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Análisis estructural de los cinco mayores emisores en el G2

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STRUCTURAL ANALYSIS OF THE TOP FIVE MOST GHG EMITTING ECONOMIES

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Abstract

In this paper, we analyze the economies of the five most GHG emitting countries in 2011, according to the data from the World Bank. These countries signed the Paris Agreement on Climate Change in December of 2015, and participated in the Conference of the Parties, of the United Nations Framework Convention for Climate Change (UNFCCC) in which they established their goals for GHG emissions reduction, called Intended National Determined Contributions (INDC).

The purpose of studying these five countries has been concentrated on analyzing the trends their GHG emissions will follow from 2011 to 2030. In order to accomplish this objective, we have used some techniques derived from Structural Analysis or Input-Output Analysis. These I-O techniques allowed us to determine which sectors of the five economies can be considered *key* sectors. Also, we could establish through these techniques what sectors were the higher GHG emitting ones in each of the economies under study.

We built an Environmental Input-Output model, with the purpose of forecasting GHG emissions of each of the five economies, under two alternative scenarios. One of the scenarios was the so-called “Business as usual” (BAU), which means doing nothing to reduce GHG emissions. The other scenario utilized a different Input-Output Matrix (IOM), one which was modified to incorporate a technological change in four selected sectors. That is, we *simulate* a technical change in the selected five economies.

The results were that three countries, the USA, Russia and Japan established clear and feasible goals for 2030 and their targets trends suggest they will be applying mitigation policies that consist in technological changes in sectors that are key or high emitting sectors, or both, like the ones we chose for the study. China’s committed goals for 2030 are very low as compared to the other four countries, relatively speaking. Our simulated forecasting of GHG emissions reduction through technical change is above the level they are committed to reach. India, is not committed to reduce the absolute GHG emissions level, so in order to actually reduce this level of emissions for 2030, it becomes clear that they should apply a technological change.

Key words: Green House Gasses, Climate Change, Input-Output, Technological Change
JEL Code: C67, Q54, Q55

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Introduction

On December 12, 2015, the United Nations Framework Convention on Climate Change (UNFCC) –made up of 196 country members– adopted the Paris Agreement text (UNFCC, 2015). The main purpose of the agreement is to preventing the increase in the planet's temperature bellow 2°C, with respect to the pre-industrial age level and keep on working to limit this rise to 1.5°C. The idea is that by the end of this century, the planet's temperature should not be higher than 1.5°C, with respect to the pre-Industrial Revolution level. The difference with respect to the Kyoto 1997 Protocol, is that by 2020 all parties which signed the agreement have the obligation of explaining, each one of them, what measures are they implementing to actually reduce GHG emissions.

Based on previously produced works on this matter with the same approach (Ruiz-Nápoles, 2011, 2012, 2013; Ruiz-Nápoles and Puchet-Anyul, 2014), we will be analyzing the 2011 top five economies that produced 50 per cent of GHG global emissions, which are China, the US, India, Russia and Japan.

We are building and developing an Environmental Input-Output (EIO) model of each one of these economies for the purpose of analyzing the effects of a change in technology in some of the key sectors in each economy, identified as both strategic and highly GHG emitters. The period in which this impact analysis is studied goes from 2011 to 2030. The main idea is to find out to what extent the use of more efficient technologies in key economic sectors, makes the reduction of GHG emissions possible under a scenario of GDP growth predicted by the OECD for these countries.

The work is divided into five sections apart from this introduction. In the first section, we discuss Climate Change, and its relation to economic activities. In the second, we present the Environmental Input-Output type models. In the third section, we present our EIO model and show the five countries committed GHG reductions for 2030 under the *Paris Agreement*. In the fourth section, we study the economic structure of the selected countries, their key and higher GHG emitting sectors. And, in the fifth section, we use the I-O model for estimating the five countries' GHG emissions in the long-run, first in a business as usual (BAU) scenario and then with the introduction of technological changes in selected sectors of the five countries for estimating their GHG long-run emissions. These trends are presented along with those trends consistent with the targeted GHG emissions, committed under the agreement for each country.

It must be said from the beginning that, although most of the information we are using here may be called hard data since it comes from official sources and has been subject to verification, the resulting forecasted data and the simulations only indicate tendencies subject to assumptions and not real values, as in any other model interpreting the economic reality.

1. ANTHROPOGENIC CLIMATE CHANGE AND MITIGATION POLICIES

Anthropogenic climate change is defined as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (IPCC, 2007, Annex II). It is in part the result of the atmospheric concentrations of greenhouse gases (GHG). They are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Besides CO_2, N_2O and CH_4, the Kyoto Protocol deals with the GHG Sulphur hexafluoride (SF_6), hydro-fluorocarbons (HFCs) and per-fluorocarbons (PFCs), (IPCC, 2007, Annex II). GHG are primarily produced by the combustion of fossil fuels, agriculture, land-use changes and production of materials such as cement, as well as the burning of waste.

Climate Change consists of a gradual increase in the planet's temperature, rise in sea levels and changes in its rainfall patterns, as well as in the frequency, magnitude and intensity of extreme weather events such as droughts and floods. Although this tendency has been scientifically verified, there is still some degree of uncertainty about the magnitude and velocity of these changes at a regional scale. However, based on the current state of knowledge it is possible to identify some of the cause-effect chain relations between GHG sources, GHG emissions, global warming and its climatic consequences.

This has allowed some economists to foresee various future scenarios for the economy, based on which we can assess, from an economic perspective, the possible consequences of climate change and the alternative options for adaptation and mitigation policies, in order to face the problem.

Mitigation has been defined as: "the technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to Climate Change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks" (IPCC, 2007, Annex II). However, as some expert has pointed out it is not only emissions intensity reduction (*i.e.*, GHG emissions per unit of output) but also absolute emissions reduction which is important in mitigation.

Mitigation policies aim to the reduction of fossils fuels consumption and substitution, towards low-carbon sources (and the capture and storage of carbon from emissions) therefore the factors that causes it must be dealt with. These factors are mainly: population dynamics, urbanization, production and consumption increases; energy efficiency and technology innovation tendencies, as well as the economic structure, in each country. All these factors are related to economic activity: production, trading, consumption and investment.

From an economic perspective, in order to design a mitigation scenario, it is necessary to identify those economic sectors of production, or industries, which directly or indirectly generate GHG emissions becoming, therefore, the sectors that call for special attention; these are key sectors for mitigation. This can be seen as a supply-side view, though, since there is also a demand-side of the problem which is related to consumption, investment and exporting and could also be subject to mitigation policy actions.

In turn, the costs of mitigation measures depend on various local circumstances, for example, in the case of production, the specific form of economic growth and the introduction of technology developments in the production process aimed to reduce GHG emissions. Besides, climate change mitigation impacts are unevenly distributed among sectors and depend on the direct or indirect use of fossil fuels combustion of each and every sector of the economy. In short, the economic costs of climate change mitigation depend fundamentally on both, the energy-use intensities of economic sectors and industries, and the absolute value of their corresponding GHG emissions. These two are associated with the technological characteristics of their respective processes of production.

Economic models of different types deal with various aspects of Climate Change mitigation policies, or with the same aspects but using different approaches and inbuilt assumptions (Macroeconomic models, Econometric models, General Equilibrium models, etc.).

The present study is in principle concerned only with those models within the Input-Output or Structural Analysis tradition, which can be defined as mezzo economic models, that is to say they are not macro, nor micro economic models. They deal with sectoral economic magnitudes.

We are building and developing an Environmental Input-Output (EIO) model applied to five economies for the purpose of analyzing the effects of a change in technology in some of the key sectors of the economy identified as both strategic and highly GHG emitters. The period in which this impact analysis is studied goes from 2011 to 2030. The main idea is to find out to what extent the use of more efficient technologies in key economic sectors makes the reduction of GHG emissions possible.

Policy instruments and economic models

In order to induce the use of technology that reduces GHG emissions by the producers (switching from a conventional technology to an abatement one), every government has a variety of instruments and measures to apply: market based programs, regulatory measures, voluntary agreements, scientific research and development (R&D), and infrastructural measures. IPCC maintains the idea that there is no best single instrument or measure to apply but rather a combination of measures adapted to national, regional and local conditions will be required (IPCC, 1996). The same position is favored by the OECD in its studies.

Whatever the extent of market oriented policies carried out between 1988 and 2005 they did very little in solving the GHG emissions problem, called Climate Change. Nicholas Stern pointed out in his Review, in 2006 after eighteen years of IPCC foundation, that Climate Change was "…the greatest and widest-ranging market failure ever seen" (Stern, 2006, 2007). Of course, he had not witnessed the so called Sub-prime financial crisis of 2008, initiated in the US but extended to rest of the world, which was also a market failure. Stern (2006, 2007) also called for a "major change" (as opposed to a marginal one) in GHG reductions which, as all major changes in the economy must, in our opinion, be led by the state in each country case.

The need for state intervention arises also from the existence of market imperfections in each and every economy in the world. It is not surprising that the OECD emphasizes that putting a price on GHG emissions through price mechanisms, has the limitation that "they do not address the full range of market imperfections that prevent emissions to be cut at least cost, such as information problems", (Duval, 2008 p.31).

The OECD finds also that empirical analysis indicates that the most important determinant of innovation in the area of renewable energy technologies is general innovative capacity. According to Furman, *et al.* (2002 p.899), "National innovative capacity is the ability of a country to produce and commercialize a flow of innovative technology over the long term. National innovative capacity depends on the strength of a nation's common innovation infrastructure, the environment for innovation in a nation's industrial clusters, and the strength of linkages between these two." However, the OECD study says in the case of energy "public policy makes a difference. Public R&D expenditures on renewable energies induce innovation, as do targeted measures such as renewable energy certificates and feed-in tariffs" (Haščič, *et al.*, 2010 p.44).

2. Applied Environmental Input-Output models

Since Leontief's works on pollution cleaning up issues (Leontief, 1970, 1973), there have been various I-O models and analytical devices developed from them. Some advances appear in input-output textbooks, for instance Miller and Blair (2009) Ten Raa (2005); others have been I-O models or analytical instruments applied to particular cases of sectors and/or regions or countries, for example: Duchin, and Lange (1992, 1994), Kratena and Scheicher (1999), Idenburg and Wilting (2004), Lenzen, Pade and Munksgaard (2004) Wilting, Faber and Idenburg (2004), Kelly (2006), and Brink and Idenburg (2007).

From a theoretical approach to the Pollution cleaning model, there have also been some developments, the most mentioned in the literature are: Steenge (1978), Lowe (1979), Qayum (1991), Arrous (1994), Lager (1998) and Luptacik and Böhm (1999).

Leontief's model, which may be called standard Environmental Input-Output model (EIO), is usually described as:

$$\begin{bmatrix} I - A_{11} & -A_{12} \\ -\alpha A_{21} & I - \alpha A_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} y \\ 0 \end{bmatrix} \qquad (1)$$

where: A_{11} = square matrix of conventional input-output coefficients; A_{12} = coefficient matrix of economic inputs per unit level of abatement activities; A_{21} = matrix showing environmental pollution per unit of production by the conventional sectors; A_{22} = matrix showing pollution generated as a by-product of abatement activities; x_1 = vector of production levels of the conventional sectors; x_2 = levels of abatement activities; y = vector of final demand for conventional goods; α = diagonal matrix with the percentage of the pollution which has to be eliminated.

All the, above mentioned, authors found that this model is characterized by a number of assumptions in the way it is formulated that cause limitations of various types when it comes to be applied for policy evaluation with respect to air pollution (Steenge, 1978, p. 482; Lowe, 1979, p.112; Qayum, 1991, p.428; Arrous, 1994, p.106; Lager, 1998, p.205; Luptacik and Böhm, 1999, p.265; Brink & Idenburg, 2007, p.3).

Leontief's system as represented by equation (1) has become an important framework for addressing economy-environment relationships. The approach is, however, characterized by a number of assumptions that cause some problems with the implementation of the model for environmental policy analysis. These have been pointed out and dealt with in several studies. We mention three of them that are relevant for the analysis of environmental policies with respect to GHG emissions.

In the first place, pollution is supposed to be eliminated once it is released into the environment (surface water, atmosphere, etc.). Although this might be the case for certain types of pollution (like waste for example), in the case of most gaseous substances (like greenhouse gases and air pollutants), once they are released into the atmosphere it is hardly possible to eliminate them (Lager, 1998). Instead, pollution has to be reduced at the source through the use of less polluting alternative production technologies. This can be achieved through the substitution of conventional production technology by less polluting production technologies or else by applying add-on abatement technologies to conventional production technologies. This has two important implications: (i) abatement activities (and their cost and effect) are directly related to the pollution at the various specific sources, and (ii) different substitution and add-on technologies will be available for each of the various sources, which implies that the cost of reduction and the reduction potentials are sector-specific.

Secondly, in the standard EIO model, it is assumed that the degree of abatement i.e. the proportions of pollutants eliminated, represented by α in (1) are exogenous to the model. Moreover, the proportional emission reduction is the same for each sector. With abatement taking place once pollutants are released into the environment this might be right, because the abatement cost for a unit of pollution are the same, regardless the source of pollution. The approach implies that the cost of abatement is spread over the sectors according to their relative contribution to total pollution. In the context of sector-specific abatement this will not result in an efficient use of scarce resources to reduce environmental pollution. In fact, it reflects the instrument of environmental policy called command and control, prescribing the same abatement technology for each sector.

Taking these limitations into account, the authors reformulated the model in a suitable way to solve the problems found for the analytical purposes they had in mind.

Pollution abatement and Technological change models

There is in the economic literature a limited number of references regarding applied I-O models specifically relating climate change, mitigation technologies and impacts evaluation at a national level. We narrow our criterion for selection to those coincidental with the purpose of our study, *i.e.*, the analysis of the introduction of new technologies for GHG emissions reduction on the economy as a whole, there are two outstanding works worth mentioning, the EIO models applied to the Dutch economy: a dynamic input-output model called *Dimitri* and an optimization of pollution-abatement technologies model.

In *Dimitri* a crucial aspect for the dynamics and the introduction of new technologies are the variables and equations regarding: investment by sector, capital goods capacity (existing, expected and planned) by sector, depreciation rates by sector, and the matrix of capital coefficients. The installed technology is a mix of technologies implemented in previous periods. As a result of depreciation and new investments, the installed technology in all sectors changes every period. After installing new technologies, the technological matrix depicts the new installed mix of technologies. The model estimates the technological matrices for each period. In the price side of this model, the costs are compiled from the operational costs, the return of capital and a revaluation of the capital stock. Sectoral prices are accounted for by the model, prices on labor and other value-added categories are external (Idenburg, 1998; Idenburg and Wilting, 2000, 2004; Wilting, Faber and Idenburg, 2004).

The Cost-effective pollution-abatement technologies model, developed by B&I (2007) is not dynamic and it is built with the purpose of studying the effects of the application of the best GHG abatement technology per sector, choosing one among various (at least two) alternatives. The selection is based on a total cost analysis implemented in an optimization I-O model. The technologies considered for election are all add-on technologies, that is, they do not imply a change in the product or in the production process. The model is to be applied to a permit scheme which works under free market rules. That is to say, the authors privilege in their model an environmental policy of GHG reduction through a permit market system.

In the building and development of an EIO model for these five selected countries we have a different objective from the studies mentioned above and some others somehow related. The EIO model we are applying to the five selected countries will show how GHG emissions reducing technologies applied in key sectors of the economy will reduce overall emissions through their direct and indirect effects in the economy. The model will assume the application of a set of abatement technologies in the strategic-pollutant sector and will estimate first its effectiveness in terms of GHG emissions reduction.

An alternative scenario will be the Business as Usual (BAU) –*i.e.*, no technical change– tendency of the economic structure and GHG emissions, taking as external data the GDP projections for 2030 from the OECD.

3. The Model and the Selected countries

Environmental Input-Output Model

We now present the EIO model for estimation of GHG emissions produced in the economy as the result of the interaction of all the sectors in the economy.

First, following Miller and Blair (2009) notation, we start with the formal Input-Output model in money terms for any economy:

$$\mathbf{x}_t = \mathbf{Z}_t \, \mathbf{i} + \mathbf{f}_t \qquad (2)$$

where: $\mathbf{x}_t$ = gross output vector in time t, $\mathbf{Z}_t$ = Input-Output matrix in time t, $\mathbf{i}$ = summation vector, and $\mathbf{f}$ = final demand vector, with all vectors of order n and the matrix of order $n \times n$.

With the introduction of $\mathbf{A}$, the technical coefficient matrix, equation (2) can be written as,

$$\mathbf{x}_t = \mathbf{A}_t \, \mathbf{x}_t + \mathbf{f}_t \qquad (3)$$

Thus, we arrive to the usual solution for the model as:

$$\mathbf{x}_t = (\mathbf{I} - \mathbf{A}_t)^{-1} \, \mathbf{f}_t \qquad (4)$$

This is the standard demand driven model to which we introduce emissions by sector to gross output ratio as $e_i = g_i / x_i$, where E_i is the total emissions by sector in GHG units and x_i is the gross product by sector in monetary units.

Thus, the equation for the vector of emissions per unit of output is:

$$\hat{\mathbf{e}} = \hat{\mathbf{g}} \, \hat{\mathbf{x}}^{-1} \qquad (5)$$

where: $\hat{\mathbf{e}}$ = diagonal matrix of coefficients of sector GHG emissions per unit of gross output in GHG CO_2 equiv. units; $\hat{\mathbf{g}}$ diagonal matrix of emissions by sector in GHG units; $\hat{\mathbf{x}}^{-1}$ = diagonal matrix of gross output by sector.

We now introduce the equation of GHG pollution by-products:

$$\mathbf{x}^p{}_t = \hat{\mathbf{e}} \, \mathbf{x}_t \qquad (6)$$

where: $\mathbf{x}^p{}_t$ = vector of pollution levels measured in GHG units; $\hat{\mathbf{e}}$ = diagonal matrix of GHG emissions per unit of output $\mathbf{x}$.

By combining (4) and (6), we get:

$$\mathbf{x}^p{}_t = \hat{\mathbf{e}} \, (\mathbf{I} - \mathbf{A}_t)^{-1} \mathbf{f}_t \qquad (7)$$

To make operational this model for our purposes, we now define the variables and its sources, which are the same for the five selected countries:

Z = Input-Output matrix (total transactions), **x =** Gross output, and **f =** final demand vector, t = 2011 and n = 35, for each of the five selected countries, reported by the World Input-Output Database WIOD, (see Dietzenbacher, *et al.* 2013).
$\mathbf{A}_t$ = Technical coefficient matrix where t =2011, and the order n = 35. This matrix was calculated for each country using data from WIOD.
$\mathbf{B}_t$ = Allocation coefficient matrix where t =2011, and the order n = 35. This matrix was calculated for each country using data from WIOD.
g = vector of GHG emissions by sector for each of the five selected countries estimated with data both from the WIOD. These emissions are measured in Giga grams of CO_2 equivalent (see Appendix Note 1).

For the matrices and vectors related as well as GHG emissions we use the 35 industrial sectors classification also from WIOD as described in Table 1.

Table 1 SECTORS IN WIOD 2011 MATRIX	
No.	**Sector Name**
1	Agriculture, Hunting, Forestry and Fishing
2	Mining and Quarrying
3	Food, Beverages and Tobacco
4	Textiles and Textile Products
5	Leather, Leather and Footwear
6	Wood and Products of Wood and Cork
7	Pulp, Paper, Paper , Printing and Publishing
8	Coke, Refined Petroleum and Nuclear Fuel
9	Chemicals and Chemical Products
10	Rubber and Plastics
11	Other Non-Metallic Mineral
12	Basic Metals and Fabricated Metal
13	Machinery, Nec
14	Electrical and Optical Equipment
15	Transport Equipment
16	Manufacturing, Nec; Recycling
17	Electricity, Gas and Water Supply
18	Construction
19	Sale, Maintenance and Repair of Motor Vehicles
20	Wholesale Trade and Commission Trade
21	Retail Trade, Repair of Household Goods
22	Hotels and Restaurants
23	Inland Transport
24	Water Transport
25	Air Transport
26	Other Supporting and Auxiliary Transport Activities
27	Post and Telecommunications
28	Financial Intermediation
29	Real Estate Activities
30	Renting of M&Eq and Other Business Activities
31	Public Admin and Defence; Compulsory Social Security
32	Education
33	Health and Social Work
34	Other Community, Social and Personal Services
35	Private Households with Employed Persons
Source: World Input-Output Database WIOD	

Main GHG emitting countries

For selecting the countries for this study, we consider the data provided by the World Bank. Table 2 shows the top five GHG emitter countries, which together represent almost half of World GHG total emissions. The selected countries were China, United States, India, Russia and Japan. They are all important countries regarding production and trade, four of them are highly populated and the first two are considered the engines for the world's economic growth. In short these are the countries in which a set of GHG emissions mitigation policies is urgently required and they can make a change in the world emissions tendencies.

Table 2
GREENHOUSE GAS EMISSIONS 2011
Top Five Countries

No.	Country	GHG Emissions Gg CO_2 equiv.	Share of World total emisions
1	China	12,064,260	23.18%
2	United States	6,571,654	12.63%
3	India	2,828,846	5.43%
4	Russia	2,777,724	5.34%
5	Japan	1,396,767	2.68%
	Total	25,639,251	49.26%

Source: World Bank, World Development Indicators

These five countries all signed and ratified the Paris Agreement of December 2015, so they committed themselves to reduce the level of GHG emissions by 2030, in a determined amount, starting in a given year. The summary of these reductions goals is shown in Table 3, and the details in the orginal sources in the Appendix (Note 2).

Table 3
COMMITED REDUCTIONS OF GHG EMISSIONS BY SELECTED COUNTRIES
***Intended Nationally Determined Contribution* INDC**

	CHINA	U.S.A.	INDIA	RUSSIA	JAPAN
Starting year	2014	2005	2021	2020	2020
GHG Emissions CO_2 Eq.	13,161,340	5,580,711	4,671,709	2,806,603	1,194,079
Goal year	2030	2025	2030	2030	2030
Min GHG reduction	5,414,375	4,129,726	6,233,604	1,838,283	829,808
Max GHG reduction	5,250,303	4,018,112	6,141,254	1,715,732	
Base year	2005	2005	2005	1990	2013
GHG Emissions CO_2 Eq.	6,382,873	5,580,711	1,805,184	2,451,045	1,121,362

Source: UNFCCC and World Resources Institute (CAIT Climate Data Explorer)

4. STRATEGIC AND HIGH GHG EMITTING SECTORS

In this section, we use various Input-Output techniques to identify those industries of the economy that may be called strategic from a structural point of view. In the second, we measure GHG emissions by industry and identify those considered as highly emitters both in relative and absolute terms. We apply these techniques to the five selected countries.

We are using the Input-Output matrices for these selected economies reported by the WIOD for 2011. The matrix we use is the total requirements matrix (including imported inputs.). For GHG emissions we are using those consistent with the matrices reported also by WIOD.

Strategic or Key economic sectors

In Input-Output analysis, sectors or industries are labelled as strategic or key, due to their effects on others, either through demand or through supply.

In particular, the relation between one sector or industry and the rest is called *linkage*, there are *forward linkages*, those related to supply, and *backward linkages*, those related to demand. We first need to find out the existence of linkages between industries and, in each case, its relative importance. So, those industries that have many linkages with others and these linkages are very strong, will transmit backwardly or forwardly economic effects to others. These industries or sector are then called *strategic* or *key*. The reason they are called this way is that the increase or decrease in their production, may cause a demand pull and/or a supply push variations to other industries with effects on overall gross production, input consumption, and/or labor employment.

We make use of some basic indicators that allow us to evaluate the relative importance of all industries and classify them according to their capacity to transmit economic impulses through the system that represents the Input-Output Matrix (IOM).

Erik Dietzenbacher (1992), following the pioneer works of Rasmussen (1956), Chennery and Watanabe (1958) and Cella (1984), in measuring backward and forward linkages within structural analysis, developed a methodology, based on Eigen-values associated to the input-output matrix, to formulate most adequate measures.

The equation for forward linkages is:

$$U_{.j} = n\boldsymbol{z}/(\mathbf{i}'\boldsymbol{z}) \text{ with } \mathbf{B}\boldsymbol{z} = \lambda\boldsymbol{z} \qquad (8)$$

and the equation for Backward Linkages is:

$$U_{i.} = n\boldsymbol{q}'/(\boldsymbol{q}'\mathbf{i}) \text{ with } \boldsymbol{q}'\mathbf{A} = \lambda\boldsymbol{q}' \qquad (9)$$

where: $U_{.j}$ = Dietzenbacher F.L. Index; $U_{i.}$ = Dietzenbacher B.L. Index; n = number of sectors in the matrix; $\mathbf{A}$ = technical coefficient matrix, $\mathbf{B}$ = allocation coefficient matrix; $\mathbf{i}$ =

summation vector; **z** = right hand side eigenvector of matrix **B**, ***q*** = left hand side eigenvector of matrix **A**; (′) = transposition; λ = dominant eigenvalue of respective matrix.

We applied this methodology to estimate forward and backward linkages in the five selected countries and determine by the value of these indexes, which are the key sectors of these economies. The results are shown in Table 4.

Table 4
KEY SECTORS OF THE FIVE SELECTED COUNTRIES

		CHINA		USA		INDIA		RUSSIA		JAPAN	
No.	**Sector Name**	**B.L.**	**F.L.**	**B.L.**	**F.L.**	**B.L.**	**F.L.**	**B.L.**	**F.L.**	**B.L.**	**F.L.**
1	Agriculture, Hunting, Forestry and Fishing	0.50	0.84	1.55	1.10	0.29	1.08	0.97	1.62	0.83	0.45
3	Food, Beverages and Tobacco	0.79	1.20	2.25	3.28	1.02	1.62	1.28	2.18	0.90	1.53
4	Textiles and Textile Products	1.45	1.84	1.60	0.19	1.61	1.93	1.04	0.12	1.01	0.17
8	Coke, Refined Petroleum and Nuclear Fuel	1.13	0.57	1.26	1.45	1.00	1.47	0.97	2.38	2.05	1.58
9	Chemicals and Chemical Products	1.36	2.13	1.57	1.74	1.47	1.54	1.26	0.99	1.61	1.97
10	Rubber and Plastics	1.60	1.09	1.62	0.51	1.82	0.68	1.51	0.45	1.66	1.01
12	Basic Metals and Fabricated Metal	1.45	3.74	1.64	1.45	1.86	4.10	1.29	2.33	1.97	4.44
13	Machinery,	1.61	2.14	1.30	0.76	1.83	1.42	1.55	1.08	1.38	1.27
14	Electrical and Optical Equipment	1.95	5.49	0.62	0.58	1.77	1.34	1.42	0.71	1.40	2.23
15	Transport Equipment	1.83	2.01	2.23	2.35	1.88	2.03	2.88	2.75	2.38	4.45
16	Manufacturing; Recycling	1.11	0.18	1.15	0.29	2.75	2.30	1.36	0.27	1.43	0.22
17	Electricity, Gas and Water Supply	1.23	1.15	0.47	0.27	1.31	1.08	1.15	2.23	1.30	1.48
18	Construction	1.40	3.96	0.97	1.72	1.42	5.74	1.11	2.64	1.06	2.68
22	Hotels and Restaurants	0.72	0.40	1.03	1.51	0.82	0.55	0.85	0.29	0.67	0.82
23	Inland Transport	0.76	0.41	0.94	0.61	1.26	3.48	1.01	1.64	0.62	0.55

FL = Forward Linkage Dietzenbacher Index
BL = Backward Linkage Dietzenbacher Index
Source: Elaborated with Data from World Input-Output Database (WIOD)

In Table 5 we present the Key sectors according to Dietzenbacher Index which were both common to two or more countries and suitable to modify their production processes in order to reduce GHG emissions.

Table 5
9 KEY SECTORS IN ALL 5 COUNTRIES

No.	Sector Name	Countries
8	Coke, Refined Petroleum and Nuclear Fuel	2
9	Chemicals and Chemical Products	4
12	Basic Metals and Fabricated Metal	5
13	Machinery,	4
14	Electrical and Optical Equipment	4
15	Transport Equipment	4
17	Electricity, Gas and Water Supply	3
18	Construction	3
23	Inland Transport	2

Source: Elaborated with data from WIOD

Main sectors emitting GHG

We take the GHG emissions in CO_2 equivalent, for each sector of the 35 in the I-O matrices from the same source WIOD, which matches roughly the World Bank data in the total for 2011. The GHG emissions are expressed in Giga-grams of carbon dioxide equivalent (Gg CO_2 eq.), that result of summing up the emissions of three gases: carbon dioxide (CO_2), methane (CH_2) and nitrous oxide (N_2O) that together represent in most countries and in the average, 98 per cent of total GHG emissions. We are considering as the sources do, only GHG emissions generated in production and distribution of goods and services and no other emissions generated in consumption.

The GHG emissions by sector for the five selected countries in 2011 are shown in Table 6.

Table 6 GHG EMISSIONS BY SECTOR IN THE FIVE SELECTED COUNTRIES 2011 Gigagrams CO_2 Eq					
Sector	**CHINA**	**USA**	**INDIA**	**RUSSIA**	**JAPAN**
Agriculture, Hunting, Forestry and Fishing	1,556,266	479,704	782,219	184,631	42,343
Mining and Quarrying	1,064,495	373,984	187,831	244,111	24,515
Food, Beverages and Tobacco	91,827	62,721	81,760	5,730	13,389
Textiles and Textile Products	64,130	9,147	12,575	568	2,312
Leather, Leather and Footwear	4,587	160	424	97	150
Wood and Products of Wood and Cork	15,683	15,070	14,147	2,017	1,923
Pulp, Paper, Paper , Printing and Publishing	67,430	63,513	10,495	1,823	13,433
Coke, Refined Petroleum and Nuclear Fuel	133,597	191,913	56,830	75,197	30,503
Chemicals and Chemical Products	395,503	156,351	68,977	70,013	58,302
Rubber and Plastics	30,261	5,467	3,883	693	3,039
Other Non-Metallic Mineral	919,931	112,403	105,200	80,344	65,635
Basic Metals and Fabricated Metal	813,545	104,222	145,240	199,977	121,640
Machinery, Nec	50,492	16,924	6,804	2,757	2,932
Electrical and Optical Equipment	24,601	11,247	4,794	1,185	6,274
Transport Equipment	32,866	20,827	13,184	2,814	6,791
Manufacturing, Recycling	7,315	3,890	1,158	536	2,541
Electricity, Gas and Water Supply	4,306,429	2,115,370	962,936	929,101	355,125
Construction	92,477	43,593	14,518	8,642	29,053
Sale, Maintenance and Repair of Motor Vehicles	213	6,104	511	1,208	1,734
Wholesale Trade and Commission Trade	10,628	32,366	1,156	6,764	14,864
Retail Trade, Repair of Household Goods	9,490	81,298	5,065	4,429	16,747
Hotels and Restaurants	28,010	64,421	24,065	2,336	12,557
Inland Transport	130,472	243,980	40,788	209,003	36,400
Water Transport	129,880	58,528	7,129	4,187	87,019
Air Transport	101,203	161,304	3,494	27,311	22,169
Other Supporting Activities	40,053	57,935	4,100	5,643	1,798
Post and Telecommunications	7,534	32,334	2,675	2,261	3,147
Financial Intermediation	4,211	31,663	773	1,820	3,873
Real Estate Activities	5,288	10,040	362	6,391	3,521
Renting of M&Eq and Other activities	33,740	107,314	5,015	2,966	18,079
Public Admin and Defence; Social Security	34,274	262,024	1,032	6,168	23,288
Education	24,898	15,902	1,765	4,731	6,165
Health and Social Work	30,074	90,408	1,209	4,071	13,424
Other Community, Social and Personal Services	314,476	205,398	145,618	98,929	43,922
Private Households with Employed Persons	0	0	0	0	0
Total	10,575,876	5,247,526	2,717,729	2,198,454	1,088,609
Sources: Word Input-Output Database and World Bank					

Sector Output Multipliers

The impacts of demand on gross output are usually measured by the so called “output multipliers”. They measure the impact of sector or total demand on gross output by sector. These output multipliers, are derived directly from matrix **A**, the technical coefficient matrix. The formula for output multipliers using Miller and Blair (2009 pp. 245-246) terminology is:

Let $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ so, $\mathbf{L} = [l_{ij}]$

$$m(o)_j = \sum_{i=1}^{n} l_{ij} \quad (10)$$

Emissions Multipliers

In order to establish the highest GHG emitter sectors in an Input-Output model like the one we built for these five economies, there are three possible indicators: (a) total emissions by sector, vector $\mathbf{g}$, (b) coefficients of emissions per unit of output, by sector, vector $\hat{\mathbf{e}}$, and (c) a total GHG emissions multiplier by sector which we can derived from matrix $(\mathbf{I}-\mathbf{\Psi})^{-1}$, an inverse of matrix of emissions by emissions, measured in GHG units per unit of output. In fact, to get this indicator (c) we have to calculate first (a) and (b). This matrix is analogous to the Leontief inverse matrix $(\mathbf{I} - \mathbf{A})^{-1}$. Like $\mathbf{A}$, $\mathbf{\Psi}$ gives us the direct and indirect (GHG emissions) requirements to satisfy a unit of final demand, expressed in GHG units. Following the methodology suggested by King *et al.* (2012) based on Hewings (1985) for the employment model, we calculate this matrix (see Appendix Note 3) from equation (5) and using equations (2) to (7).

$$\hat{\mathbf{e}} = \hat{\mathbf{g}}\ \hat{\mathbf{x}}^{-1}$$

We obtained:

$$(\mathbf{I} - \hat{\mathbf{e}}\,\mathbf{Z}\,\hat{\mathbf{g}}^{-1})^{-1}\hat{\mathbf{e}}\,\mathbf{f} = \mathbf{g} \qquad (11)$$

Which is equal to:

$$(\mathbf{I} - \mathbf{\Psi})^{-1}\hat{\mathbf{e}}\,\mathbf{f} = \mathbf{e} \qquad (12)$$

where: $\mathbf{\Psi}$ = emissions by emissions coefficient matrix.

It is possible to show that the matrix emissions by emissions $(\mathbf{I}-\mathbf{\Psi})^{-1}$ is a similar matrix to the inverse Leontief matrix $(\mathbf{I}-\mathbf{A})^{-1}$. So, if we treat $(\mathbf{I}-\mathbf{\Psi})^{-1}$ as we do with $(\mathrm{I} - \mathbf{A})^{-1}$, so we can define:

$$\mathbf{D} = (\mathbf{I}-\mathbf{\Psi})^{-1} = [d_{ij}] \qquad (13)$$

Then we can estimate GHG emissions multipliers by the formula,

$$m\,(e)_j = \sum_{i=1}^{n} d_{ij} \qquad (14)$$

Each one of the emission multipliers gives us the total emissions per unit of gross output in a given sector produced by gross output. So, it measures all the direct and indirect effects generated in all the whole economy, produced by a unit of gross output in one sector, in terms of GHG emissions.

Thus, we estimated these multipliers for the selected countries in the 35 sectors of production that reported the WIOD in 2011. These multipliers are shown in Table 7 and Figure 1.

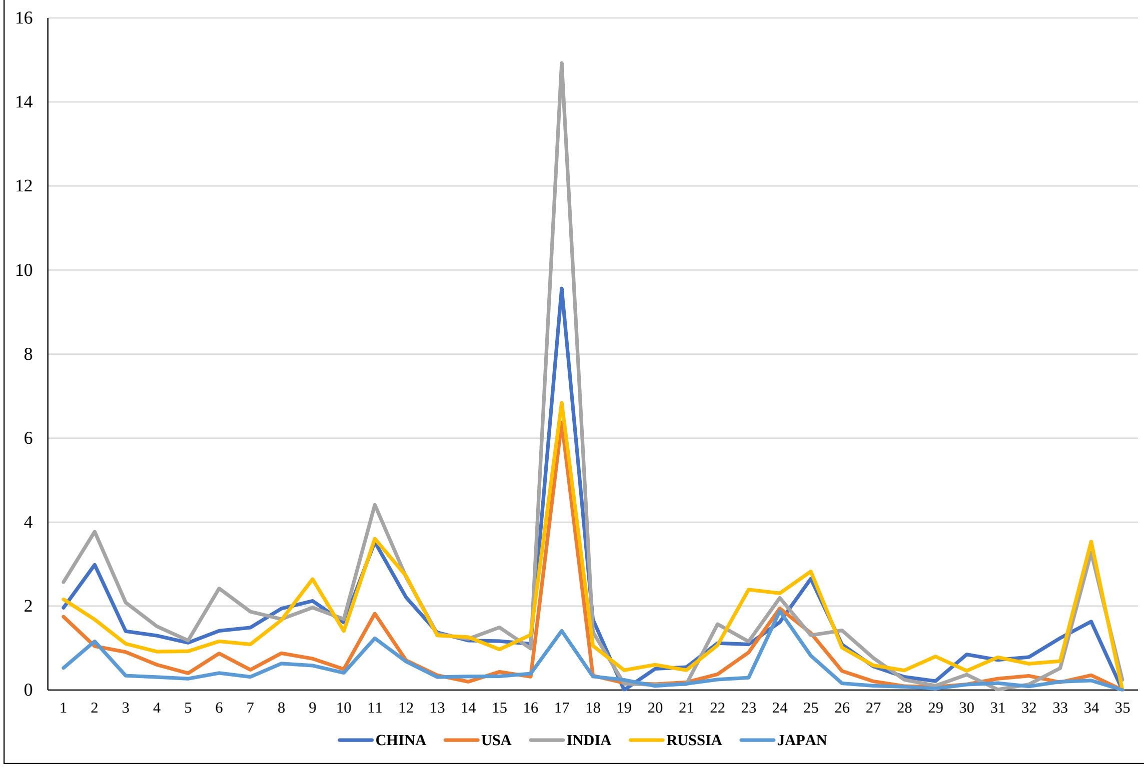
Table 7

EMISISON MULTIPLIERS BY SECTOR OF THE FIVE SELECTED COUNTRIES 2011

		CHINA	USA	INDIA	RUSSIA	JAPAN
1	Agriculture, Hunting, Forestry and Fishing	1.958	1.749	2.570	2.161	0.527
2	Mining and Quarrying	2.983	1.045	3.772	1.679	1.163
3	Food, Beverages and Tobacco	1.401	0.904	2.086	1.104	0.343
4	Textiles and Textile Products	1.297	0.605	1.517	0.916	0.311
5	Leather, Leather and Footwear	1.125	0.400	1.182	0.924	0.271
6	Wood and Products of Wood and Cork	1.412	0.874	2.419	1.160	0.407
7	Pulp, Paper, Paper , Printing and Publishing	1.489	0.485	1.869	1.088	0.316
8	Coke, Refined Petroleum and Nuclear Fuel	1.939	0.878	1.689	1.664	0.630
9	Chemicals and Chemical Products	2.124	0.748	1.963	2.642	0.581
10	Rubber and Plastics	1.607	0.498	1.688	1.408	0.411
11	Other Non-Metallic Mineral	3.527	1.821	4.409	3.603	1.234
12	Basic Metals and Fabricated Metal	2.210	0.709	2.693	2.719	0.680
13	Machinery,	1.374	0.353	1.341	1.302	0.309
14	Electrical and Optical Equipment	1.180	0.200	1.217	1.262	0.322
15	Transport Equipment	1.167	0.433	1.491	0.968	0.330
16	Manufacturing, Recycling	1.099	0.319	0.989	1.316	0.391
17	Electricity, Gas and Water Supply	9.560	6.371	14.929	6.841	1.410
18	Construction	1.678	0.344	1.382	1.055	0.323
19	Sale, Maintenance and Repair of Motor Vehicles	0.000	0.172	0.150	0.472	0.242
20	Wholesale Trade and Commission Trade,	0.506	0.139	0.125	0.602	0.099
21	Retail Trade, Except of Motor Vehicles	0.547	0.185	0.142	0.475	0.150
22	Hotels and Restaurants	1.117	0.378	1.570	1.067	0.253
23	Inland Transport	1.087	0.894	1.156	2.394	0.293
24	Water Transport	1.618	1.942	2.193	2.304	1.882
25	Air Transport	2.651	1.359	1.304	2.822	0.820
26	Other Supporting and Auxiliary Activities	1.082	0.454	1.420	1.011	0.159
27	Post and Telecommunications	0.563	0.210	0.766	0.589	0.101
28	Financial Intermediation	0.316	0.091	0.245	0.466	0.079
29	Real Estate Activities	0.214	0.076	0.103	0.800	0.034
30	Renting of M&Eq and Other Business Activities	0.847	0.134	0.365	0.457	0.133
31	Public Admin and Defence; Social Security	0.718	0.273	0.009	0.782	0.164
32	Education	0.785	0.339	0.137	0.628	0.086
33	Health and Social Work	1.239	0.182	0.522	0.691	0.201
34	Other Community, Social and Personal Services	1.631	0.351	3.279	3.535	0.226
35	Private Households with Employed Persons	0.000	0.000	0.240	0.000	0.000

Source: Elaborated with data from World Input-Output Databade and the World Bank

Figure 1
EMISSIONS MULTIPLIERS BY SECTOR 2011



Source: Estimated with data from WIOD

With the information of Table 7 we elaborated short list of high emitting sectors for all five countries in 2011, which is shown in Table 8.

Table 8
HIGH GHG EMITTING SECTORS 2011

No.	Sector	Countries
2	Mining and Quarrying	3
8	Coke, Refined Petroleum and Nuclear Fuel	3
9	Chemicals and Chemical Products	3
11	Other Non-Metallic Mineral	4
12	Basic Metals and Fabricated Metal	3
17	Electricity, Gas and Water Supply	5
23	Inland Transport	3
24	Water Transport	5
25	Air Transport	2

Source: Elaboated with data from WIOD

If we compare Table 8 with Table 5 we found that the intersection of the two sets is made up of five sectors, those shadowed in Table 8 and from that group we established the subgroup of four sectors in which we propose to make a technological change in the five economies under study, these are: (8) Coke, Refined Petroleum and Nuclear Fuel; (12) Basic Metals and Fabricated Metal; (17) Electricity, Gas and Water Supply and (23) Inland Transport. In this selection, we left out of consideration sector (9) Chemicals and Chemical

Products, because this sector includes a great variety of products which involve quite different techniques of production. We carried out a detailed analysis of these four sectors which is included in the Appendix.

5. Projected tendencies for GHG Emissions of the five selected countries

GHG emissions projected to 2030 with no technical change (BAU)

We use the model specified in equations (2) to (7) for estimating the GHG emissions of each of the five selected countries from 2011 to 2030 under the business as usual (BAU) scenario. Equation (7) will give us these estimations in which the independent variable is the final demand vector **f**, which is measured in money terms to be precise in US dollars.

Thus, we recall equation (7) as:

$$\mathbf{x}^{p}_{t} = \hat{\mathbf{e}}\,(\mathbf{I} - \mathbf{A}_{t})^{-1}\mathbf{f}_{t}$$

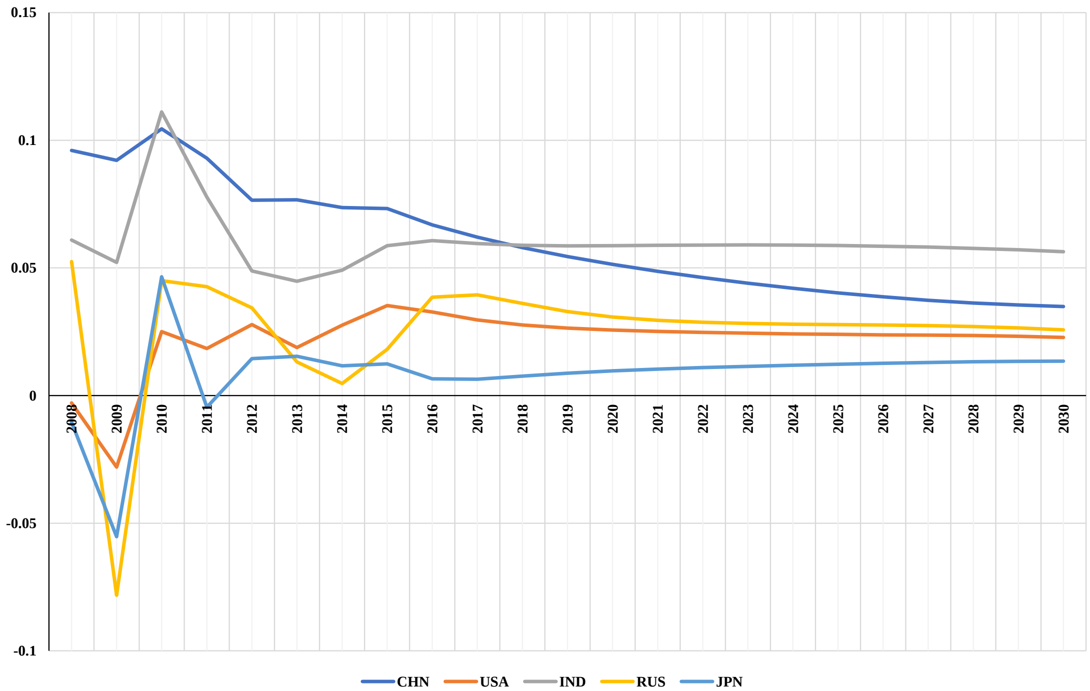
Assumptions about GDP growth

This variable **f** should be forecasted first, so we estimated **f** for the years from 2012 to 2030 taken the rates of growth of GDP for each country estimated and forecasted by OECD for those years. The rates are shown in Table 9. The line between 2015 and 2016 values means that those above the line are actual values and those below are forecasted ones.

Table 9					
REAL GDP GROWTH RATES 2008-2030					
Year	China	USA	India	Russia	Japan
2008	9.6%	-0.3%	6.1%	5.2%	-1.0%
2009	9.2%	-2.8%	5.2%	-7.8%	-5.5%
2010	10.4%	2.5%	11.1%	4.5%	4.7%
2011	9.3%	1.8%	7.8%	4.3%	-0.5%
2012	7.7%	2.8%	4.9%	3.4%	1.4%
2013	7.7%	1.9%	4.5%	1.3%	1.5%
2014	7.4%	2.8%	4.9%	0.5%	1.2%
2015	7.3%	3.5%	5.9%	1.8%	1.2%
2016	6.7%	3.3%	6.1%	3.9%	0.7%
2017	6.2%	3.0%	6.0%	3.9%	0.6%
2018	5.8%	2.8%	5.9%	3.6%	0.8%
2019	5.4%	2.6%	5.9%	3.3%	0.9%
2020	5.1%	2.6%	5.9%	3.1%	1.0%
2021	4.9%	2.5%	5.9%	2.9%	1.0%
2022	4.6%	2.5%	5.9%	2.9%	1.1%
2023	4.4%	2.4%	5.9%	2.8%	1.1%
2024	4.2%	2.4%	5.9%	2.8%	1.2%
2025	4.0%	2.4%	5.9%	2.8%	1.2%
2026	3.9%	2.4%	5.9%	2.8%	1.3%
2027	3.7%	2.4%	5.8%	2.7%	1.3%
2028	3.6%	2.4%	5.8%	2.7%	1.3%
2029	3.5%	2.3%	5.7%	2.6%	1.3%
2030	3.5%	2.3%	5.6%	2.6%	1.4%
Source: Organization for Economic Cooperation and Development					

With data from Table 9, we draw the graphs in Figure 2, showing the forecasted trends of GDP growth by OECD for the period 2015-2030. We can observe that what is expected from these countries is a moderate rate of economic growth, which is below 5 per cent a year, except for India, the lowest by 2030 being Japan.

Figure 2
GDP GROWTH OF FIVE SELECTED COUNTRIES 2008-2030
Annual rates of variation



Source: Elaborated with data from OECD.

These data make up the scenario on which we are calculating GHG emissions trends for the period 2011-2030. The important aspect of this estimation is that we are assuming that no one of these five countries is doing a technological change in this period so as to reduce the level of GHG emissions on the side of production and distribution of goods and services. In other words, what is called "business as usual" or BAU with respect to changes in the technology aimed to reduce the use of fossil-fuels.

Results of the BAU model

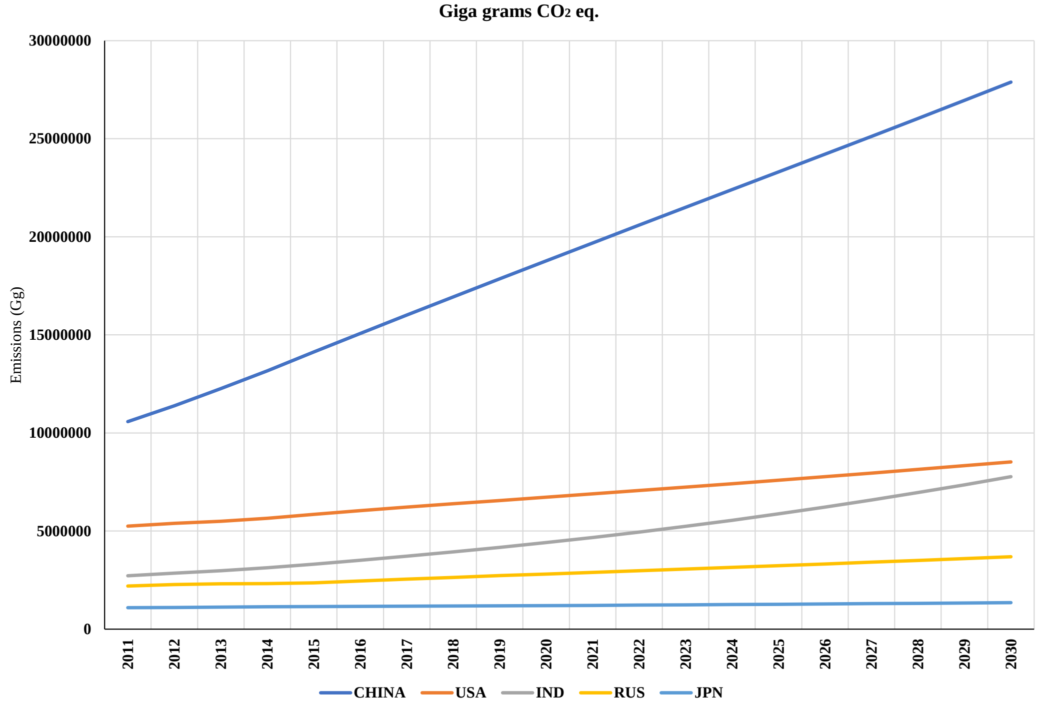
The results of our model estimation of GHG emissions for the five selected countries are shown in Table 10 and Figure 3. They indicate that the selected five countries together, will increase their GHG emissions in 2030 almost by double they were in 2011, but not all at the same rate. China shows the most striking results, since the forecasted level in GHG emissions for 2030 is about three times that of 2011, and in the same period, China is said to reduce its rate of growth from 9.3 per cent in 2011 to 3.5 per cent in 2030. Another quite interesting case is India, which will increase its GHG emissions 2.8 times by 2030 from what it was in 2011. In this case India is assumed to be growing at a rate between 5 and 6 per cent in the period 2015-2030, the highest rate of this group (see Table 9). The US will keep its position as second in the most GHG emitting countries group. All this is a simulation given the assumption that there is no technological change in any of these five economies.

Table 10
ESTIMATED TOTAL EMISSIONS OF FIVE SELECTED COUNTRIES
BAU scenario GHG (Gg CO2 eq.)

Year	China	U.S.A.	India	Russia	Japan
2011	10,575,876	5,247,526	2,717,729	2,198,454	1,088,609
2012	11,385,201	5,393,370	2,850,429	2,273,982	1,104,361
2013	12,258,581	5,494,670	2,978,033	2,303,969	1,121,362
2014	13,161,340	5,646,045	3,124,425	2,314,854	1,134,421
2015	14,125,851	5,844,986	3,307,780	2,356,769	1,148,545
2016	15,070,829	6,036,512	3,508,615	2,447,625	1,156,066
2017	16,005,874	6,215,568	3,717,652	2,544,206	1,163,468
2018	16,933,496	6,387,297	3,936,576	2,635,992	1,172,301
2019	17,855,556	6,555,933	4,167,504	2,722,793	1,182,597
2020	18,773,232	6,724,076	4,412,134	2,806,603	1,194,079
2021	19,687,023	6,893,130	4,671,709	2,889,292	1,206,498
2022	20,597,050	7,063,806	4,947,108	2,972,191	1,219,708
2023	21,503,476	7,236,502	5,238,977	3,056,160	1,233,645
2024	22,406,769	7,411,512	5,547,804	3,141,709	1,248,281
2025	23,308,008	7,589,113	5,873,958	3,229,082	1,263,596
2026	24,209,245	7,769,649	6,217,729	3,318,310	1,279,576
2027	25,113,612	7,953,497	6,579,321	3,409,213	1,296,197
2028	26,024,986	8,140,780	6,958,782	3,501,365	1,313,392
2029	26,947,814	8,330,223	7,356,007	3,594,099	1,331,048
2030	27,887,117	8,520,096	7,770,808	3,686,551	1,349,035

Source: Elaborated with data estimated by the Model

Figure 3
ESTIMATED GHG EMISSIONS BY COUNTRY 2011-2030
Giga grams CO_2 eq.



Source: Elaborated with data from WIOD.

Projections of GHG emissions with technical change

The Model and its assumptions

We are now simulating a technological change in fours sectors of the five economies under study, to discover what would be their GHG emissions trend were these changes adopted. The four sectors are those we chose in the previous section: 8) Coke, Refined Petroleum and Nuclear Fuel; (12) Basic Metals and Fabricated Metal; (17) Electricity, Gas and Water Supply and (23) Inland Transport.

We selected from the same Database (WIOD) the countries were these sectors were the less GHG emitting and take the input vectors from their respective matrix and introduced them in the matrices of the five selected countries. Then we run the model. For this purpose, we now use the following equation:

$$\mathbf{x}^{p}_{t} = \hat{\mathbf{e}}^{+} (\mathbf{I} - \mathbf{A}^{+}_{t})^{-1}\mathbf{f}_{t} \qquad (15)$$

where: $\mathbf{A}^{+}_{t}$ = matrix modified with different inputs vectors for four sectors, $\mathbf{f}_t$ = final demand projected for each country as shown in Table 9 above; $\hat{\mathbf{e}}^{+}$ **=** emissions vector in which some coefficients are substituted for the corresponding to the new four sectors introduced.

The vectors of any **A** matrix can be interpreted as technologies of particular industries or sectors in the respective economy, that is a technical combination of inputs to produce a given product or a set of them which are close substitutes.

To select each matrix vector to produce a technological change we chose the sector with the lowest GHG emission multiplier, from the whole database of WIOD. It is implied that this vector corresponds to a country that is utilizing the technology producing that low level of GHG emissions. The names of sectors and the countries' Input-Output Matrices from which they were taken are shown in Table 11.

Table 11
SELECTED SECTORS WITH LOWEST GHG EMISSIONS MULTIPLIERS

Sector	No.	Country
Coke, Refined Petroleum and Nuclear Fuel	8	Denmark
Basic Metals and Fabricated Metal	12	Denmark
Electricity, Gas and Water Supply	17	France
Inland Transport	23	Sweden

Source: World Input-Output Database

Projections results and comparisons by country

With the results of all the projections to 2030, GHG emissions goals, GHG emissions under BAU scenario and GHG emissions with technical change, we are now to analyze these GHG emissions trends country by country. In the following figures, the line that represents the technical change scenario trend falls down in a straight one year and then starts growing again. It is a very strong down swing due to the fact that we are not assuming a period of adaptation of the new technologies to each economy of various years but one. In the end, it has no consequences, what matters is the year 2030 in which we are assuming all new technologies should be well adapted.

China

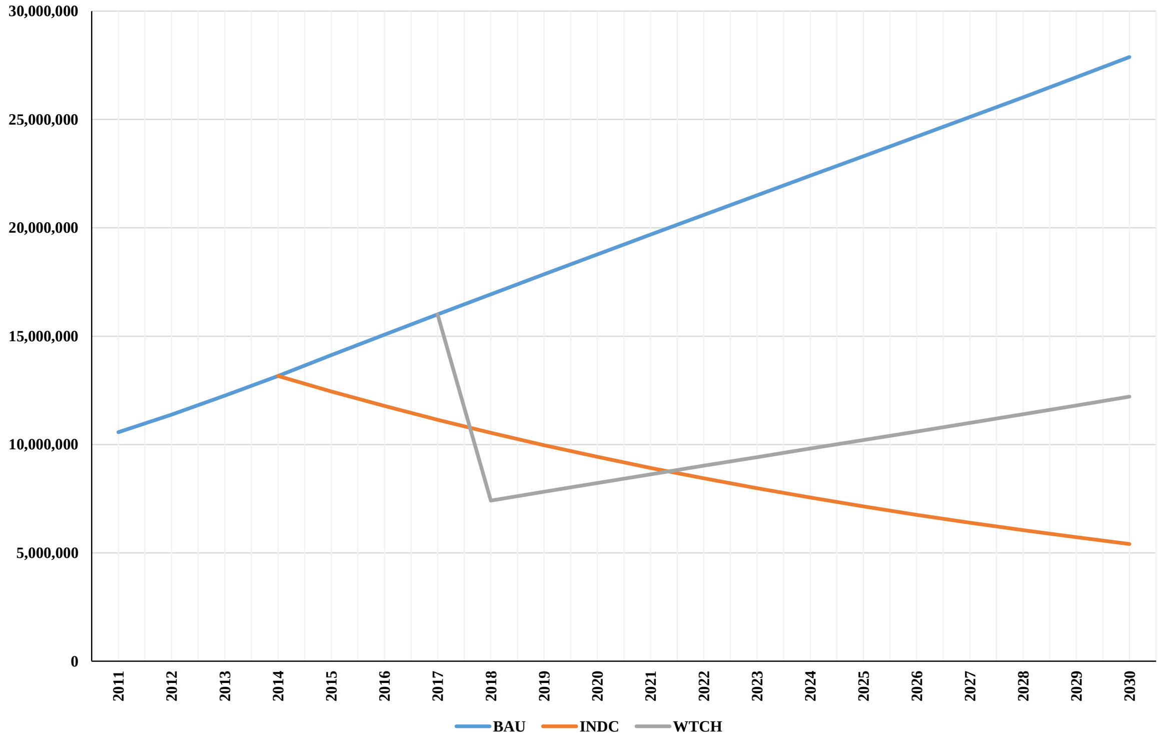
The results for China are shown in Table 12 and Figure 4. China has committed itself to accomplish a very strong reduction of its GHG Emissions by 2030, almost half of the estimated level of 2011, starting in 2014. In our model, we estimate that China would increase this level around 164 per cent in the same period in our BAU scenario. Thus, its goal is 80 percent below the estimated BAU level, which means doing nothing. Now, our alternative scenario, that is, to change the technology in four selected sectors of the economy, would produce a forecasted level for 2030 that is not below the 2011 level, in fact it is higher by 15 percent, but below the BAU forecasting by 56 percent. In short, China would do better if they can accomplish the GHG Emissions goal. The question is: what is the mitigation policy necessary to obtain the desired results?

Table 12
ESTIMATED TOTAL EMISSIONS OF CHINA
GHG (Gg CO2 eq.)

Year	BAU	INDC	WTCH
2011	10,575,876		
2012	11,385,201		
2013	12,258,581		
2014	13,161,340	13,161,340	
2015	14,125,851	12,450,610	
2016	15,070,829	11,778,260	
2017	16,005,874	11,142,218	16,005,874
2018	16,933,496	10,540,523	7,417,287
2019	17,855,556	9,971,321	7,821,171
2020	18,773,232	9,432,856	8,223,136
2021	19,687,023	8,923,469	8,623,399
2022	20,597,050	8,441,590	9,022,013
2023	21,503,476	7,985,732	9,419,050
2024	22,406,769	7,554,492	9,814,715
2025	23,308,008	7,146,539	10,209,479
2026	24,209,245	6,760,617	10,604,243
2027	25,113,612	6,395,534	11,000,378
2028	26,024,986	6,050,167	11,399,582
2029	26,947,814	5,723,449	11,803,804
2030	27,887,117	5,414,375	12,215,241

BAU : Business as usual (no technological change)
INDC: Intended National Determined Contribution
WTCH: Modifed trend with techological Change
Source: Elaborated with data estimated by the Model

Figure 4
ESTIMATED TOTAL EMISSIONS OF CHINA
GHG Gg CO_2 eq.



Source: Elaborated with data from our model and from WIOD

<u>The United States</u>

The United States results appear in Table 13 and Figure 5. In this case the committed GGH Emissions goal by 2030, is also below the 2011 level, but by 21 per cent. With respect to the forecasted level in the BAU scenario, the goal level is below by 51 percent. In this case our forecasted level with technical change is below the BAU level 45 per cent that is close to the goal level. This might mean that mitigation policies applied must be somehow similar to the ones we are suggesting.

Table 13

ESTIMATED TOTAL EMISSIONS OF THE USA

GHG (Gg CO2 eq.)

Year	BAU	INDC	WTCH
2011	5,247,526	5,098,695	
2012	5,393,370	5,022,508	
2013	5,494,670	4,947,459	
2014	5,646,045	4,873,532	
2015	5,844,986	4,800,709	
2016	6,036,512	4,728,974	
2017	6,215,568	4,658,312	6,215,568
2018	6,387,297	4,588,705	3,498,141
2019	6,555,933	4,520,138	3,590,498
2020	6,724,076	4,452,596	3,682,585
2021	6,893,130	4,386,063	3,775,171
2022	7,063,806	4,320,525	3,868,646
2023	7,236,502	4,255,965	3,963,226
2024	7,411,512	4,192,370	4,059,074
2025	7,589,113	4,129,726	4,156,341
2026	7,769,649	4,129,726	4,255,215
2027	7,953,497	4,129,726	4,355,904
2028	8,140,780	4,129,726	4,458,473
2029	8,330,223	4,129,726	4,562,226
2030	8,520,096	4,129,726	4,666,214

Source: Elaborated with data estimated by the Model

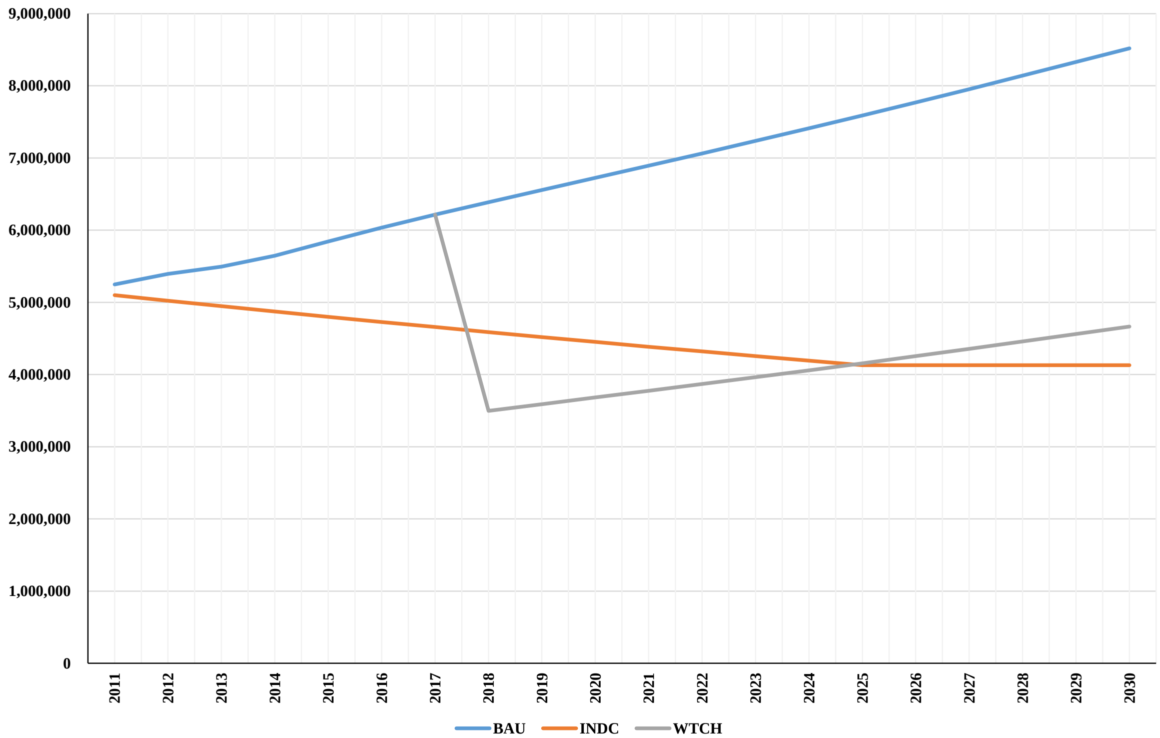
BAU : Business as usual (no technological change)

INDC: Intended National Determined Contribution

WTCH: Modifed trend with techological Change

Source: Elaborated with data estimated by the Model

Figure 5
ESTIMATED TOTAL EMISSIONS OF THE USA
GHG Gg CO_2 Eq.



Source: Elaborated with data from our model and from WIOD

India

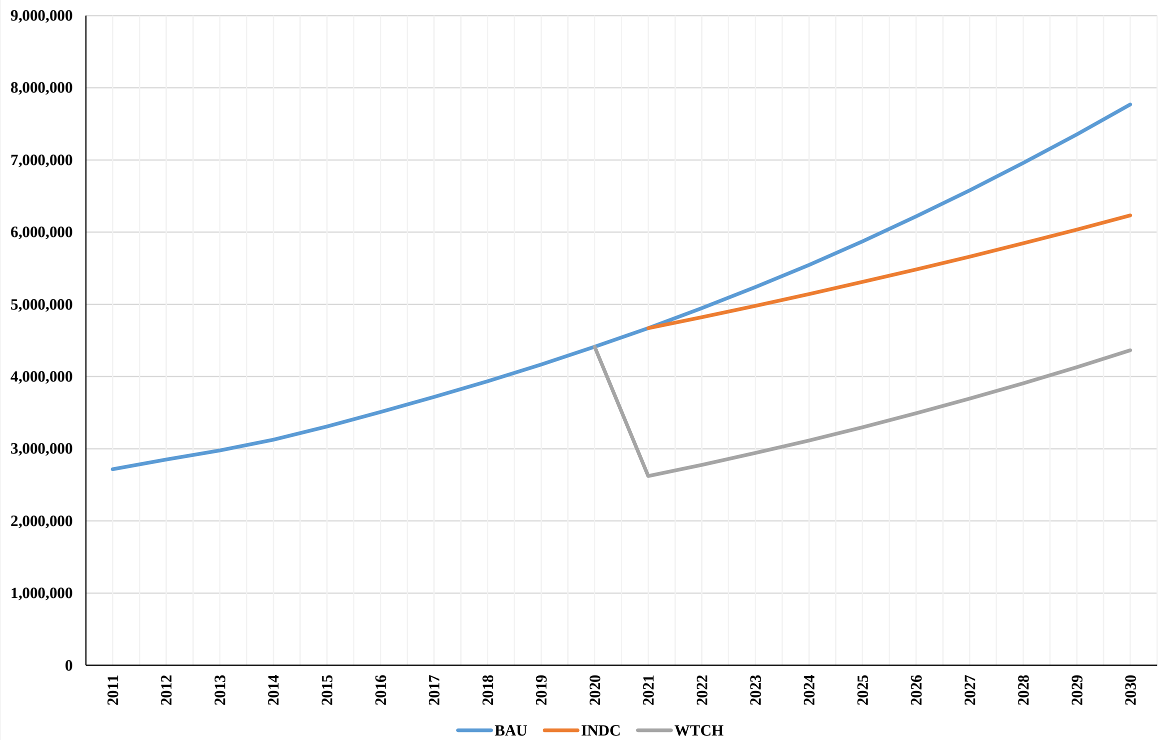
India is the only country in this group that has not made a commitment that implies to reducing its absolute level of GHG emissions for 2030, but only the coefficient of emissions per unit of output, so the forecasted GHG Emissions goal in absolute terms will be in 2030, 129 per cent above the one reported in 2011. And it is only 20 percent below the forecasted BAU level. The level of GHG emissions forecasted by our model under the scenario of technical change for 2030, is almost 44 percent of the level in the BAU scenario. This is shown in Table 14 and Figure 6. This suggest that if India follows this type of mitigation policy will be able to reduce, in fact, its absolute level of GHG emissions by 2030.

Table 14
ESTIMATED TOTAL EMISSIONS OF INDIA
GHG (Gg CO_2 Eq.)

Year	BAU	INDC	WTCH
2011	2,717,729		
2012	2,850,429		
2013	2,978,033		
2014	3,124,425		
2015	3,307,780		
2016	3,508,615		
2017	3,717,652		
2018	3,936,576		
2019	4,167,504		
2020	4,412,134		4,412,134
2021	4,671,709	4,671,709	2,623,279
2022	4,947,108	4,823,852	2,777,921
2023	5,238,977	4,980,949	2,941,813
2024	5,547,804	5,143,163	3,115,227
2025	5,873,958	5,310,659	3,298,370
2026	6,217,729	5,483,610	3,491,407
2027	6,579,321	5,662,194	3,694,449
2028	6,958,782	5,846,593	3,907,526
2029	7,356,007	6,036,998	4,130,577
2030	7,770,808	6,233,604	4,363,498

Source: Elaborated with data estimated by the Model
BAU : Business as usual (no technological change)
INDC: Intended National Determined Contribution
WTCH: Modifed trend with techological Change
Source: Elaborated with data estimated by the Model

Figure 6
ESTIMATED TOTAL EMISSIONS OF INDIA
GHG Gg CO_2 Eq.



Source: Elaborated with data from our model and from WIOD

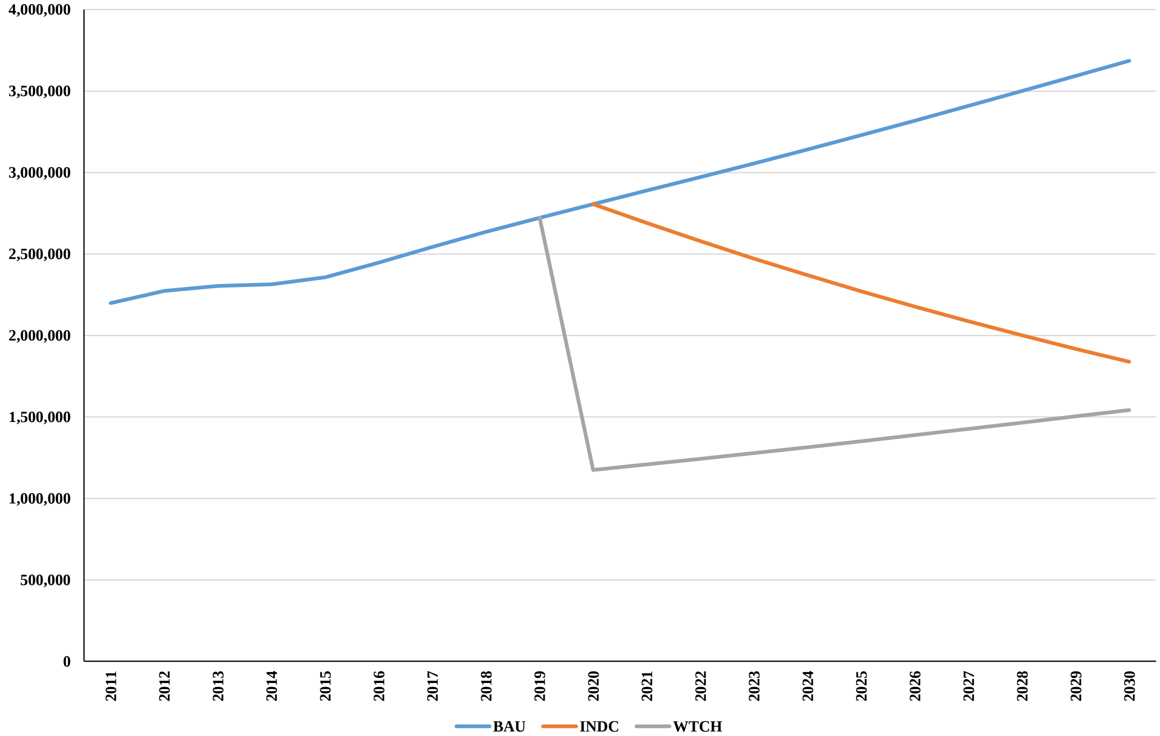
<u>Russia</u>

The Russia forecasted levels of GHG emissions, under the alternative scenarios and the committed goals, for 2030, are shown in Table 15 and Figure 7. This case is similar to that of the USA, but not in the level of course. The goal for Russia means to reduce by 2030 the level of GHG Emissions in absolute terms 16 percent with respect to the level reported in 2011. This would a level 51 per cent below of our forecast under the BAU scenario. The forecasted level with technical change is 30 percent below that of 2011 and 58 percent below the BAU forecasted level for 2030. So, it seems that they too are following a mitigation policy similar to the one we are suggesting.

Table 15 ESTIMATED TOTAL EMISSIONS OF RUSSIA GHG (Gg CO2 eq.)			
Year	BAU	INDC	WTCH
2011	2,198,454		
2012	2,273,982		
2013	2,303,969		
2014	2,314,854		
2015	2,356,769		
2016	2,447,625		
2017	2,544,206		
2018	2,635,992		
2019	2,722,793		2,722,793
2020	2,806,603	2,806,603	1,174,125
2021	2,889,292	2,690,321	1,208,718
2022	2,972,191	2,578,857	1,243,398
2023	3,056,160	2,472,011	1,278,526
2024	3,141,709	2,369,592	1,314,315
2025	3,229,082	2,271,416	1,350,867
2026	3,318,310	2,177,308	1,388,195
2027	3,409,213	2,087,098	1,426,224
2028	3,501,365	2,000,627	1,464,775
2029	3,594,099	1,917,738	1,503,570
2030	3,686,551	1,838,283	1,542,247

Source: Elaborated with data estimated by the Model
BAU : Business as usual (no technological change)
INDC: Intended National Determined Contribution
WTCH: Modifed trend with techological Change
Source: Elaborated with data estimated by the Model

Figure 7
ESTIMATED TOTAL EMISSIONS OF RUSSIA
GHG Gg CO2 Eq.



Source: Elaborated with data from our model and from WIOD

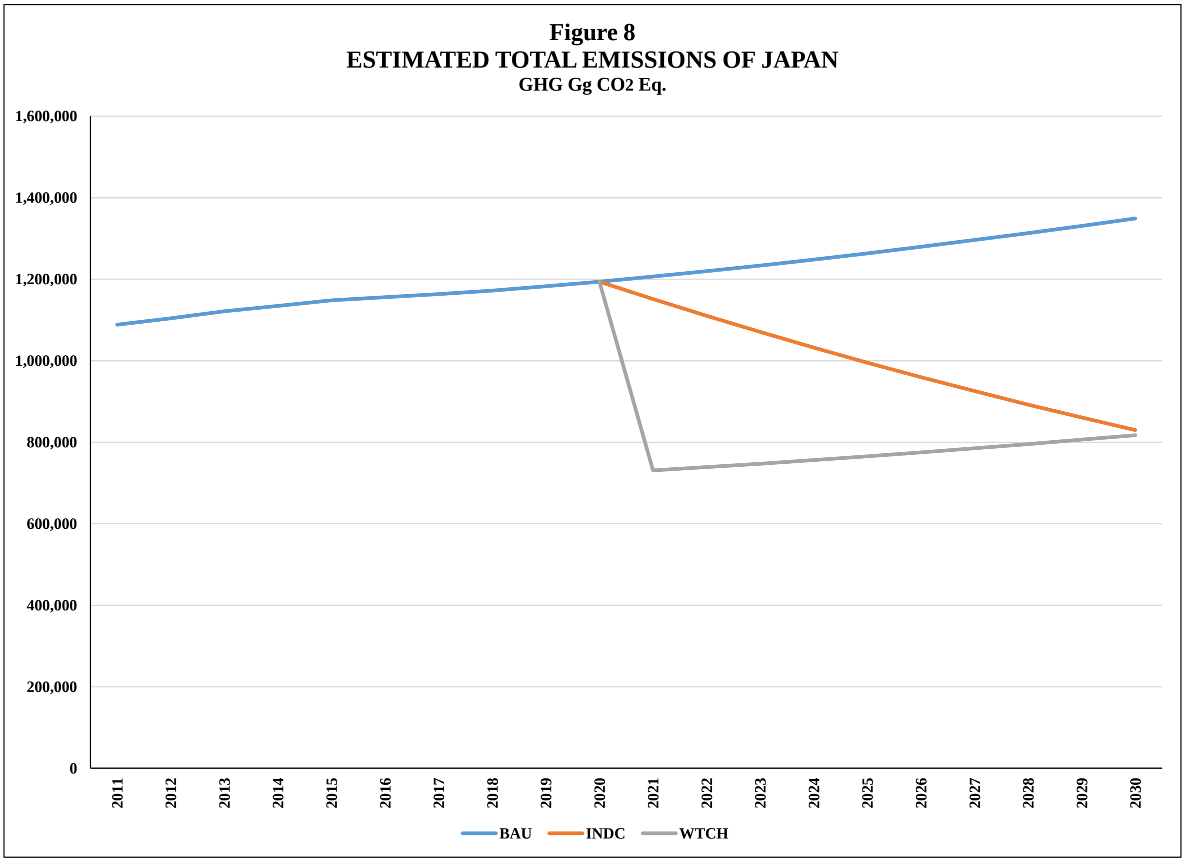
Japan

The Japan forecasted levels of GHG emissions are shown in Table 16 and Figure 8. It is one country that expects a very low level of growth in the following years to 2030, so its forecasted level under the BAU scenario is only 24 percent higher than the level reported in 2011. The committed goal means to reduce that level of 2011 in 24 percent and the level forecasted by our model under technical change coincides with the countries goal level, meaning that both levels are around 39 per cent below the BAU forecasted level of GHG emissions. So in this case it seems they are actually following a mitigation policy similar to the one suggested here, that is a technical change in a few sectors.

Table 16
ESTIMATED TOTAL EMISSIONS OF JAPAN GHG (Gg CO_2 eq.)

Year	BAU	INDC	WTCH
2011	1,088,609		
2012	1,104,361		
2013	1,121,362		
2014	1,134,421		
2015	1,148,545		
2016	1,156,066		
2017	1,163,468		
2018	1,172,301		
2019	1,182,597		
2020	1,194,079	1,194,079	1,194,079
2021	1,206,498	1,151,403	730,869
2022	1,219,708	1,110,253	738,871
2023	1,233,645	1,070,573	747,314
2024	1,248,281	1,032,312	756,180
2025	1,263,596	995,418	765,458
2026	1,279,576	959,842	775,138
2027	1,296,197	925,538	785,207
2028	1,313,392	892,460	795,623
2029	1,331,048	860,564	806,319
2030	1,349,035	829,808	817,215

Source: Elaborated with data estimated by the Model
BAU : Business as usual (no technological change)
INDC: Intended National Determined Contribution
WTCH: Modifed trend with techological Change
Source: Elaborated with data estimated by the Model



Source: Elaborated with data from our model and from WIOD

SUMMARY AND CONCLUSIONS

We have studied the economies of five countries which were regarded as the most GHG emitting countries in 2011 according to the data from the World Bank. These countries have signed the Paris Agreement on Climate Change in December of 2015, produced by the United Nations, and also have participated in the Conference of the Parties, of the United Nations Framework Convention for Climate Change (UNFCCC) in which the parties established their goals for GHG emissions reduction, called Intended National Determined Contributions (INDC).

The importance of these countries is that their GHG emissions represented in 2011 around half of all GHG emissions in the world, according to the various international sources. This means that what they do or do not do for reducing the GHG emissions, surely has an impact on anthropogenic climate change.

Thus, the purpose of studying these five countries has been concentrated on analyzing the trends their GHG emissions will follow from 2011 to 2030. In order to accomplish this objective, we have used some techniques derived from Structural Analysis or Input-Output Analysis. We use all Input-Output data from the World Input-Output Database, including GHG emissions by sector.

These I-O techniques allowed us to determine which sectors of the five economies can be considered key sectors in the sense that they have the stronger linkages to the rest of them in the economy under study. We determined those sectors for the five economies and chose those that were common to all five. Also, we could establish through these techniques what sectors were the higher GHG emitters in each of the economies under study, and we also selected those high emitting sectors that were common to all five.

Based on previous studies, we built an Environmental Input-Output model, with the purpose of forecasting GHG emissions of each of the five economies, under two alternative scenarios. Since the Input-Output model is a demand driven one, we use the concept and values of Final Demand as the independent variable. We obtained the reported values of final demand from 2012 to 2014, and we applied the growth rates forecasted by the OECD for GDP to the Final Demand for 2015 to 2030. One of the scenarios was the so- called “Business as usual” or BAU, means doing nothing to reduce GHG emissions. The other scenario utilized the same independent variable with the same values, but a different Input-Output Matrix (IOM), one which was modified to incorporate a technological change in four selected sectors which were identified both as key sectors and high GHG emitters. This was done taking the technical vectors from other economies and introducing them in our five economies. That is, we *simulate* a technical change in our five economies.

The comparison of the three trends of GHG emissions by country can be summarize as follows:

- Three countries, the USA, Russia and Japan established clear and feasible goals for 2030 and their targets trends suggest they will be (or maybe already are) applying mitigation policies that consist in technological changes in sectors that are key or high emitting sectors, or both like the ones we chose for the study.
- China is a special case, because it has been identified as the highest GHG emitter country. Their committed goals for 2030 are very low as compared to the other four countries, relatively speaking. Our simulated forecasting of GHG emissions reduction through technical change is above the level they are committed to reach. The question is: what is the adequate mitigation policy to get these results?
- The other case is India that is not committed to reduce the absolute GHG emissions level, so in order to actually reduce this level of emissions for 2030, they should apply a technological change like the one we are suggesting here and in the sectors chosen.

Using this model with technical change to forecast Gross Output, we predict an increase in gross output without additional GHG emissions, which proves that the sectors chosen in the countries from which we took them, are not only less GHG emitters but also more productive than the existing ones in the five countries in the study. Although this is not shown in this already long paper.

We now include a final table, Table 16, that shows the overall results and allow us to make comparisons between countries.

Table 17 GHG EMISSIONS 2011-2030 Giga grams CO2 Equiv					
	2011		2030		
Countries	Wolrd Bank	WIOD	INDC	BAU	WTCH
CHINA	12,064,260	10,575,876	5,414,375	27,887,117	12,215,241
USA	6,571,654	5,247,526	4,129,726	8,520,096	4,666,214
INDIA	2,828,846	2,717,729	6,233,604	7,770,808	4,363,498
RUSSIA	2,777,724	2,198,454	1,838,283	3,686,551	1,542,247
JAPAN	1,396,767	1,088,609	829,808	1,349,035	817,215
Subtotal	25,639,251	21,828,194	18,445,796	49,213,606	23,604,414
Rest of the World	26,410,600	22,484,888	19,000,732	50,694,181	24,314,545
WORLD Total	52,049,851	44,313,082	37,446,528	99,907,788	47,918,959
Stern Review	50,000,000			62,000,000	
WIOD = World Input-Output Database					
INDC = Intended National Determined Contribution					
BAU = Buisness as usual trend					
WTCH = With technological change trend					

The comparisons we have made in the last section of this paper are shown in Table 17. To conclude we must pay attention to the comparison of our figures, those from different sources and from our model with those of Stern (2007 p.173) according to which in 2011 we were already above his projected BAU trend line and if we do nothing, we will be in 2030 generating close to 100,000,000 Gg of GHG emissions, well above Stern's figure which was 62,000,000 Gg of GHG emissions, roughly.

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World Bank data: http://data.worldbank.org/
World Bank, World Development Indicators: http://data.worldbank.org/
World Bank Emissions: http://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE

World Input-Output Data Base WIOD: http://www.wiod.org/home
WIOD, Environmental Accounts: http://www.wiod.org/database/eas13
WIOD, World input-output tables: http://www.wiod.org/database/wiots13

World Resources Institute, CAIT Contributions Map http://cait.wri.org/indc/

APPENDIX

METHODOLOGICAL NOTES

1. Note on GHG emissions

GHG emissions data we used for the five countries under study to analyze and forecast their trends were the GHG emissions vector by sector from the World Input-Output Database WIOD Environmental Accounts (http://www.wiod.org/database/eas13). They are consistent with the WIOD Input-Ouput matrices for the same countries.

However, these vectors by sector (35) are estimated by WIOD separately for the three main greenhouse gasses. Thus, there are three emissions vectors: carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), with information available up to 2009. In order to get one single vector of total GHG emissions we had to sum up the three vectors in common CO_2 equivalent units, utilizing conversion factors for the three gasses provided by the Intergovernmental Panel on Climate Change (IPCC).

Now in order to estimate the GHG emission vector for 2011, we used a different source, the World Bank that estimates the same group of gasses and the same unit measure CO_2 equivalent.

We then compared the annual information we get from these two sources for the period 1995-2009 checking that the differences were very small and the total followed the same trend in that period.

Now, since we were analyzing GHG emissions generated in production and not in consumption, we took the proportion of intermediate uses to total uses, from WIOD data and applied it to the World Bank data for 2011. And we distribute the GHG emissions by sector according to the WIOD proportions for 2009. The same process is carried out for each of the five countries under study.

2. Note on Intended National Determined Contributions INDC

In accordance to the Paris Agreement (UNFCCC, 2015) each signing country is assumed to make public its Intended National Determined Contributions, that is, its committed goals of GHG emissions reduction for 2030. The source that is following these INDC is the World Resources Institute WRI in its CAIT Paris Contributions Map, website: http://cait.wri.org/indc/

We found for our selected countries the respective website for INDC:

China:
http://www4.unfccc.int/submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf
www4.unfccc.int

USA:
http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf

India:
http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf
www4.unfccc.int

Russia:
http://www4.unfccc.int/submissions/INDC/Published%20Documents/Russia/1/Russian%20Submission%20INDC_eng_rev1.doc
Russian Submission INDC_eng_rev1.doc - Climate change
www4.unfccc.int

Japan:
http://www4.unfccc.int/submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf
www4.unfccc.int

3. Note on the emissions by emissions matrix

We can obtain matrix$(\mathbf{I}-\mathbf{\Psi})^{-1}$, following Hewings (1985) and King *et al.* (2012) for the analysis of employment. We start from equations (2) and (5) in the model:

$$\mathbf{x} = \mathbf{Z}\,\mathbf{i} + \mathbf{f} \qquad \text{(A.1)}$$

$$\hat{\mathbf{e}} = \hat{\mathbf{g}}\;\hat{\mathbf{x}}^{-\mathbf{1}} \qquad \text{(A.2)}$$

We multiply both sides of equation (A.1) by $\hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}$ so, we get:

$$\hat{\mathbf{g}}\;\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{x} = \hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{Z}\,\mathbf{i} + \hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\,\mathbf{f} \qquad \text{(A.3)}$$

We now substitute **i** the summation column vector by $\hat{\mathbf{g}}^{-1}\mathbf{g}$ in equation (A.3) and solving for $\mathbf{g}$ we get:

$$\hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{Z}\;\hat{\mathbf{g}}^{-1}\mathbf{g} + \hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{f} = \mathbf{g} \qquad \text{(A.4)}$$

It follows that:

$$\hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{f} = \mathbf{g} - \hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{Z}\;\hat{\mathbf{g}}^{-1}\mathbf{g} \qquad \text{(A.5)}$$

$$\hat{\mathbf{g}}\,\hat{\mathbf{x}}^{-\mathbf{1}}\mathbf{f} = (\mathbf{I} - \hat{\mathbf{g}}\;\hat{\mathbf{x}}^{-\mathbf{1}}\,\mathbf{Z}\,\hat{\mathbf{g}}^{-1})\,\mathbf{g} \qquad \text{(A.6)}$$

Now, substituting $\hat{\mathbf{e}}$ for $\hat{\mathbf{g}}\;\hat{\mathbf{x}}^{-\mathbf{1}}$ in (A.6) we get:

$$(\mathbf{I} - \hat{\mathbf{e}}\,\mathbf{Z}\,\hat{\mathbf{g}}^{-1})^{-1}\hat{\mathbf{e}}\,\mathbf{f} = \mathbf{g} \qquad \text{(A.6)}$$

$$(\mathbf{I} - \mathbf{\Psi})^{-1}\hat{\mathbf{e}}\,\mathbf{f} = \mathbf{g} \qquad \text{(A.7)}$$

where: $\mathbf{\Psi} = \hat{\mathbf{e}}\,\mathbf{Z}\,\hat{\mathbf{g}}^{-1}$ a matrix of GHG emissions by GHG emissions,

4. Note on High GHG emissions calculations

Following the model for Emissions multipliers shown in the previous note we calculated the three indicators mentioned for four sectors in the five selected countries. To determine whether these sectors were high GHG emitting ones to be included in our final set of selected sectors, we estimated their measures of central tendency, which results are shown in Table A.1

Table A.1

MEASURES OF CENTRAL TENDENCY OF EMISSIONS IN FOUR SECTORS OF THE FIVE COUNTRIES

Giga grams CO_2 Equiv. and relative values

	No. of Obs.	Mean value	Sta. Dev.	Max value	Sector 8	Mean > or <	Sector 12	Mean > or <	Sector 17	Mean > or <	Sector 23	Mean > or <
CHINA												
Total Emissions	35	302,168	781,549	4,306,430	133,597	<	813,545	>	4,306,429	>	130,472	>
Emissions coeff.	35	0.47	1.08	6.06	0.35	<	0.42	<	6.06	>	0.32	<
Emissions mult.	35	1.54	1.60	9.56	1.94	>	2.21	>	9.56	>	1.09	>
USA												
Total Emissions	35	149,929	359,369	2,115,370	191,913	>	104,222	<	2,115,370	>	243,980	>
Emissions coeff.	35	0.43	1.07	6.16	0.28	<	0.20	<	6.16	>	0.63	<
Emissions mult.	35	0.74	1.10	6.37	0.88	>	0.71	<	6.37	>	0.89	>
INDIA												
Total Emissions	35	77,649	205,421	962,936	56,830	<	145,240	>	962,936	>	40,788	>
Emissions coeff.	35	0.84	2.03	11.38	0.38	<	0.64	<	11.38	>	0.14	<
Emissions multi.	35	1.80	2.53	14.93	1.69	<	2.69	>	14.93	>	1.16	>
RUSSIA												
Total Emissions	35	62,813	165,425	929,101	75,197	>	199,977	>	929,101	>	209,003	>
Emissions coeff.	35	0.58	1.09	5.56	0.36	<	1.29	>	5.56	>	1.49	>
Emissions multi.	35	1.51	1.29	6.84	1.66	>	2.72	>	6.84	>	2.39	>
JAPAN												
Total Emissions	35	31,103	62,429	355,125	30,503	<	121,640	>	355,125	>	36,400	>
Emissions coeff.	35	0.16	0.28	1.07	0.14	<	0.19	>	1.07	>	0.14	<
Emissions multi.	35	0.42	0.42	1.88	0.63	>	0.68	>	1.41	>	0.29	<

Sector 8 Coke, Refined Petroleum and Nuclear Fuel
Sector 12 Basic Metals and Fabricated Metal
Sector 17 Electricity, Gas and Water Supply
Sector 23 Inland Transport