Construction subsystem and carbon dioxide emissions[1]

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Abstract

The Construction sector activities exponentially expanded during the last decades. This is a very particular sector because it is not only important for providing the people a place where to live and amenities for development through investment projects, but also it is employed as business by building promoters and house owners that use it as an asset for rent seeking. The Construction sector has a very heavy material base, and its production processes is very intensive in greenhouse gas terms, both through the primary inputs extraction as well as through the construction process.

The present paper analyzes the total, i.e. direct and indirect, carbon dioxide emissions generated by the Construction sector subsystem around the world emissions embodied in final demand (EEFD) through a multiregional input-output framework. The results show that the Construction sector total emissions are three times as high as its direct emissions. 19% of these emissions are embodied in imported inputs that are finally employed for satisfying the national's Construction sector final demand. When looking at the absolute value of emissions, China, USA, Japan, India, and Russia together represent two thirds of the Construction sector total pollution. The picture substantially changes when looking to per-capita emissions, dominated by small countries

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where the Construction sector has developed considerably, and many of their emissions are embodied in inputs imported from outside of their economy.

1. Motivation

The Construction sector has expanded exponentially during last decades. In the USA, around 20 million new privately owned houses units has been authorized between 1998 and 2010, representing 15% of the total housing units.[2] This trend can be generalized almost globally. Spain is a clear example of the drivers of building growth, where 5.4 million new housing units permits have been given during the same period (around 20% of total dwellings stock). However, the 2011 census showed that 13.7% of the total dwellings were empty (3.44 millions).[3] This depicts the double rationality behind the building sector. It has not been only considered as important for providing the people a place where to live, but also it is employed as business, both by building promoters as well as by owners that use it as an asset for rent seeking.

This double role makes the Construction sector to be controversial. On the one hand, housing is a human right, and a decent livelihood must be given to every people. On the other hand, it is a sector that involves many economic and political interests. It gives high profit margins, both through the investment in construction and selling, as well as for the owners of non developed land that is re classified as urban land. This makes this sector to be managed as an asset, where speculation plays a central role, and universal access is not always guarantee. It is also an attractive sector in political terms because it is intensive in non skilled labour. In this way, is a sector that allows combating unemployment easily, straight tackling non qualified workers that are less flexible to be reallocated across economic activities. These facts make governments to create financial instruments for promoting new house building, consequence of the dual pressure made by construction investors and individuals demand. Moreover, this sectors growth has a very heavy material base, and the production processes are very intensive in greenhouse gas terms, both through the primary inputs extraction as well as through the

[2] http://www.census.gov/compendia/statab/cats/construction_housing/housing_units_and_characteristics.html

[3] http://www.ine.es/censos2011_datos/cen11_datos_inicio.htm

construction process. This makes that despite the building sector can be very popular, it can be producing severe environmental pressure.

Bielsa and Duarte (2011) employ a vertical integration approach to analyze the size and linkages of the Spanish construction industry, and compares it with a group of eleven OECD countries for the year 2000. They find that the construction industry share in the whole employment and value added is bigger than in the other ´mature´ countries. This is contrary to Piertoforte and Gregori (2003) who show that the construction share tends to decrease in terms of gross output, value added and GNP when the economies grow. Aquaye and Duffy (2010) analyze the greenhouse gas emissions of the Irish construction sector in 2005. They found that 83% of total Irish construction emissions are indirectly produced (either inside the country or abroad). Given these very high shares of indirect emissions, they propose to motivate the provision of information to allow the design and specification of low-emissions materials followed by regulation of construction procurement to achieve maximum construction emissions standards. This would complement direct emissions mitigation through construction direct emission processes.

The present paper analyzes the carbon dioxide emissions generated by the Construction sector subsystem worldwide. Through input-output analysis, the Construction sector can be analyzed isolated from the rest of the economy without losing its interrelationship with the rest of the economy. Following the MRIO production based approach (Peters, 2008), total emissions (i.e. direct and indirect) produced for satisfying the Construction sector final demand e.g. in country A are accounted. This approach allows to distinguish between the domestic emissions and international emissions embodied in final demand. Domestic emissions are those that are directly produced by the Construction sector in a country A for satisfying its final demand, but also those indirect emissions that are consequence of producing inputs for this sector by other sectors of the same country. International emissions embodied in final demand are those emissions that are consequence of producing inputs in other countries different than country A, and that are imported and employed, directly or indirectly, for satisfying the Construction sector final demand of country A.

This emissions can be embodied in imports from country A, for satisfying the Construction sector final demand, as well as in inputs that are imported by other countries for later exporting inputs to country A, and that are going to be employed sooner or later for satisfying the Construction sector final demand of country A. Moreover, the final demand includes both, domestic final demand as well as exports. This differs from the carbon footprint analysis, because it does not include the emissions that are consequence of the consumers in country A. When computing the carbon footprint, the emissions that are embodied in the Construction sector exports are extracted, and the emissions embodied in the production of the Construction sector somewhere else consumed in country A are added.

In the MRIO literature, the term 'production based' approach is usually linked to the concept of territorial GHG emissions (or domestic emissions). In this sense, the term 'MRIO production-based accounting' might be misleading. For avoiding confusions, along this paper this concept is going to be referred as 'emissions embodied in final demand' (EEFD). The EEFD allocates the emissions responsibility in the sector (and country) that produces the product that is destined to final demand (independently of whoever consumes it). But it also accounts for imported emissions. I think that this is the more appropriate approach because the construction final output is mainly destined to domestic final demand, by the time that mitigation policies are mostly designed at a national level. In this sense, the MRIO production approach allows to distinguish in which sectors technological and better practices improvements are going to be useful, but also to incentive inputs substitution from both, domestic and imported inputs. Trade instruments can be employed in the last case.

Next section depicts the methodology to be employed. The third section presents the data and results. The conclusions are presented in the last section.

2. Methodology

The present section introduces the subsystem concept into the multiregional input-output analysis. Then, the environmental extension of this model is shown.

The subsystem analysis and the multiregional input-output concept

Sometimes it is relevant to focus on some specific sectors, and not to analyze the environmental impact of the whole economic system. This allows the study of their relationship with the environment with greater complexity, without losing their linkages with the entire production system (Alcántara, 1995). Sraffa (1966) calls a *subsystem* a smaller self-replacing system of which the net product consists of only one kind of commodity. This concept can be straight translated to a symmetric input – output analysis, because this benchmark assumes that each branch produces only one output. In this way, the study of the structure of each of the industries involved in the economic system can be done, providing a greater level of disaggregation of the linkages between those branches within the subsystem and between the subsystem branches and the rest of the economy (Alcántara and Padilla, 2009; Navarro and Alcántara, 2010).

Subsystem analysis of the relationship between the productive structure and the environment was first proposed by Alcántara (1995), who applied it to sulfur dioxide, nitrogen oxides and volatile organic compound emissions in Spain in 1985 through additive decomposition of the emissions generated by each industry into five components: i) scale; ii) feedback; iii) own; iv) spillover; and v) the spillover of the rest of the economy. Alternative additive decompositions were employed to analyze the environmental impact in water resources pollution in Aragon, Spain, in 1995 by Sánchez-Chóliz and Duarte (2003), carbon dioxide emissions in the services subsystem in Spain in 2000 by Alcántara and Padilla (2009), methane emissions in the agricultural and food industry in Catalonia, Spain, in 2001 by Navarro and Alcántara (2010) and six greenhouse gases in Ireland in 2005 by Llop and Tol (2012). Multiplicative decomposition derived from the Miyazawa (1966, 1968, 1971) multipliers was employed by Fritz et al. (1998) to analyze how the subsystem of non-polluting sectors influenced the emissions of air polluting sectors in the Chicago region through a structural decomposition analysis between 1975 and 2010.

However, all the above applications analyses a specific subsystem of an economy, and its relationship with the rest of the same national economy, without considering its relationship with the rest of the world. In this paper, I look to integrate the subsystem concept in the multi-regional input-output analysis (MRIO).

A specific subsystem can be considered as a sub-national region. In this context, the regular methodological MRIO can be employed, where one of the regions considered is the subsystem of interest of a specific country. Only some considerations about the final demand components must be done. In the present paper the method employed by Peters (2008) is followed.[4]

For the sake of simplicity, the assumption that each region is a specific country is made ($\forall\, r = s = 1 \ldots m$). Countries are denoted by superscripts. Departing from the Leontief (1936) identity, the output vector of region *r*, $\boldsymbol{x}^r$, can be written as:

(1) $$\boldsymbol{x}^r = \boldsymbol{A}^{rr}\boldsymbol{x}^r + \boldsymbol{y}^{rr} + \sum_{s \neq r} \boldsymbol{A}^{rs}\boldsymbol{x}^s + \sum_{s \neq r} \boldsymbol{y}^{rs}$$

Where $\boldsymbol{A}^{rr}$ is a squared matrix that represents the interindustry requirements of domestically produced products in region *r*, $\boldsymbol{y}^{rr}$ is a vector that represents domestic final consumption (households, governments, and capital). $\boldsymbol{A}^{rs}$ is a matrix that represents the interindustry requirements of exported products from region *r* to region *s*, and $\boldsymbol{y}^{rs}$ is a vector that accounts for final consumption from region *r* to region *s*.

[4] But some changes on notation for allowing a more clear reading is made. Elements in **bold** denote vectors and matrices (lower case and upper case, respectively), while the scalars are expressed in plain text. In turn, the ^ symbol over a vector element refers to a diagonal matrix composed of the specified vector.

This can be generalized considering m regions, and the expression that considers the equation in each region can be obtained through a partitioned matrix.

(2) $$\begin{pmatrix} \boldsymbol{x}^1 \\ \boldsymbol{x}^2 \\ \boldsymbol{x}^3 \\ \vdots \\ \boldsymbol{x}^m \end{pmatrix} = \begin{pmatrix} \boldsymbol{A}^{11} & \boldsymbol{A}^{12} & \boldsymbol{A}^{13} & \dots & \boldsymbol{A}^{1m} \\ \boldsymbol{A}^{21} & \boldsymbol{A}^{22} & \boldsymbol{A}^{23} & \dots & \boldsymbol{A}^{2m} \\ \boldsymbol{A}^{31} & \boldsymbol{A}^{32} & \boldsymbol{A}^{33} & \cdots & \boldsymbol{A}^{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}^{m1} & \boldsymbol{A}^{m2} & \boldsymbol{A}^{m3} & \dots & \boldsymbol{A}^{mm} \end{pmatrix} \begin{pmatrix} \boldsymbol{x}^1 \\ \boldsymbol{x}^2 \\ \boldsymbol{x}^3 \\ \vdots \\ \boldsymbol{x}^m \end{pmatrix} + \begin{pmatrix} \sum_r \boldsymbol{y}^{1r} \\ \sum_r \boldsymbol{y}^{2r} \\ \sum_r \boldsymbol{y}^{3r} \\ \vdots \\ \sum_r \boldsymbol{y}^{mr} \end{pmatrix}$$

As exposed before, sometimes it would be relevant to look into detail to the linkages of a specific subsystem of a certain economy (e.g. the construction subsystem). In this way, equation (2) can be expressed partitioning the national matrix of interest. Let's consider that we want to look into detail to the subsystem p of country 1, while the rest of the economy of country 1 is denoted as q: Subsystems are denoted by subscripts for distinguishing them from regions.

(3)

$$\begin{pmatrix} \boldsymbol{x}_p^1 \\ \boldsymbol{x}_q^1 \\ \boldsymbol{x}^2 \\ \boldsymbol{x}^3 \\ \vdots \\ \boldsymbol{x}^m \end{pmatrix} = \begin{pmatrix} \boldsymbol{A}_{pp}^{11} & \boldsymbol{A}_{pq}^{11} & \boldsymbol{A}_p^{12} & \boldsymbol{A}_p^{13} & \dots & \boldsymbol{A}_p^{1m} \\ \boldsymbol{A}_{qp}^{11} & \boldsymbol{A}_{qq}^{11} & \boldsymbol{A}_q^{12} & \boldsymbol{A}_q^{13} & \dots & \boldsymbol{A}_q^{1m} \\ \boldsymbol{A}_p^{21} & \boldsymbol{A}_q^{21} & \boldsymbol{A}^{22} & \boldsymbol{A}^{23} & \dots & \boldsymbol{A}^{2m} \\ \boldsymbol{A}_p^{31} & \boldsymbol{A}_q^{31} & \boldsymbol{A}^{32} & \boldsymbol{A}^{33} & \dots & \boldsymbol{A}^{3m} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_p^{m1} & \boldsymbol{A}_q^{m1} & \boldsymbol{A}^{m2} & \boldsymbol{A}^{m3} & \dots & \boldsymbol{A}^{mm} \end{pmatrix} \begin{pmatrix} \boldsymbol{x}_p^1 \\ \boldsymbol{x}_q^1 \\ \boldsymbol{x}^2 \\ \boldsymbol{x}^3 \\ \vdots \\ \boldsymbol{x}^m \end{pmatrix} + \begin{pmatrix} \sum_r y_p^{1r} \\ \sum_r y_q^{1r} \\ \sum_r y^{2r} \\ \sum_r y^{3r} \\ \vdots \\ \sum_r y^{mr} \end{pmatrix}$$

From above, $\boldsymbol{A}_{pp}^{11}, \boldsymbol{A}_{pq}^{11}$, $\boldsymbol{A}_{qp}^{11}$, and $\boldsymbol{A}_{qq}^{11}$ represents the domestic interindustry requirements of country 1, allowing to consider separately the interindustry linkages of the branches of the subsystem considered the other sectors of the economy. Also, $\sum_r y_p^{1r} = y_p^{11} + y_p^{12} + y_p^{13} + \cdots + y_p^{1r}$ depicts total final consumption of the subsystem considered. It is worth to note that the national final demand for goods of the subsystem considered is only y_p^{11}, and $y_q^{11} = 0$ in this equation, because the subsystem considered cannot provide goods that it do not produce to its domestic final demand (see Appendix 2 for a clarification on the construction of the final demand vector in a subsystem in a MRIO model). The other $y_p^{13} + \cdots + y_p^{1m}$ are exports of the national economy considered of goods produced by the subsystem considered to the rest of the world. Also $y_q^{11} = 0$ in the second equation, because the rest of the economy of country 1 cannot sell goods that are produced by the subsystem to its domestic final demand (see Appendix 2 for a clarification on the construction of the final demand vector in a subsystem in a MRIO model).

The solution to the system of equations above is given by:

$$(4) \quad \begin{pmatrix} \boldsymbol{x_p^1} \\ \boldsymbol{x_q^1} \\ \boldsymbol{x^2} \\ \boldsymbol{x^3} \\ \vdots \\ \boldsymbol{x^m} \end{pmatrix} = \begin{pmatrix} \boldsymbol{L_{pp}^{11}} & \boldsymbol{L_{pq}^{11}} & \boldsymbol{L_p^{12}} & \boldsymbol{L_p^{13}} & \cdots & \boldsymbol{L_p^{1m}} \\ \boldsymbol{L_{qp}^{11}} & \boldsymbol{L_{qq}^{11}} & \boldsymbol{L_q^{12}} & \boldsymbol{L_q^{13}} & \cdots & \boldsymbol{L_q^{1m}} \\ \boldsymbol{L_p^{21}} & \boldsymbol{L_q^{21}} & \boldsymbol{L^{22}} & \boldsymbol{L^{23}} & \cdots & \boldsymbol{L^{2m}} \\ \boldsymbol{L_p^{31}} & \boldsymbol{L_q^{31}} & \boldsymbol{L^{32}} & \boldsymbol{L^{33}} & \cdots & \boldsymbol{L^{3m}} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{L_p^{m1}} & \boldsymbol{L_q^{m1}} & \boldsymbol{L^{m2}} & \boldsymbol{L^{m3}} & \cdots & \boldsymbol{L^{mm}} \end{pmatrix} \begin{pmatrix} \sum_r y_p^{1r} \\ \sum_r y_q^{1r} \\ \sum_r y^{2r} \\ \sum_r y^{3r} \\ \vdots \\ \sum_r y^{mr} \end{pmatrix}$$

Where $\boldsymbol{L}$ is the Leontief inverse matrix.

Emissions embodied in final demand - EEFD through and environmentally-extended MRIO

Lets define $\boldsymbol{f}' = \begin{pmatrix} \boldsymbol{f}_p^1 & \boldsymbol{f}_q^1 & \boldsymbol{f}^2 & \boldsymbol{f}^3 & \dots & \boldsymbol{f}^m \end{pmatrix}'$ a vector of emissions per unit of output for the two subsystems of country 1, and for every other country of the multi regional model. From this, we can define:

(5)
$$\boldsymbol{F} = \begin{pmatrix} \widehat{\boldsymbol{f}_p^1} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \dots & \boldsymbol{0} \\ \boldsymbol{0} & \widehat{\boldsymbol{f}_p^1} & \boldsymbol{0} & \boldsymbol{0} & \dots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \widehat{\boldsymbol{f}^2} & \boldsymbol{0} & \dots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \widehat{\boldsymbol{f}^3} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \dots & \widehat{\boldsymbol{f}^m} \end{pmatrix} \begin{pmatrix} \boldsymbol{L}_{pp}^{11} & \boldsymbol{L}_{pq}^{11} & \boldsymbol{L}_p^{12} & \boldsymbol{L}_p^{13} & \dots & \boldsymbol{L}_p^{1m} \\ \boldsymbol{L}_{qp}^{11} & \boldsymbol{L}_{qq}^{11} & \boldsymbol{L}_q^{12} & \boldsymbol{L}_q^{13} & \dots & \boldsymbol{L}_q^{1m} \\ \boldsymbol{L}_p^{21} & \boldsymbol{L}_q^{21} & \boldsymbol{L}^{22} & \boldsymbol{L}^{23} & \dots & \boldsymbol{L}^{2m} \\ \boldsymbol{L}_p^{31} & \boldsymbol{L}_q^{31} & \boldsymbol{L}^{32} & \boldsymbol{L}^{33} & \dots & \boldsymbol{L}^{3m} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{L}_p^{m1} & \boldsymbol{L}_q^{m1} & \boldsymbol{L}^{m2} & \boldsymbol{L}^{m3} & \dots & \boldsymbol{L}^{mm} \end{pmatrix} =$$
$$\begin{pmatrix} \boldsymbol{F}_{pp}^{11} & \boldsymbol{F}_{pq}^{11} & \boldsymbol{F}_p^{12} & \boldsymbol{F}_p^{13} & \dots & \boldsymbol{F}_p^{1m} \\ \boldsymbol{F}_{qp}^{11} & \boldsymbol{F}_{qq}^{11} & \boldsymbol{F}_q^{12} & \boldsymbol{F}_q^{13} & \dots & \boldsymbol{F}_q^{1m} \\ \boldsymbol{F}_p^{21} & \boldsymbol{F}_q^{21} & \boldsymbol{F}^{22} & \boldsymbol{F}^{23} & \dots & \boldsymbol{F}^{2m} \\ \boldsymbol{F}_p^{31} & \boldsymbol{F}_q^{31} & \boldsymbol{F}^{32} & \boldsymbol{F}^{33} & \dots & \boldsymbol{F}^{3m} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{F}_p^{m1} & \boldsymbol{F}_q^{m1} & \boldsymbol{F}^{m2} & \boldsymbol{F}^{m3} & \dots & \boldsymbol{F}^{mm} \end{pmatrix}$$

Matrix $\boldsymbol{F}$ is a linear operator that converts final demand increases into the emissions embodied on it. In this way, $\boldsymbol{F}^{rs}$ refers to the pollution per output unit produced in region *r* for attending region *s* final demand. Looking into detail to the elements of $\boldsymbol{F}^{rs}$, f_{ij}^{rs} denotes the pollution per unit of output produced by sector *i* from region *r* to satisfy final demand of sector *j* in region *s*. Pre multiplying each sub matrix by a conformable summation vector $\boldsymbol{u}$, we get a vector $\boldsymbol{e}^{rs\prime} = \boldsymbol{u}'\ \boldsymbol{F}^{rs}$ that accounts for the total (direct plus indirect) emissions per output unit produced in region *r* for every region *s* sector when increasing in one unit their final demand.

The MRIO analysis considers not only domestic emissions for attending national final demand, but also emissions contained in imported inputs. Consider $\boldsymbol{f}^r$ the vector of emissions per unit of output for each sector of region (subsystem) *r* exposed above. Let's consider the emissions produced by subsystem *p* in country 1. Given the output of this economy, the total (direct plus indirect) emissions produced for attending subsystem *p* of country 1 final demand is given by:

(6) $$e_p^1 = \boldsymbol{f}'(\boldsymbol{I}-\boldsymbol{A})^{-\mathbf{1}}\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}} = \boldsymbol{f}'\boldsymbol{L}\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}$$

Where $\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}} = \begin{pmatrix} \boldsymbol{y}_{\boldsymbol{p}}^{\mathbf{11}} + \sum_{s\neq 1}\boldsymbol{y}_{\boldsymbol{p}}^{\mathbf{1}s} \\ 0 \\ \vdots \\ 0 \end{pmatrix}$. Eq. (6) reflects the EEFD from subsystem *p* from country 1.

Also, the EEFD can be disentangled for every sector of subsystem *p* from country 1 diagonalizing the final demand vector, such that:

(7) $$\boldsymbol{e}_{\boldsymbol{p}}^{\mathbf{1}} = \boldsymbol{f}'(\boldsymbol{I}-\boldsymbol{A})^{-\mathbf{1}}\widehat{\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}} = \boldsymbol{f}'\boldsymbol{L}\widehat{\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}}$$

Eq. (7) describes the EEFD from each specific sector from subsystem *p* from country 1. The pollution can also be disentangled by its origin. That is, how much of the EEFD from the Construction subsystem (both direct and indirect), is consequence of its own production process, and how much of its EEFD is consequence of the inputs demanded to the rest of the economy, or to the rest of the world.

(8) $$e1_p{}' = \underbrace{\boldsymbol{u}'\ \boldsymbol{F}_{\boldsymbol{pp}}^{\mathbf{11}}\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}}_{\text{national own}} + \underbrace{\boldsymbol{u}'\ \boldsymbol{F}_{\boldsymbol{qp}}^{\mathbf{11}}\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}}_{\text{national spillover}} + \underbrace{\sum_s \boldsymbol{u}'\ \boldsymbol{F}_{\boldsymbol{p}}^{s\mathbf{1}}\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}}_{\text{international spillover}}$$

The *national own* component accounts for the pollution produced by subsystem *p* of country 1 for satisfying its final demand. The *national spillover* component accounts for the pollution that the subsystem *p* of country 1 makes the rest of the country 1 economy to produce. In this way, the domestic pollution for attending subsystem *p* of country 1 final demand is given by the sum of these two components. Finally, the *international spillover* component accounts for the pollution embodied in imports of intermediate inputs for attending subsystem *p* of country 1 final demand.

Again, each component can be computed for each specific sector of the subsystem of interest diagonalizing vector $\boldsymbol{g}_{\boldsymbol{p}}^{\mathbf{1}}$.

3. Data and results

Data

The analysis was conducted employing the 25-sector common classification for 186 countries plus rest of the world Eora database (Lenzen et al., 2012, 2013). The subsystem analysis isolates the direct and indirect emissions of the Construction sector (14) for the year 2007. This year was chosen because the most recent global economic crisis, that had hard consequences for the building sectors didn't exploited yet.

The 25-sector common classification Eora database includes 25 sectors per country plus a sector that accounts for re-exports and re-imports. Recycling sector (12) from South Korea and Others sector (25) from Spain were removed because their elements were all null. This makes impossible to invert the matrix if they were kept. The Eora database provides information about intermediate transactions intra and inter-country, sectoral direct greenhouse gas emissions, final demand, and primary inputs. Population data for computing per capita emissions (for comparison porpoises) were taken from the World Development Indicators (World Bank, 2005). Because population data for British Virgin Islands, Netherlands Antilles, and Taiwan is not available, they were also removed from the final results.

The Construction subsystem CO_2 emissions

The total amount of carbon dioxide emissions from the productive sectors reached 30 million Gg in 2007. Direct emissions from the Construction sector represented 4.3% of total world emissions this year. When computing the EEFD from the Construction sector (adding the emissions produced by other sectors for providing inputs to it and subtracting the emissions produced by it when selling inputs to other sectors), its share in total world CO_2 emissions grows more than three times (Figure 1). 19% of these emissions are consequence of the international spillover, that is, emissions embodied in imported inputs for the Construction sector (directly or indirectly).

Figure 1: World and Construction sector CO_2 emissions in 2007

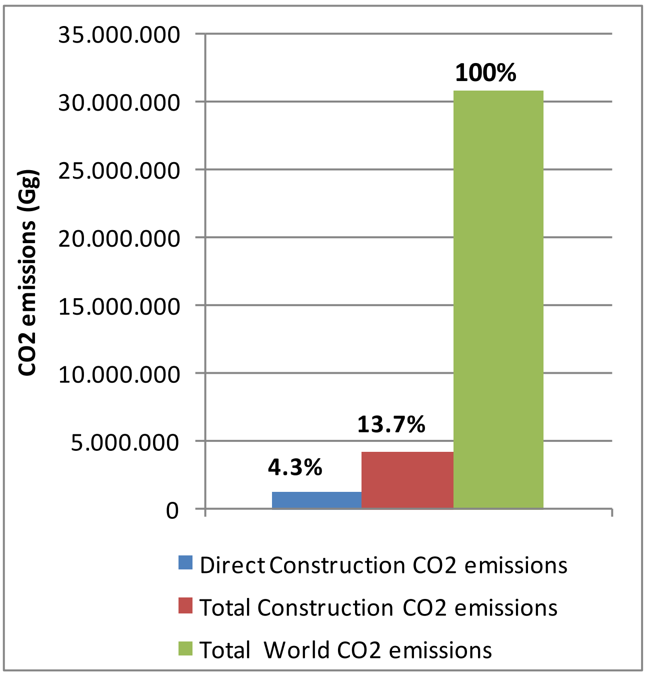
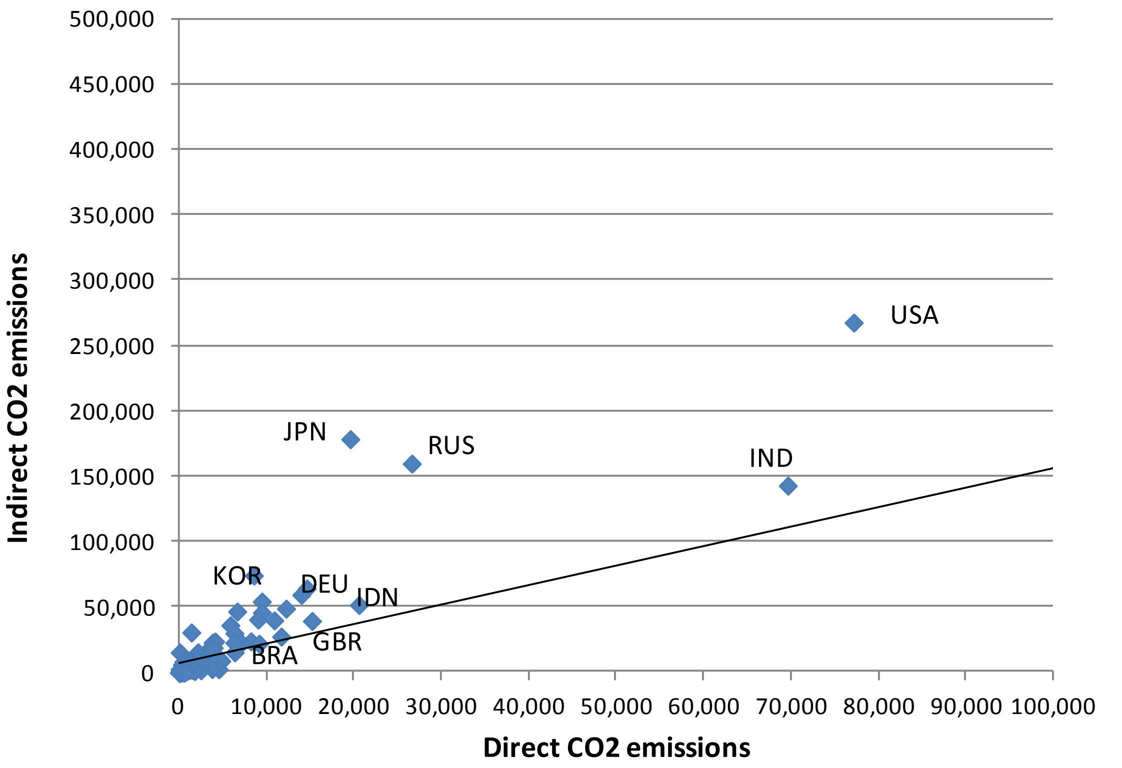


Table A1 in the Appendix shows direct and total CO_2 emissions from the Construction sector for each of the countries in the sample. China's emissions represent 62.3% of the direct emissions produced by this sector at the world level. Moreover, when considering the indirect emissions, China's Construction sector share descends to 45.3%. Similar is the case for India (from 5.2% to 4.6%). However, total EEFD from the Construction sector are higher than its direct emissions for all the countries (except for Belarus and Moldova). Figure 2 shows that apparently there exists a direct correlation between the direct and the indirect (both national plus international) emissions. This means that those direct polluters are also the main polluters when considering indirect emissions.

As was expected, the countries with higher share in Construction sector total pollution are those with a bigger scale in population and final demand expenditure (Figure 3, panel (a)). China, USA, Japan, India, and Russia together represent two thirds of the Construction sector total EEFD. However, there is a great dispersion in geographical and social aspects within the top 20 polluters.

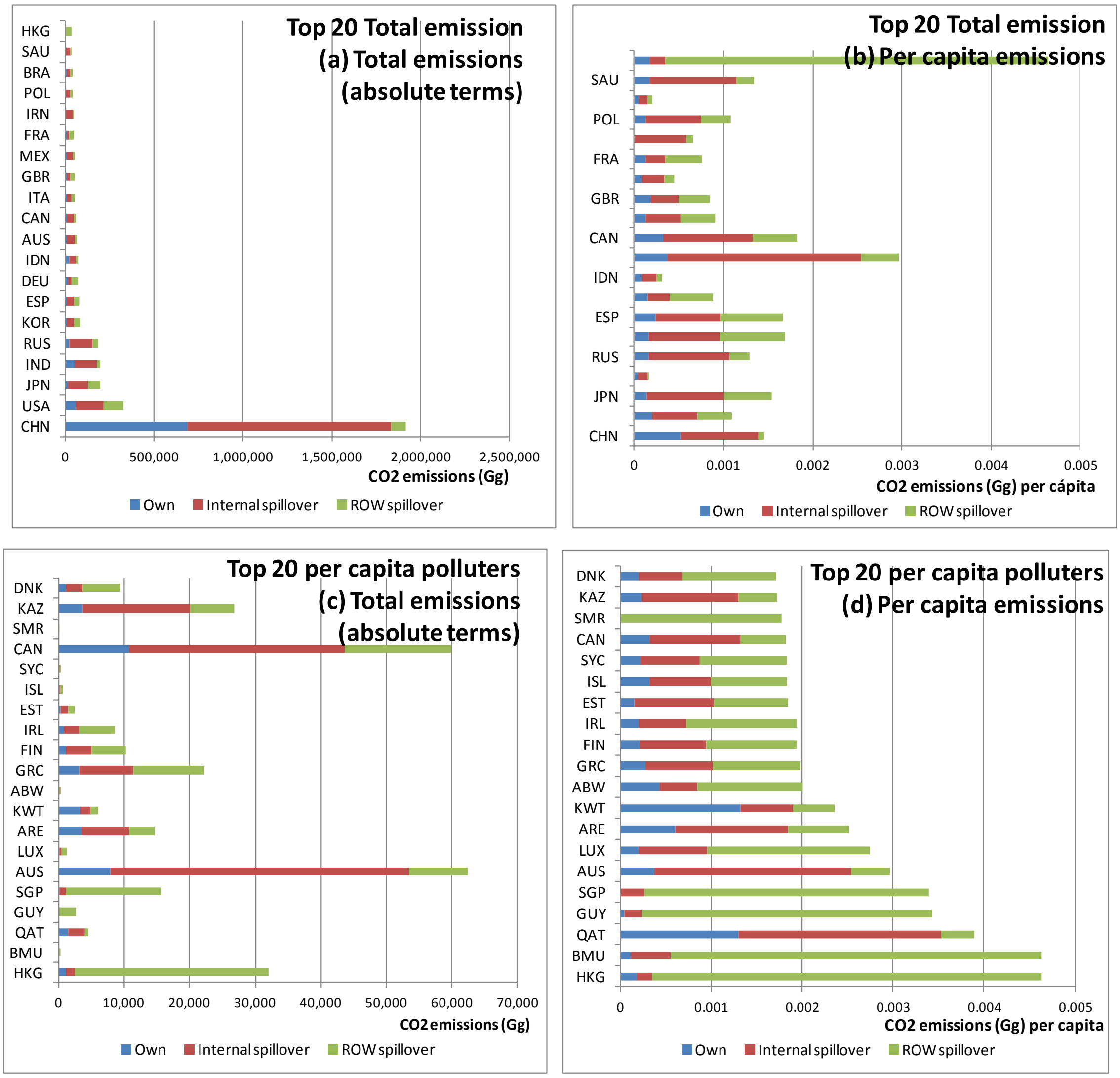
Figure 2: Direct and Indirect CO_2 emissions from the Construction sector, 186 countries



Note: China was not shwon in this Figure

When looking at per capita emissions, the picture is totally different. The top 20 countries in reference to per capita emissions are dominated by small countries where the Construction sector has developed considerably, but show an external dependency in inputs provision. This makes that many of their emissions are embodied in inputs imported from outside of their economy. This is a very interesting result, because they would not be identified without a MRIO analysis. There are only three countries that stay in both top 20 rankings: Australia, Canada, and Hong Kong (Figure 3, panel (b) and (d)). Slightly lower are the per capita emissions of other countries relevant because of the emissions of the Construction sector in absolute terms, like South Korea, Spain, Japan, South Africa, and China (Figure 3, panel (b)).

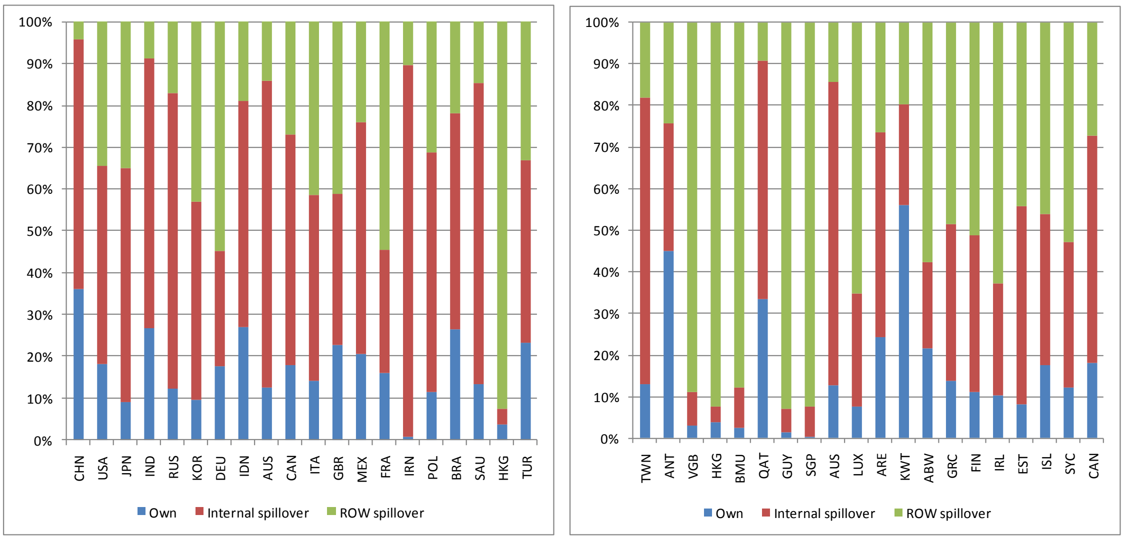
Figure 3: Top 20 countries in reference to total emissions (absolute terms) and Top 20 countries in reference to per capita emissions. Total and per capita emissions.



However, the international spillover component from Hong Kong is much more significant than in the case of Australia and Canada, where the domestic emissions of the Construction sector (both direct plus indirect) represents 85% and 73% respectively.

Looking to the components into detail, Figure 4 shows that the pattern between the main polluters in reference to the absolute value of total emissions is different from that of the main polluters in reference to per capita emissions. The share of the international spillover component is higher in the main per capita polluters. This result is reasonable, given that most of these countries has to import their inputs, given their resource scarcity.

Figure 4: Own, domestic spillover and international spillover share in total emissions for the Top 20 in total and per capita Construction sector emissions



Leaving Hong Kong aside, because of the reasons about the relevance of the international spillover component depicted above, the imported emissions are also very significant for Germany and France (55%), South Korea (43%), United Kingdom and Italy (41%), and USA and Japan (35%). The international spillover is not only important for those small countries that are scarce in raw materials, but also in big countries. In this sense, considering emissions embodied in imported inputs on mitigation policy design would not only have an effect on those small countries, but also on the emissions scale. This is a very important point looking for global emissions reduction.

4. Conclusions

The building sector grew exponentially during last decades. The construction of new houses has a double purpose of satisfying people's demand, but also as an asset for both, building promoters and owners that use it for rent seeking. The infrastructure construction also plays an important role in the growth of the construction sector. It also plays a double role, being important for providing amenities by the time that gives place to high benefit investment. This produces a pressure for developing these projects that not always is justified.

The astonishing growth of the construction sector has produces an important pressure on the environment. For example, land changes from rural to urban use. Also, it has a very heavy material base, and the production processes are very intensive in greenhouse gas terms, both through the primary inputs extraction as well as through the construction process.

Greenhouse gas emissions are not only produced during the construction process, but also while providing inputs and energy to it. Also, they can be produced by other sectors of the economy or abroad. In this paper we introduce the emissions embodied in final demand (EEFD) concept in the subsystem framework. It accounts for the emissions that are produced when, both directly and indirectly, and also in the country and abroad, for satisfying the final demand of the Construction subsystem. Results show that the inputs employed by the Construction sector passes through a long way until attending its final demand with a significant international spillover.

Given the important share the Construction sector in total world emissions (13% when indirect emissions are considered), it is a sector that should be seriously considered when thinking about emissions reduction goals. Technical improvements and better practices on the construction sector would help to diminish its own emissions. Also, inputs substitution for most environmental friendly materials as proposed by Acquaye and Duffy (2010), and the provision of cleaner energy would help to diminish the emissions associated to the spillover components.

Also important is to look at per capita EEFD. Despite measures on the Construction sector in these countries are not going to be very effective in absolute terms (except on those countries that are relevant in both measures), it can help to allocate responsibilities. In general, those countries show a high dependence on non-domestic resources. In this way, trade policies including environmental aspects, and encouraging inputs more environmentally friendly for the Construction sector can be a plausible approach for diminishing international spillover.

Finally, an important first step would be to ask ourselves which part of these emissions are really needed to be produced for satisfying people needs, and which part is consequence of the profitability of the sector that impulses projects that are not needed. If the first one is our target, directing credit for encouraging the second-hand house market, and implementing taxes that seriously discourages more than one residence property can be effective policies also.

5. Lines to follow

This paper is a first approach to analyze the environmental impact of the Construction sector considering the emissions embodied on imported inputs. The objective of this work is to get certification from the Input-Output School 2013. I took this as an opportunity to get in touch with the MRIO models, and show a simple application.

Looking for a further paper based in this work, the paper can be complemented including the following items:

- Include other sectors from a matrix with higher disaggregation level, for constructing a 'Building subsystem' containing also sectors related to Real Estate activities. Also in some countries would be possible to distinguish between residential and infrastructure.

- Extend the time period of analysis, and see change in the patterns of the emissions decomposition. A challenge when working with Eora is about valuation, because matrices are in current prices. I couldn't find how you did it in Wiedmann et al. (2013), but probably this strategy can be followed.

- Finally, I think that other relevant dimensions when studyng a sector or a group of sectors should be considered. In this case I think that value added, employment, and material use are particularly relevant.

- Also, for a journal paper we would have to have a closer look at the (IO and non-IO) literature on emissions from the construction sector so we can put your findings into context.

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Appendix

Table A1. Direct and Total CO_2 emissions from the Construction sector – 186 countries

Country		Direct CO2 emissions		Total CO2 emissions	
		Gigagram (Gg)	%	Gigagram (Gg)	%
Afghanistan	AFG	16.0	0.0%	214.6	0.0%
Albania	ALB	162.6	0.0%	904.6	0.0%
Algeria	DZA	1,488.5	0.1%	3,195.1	0.1%
Andorra	AND	20.7	0.0%	75.7	0.0%
Angola	AGO	628.4	0.0%	1,397.4	0.0%
Antigua	ATG	11.9	0.0%	77.8	0.0%
Argentina	ARG	4,814.6	0.4%	12,964.2	0.3%
Armenia	ARM	304.7	0.0%	472.3	0.0%
Aruba	ABW	50.3	0.0%	203.0	0.0%
Australia	AUS	9,455.0	0.7%	62,389.1	1.5%
Austria	AUT	1,850.8	0.1%	11,008.7	0.3%
Azerbaijan	AZE	719.9	0.1%	1,736.9	0.0%
Bahamas	BHS	64.2	0.0%	320.0	0.0%
Bahrain	BHR	650.4	0.0%	1,203.1	0.0%
Bangladesh	BGD	1,249.8	0.1%	3,832.9	0.1%
Barbados	BRB	26.0	0.0%	190.2	0.0%
Belarus	BLR	569.7	0.0%	9.2	0.0%
Belgium	BEL	3,252.9	0.2%	11,816.8	0.3%
Belize	BLZ	8.5	0.0%	78.0	0.0%
Benin	BEN	208.5	0.0%	521.8	0.0%
Bermuda	BMU	8.2	0.0%	300.8	0.0%
Bhutan	BTN	25.8	0.0%	96.2	0.0%
Bolivia	BOL	276.7	0.0%	987.6	0.0%
Bosnia and Herzegovina	BIH	360.1	0.0%	1,445.7	0.0%
Botswana	BWA	290.2	0.0%	1,179.1	0.0%
Brazil	BRA	11,666.3	0.9%	37,569.4	0.9%
British Virgin Islands	VGB	2.0	0.0%	44.7	0.0%
Brunei	BRN	200.6	0.0%	506.1	0.0%
Bulgaria	BGR	777.2	0.1%	2,403.0	0.1%
Burkina Faso	BFA	37.1	0.0%	120.5	0.0%
Burundi	BDI	61.1	0.0%	178.2	0.0%
Cambodia	KHM	2,471.9	0.2%	3,466.5	0.1%
Cameroon	CMR	224.7	0.0%	882.2	0.0%
Canada	CAN	12,216.6	0.9%	59,905.9	1.4%
Cape Verde	CPV	6.3	0.0%	58.6	0.0%
Cayman Islands	CYM	9.6	0.0%	84.2	0.0%
Central African Republic	CAF	64.1	0.0%	160.7	0.0%
Chad	TCD	10.3	0.0%	78.5	0.0%
Chile	CHL	2,672.4	0.2%	10,065.7	0.2%
China	CHN	835,952.3	62.4%	1,917,598.4	45.3%
Colombia	COL	2,075.9	0.2%	6,662.9	0.2%
Congo	COG	298.5	0.0%	709.6	0.0%
Costa Rica	CRI	180.4	0.0%	688.5	0.0%
Croatia	HRV	574.8	0.0%	2,189.4	0.1%
Cuba	CUB	635.9	0.0%	1,756.7	0.0%
Cyprus	CYP	256.8	0.0%	1,023.5	0.0%
Czech Republic	CZE	2,185.7	0.2%	11,250.7	0.3%

Country		Direct CO2 emissions		Total CO2 emissions	
		Gigagram (Gg)	%	Gigagram (Gg)	%
Cote dIvoire	CIV	107.7	0.0%	612.9	0.0%
North Korea	PRK	3,755.7	0.3%	5,262.7	0.1%
DR Congo	COD	109.8	0.0%	594.0	0.0%
Denmark	DNK	1,384.3	0.1%	9,344.0	0.2%
Djibouti	DJI	45.0	0.0%	132.2	0.0%
Dominican Republic	DOM	259.6	0.0%	1,480.5	0.0%
Ecuador	ECU	506.4	0.0%	2,171.2	0.1%
Egypt	EGY	4,287.0	0.3%	14,127.1	0.3%
El Salvador	SLV	185.5	0.0%	692.5	0.0%
Eritrea	ERI	10.0	0.0%	51.2	0.0%
Estonia	EST	269.0	0.0%	2,478.4	0.1%
Ethiopia	ETH	222.6	0.0%	717.7	0.0%
Fiji	FJI	62.3	0.0%	232.7	0.0%
Finland	FIN	1,396.1	0.1%	10,288.5	0.2%
France	FRA	9,019.1	0.7%	48,563.3	1.1%
French Polynesia	PYF	22.3	0.0%	137.1	0.0%
Gabon	GAB	88.4	0.0%	302.5	0.0%
Gambia	GMB	7.3	0.0%	48.3	0.0%
Georgia	GEO	313.4	0.0%	1,490.5	0.0%
Germany	DEU	13,967.1	1.0%	72,350.3	1.7%
Ghana	GHA	726.0	0.1%	2,150.6	0.1%
Greece	GRC	3,537.4	0.3%	22,215.8	0.5%
Greenland	GRL	0.0	0.0%	32.4	0.0%
Guatemala	GTM	349.7	0.0%	1,173.9	0.0%
Guinea	GIN	188.0	0.0%	480.2	0.0%
Guyana	GUY	45.1	0.0%	2,640.0	0.1%
Haiti	HTI	56.4	0.0%	144.3	0.0%
Honduras	HND	253.6	0.0%	848.8	0.0%
Hong Kong	HKG	1,382.9	0.1%	32,067.0	0.8%
Hungary	HUN	560.6	0.0%	6,675.3	0.2%
Iceland	ISL	126.9	0.0%	573.4	0.0%
India	IND	69,636.5	5.2%	195,658.1	4.6%
Indonesia	IDN	20,556.9	1.5%	71,168.8	1.7%
Iran	IRN	6,629.8	0.5%	47,279.1	1.1%
Iraq	IRQ	1,760.0	0.1%	2,614.1	0.1%
Ireland	IRL	983.4	0.1%	8,468.4	0.2%
Israel	ISR	311.1	0.0%	6,402.8	0.2%
Italy	ITA	9,464.5	0.7%	53,623.1	1.3%
Jamaica	JAM	169.9	0.0%	892.8	0.0%
Japan	JPN	19,573.1	1.5%	196,586.1	4.6%
Jordan	JOR	511.8	0.0%	1,907.2	0.0%
Kazakhstan	KAZ	3,828.3	0.3%	26,794.9	0.6%
Kenya	KEN	393.5	0.0%	2,716.2	0.1%
Kuwait	KWT	4,523.8	0.3%	6,022.8	0.1%
Kyrgyzstan	KGZ	148.4	0.0%	740.2	0.0%
Laos	LAO	228.4	0.0%	370.8	0.0%
Latvia	LVA	275.2	0.0%	1,950.6	0.0%

Country		Direct CO2 emissions		Total CO2 emissions	
		Gigagram (Gg)	%	Gigagram (Gg)	%
Lebanon	LBN	312.0	0.0%	1,346.6	0.0%
Lesotho	LSO	4.7	0.0%	175.0	0.0%
Liberia	LBR	18.7	0.0%	37.2	0.0%
Libya	LBY	507.5	0.0%	1,641.1	0.0%
Liechtenstein	LIE	0.0	0.0%	54.3	0.0%
Lithuania	LTU	320.8	0.0%	3,063.2	0.1%
Luxembourg	LUX	159.5	0.0%	1,317.5	0.0%
Macao SAR	MAC	44.6	0.0%	598.4	0.0%
Madagascar	MDG	66.6	0.0%	312.2	0.0%
Malawi	MWI	18.1	0.0%	171.5	0.0%
Malaysia	MYS	3,584.1	0.3%	20,906.5	0.5%
Maldives	MDV	27.5	0.0%	163.7	0.0%
Mali	MLI	188.3	0.0%	455.0	0.0%
Malta	MLT	9.1	0.0%	346.8	0.0%
Mauritania	MRT	42.4	0.0%	161.2	0.0%
Mauritius	MUS	181.1	0.0%	1,006.3	0.0%
Mexico	MEX	10,871.7	0.8%	50,464.7	1.2%
Monaco	MCO	0.0	0.0%	50.6	0.0%
Mongolia	MNG	140.1	0.0%	494.6	0.0%
Montenegro	MNE	76.2	0.0%	395.0	0.0%
Morocco	MAR	652.7	0.0%	3,392.3	0.1%
Mozambique	MOZ	126.1	0.0%	686.7	0.0%
Myanmar	MMR	336.6	0.0%	488.6	0.0%
Namibia	NAM	69.4	0.0%	458.2	0.0%
Nepal	NPL	91.5	0.0%	319.3	0.0%
Netherlands	NLD	6,340.2	0.5%	20,446.1	0.5%
Netherlands Antilles	ANT	443.1	0.0%	925.0	0.0%
New Caledonia	NCL	74.9	0.0%	285.3	0.0%
New Zealand	NZL	1,143.4	0.1%	5,573.7	0.1%
Nicaragua	NIC	102.6	0.0%	609.0	0.0%
Niger	NER	20.3	0.0%	115.6	0.0%
Nigeria	NGA	1,197.1	0.1%	2,933.0	0.1%
Norway	NOR	1,343.4	0.1%	4,882.6	0.1%
Gaza Strip	PSE	99.0	0.0%	574.3	0.0%
Oman	OMN	997.1	0.1%	3,251.8	0.1%
Pakistan	PAK	3,576.4	0.3%	10,097.1	0.2%
Panama	PAN	248.1	0.0%	1,048.2	0.0%
Papua New Guinea	PNG	103.0	0.0%	515.2	0.0%
Paraguay	PRY	33.1	0.0%	785.8	0.0%
Peru	PER	1,646.4	0.1%	7,633.4	0.2%
Philippines	PHL	1,045.5	0.1%	6,803.2	0.2%
Poland	POL	5,850.8	0.4%	41,144.2	1.0%
Portugal	PRT	2,435.9	0.2%	13,860.7	0.3%
Qatar	QAT	1,752.2	0.1%	4,482.1	0.1%
South Korea	KOR	8,541.7	0.6%	82,348.7	1.9%
Moldova	MDA	86.7	0.0%	19.4	0.0%
Romania	ROU	2,888.6	0.2%	12,586.1	0.3%

Country		Direct CO2 emissions		Total CO2 emissions	
		Gigagram (Gg)	%	Gigagram (Gg)	%
Russia	RUS	26.612,9	2,0%	182.713,3	4,3%
Rwanda	RWA	17,1	0,0%	102,5	0,0%
Samoa	WSM	2,1	0,0%	16,9	0,0%
San Marino	SMR	0,0	0,0%	53,7	0,0%
Sao Tome and Principe	STP	0,9	0,0%	17,1	0,0%
Saudi Arabia	SAU	6.316,6	0,5%	34.905,3	0,8%
Senegal	SEN	180,2	0,0%	973,1	0,0%
Serbia	SRB	1.687,3	0,1%	4.267,1	0,1%
Seychelles	SYC	23,4	0,0%	155,9	0,0%
Sierra Leone	SLE	141,0	0,0%	263,1	0,0%
Singapore	SGP	63,1	0,0%	15.586,8	0,4%
Slovakia	SVK	1.200,2	0,1%	6.308,9	0,1%
Slovenia	SVN	488,4	0,0%	2.931,8	0,1%
Somalia	SOM	12,3	0,0%	98,0	0,0%
South Africa	ZAF	9.131,8	0,7%	30.020,9	0,7%
Spain	ESP	14.598,0	1,1%	74.931,0	1,8%
Sri Lanka	LKA	201,2	0,0%	939,3	0,0%
Suriname	SUR	42,4	0,0%	231,5	0,0%
Swaziland	SWZ	15,8	0,0%	211,0	0,0%
Sweden	SWE	1.056,8	0,1%	5.664,0	0,1%
Switzerland	CHE	468,9	0,0%	8.773,3	0,2%
Syria	SYR	1.016,7	0,1%	3.644,2	0,1%
Taiwan	TWN	3.741,8	0,3%	20.811,3	0,5%
Tajikistan	TJK	99,7	0,0%	147,6	0,0%
Thailand	THA	4.108,7	0,3%	27.932,5	0,7%
TFYR Macedonia	MKD	482,8	0,0%	1.913,7	0,0%
Togo	TGO	381,8	0,0%	704,1	0,0%
Trinidad and Tobago	TTO	868,4	0,1%	1.609,5	0,0%
Tunisia	TUN	464,8	0,0%	2.582,1	0,1%
Turkey	TUR	8.193,9	0,6%	31.372,9	0,7%
Turkmenistan	TKM	458,5	0,0%	1.842,0	0,0%
Uganda	UGA	44,2	0,0%	423,7	0,0%
Ukraine	UKR	6.308,1	0,5%	28.945,2	0,7%
UAE	ARE	4.551,8	0,3%	14.586,0	0,3%
UK	GBR	15.190,6	1,1%	51.334,4	1,2%
Tanzania	TZA	173,5	0,0%	600,8	0,0%
USA	USA	77.171,9	5,8%	328.053,8	7,7%
Uruguay	URY	254,8	0,0%	947,6	0,0%
Uzbekistan	UZB	2.140,1	0,2%	17.747,4	0,4%
Vanuatu	VUT	1,5	0,0%	31,9	0,0%
Venezuela	VEN	7.094,9	0,5%	29.013,5	0,7%
Viet Nam	VNM	3.951,6	0,3%	22.692,7	0,5%
Yemen	YEM	337,5	0,0%	1.381,9	0,0%
Zambia	ZMB	88,4	0,0%	349,7	0,0%
Zimbabwe	ZWE	190,7	0,0%	850,0	0,0%
Total Construction		1.338.730,4	4,3%	4.237.198,9	13,7%
Total		30.854.000,8			

Appendix 2

Lets illustrate why $y_q^{11} = 0$ and $y_q^{11} = 0$ in the first and second equation, respectively, that emerges from equation (3) with an example for a single country with five productive sectors.

The transactions matrix of a five sectors single country would look like this:

	1	2	3	4	5	Y
1	T11	T12	T13	T14	T15	Y1
2	T21	T22	T23	T24	T25	Y2
3	T31	T32	T33	T34	T35	Y3
4	T41	T42	T43	T44	T45	Y4
5	T51	T52	T53	T54	T55	Y5
PI	PI1	PI2	PI3	PI4	PI5	

where Tij denotes for the inputs from sector *i* that are bought by sector *j*, PI are the primary inputs, and Y is the final demand. Now, imagine the we want to concentrate in a subsystem containing sector 1 and 2. For notation following the notation in the MRIO, treating the subsystem as if it were a region, the final demand vector needs to be split in a vector that only contains the elements of the final demand corresponding to the sectors 1 and 2, and a vector that contains all the other sectors. In this case, subsystem *q* contains sectors 1 and 2, and the rest of the economy, *p*, contains sectors 3 to 5.

	1	2	3	4	5	Yq	Yp
1	T11	T12	T13	T14	T15	Y1	0
2	T21	T22	T23	T24	T25	Y2	0
3	T31	T32	T33	T34	T35	0	Y3
4	T41	T42	T43	T44	T45	0	Y4
5	T51	T52	T53	T54	T55	0	Y5
PI	PI1	PI2	PI3	PI4	PI5		

This is because the final demand of a country that is destined to subsystem *q* cannot have any element of the rest of the national economy. When introducing the subsystem as a region, demand vector needs to be linked to that "region".