898
Germany	383,696	3,737	4,448	242,989	422,677
Spain	167,355	726	1,569	66,901	171,705
France	167,220	809	2,249	78,092	262,037
United Kingdom	307,722	1,184	1,862	121,335	270,579
Italy	248,004	1,206	2,143	100,944	225,623
Other EU27	840,613	4,528	6,601	410,874	638,175
Japan	751,063	2,243	2,834	207,223	419,360
Korea	294,521	2,116	1,353	186,160	169,024
Taiwan	127,234	1,757	601	138,882	65,032
Other countries + RoW	3,895,511	36,558	25,600	1,490,581	1,580,873
Foreign countries	16,866,669	105,982	74,880	6,476,329	6,476,329

Inter-regional and international trade are more relevant for the generation of global and Brazil's CO2 emissions than for value added, which is emphasized comparing the figures for trade in value added (TiVA). In 2008, 20% of global value added were attributed to international traded (versus 28% for CO2 emissions). In Brazil, inter-regional trade responded to 27% of the country's value added (versus 36% for CO2 emissions). The greater relevance of inter-regional trade for generating CO_2 emissions (in comparison with value added) also holds for every state in Brazil.

Chart 1 – Participation of inter-regionally and internationally traded components

Participation of traded components in CO2 emissions	
Global CO2 emissions:	23,776,219 kt
Emissions in international trade:	6,657,190 kt → 28% of global emissions
Brazil's production-based CO2 emissions:	327,240 kt
Emissions in inter-regional trade:	118,602 kt → 36% of Brazil's emissions
Emissions in international trade:	74,880 kt → 23% of Brazil's emissions
Participation of traded components in value added	
Global value added:	59,869,267 million US$
Value added in international trade:	12,097,671 million US$ → 20% of global VA
Brazil's value added:	1,546,495 million US$
Value added in inter-regional trade:	420,706 million US$ → 27% of Brazil's VA
Value added in international trade:	195,610 million US$ → 13% of Brazil's VA

3.2. Production-based and consumption-based CO2 emissions

In order to quantify the emission transfers via inter-regional and international trade, we rearrange the results of TiCE presented in Table 1. For computing the production-based emissions, we sum the components "domestic", "exports (outflows) to Brazilian regions", and "exports to foreign countries". For consumption-based emissions, "domestic", "imports (inflows) from Brazilian regions", and "imports from foreign countries". The difference between production-based and consumption-based emissions is defined as "net emission transfer" via trade (PETERS *et al*, 2011). Here, we are considering the transfers via international and inter-regional trade inside Brazil. Thus the net emissions transfer corresponds to CO_2 emissions in each region (state or country) to produce goods and services that are ultimately consumed in a different region minus the emissions in other regions to produce goods and services that are ultimately consumed in the first region. Following the sign convention as for an economic balance of trade, net exports are positive and net imports are negative. The results are presented in Table 2.

For the Brazilian states, where emission transfers also happen via inter-regional trade, out of 27 states seven were sources of net emission transfer to other states or foreign countries. Espírito Santo and Minas Gerais were outstanding net exporters of CO_2 emissions. São Paulo, the greatest emitter in the country both production and consumption-based, was also the recipient of the largest net emission transfer. These results are analyzed with further detail in sub-section 3.4.

Considering Brazil as a whole, its consumption-based emissions surpassed its production-based emissions, so that it received net emission transfers via international trade. This is dissimilar for other BRICs countries, which presented positive net emission transfer via international trade. Especially China, with net exports emissions amounting in 1.6 Gt CO_2. Concerning the countries included in the Annex B to the Kyoto Protocol and that are treated individually in our model, each of them (with exception of Bulgaria, Denmark, Estonia, Poland, and Russia) received net emission transfers via international trade. This finding adds to the literature about the inadequacy of the territorial principle for mitigation targets under a fragmented, two-tier mitigation strategy as in Kyoto Protocol (PETERS *et al*, 2011).

Table 3 breaks down these results by groups of trade partners (domestic components, Brazilian states, and foreign countries). It shows there was great variation concerning the importance of both inter-regional and international traded components among both Brazilian states and foreign countries.

Table 2 – Production-based and consumption-based CO2 emissions, net emission transfers (in thousand tons)

	Production-based emissions	Consumption-based emissions	Net emission transfer
Acre	401	780	-378
Amapá	435	895	-460
Amazonas	7,058	7,336	-278
Pará	9,711	8,735	976
Rondônia	1,680	2,500	-819
Roraima	245	453	-208
Tocantins	1,163	1,730	-567
Alagoas	1,567	2,408	-840
Bahia	19,730	21,031	-1,301
Ceará	3,913	7,950	-4,037
Maranhão	6,546	5,749	797
Paraíba	2,212	4,213	-2,001
Pernambuco	8,502	10,992	-2,490
Piauí	1,396	2,975	-1,578
Sergipe	2,621	2,581	39
Rio Grande do Norte	2,222	3,573	-1,351
Distrito Federal	5,450	11,523	-6,074
Goiás	8,693	10,933	-2,240
Mato Grosso	7,435	4,948	2,486
Mato Grosso do Sul	4,389	4,504	-115
Espírito Santo	18,987	6,849	12,137
Minas Gerais	45,173	37,279	7,893
Rio de Janeiro	39,217	45,816	-6,600
São Paulo	74,312	92,412	-18,100
Paraná	20,439	21,638	-1,199
Santa Catarina	16,244	16,133	111
Rio Grande do Sul	17,502	22,406	-4,905
Brazil	327,240	358,343	-31,102
China	5,490,880	3,868,982	1,621,898
India	1,265,525	1,208,975	56,550
Russia	1,332,766	997,572	335,194
USA	4,357,361	5,070,614	-713,254
Mexico	324,155	382,938	-58,783
Canada	396,510	431,510	-35,000
Germany	630,422	810,821	-180,399
Spain	234,982	340,629	-105,647
France	246,121	431,507	-185,386
United Kingdom	430,240	580,163	-149,923
Italy	350,154	475,771	-125,617
Other EU27	1,256,015	1,485,389	-229,374
Japan	960,528	1,173,257	-212,729
Korea	482,798	464,898	17,900
Taiwan	267,873	192,867	75,006
Other countries + RoW	5,422,650	5,501,985	-79,335
Foreign countries	23,448,979	23,417,877	31,102

As indicated previously, 36% of the Brazilian production-based CO2 emissions were attributed to inter-regional trade. Among the states, this ranges from 17%, in Amapá, to 60%, in Amazonas. The internationally traded component of CO2 emissions also has great variance among the states, corresponding to shares of production-based CO2 emissions that range from

4%, in Distrito Federal, to 55% in Pará. Its importance in Espírito Santo is also outstanding (49% of production-based CO2 emissions in this state), so that only 10% of this state's CO2 emisions were due to its own final demand.

Table 3 – Participation of domestic, Brazilian states, and foreign countries' components in production-based and consumption-based CO2 emissions (%)

	Production-based			Consumption-based		
	Domestic	BRA states	Foreign countries	Domestic	BRA states	Foreign countries
Acre	58.83	33.57	7.60	30.29	49.25	20.46
Amapá	55.22	16.60	28.18	26.82	47.97	25.21
Amazonas	27.71	60.05	12.24	26.66	24.53	48.81
Pará	25.02	20.15	54.83	27.81	48.02	24.17
Rondônia	44.28	42.40	13.32	29.77	45.80	24.44
Roraima	59.48	33.93	6.60	32.16	46.89	20.95
Tocantins	46.59	41.20	12.22	31.32	44.45	24.23
Alagoas	49.31	36.72	13.97	32.10	46.28	21.63
Bahia	43.02	31.91	25.07	40.36	33.52	26.12
Ceará	64.57	27.33	8.10	31.78	41.89	26.33
Maranhão	29.06	39.92	31.02	33.09	35.26	31.65
Paraíba	56.72	37.09	6.19	29.78	44.72	25.50
Pernambuco	51.42	38.50	10.08	39.77	34.51	25.71
Piauí	65.07	27.42	7.51	30.54	47.40	22.06
Sergipe	36.95	51.28	11.77	37.51	40.04	22.45
Rio Grande do Norte	48.18	39.31	12.51	29.96	48.30	21.74
Distrito Federal	70.50	25.72	3.77	33.34	43.49	23.16
Goiás	50.26	33.12	16.62	39.96	34.56	25.48
Mato Grosso	25.56	44.89	29.55	38.40	40.51	21.09
Mato Grosso do Sul	37.61	42.97	19.42	36.65	34.43	28.92
Espírito Santo	10.11	41.22	48.67	28.03	40.81	31.15
Minas Gerais	36.48	32.29	31.24	44.20	30.85	24.95
Rio de Janeiro	48.22	32.43	19.35	41.27	35.08	23.64
São Paulo	46.46	35.77	17.77	37.36	26.66	35.99
Paraná	38.49	43.96	17.55	36.36	29.87	33.77
Santa Catarina	37.08	44.72	18.20	37.33	30.96	31.71
Rio Grande do Sul	44.12	35.50	20.38	34.46	33.43	32.11
Brazil	40.87	36.24	22.88	37.33	33.10	29.58
China	62.35	0.54	37.10	88.49	0.17	11.34
India	80.71	0.26	19.03	84.48	0.06	15.45
Russia	64.46	0.40	35.14	86.11	0.13	13.76
USA	88.90	0.21	10.89	76.40	0.27	23.33
Mexico	81.05	0.19	18.76	68.61	0.47	30.92
Canada	61.30	0.72	37.98	56.33	0.36	43.31
Germany	60.86	0.59	38.54	47.32	0.55	52.13
Spain	71.22	0.31	28.47	49.13	0.46	50.41
France	67.94	0.33	31.73	38.75	0.52	60.73
United Kingdom	71.52	0.28	28.20	53.04	0.32	46.64
Italy	70.83	0.34	28.83	52.13	0.45	47.42
Other EU27	66.93	0.36	32.71	56.59	0.44	42.96
Japan	78.19	0.23	21.57	64.02	0.24	35.74
Korea	61.00	0.44	38.56	63.35	0.29	36.36
Taiwan	47.50	0.66	51.85	65.97	0.31	33.72
Other countries + RoW	71.84	0.67	27.49	70.80	0.47	28.73
Foreign countries	71.93	0.45	27.62	72.02	0.32	27.66

Among the foreign countries in Table 3, Taiwan is where international trade presented the most important role in production-based CO2 emissions (52%). Although China was the largest exporter of CO2 emissions in the world, in this country the internationally traded component was (slightly) less important than in, for example, Germany and Korea, given the dimension of the Chinese domestic final demand. This observation also applies to the importance of the internationally traded component of CO_2 emissions in the USA, from the consumption perspective: although they are by far the greatest importer of CO_2 emissions, the internationally traded component is more relevant to the EU countries, for example.

3.3. Intensity of CO2 emissions

In addition to analyzing the magnitude of production and consumption-based CO2 emissions, for policy purposes it is relevant to assess the intensity of emissions.

In addition to analyzing the magnitude of production and consumption-based CO2 emissions, for policy purposes it is relevant to assess the intensity of emissions. For production-based emissions, their intensity can be evaluated by the ratio between the total emissions and the total value added in a region. The Brazilian economy was less intensive in production-based CO2 emissions than the world average (0.21 thousand ton of CO2 per US$ million of value added in 2008) and all the developing countries depicted in Table 4. The other three BRICs, notably China, presented production-based CO2 intensities much larger than the world average in 2008.

For the Brazilian states, it is relevant that São Paulo, the main state in economic terms, presented an intensity of production-based CO2 emissions that was quite smaller than the national average (0.15 thousand ton of CO2 per US$ million of value added). On the other hand, the three highest intensities corresponded to Espírito Santo, Minas Gerais and Bahia, in that order. In Espírito Santo, it was 0.56 thousand ton of CO2 per US$ million of value added, thus above the world average.

As for consumption-based CO2 emissions, their intensities can be assessed in per capita terms. The results are presented in Table 4. Among the 40 countries in our model, per capita consumption-based CO2 emissions vary from 1.03 ton per person per year (py) for India to 16.54 ton / py for the USA. In Brazil, the lowest intensity corresponded to Alagoas (0.77 ton / py), while Distrito Federal was the other extreme (4.51 ton / py, above the world average).

As Peters *et al* (2011) also observed, the per capita consumption-based CO2 emissions are strongly correlated with per capita final demand expenditures. Using a regression of log-transformed data, we derived its elasticity. Considering the countries in our model, CO2 emissions strongly increase with final demand expenditures as can be seem in Figure 3, with an elasticity $\varepsilon = 0.63$ ($R^2 = 0.84$). Therefore, as countries become wealthier its consumption-based CO2 emissions increase by 63% for each doubling of per capita final demand expenditure. Since the elasticity is less than one, the intensity of consumption-based CO2 emissions decreases with final demand expenditures.

Applying this exercise to Brazilian states (Figure 4), we obtained an elasticity $\varepsilon = 0.87$ ($R^2 = 0.86$), which is larger than when we consider countries. Thus the increase in consumption-based CO2 emissions is greater as states become wealthier. However, the intensity of consumption-based emissions still decreases with final demand expenditures.

Table 4 – Intensity of production-based CO2 emissions in relation to value-added (kt / million US$) and per capita consumption-based CO2 emissions (ton per person per year)

	Production-based emissions (kt) / Value added (million US$)	Per capita consumption-based CO2 emissions (ton / py)
Acre	0.12	1.15
Amapá	0.12	1.46
Amazonas	0.27	2.20
Pará	0.32	1.19
Rondônia	0.19	1.67
Roraima	0.10	1.10
Tocantins	0.17	1.35
Alagoas	0.16	0.77
Bahia	0.32	1.45
Ceará	0.13	0.94
Maranhão	0.31	0.91
Paraíba	0.17	1.13
Pernambuco	0.24	1.26
Piauí	0.17	0.95
Sergipe	0.26	1.29
Rio Grande do Norte	0.17	1.15
Distrito Federal	0.09	4.51
Goiás	0.23	1.87
Mato Grosso	0.27	1.67
Mato Grosso do Sul	0.25	1.93
Espírito Santo	0.56	1.98
Minas Gerais	0.32	1.88
Rio de Janeiro	0.22	2.89
São Paulo	0.15	2.25
Paraná	0.22	2.04
Santa Catarina	0.26	2.67
Rio Grande do Sul	0.17	2.06
Brazil	0.21	1.89
China	1.19	2.88
India	0.98	1.03
Russia	0.88	6.94
USA	0.30	16.54
Mexico	0.30	3.33
Canada	0.27	12.93
Germany	0.18	9.72
Spain	0.15	7.53
France	0.09	6.90
United Kingdom	0.17	9.46
Italy	0.16	7.95
Other EU27	0.25	7.99
Japan	0.20	9.22
Korea	0.53	9.71
Taiwan	0.68	8.37
Other countries + RoW	0.53	1.87
Foreign countries	0.40	3.42

Figure 1 – Consumption-based CO2 emissions (ton per capita) as a function of final demand expenditures (US$ per capita), countries

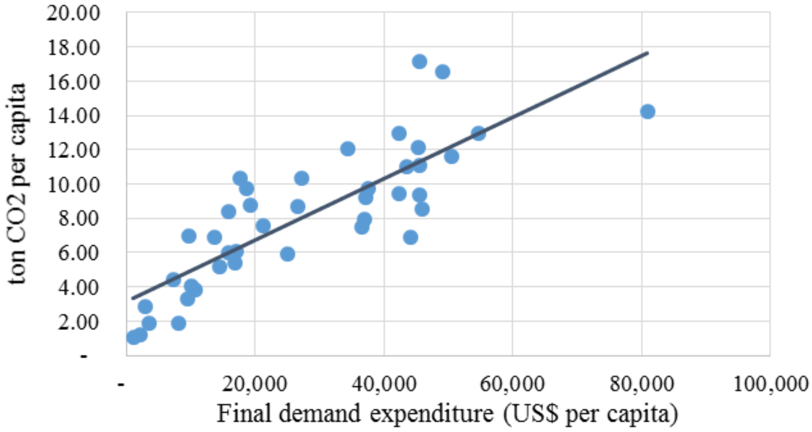
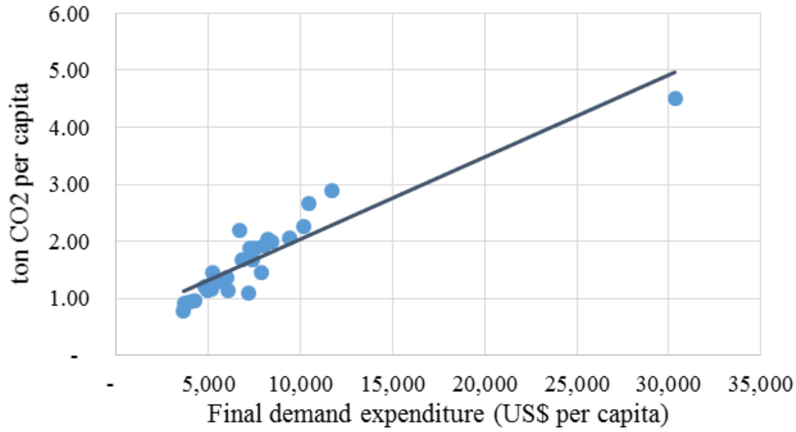


Figure 2 – Consumption-based CO2 emissions (ton per capita) as a function of final demand expenditures (US$ per capita), Brazilian states



3.4. Brazilian states' inter-regional and international trade in CO2 emissions

In this sub-section, we analyze with further detail the results for Brazilian states' TiCE, since it is relevant for policy purposes to identify and quantify the most important CO2 emissions flows, between each pair of trade partners.

Table A1, in the Annex, summarizes the inter-regional flows in CO2 emissions, with aggregation across the 28 industries of our model. An important share of Brazil's inter-regional TiCE (23%) took place among the states in the Southeast region. São Paulo is dominant in the inter-regional trade in CO2 emissions, responding for 22% of outflows and 21% of inflows of emissions in Brazil. For all the states, São Paulo is the most important source of inter-regional TiCE and, except for Roraima, Alagoas, and Distrito Federal, it is also the most important destination. São Paulo's most important trade partners (in CO2 emission terms) are the other states in the Southeast region, for which São Paulo sources 37% of its outflows and from which it acquires 44% of its inflows. The key emission flows from São Paulo to Rio de Janeiro and from Minas Gerais to São Paulo alone amounted respectively in 5% and 4% of Brazil's inter-regional TiCE. However, it is noteworthy that comparing this with the results from the TiVA analysis (DIETZENBACHER *et al*, 2013) reveals that São Paulo's dominance is less intense in terms of emissions – the state responded for the larger share of 37% of outflows in value added terms. This is because São Paulo presents a low consumption-based CO2 emissions intensity, as presented in Table 4. Despite such low intensity, São Paulo's inter-regional trade flows (in value added terms) are so large that the state also takes the lead in TiCE.

On the other hand, Espírito Santo and Minas Gerais are more relevant as sources for inter-regional TiCE (than for TiVA). This is largely due to the large amounts of CO2 emission that are generated in their "Mining and Quarrying" and "Basic Metals and Fabricated Metal" sectors in response to the final demands of other states. For both states, Rio de Janeiro and São Paulo were the most important destinations of their outflows, concentrating more than 46% of them.

In fact, the highest intensity of CO2 corresponds to the flows from Espírito Santo: on average, for each US$ one million of value added due other states' final demand, 0.78 thousand ton of CO2 emissions was produced there (in the whole inter-regional system, the average was 0.28 thousand ton of CO2 emissions / US$ one million of value added). Bahia's outflows presented the second highest CO2 intensity, 0.49 thousand ton of CO2 emissions / US$ one million of value added, quite below Espírito Santo's.

From the data in Table A1, we can compute the net emission transfers between the states. Due to space limitation, here we only describe some of the main results. Espírito Santo was a source of net emission transfers to every other state in Brazil. Its largest surplus was with São Paulo (1.9 thousand ton of CO2). Surpluses of TiCE were also verified for Amazonas with all trade partners in Brazil (except Espírito Santo). The latter result is mainly due to the Free Trade Zone of Manaus, which comprehends an industrial hub directed to the demand of the rest of the country. In the case of São Paulo, differently for what was observed considering TiVA (DIETZENBACHER *et al*, 2013), when the state presented surpluses with all other states (except Amazonas), here the sum of its deficits (especially with Espírito Santo and Minas Gerais) greatly compensates its surpluses in inter-regional trade in CO2 emissions. This results in its positive net emissions transfer to other states amounting in only 3% of its consumption-based CO2 emissions. On the other hand, the state that received the largest net emission transfer via inter-regional trade was Distrito Federal, what is comprehensible given its limited productive structure and its high final demand expenditures. In 2008, it received 3,610 thousand tons of CO2 from other states, in net terms (corresponding to 66% of its production-based CO2 emissions).

The states' exports and imports in CO2 emissions are respectively detailed by trade partner in Tables A2 and A3[8], in the Annex. According to Table A2, the main exporter of CO2 emissions was Minas Gerais (almost 19% of the national exports), which surpassed São Paulo (about 17% of national exports). Corresponding to approximately 12.5%, Espírito Santo also stands out. Concerning the exports by trade partners, the largest share (34%) corresponded to the group of countries "Other + ROW", being followed by EU 27 (25.2%), USA (18.4%) and China (8.7%). However, this ranking of trade partners does not hold for every state. For Pará and Espírito Santo, the USA are more important destination of exports of CO2 than EU27.

It is interesting that, on average, Brazil's exports are more intense in CO2 emissions than its inter-regional flows (0.38 thousand ton of CO2 emissions / US$ one million of exported value added versus 0.28 in inter-regional trade). As observed for total production-based CO2 emissions and inter-regional outflows, the intensity of Espírito Santo's exports of CO2 emissions was the highest in Brazil (1.08 thousand ton of CO2 emissions / US$ one million of exported value added, on average). We observe that the average CO2 intensity varies with the

[8] In the next Tables, for better presentation, the countries in our model are classified as follows: CHN: China; IND: India, RUS: Russia; USA: United States; MEX: Mexico; CAN: Canada; DEU: Germany; ESP: Spain; FRA: France; GBR: United Kingdom; ITA: Italy; Other EU27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden; JPN: Japan; KOR: Korea; TWN: Taiwan; ther + ROW: Australia, Indonesia, Turkey, and ROW.

trade partner. So, in Brazil as whole, USA's final demand generates a higher CO2 / value added ratio than China's or EU27's (0.44 thousand ton of CO2 emissions / US$ one million of exported value added versus 0.37).

São Paulo was largely dominant in the imports in CO2 emissions (31% of national imports). In fact, the emission transfer of foreign countries to São Paulo greatly surpassed those via inter-regional trade, i.e. the final demand of São Paulo had a greater impact in CO2 emissions of foreign countries than in other states of Brazil. Thus the main sources of emission transfer to São Paulo were the group "Other + ROW", China, EU27, and the USA, before even the states in Brazilian southeast region. The group "Other + ROW" and China produced the largest amounts of CO2 emissions in foreign countries due to Brazilian states' final demand (34% and 28%, respectively), being followed by EU27 (12%) and the USA (9%).

Concerning the CO2 intensities of Brazilian states' imports of CO2 emissions, it is noticeable that BRICs exports to Brazil presented quite high CO2 / value added ratio. In the case of China, for example, each US$ one million of exported value added to Brazilian states embodied 1.46 thousand ton of CO2 emissions. This reflects the high intensity of the production-based CO2 emissions in these countries, as presented in Table 4.

Combining the data in Tables A2 and A3, we obtain the net emission transfers relating Brazilian states and foreign countries. São Paulo received a large net emission transfer from foreign countries in 2008 (20,046 thousand tons). In fact, from the countries depicted in Tables A2 and A3, São Paulo presented net imports with all of the (except Mexico, Spain, and France). On the other hand, Espírito Santo, Minas Gerais, and Pará were important net exporters of CO2 emissions to foreign countries. Especially Espírito Santo, which was a source of net emission transfers amounting in 7,107 thousand tons CO2. Considering the foreign trade partners, the BRICs and the group "Other + ROW" were sources of net emission transfers to almost every state in Brazil. China outstands, presenting a total net emission transfer of 23,327 thousand tons to Brazilian states. On the other hand, the countries from UE27 and the USA were net importers of CO2 emissions in Brazil as a whole.

4. Concluding Remarks

The emergence of the global value chains, resulting in many of today's products and services being no longer produced within a single country, raises many relevant questions. Among them, what are the environmental effects of fragmentation of production, including those with global scale, such as the emission of GHGs? Given the inter-regional fragmentation of production, these questions also apply at the regional level, and perhaps even to a larger extent. The present paper aimed to contribute to this discussion, analyzing the CO2 emissions in the Brazilian states in the context of global and domestic value chains.

Since the fragmentation of production processes leads to an interdependent structure which has to be accounted for, the input-output methodology is especially suitable. In our analysis, we combined a world input-output table with an inter-regional input-output table. From this we obtained a model covering the interdependence of 27 Brazilian states and 40 other countries (with the rest of the world as a country) in 2008, with the economic structures and corresponding CO2 emissions arranged in 28 industries.

A central finding of our analysis is that, next to 28% of global emissions being embodied in international trade, 36% of territorial emissions in Brazil were traded between states. Thus, international and inter-regional trade play an important role in emissions, and thus should be weighted in the elaboration of climate change policies.

The quantification of consumption-based emissions produces an alternative indicator to the territorial principle that guides the mitigation commitments in current international agreements. However, arguably it goes from an extreme to another, shifting the burden of mitigation entirely from producers (that benefit from economic activity in their territory) to finals consumers. As an intermediate solution, consumption-based indicators may help establishing differentiate commitments that are trade-adjusted, adhering to the principle of “common but differentiated responsibilities”. Also, consumption-based indicators can be used to identify priority mitigation activities under a “Clean Development Mechanism” in areas that are source of exports / outflows of CO2 emissions.

This is not possible under the current framework of subnational climate change policies in Brazil, which autonomously emerged and are fundamentally detached from each other. Since to achieve a nation-wide goal of mitigation inter-regional carbon leakage has to be taken into consideration, coordination among the interlinked economies is fundamental. In fact, a central arrangement is easier inside countries, than at global level, since the federal government can design policies gathering the subnational regions.

Our study indicated many heterogeneities among Brazilian states concerning CO2 emissions. There is great variation on production and consumption-based emission intensities, as well very different carbon contents in the inter-regional and international trade flows. Such points should be considered in the design of climate policies and they indicate possible paths for reducing emissions. For example, the existence of different production-based emission intensities brings out the possibility of technology transfers as mitigation strategy. The verification of decreasing consumption-based emissions as states become wealthier leads to questioning where it is due to better technology, structural change of what is consumed, or some other factor that can be appropriated by mitigation policies. Identifying the most important flows in inter-regional trade in emissions can ground environmental agreements between states. In this way, the present study may contribute to the elaboration of commitments based not only on political negotiations, but also in scientific and economic analysis.

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Annex

Table A1 – Inter-regional trade in CO_2 emissions (in thousand tons)

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
AC	-	0	2	4	2	0	1	1	7	3	2	4	5	1	1	2	7	3	2	2	3	12	14	30	7	6	12	135
AP	0	-	1	2	0	0	0	0	4	2	1	1	2	0	1	1	4	2	1	1	2	8	8	17	4	3	7	72
AM	12	13	-	136	46	9	20	28	172	84	60	47	116	38	33	44	161	97	72	42	91	352	532	1,509	171	134	221	4,238
PA	5	6	34	-	14	3	11	16	86	51	60	26	58	23	13	30	119	45	26	25	44	165	242	486	105	86	176	1,956
RO	6	2	36	17	-	1	2	5	31	13	15	8	17	6	5	7	53	14	10	11	22	63	76	161	42	22	69	713
RR	0	0	1	3	1	-	0	0	5	2	1	1	2	1	0	1	3	2	1	1	1	7	23	15	3	4	5	83
TO	1	2	7	23	3	1	-	3	24	16	21	7	14	7	4	5	31	18	5	6	11	57	51	95	18	14	36	479
AL	1	2	6	16	6	1	3	-	52	19	6	16	62	8	11	7	16	10	6	5	7	38	112	95	22	21	28	576
BA	18	20	85	177	54	10	37	80	-	189	107	102	285	77	103	98	272	166	100	86	165	588	692	1,778	323	293	389	6,296
CE	3	5	16	45	8	2	5	10	78	-	32	38	70	49	9	70	33	30	11	10	17	79	95	213	38	48	54	1,069
MA	12	9	35	176	29	6	39	26	200	85	-	39	85	83	16	43	108	88	60	23	40	365	244	480	103	80	138	2,613
PB	5	2	9	20	5	1	3	15	57	61	15	-	71	10	9	61	41	12	7	9	16	58	68	162	24	30	48	820
PE	7	9	40	82	21	5	14	82	372	206	76	213	-	50	45	98	158	56	34	37	71	221	289	662	117	93	216	3,274
PI	1	2	5	16	3	1	3	3	22	33	45	5	12	-	2	4	12	8	4	4	6	26	36	75	17	14	25	383
SE	3	4	16	27	10	2	6	23	142	36	24	15	42	14	-	16	87	37	14	17	31	108	145	309	55	45	118	1,344
RN	2	3	14	24	7	1	4	6	67	50	12	22	34	10	8	-	31	20	12	9	17	79	64	234	48	36	59	873
DF	4	7	15	44	18	2	13	7	80	25	12	21	25	17	6	14	-	127	11	12	18	209	387	205	34	39	51	1,402
GO	9	11	38	110	22	5	39	23	145	75	49	45	85	33	22	48	169	-	50	35	49	384	303	729	166	97	139	2,879
MT	10	15	60	134	50	5	16	26	204	86	62	60	95	46	27	41	98	74	-	64	55	280	598	672	258	131	171	3,337
MS	6	7	43	68	17	3	9	14	102	41	30	26	45	21	14	20	53	45	43	-	28	147	256	530	142	87	88	1,886
ES	18	18	117	185	52	10	36	55	440	155	101	83	222	59	57	82	248	219	115	82	-	817	1,013	2,543	429	272	395	7,826
MG	40	44	227	401	112	24	82	116	843	460	230	176	438	127	122	164	555	587	226	175	552	-	2,237	4,565	778	538	764	14,585
RJ	42	42	210	464	124	25	84	116	717	338	226	177	449	136	121	181	572	448	244	171	504	1,444	-	3,665	692	691	837	12,718
SP	95	117	499	1,082	310	54	183	262	1,932	769	440	435	971	334	232	403	1,320	1,032	548	432	630	3,702	5,535	-	1,807	1,317	2,141	26,581
PR	37	37	105	402	96	19	68	76	527	178	125	123	212	97	60	113	338	268	191	122	140	1,006	1,225	2,309	-	529	582	8,986
SC	24	26	98	271	63	13	45	63	387	172	136	90	196	74	58	86	295	183	106	99	150	683	835	1,675	716	-	721	7,265
RS	24	25	79	266	72	11	48	56	354	183	138	102	183	88	53	87	229	187	103	71	125	604	992	1,421	345	366	-	6,212
Total	384	430	1,800	4,194	1,145	212	769	1,114	7,050	3,330	2,027	1,884	3,794	1,410	1,034	1,726	5,012	3,778	2,005	1,550	2,796	11,500	16,075	24,635	6,463	4,995	7,490	118,602

Table A2 – Exports in CO2 emissions (in thousand tons), Brazilian states

	CHN	IND	RUS	USA	MEX	CAN	DEU	ESP	FRA	GBR	ITA	Other EU27	JPN	KOR	TWN	Other + RoW	Total
AC	3	0	1	3	0	0	2	1	1	2	1	3	1	0	0	12	31
AP	12	1	1	44	2	3	4	1	2	3	2	8	3	1	1	32	123
AM	56	8	14	137	28	16	52	15	24	24	23	74	20	8	4	362	864
PA	543	60	57	1,249	110	289	270	93	188	102	126	410	442	86	27	1,272	5,325
RO	14	1	23	21	2	3	11	6	6	11	8	21	6	2	1	86	224
RR	1	0	0	2	0	0	1	0	1	1	1	2	1	0	0	6	16
TO	25	1	6	12	1	2	7	12	5	4	3	15	4	1	0	44	142
AL	12	4	10	33	3	7	13	4	7	6	5	26	4	3	1	83	219
BA	406	50	66	911	168	89	422	101	166	137	220	537	134	48	25	1,465	4,946
CE	17	3	7	56	7	7	27	8	13	15	15	43	7	2	1	88	317
MA	208	26	27	460	58	48	90	57	56	44	48	165	75	24	10	633	2,030
PB	9	1	3	30	3	3	8	3	4	4	5	13	4	2	1	44	137
PE	54	9	16	150	19	20	50	17	25	30	24	83	21	8	4	328	857
PI	12	1	2	13	2	2	7	3	5	4	3	10	5	1	1	34	105
SE	21	3	5	51	6	5	16	6	8	8	8	36	8	3	1	125	308
RN	14	2	4	61	4	5	15	9	9	12	8	34	6	2	1	93	278
DF	14	1	5	24	3	3	19	4	7	8	9	29	9	2	1	67	205
GO	159	34	49	134	19	18	105	87	58	48	42	163	53	18	5	454	1,444
MT	375	14	52	168	13	23	107	107	80	79	71	254	59	39	10	745	2,197
MS	94	7	28	139	9	13	43	13	31	22	22	72	28	13	3	314	852
ES	722	93	114	2,484	279	176	393	192	217	164	231	590	436	383	138	2,630	9,241
MG	1,178	159	207	2,799	359	272	936	245	407	333	427	1,196	634	365	214	4,380	14,110
RJ	893	98	101	1,132	181	122	364	156	212	179	200	619	198	86	41	3,009	7,590
SP	847	118	257	2,157	330	244	830	249	404	349	365	1,255	336	137	70	5,261	13,209
PR	332	29	74	428	60	64	280	71	132	98	106	366	115	48	15	1,367	3,586
SC	185	25	60	425	62	58	175	53	85	90	80	263	127	31	12	1,225	2,957
RS	298	30	85	603	69	48	202	58	96	86	89	313	97	38	14	1,441	3,567
Total	6,502	778	1,274	13,725	1,798	1,542	4,448	1,569	2,249	1,862	2,143	6,601	2,834	1,353	601	25,600	74,880

Table A3 – Imports in CO2 emissions (in thousand tons), Brazilian states

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
CHN	33	69	1,976	499	187	19	117	138	1,341	544	263	356	610	197	130	184	544	625	230	341	769	2,579	2,589	10,044	2,226	1,718	1,499	29,829
IND	4	5	55	51	19	2	12	14	145	203	127	31	69	20	21	26	103	87	31	44	58	277	305	955	223	183	209	3,279
RUS	9	11	95	113	29	5	21	28	331	96	182	52	152	34	33	41	144	162	68	66	89	539	531	1,500	385	220	441	5,378
USA	15	20	193	249	48	9	35	51	405	158	163	81	262	53	62	76	264	242	91	102	165	792	1,159	3,043	534	352	519	9,141
MEX	1	1	24	10	3	1	2	2	40	9	7	5	26	3	3	4	15	11	5	5	13	53	55	208	62	25	37	630
CAN	6	7	44	62	17	3	12	19	129	58	41	29	86	20	17	25	89	114	42	39	54	363	304	777	215	105	184	2,861
DEU	9	10	77	88	27	6	18	19	160	77	48	35	107	24	25	33	115	88	34	53	61	348	463	1,209	240	147	215	3,737
ESP	1	1	10	13	4	1	5	3	58	16	8	6	17	4	4	5	19	15	7	8	13	56	94	229	54	32	44	726
FRA	1	2	13	15	4	1	3	4	30	13	9	6	20	4	4	5	28	18	7	9	15	71	119	269	65	30	44	809
GBR	2	2	21	21	6	1	4	5	55	21	25	10	37	7	6	9	42	26	10	15	19	94	177	380	76	45	68	1,184
ITA	2	2	18	22	6	1	5	6	49	20	12	10	25	7	6	9	35	26	10	14	23	156	141	394	81	51	78	1,206
Other EU27	9	11	91	101	28	5	19	24	201	87	71	41	123	28	27	37	141	111	47	65	76	402	551	1,434	325	190	282	4,528
JPN	3	4	118	41	10	2	7	10	94	35	23	18	43	11	11	15	47	85	20	20	49	201	222	791	145	89	128	2,243
KOR	2	3	128	33	9	1	6	9	90	30	29	16	41	9	9	13	41	189	17	19	70	156	192	674	127	90	112	2,116
TWN	2	3	87	30	10	1	6	8	76	30	40	16	33	9	8	11	36	36	15	17	40	148	154	639	123	82	96	1,757
Other + RoW	60	74	630	764	203	36	146	183	2,290	696	770	363	1,174	227	215	283	1,005	951	410	485	617	3,065	3,778	10,709	2,426	1,758	3,239	36,558
Total	160	226	3,580	2,111	611	95	419	521	5,493	2,093	1,819	1,074	2,827	656	579	777	2,669	2,786	1,043	1,302	2,134	9,301	10,833	33,255	7,308	5,116	7,194	105,982