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Input-Ouput Analysis of the Key Sectors in Philippine Carbon Dioxide Emissions from a Production Perspective

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The study computes the carbon dioxide emissions of the Philippines for the period of 2000 to 2006 and applies a production perspective input-output analysis to identify the key sectors whose value-added growth were responsible for the increase in emissions of the country and those that exhibited increased sectoral emissions from overall income growth. Power generation turned out to be the primary sector while cement manufacture, wholesale/retail trade, mining, road and water transport, and private services were revealed as the secondary sectors, jointly accounting for 0.66% increase in the country's emissions from a 1% growth in their value-added and experiencing 0.75% higher emissions from a 1% increase in the economy's income.

***Keywords**:* Emissions, input output analysis, production functions

Myriad scientific evidence points to a changing global climate due to anthropogenic activities. The most dramatic rise in average global temperature has manifested within the current century from the increased presence of heat-trapping greenhouse gases (GHGs) in the earth's atmosphere, primarily carbon dioxide. Hence, globally concerted efforts are being geared towards reducing gas emissions from the use of fossil fuels. Since the links between economic activity and environmental pressure are insightful in conceiving environmental policies and assessing the direction and size of their economic implications (Dellink, 2005), a successful implementation of a carbon emission mitigation program requires better understanding and consideration of the sources of emissions, the contribution of different productive sectors to carbon dioxide emissions, and the emissions impact of income generation in the economy, for a more effective and efficient targeting.

For the Philippines to adopt policies that address climate change, a taxonomy that relates the relative contribution of growth of each sector to overall carbon dioxide emissions, as well as overall growth with sectoral emissions, is of paramount importance. This study aims to show such a quantitative assessment with emphasis on measuring the link between sectoral income generation capacity (in the form of value-added) and carbon dioxide emissions. The key productive sectors that exhibit the greatest income generation elasticities of emissions are then identified. For a more comprehensive coverage, it utilizes a production perspective input-output analytical framework to complement previous works on carbon dioxide accounting that analyze from a demand perspective. In addition, commonly believed sectoral emission intensities and relationships are either validated or disproved. Finally, the policy implications of the findings are presented.

Some caveats are in order. Utilizing an input-output framework assumes homogeneity and proportionality. The use of the latest 2000 Philippine Input-Output Accounts for all the years covered in the study – 2000 to 2006 – assumes that the productive structure and interdependencies of the various sectors remain constant over time and can be considered representative of the period. Next, this study explores only the carbon dioxide emissions from industrial fossil fuel combustion within the economy without adjustments for emissions emanating from the production of import and export goods. The fuels considered are petroleum, natural gas and coal that account for about 90% of the global carbon dioxide emissions (Padilla, 2008). Those from other sources like land-use change and agriculture are not tracked due to the laborious procedure involved. Also, emissions of other GHGs like methane and nitrous oxide and their carbon dioxide-equivalents based on their long-term global warming potential (GWP) are excluded due to the dependence of these discharges not only on fuel type but also on the varying efficiency of the burning facility. These exclusions should only have a minimal impact since 95% of the GHGs is carbon dioxide (Padilla, 2008). Lastly, the level of sectoral classification in this study follows the sectoral groupings found in the Department of Energy's (DOE) report on fuel use, since the emissions calculation here is primarily based on the said report.

LITERATURE REVIEW

The basis of most input-output (I-O) analyses done today is that of Wassily W. Leontief (1970), which earned him the Nobel Prize in Economics in 1973. His I-O model, first applied to the United States economy in 1932, gained popularity for its meticulous analytical framework that can be easily adopted and extended. The static version of this I-O analysis describes and explains the level of output of each sector of an economy in terms of its relationship to the corresponding levels of activities in all the other sectors. In 1970, Leontief extended the I-O approach to incorporate an environmental externality, pollution. This approach has become the foundation for analyzing the environmental implications of economic activities, appropriately dubbed environmental input-output (E I-O) analysis.

Common applications involve appending the model with environmental impact vector or vectors and executing a demand-side analysis such as those done by Hayami, Nakamura, Suga, and Yoshioka (1997) in Japan, Sousa (2001) in Portugal, and Tan and Tanchuco (2007) in the Philippines. Hayami et al. (1997) examined technology management issues like the carbon dioxide emission effects of the use of blast furnace cement, use of recycled paper, transportation energy consumption, house insulation, and others. Sousa (2001) used the model together with life cycle assessment (LCA) in computing for the GHG emissions associated with a certain change in the final output. Tan and Tanchuco (2007) analyzed the industrial carbon dioxide emissions from combustion using a low-resolution, that is, 11-sector, input-output model and found power generation and transportation to have the highest carbon dioxide intensities as well as the greatest indirect emissions contribution to the upstream sectors. All these applications took the demand perspective.

Another aspect that is explored using input-output analysis is the identification of key sectors. Elasticities calculated from the extended I-O framework that establishes intersectoral linkages in relation to carbon dioxide emissions are evaluated and ranked to pinpoint the key sectors. This methodology has been repeatedly applied in various studies in Spain including those of Alcantara and Padilla (2006) and Tarancon and del Rio (2007), where the former used the production perspective.

In the Philippines, however, there is a deficiency of studies that revolve around these themes other than that of Tan and Tanchuco (2007). This can largely be attributed to environmental data constraints. Hence, this study fills the gap by implementing emissions accounting, particularly one from a production perspective, and computing income elasticities of emissions to identify key sectors. This can then serve as input in devising future programs of the country to combat the cause of climate change.

METHODOLOGY

The study follows heavily the methodology developed by Alcantara and Padilla (2006) in establishing the relationship between carbon dioxide emissions and income generation in the form of the value-added generated in the economy using input-output analysis. For an *n*-sector economy let **x** be the $n \times 1$ vector of total productions; **A** be the $n \times n$ matrix of technical coefficients, or direct requirements, with the characteristic element a_{ij} representing the use of sector *i* as input in the production of a monetary unit of output of sector *j*; **u** be an $n \times 1$ unitary vector; **v** be the $n \times 1$ vector of value-added; **s** be the $n \times 1$ vector of value-added coefficients with the characteristic element $s_j = \frac{v_j}{x_j}$; **c** be the $n \times 1$ vector of sectoral direct carbon dioxide emissions; *C* be the scalar of total level of carbon dioxide emissions; **g** be the $n \times 1$ vector of the distribution of total emissions among the *n* productive sectors with the characteristic element $g_i = \frac{c_i}{C}$ such that $\sum_{i=1}^{n} g_i = 1$; ^ indicates diagonalization of a vector signifying that the elements in the vector become the elements in the principal diagonal of a square matrix with the rest of the elements as zeros; and **'** indicates transposition of a matrix or vector, that is, interchange of the elements in the rows and columns.

Here the input-output system consists of n linear identities stating that total production equals the sum of intermediate inputs and the value-added

$$\mathbf{x} = \hat{\mathbf{x}}\mathbf{A}'\mathbf{u} + \mathbf{v} \tag{1}$$

Premultiplying both sides of the equation with $\hat{\mathbf{x}}^{-1}$ results in

$$\hat{\mathbf{x}}^{-1}\mathbf{x} = \hat{\mathbf{x}}^{-1}\left(\hat{\mathbf{x}}\mathbf{A}'\mathbf{u} + \mathbf{v}\right) \tag{2.a}$$

Eq. 2.a. can now be expressed as

$$\mathbf{u} = \mathbf{A}'\mathbf{u} + \mathbf{s} \tag{2.b}$$

where , consistent with the definition of vector of value-added coefficients.

Rearranging the above equation, we have

$$(\mathbf{I} - \mathbf{A}')\mathbf{u} = \mathbf{s} \tag{3.a}$$

and solving for **u** allows us to write

$$\mathbf{u} = (\mathbf{I} - \mathbf{A}')^{-1}\mathbf{s} \tag{3.b}$$

Eq. 3.b allows distribution among sectors of any variable related to production according to the productive structure and the weight of the income generated in relation to the sector's production. For this study, the relevant variable is carbon dioxide emissions. Accordingly, Eq. 3.b is premultiplied by vector **c** in its conformable form as in

$$\mathbf{c} = \hat{\mathbf{c}}(\mathbf{I} - \mathbf{A}')^{-1}\mathbf{s} \tag{4}$$

Since vector **c** can also be expressed as

$$\mathbf{c} = C\mathbf{g} \tag{5}$$

substitution to Eq. 4 of its conformable form yields

$$\mathbf{c} = C\hat{\mathbf{g}}(\mathbf{I}-\mathbf{A}')^{-1}\mathbf{s} \tag{6}$$

and premultiplying both sides of the equation by translates Eq. 6 to a scalar equation

$$C = C\mathbf{g}'(\mathbf{I}-\mathbf{A}')^{-1}\mathbf{s} \tag{7}$$

The next expression shows how total emissions vary from a proportional change of α in the value-added, *ceteris paribus*,

$$\Delta C = C\mathbf{g}'(\mathbf{I}-\mathbf{A}')^{-1}\mathbf{s}\alpha \tag{8}$$

where $\alpha = \frac{\Delta v_j}{v_j}$ for each sector representing proportional increase in the value-added or income. Dividing both sides of Eq. 8 by total emissions *C*, one obtains

$$\frac{\Delta C}{C} = \mathbf{g}'(\mathbf{I}-\mathbf{A}')^{-1}\mathbf{s}\alpha \tag{9}$$

while diagonalization of **s** and assuming $\alpha = 1\%$ allow writing the scalar Eq. 9 as vector

$$\varepsilon' = \mathbf{g}'(\mathbf{I}-\mathbf{A}')^{-1}\hat{\mathbf{s}} \tag{10}$$

denoting elasticities since its characteristic element is expressed as

$$\varepsilon_j = \frac{\Delta C / C}{\Delta v_j / v_j} \tag{11}$$

ε_j represents the proportional change in (direct and indirect) total emissions from a percentage change in the value-added, or a proportional change in income, of sector *j*, that is, income elasticity of total emissions, likewise interpreted as a measure of sectoral impact.

For more flexibility in terms of interpretation, $\mathbf{g}'$ is diagonalized so that

$$\mathbf{E}^V = \hat{\mathbf{g}}(\mathbf{I}-\mathbf{A}')^{-1}\hat{\mathbf{s}} \tag{12}$$

This matrix of elasticities has the characteristic element, $\mathbf{E}_{ij}^V$, which captures the percentage change in the emissions of sector *i*, as a proportion of total emissions, in response to a 1% growth in the value-added generated in sector *j*. The sum of the elements over *i*, that is, column sum $\sum_i^n \mathbf{E}_{ij}^V \forall j = 1,\ldots,n$, gives the total impact or **total effect** of sector *j*'s income generation or value-added growth on the economy's total emissions. Both the direct and indirect components can be extracted from the total effect.

On the other hand, the sum of the elements over *j*, that is, row sum $\sum_j^n \mathbf{E}_{ij}^V \quad \forall i = 1,\ldots,n$, shows the direct impact on the emissions of the economy from sector *i* of a percentage growth in the overall value-added. All the row sums demonstrate the sectoral distribution of emissions, thus, the direct impact is also referred to as the sectoral or **distributive effect**.

High elasticity indices are indicative of the relevance of the sector in carbon dioxide emissions. Consistent with Tarancon and del Rio (2007), the "relevant" sectors pertaining to carbon dioxide emissions are picked based on the rescaled elasticities. Rescaling of the total and distributive impacts or elasticities, respectively, makes use of the following formulae,

$$\frac{\sum_i^n \mathbf{E}_{ij}^V}{\frac{\sum_j^n \sum_i^n \mathbf{E}_{ij}^V}{n}} \cdot 100 \quad \text{and} \quad \frac{\sum_j^n \mathbf{E}_{ij}^V}{\frac{\sum_i^n \sum_j^n \mathbf{E}_{ij}^V}{n}} \cdot 100$$

The presence of above average index value, that is, greater than 100, in at least one of the two effects makes the sector a candidate key sector in carbon dioxide emissions. Above average indices for both total and distributive effects automatically qualify the sector as a key sector for exhibiting the most intense impacts. The key sectors require the closest examination for emissions reduction since their income generation growth is associated with a higher increase in total emissions and overall economic growth translates to greater emissions in the economy from these sectors. The above also indicate that income generation growth in these sectors pose greater environmental repercussion, hence, larger opportunity for improvement.

Further evaluation of the key and other candidate sectors involve delving into the details of the elasticity matrix generated by Eq. 12. Relevant relations are those left after filtering out low elasticity values of $\mathbf{E}_{ij}^{V}$. The selection of filter is such "that it provides a balanced outlook of the economic relationships, which are neither too high for the information supplied to be too poor, nor too low for the results to be unclear since nearly all coefficients surpass the filter" (Tarancon & del Rio, 2007, p. 592).

Finally, the consideration of the relevant intersectoral sensitivities that signify interdependence among sectors, along with manifestation of above average elasticities, points to the conclusive list of "key sectors" in carbon dioxide emissions in the Philippines. These sectors are further classified into sub-sectors, primary and secondary key sectors, based on the intensity of their impact for a more appropriate nomenclature.

DATA

The basic inputs to this study are the Philippine emissions data and I-O table. Since emissions data are not readily available for the Philippines, the study first calculates the sectoral carbon dioxide emissions from fossil fuel combustion based on fuel use and engineering formulae. The 33 sectors defined in the Department of Energy's (DOE) fuel usage report for the years 2000 to 2006 are the basis of the level of sectoral segregation in this study. The details of the carbon dioxide computation from burning petroleum, including premium and regular gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas (LPG), jet fuel and aviation gas, coal, and natural gas, together with the relevant emissions vectors used in the study, are found in Appendix A.

The 240-sector industry/commodity input-output (I-O) transactions table of the Philippines for year 2000 published by the National Statistical Coordination Board (NSCB; 2006) is condensed to a 33-sector table to match the DOE classification. The report captures all production flows, in monetary terms, within the economy showing the allocation of a sector's output over the economy by row and the allotment of inputs required by a particular sector to produce its output by column. It further shows details of intermediate use of output, final deliveries of goods and services for personal consumption, investments, net exports and government spending, and payments to primary inputs, like salary and wages paid to workers, depreciation allowance for the use of capital, net indirect taxes paid to government, and operating surplus paid to entrepreneurs, representing the value-added of each sector. Appendix A also presents how the I-O data used in this study are derived and applied to the model.

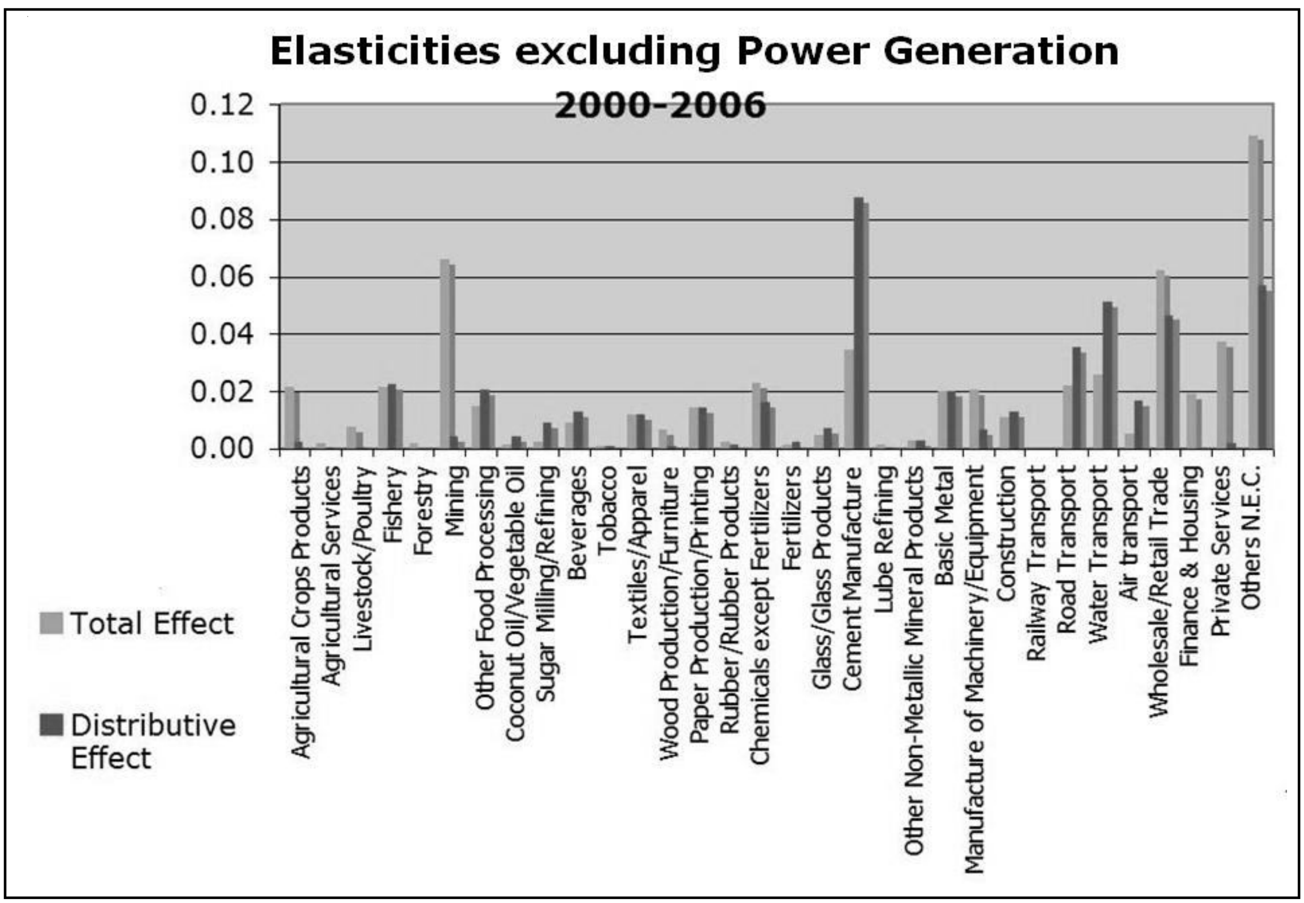
RESULTS AND DISCUSSION

This study finds power generation as undoubtedly the greatest contributor to carbon dioxide emissions in the Philippines. The elasticities, computed as the column (total effect) and row (distributive effect) sums of matrix $\mathbf{E}^{V}$, confirm and quantify the strong association between value-added growth and emissions from the sector. The link appears to be almost eight times stronger on the average than that of the next sector with highest elasticities. This study asserts that a value-added growth of 1% in power generation translates to a 0.41%, or more than two-fifths increase in total carbon dioxide emissions in the country, while a 1% increase in the overall value-added of the economy leads to a 0.53%, or more than half, increment in the country's emissions from power generation. Thus, power generation is singled out as the primary key sector in the Philippine carbon dioxide emissions. Effective mitigation strategies focused on this sector will likely engender large reductions of the undesired emissions.

The calculated elasticities of the rest of the sectors are illustrated in Figure 1. For a better picture of these sectors, power generation is deliberately excluded from the chart since it possesses extraordinarily high elasticities compared with the others. The following sectors: mining, wholesale/retail trade, private services, and others not elsewhere classified, display not only high total effects but relatively higher total impact than distributive impact. This means that their value-added growth leads to greater impact on overall emissions than the impact of economy-wide value-added growth on these sectors' emissions. The significant impact on total emissions is reflective of the subsequent increase in emissions of the users of these sectors to whom their output are supplied to, that is, their indirect effects. Thus, in this case, total effect dominates distributive effect since growth in these sectors spurs higher emissions of user sectors while these sectors' shares are tempered by huge emitters when there is growth in the entire economy.

Cement manufacture, road transport, and water transport, on the other hand, exhibit higher

Figure 1. *Elasticities excluding power generation, 2000-2006.*



distributive effect than total effect, so that an increase in the income generation capacity of the economy increases the carbon emissions from these sectors. This can be attributed to greater production, incidentally more emissions, driven by the simultaneous growth of the supplier sectors.

Table 1 presents the computed elasticities and indices, namely, the total impact, disaggregated to the direct and indirect components, the distributive impact, and their corresponding rescaled values. Sectors with scaled elasticities over 100 are distinguished by the dark highlight. They

Table 1
Scaled Elasticities

Sectors	Direct	Indirect	Scaled Direct	Scaled Indirect	Total Effect	Dist. Effect	Scaled Total Effect	Scaled Dist. Effect
Agricultural Crops Products	0.0020	0.0195	10	181	0.0215	0.0024	71	8
Agricultural Services	0.0006	0.0015	3	14	0.0021	0.0006	7	2
Livestock/Poultry	0.0005	0.0071	2	65	0.0075	0.0007	25	2
Fishery	0.0187	0.0030	96	28	0.0217	0.0227	72	75
Forestry	0.0003	0.0017	1	16	0.0020	0.0003	6	1
Mining	0.0028	0.0634	14	587	0.0662	0.0042	218	14
Other Food Processing	0.0071	0.0077	36	72	0.0148	0.0206	49	68
Coconut Oil/Vegetable Oil	0.0013	0.0004	7	4	0.0017	0.0045	6	15
Sugar Milling/Refining	0.0021	0.0005	11	4	0.0026	0.0092	9	30
Beverages	0.0075	0.0016	38	15	0.0091	0.0130	30	43
Tobacco	0.0007	0.0002	4	2	0.0009	0.0012	3	4
Textiles/Apparel	0.0077	0.0041	39	38	0.0118	0.0117	39	39
Wood Production/Furniture	0.0006	0.0060	3	56	0.0066	0.0010	22	3
Paper Production/Printing	0.0085	0.0058	44	54	0.0143	0.0143	47	47
Rubber/Rubber Products	0.0006	0.0016	3	15	0.0023	0.0014	7	5
Chemicals except Fertilizers	0.0086	0.0144	44	133	0.0230	0.0163	76	54
Fertilizers	0.0011	0.0007	5	6	0.0017	0.0026	6	9
Glass/Glass Products	0.0035	0.0014	18	13	0.0048	0.0070	16	23
Cement Manufacture	0.0340	0.0006	175	5	0.0346	0.0876	114	289
Lube Refining	0.0001	0.0014	1	13	0.0015	0.0005	5	2
Other Non-Metallic Mineral Products	0.0016	0.0015	8	13	0.0031	0.0028	10	9
Basic Metal	0.0111	0.0090	57	83	0.0201	0.0200	66	66
Manufacture of Machinery/ Equipment	0.0040	0.0169	20	156	0.0209	0.0067	69	22
Construction	0.0072	0.0038	37	35	0.0110	0.0129	36	42
Power Generation	0.3955	0.0174	2028	161	0.4129	0.5261	1362	1736
Railway Transport	0.0000	0.0001	0	0	0.0001	0.0001	0	0
Road Transport	0.0188	0.0031	96	29	0.0219	0.0355	72	117
Water Transport	0.0246	0.0014	126	13	0.0259	0.0515	86	170
Air transport	0.0044	0.0010	22	9	0.0053	0.0169	18	56
Wholesale/Retail Trade	0.0316	0.0307	162	284	0.0623	0.0467	206	154
Finance & Housing	0.0002	0.0190	1	176	0.0192	0.0002	63	1
Private Services	0.0013	0.0359	7	332	0.0373	0.0021	123	7
Others N.E.C.	0.0351	0.0743	180	688	0.1094	0.0568	361	187
Total	0.6435	0.3565			1.0000	1.0000		
Average	0.0195	0.0108			0.0303	0.0303		

automatically qualify as key sectors for exhibiting intensive effects on the country's emissions based on the two-pronged identification of above average total effect and above average distributive effect. Other than power generation, these are cement manufacture, wholesale/retail trade, and others not elsewhere classified. A lighter highlight on mining, road and water transport, and private services denote significance of either the total or distributive effect but not both on these sectors.

Table 2 rationalizes the final identification of key sectors by showing the relevant relations or sensitivities, with rounded values of $\mathbf{E}_{ij}^{V}$ >0.001 used as filter, following the criterion specified in the methodology. It presents the intersectoral productive and emissions linkages. Specifically, Table 2 displays as blocks in a row the supplier sectors that induce carbon dioxide emissions from sector *i* while the blocks in a column signify the user sectors that indirectly produce carbon dioxide emissions of sector *j*.

Secondary Key Sectors

Mining and private services. Mining and private services qualified as key sectors because of their significant total impact on overall emissions of 0.07% and 0.04%, respectively, as a result of these sectors' 1% income generation growth, notwithstanding income growth in the entire economy has minimal impact on their emissions. What may initially appear as a counterintuitive outcome for private services is justified by the dominance of the indirect effects brought in by nine user sectors, but primarily from power generation. As for the mining sector, which has eight relevant user sectors, the greatest indirect effects are from power and cement manufacture. By themselves mining and private services do not pose intensive carbon dioxide emissions impact. But the uncovered structure means that user sector-focused policies are most appropriate for carbon mitigation on these industries.

Cement and road and water transport. Cement manufacture typically ranks high in terms of carbon dioxide emissions due to the coal-intensive nature of production in the sector. The same is true for road and water transport. The results verify that their emissions are notably linked to income generation and reveal that these sectors exhibit relatively higher distributive effects than total effects where the former is double, if not more than double, of the latter (0.09% versus 0.03% for cement, 0.04% versus 0.02% for road transport, and 0.05% versus 0.03% for water transport). This is explained by the strong sensitivity of the carbon emissions from these sectors on the supplier sectors' income growth. Cement is significantly linked with 15 suppliers while road and water transport are connected with 14 and nine suppliers, respectively. Other than that, majority of the total effects of these sectors' income growth on emissions are directly produced suggesting that the appropriate regulatory measures for cement, road transport and water transport should be directed at the production side. It may be in the form of incentivizing adoption of efficient and less carbon emitting technology for cement while utilization of alternative energy for transport may be further promoted.

Wholesale/retail trade. Wholesale and retail trade sector seems to exhibit a surprising outcome. It turns out as a key sector in carbon dioxide emissions despite being primarily a service type sector. A closer look reveals that only around half of its 0.06% total effect is directly generated while the other half is indirectly contributed by the resulting emissions increase of its 13 user sectors. Similarly, its significant distributive effect of 0.05% takes into account its emissions' sensitivity to 10 supplier sectors. In fact it is found to be one of the most linked sectors in terms of emissions. Considering all these, a combination of both production side and demand side regulations should be explored. Further investigation and research may be required in identifying a more definitive carbon dioxide mitigation strategy for the sector. In the interim, energy efficiency and conservation efforts in the sector are likely to result to some emissions reduction even if marginal.

Table 2

Relevant Elasticities with Rounded Values of $\mathbf{E}_{ij}^{V} > 0.001$ *as Filter*

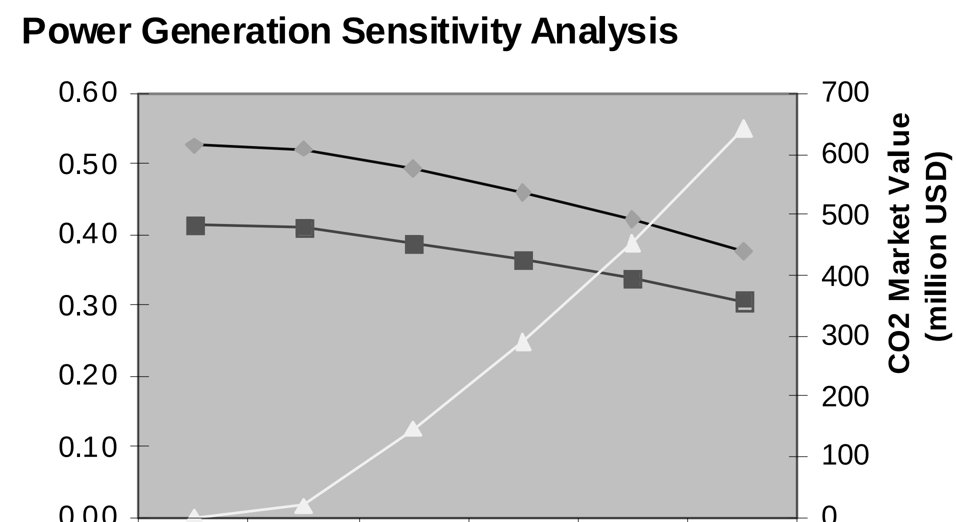
	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
1	Agricultural Crops Products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	Agricultural Services	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	Livestock/Poultry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	Fishery	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
5	Forestry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	Mining	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	Other Food Processing	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	6
8	Coconut Oil/Vegetable Oil	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
9	Sugar Milling/Refining	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
10	Beverages	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	5
11	Tobacco	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12	Textiles/Apparel Wood	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
13	Production/Furniture	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14	Paper Production/Printing	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	5
15	Rubber/Rubber Products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	Chemicals except Fertilizers	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	6
17	Fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18	Glass/Glass Products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
19	Cement Manufacture	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	16
20	Lube Refining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	Other Non-Metallic Mineral Products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
22	Basic Metal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	1	1	5
23	Manufacture of Machinery/Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2
24	Construction	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	4
25	Power Generation	1	0	1	1	0	1	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	1	1	1	1	0	1	0	0	1	1	1	1	18
26	Railway Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	Road Transport	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	1	0	0	1	1	1	1	10
28	Water Transport	1	0	1	0	0	1	1	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1	15
29	Air transport	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6
30	Wholesale/Retail Trade	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	11
31	Finance & Housing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	Private Services	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
33	Others N.E.C.	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	12
		10	1	3	3		9	6	1	1	1	1	3	4	4	1	9	1	1	1	1	2	7	7	4	8		3	2	1	14	7	10	15	

The Primary Key Sector: Power Generation

As the most critical sector in terms of carbon dioxide emissions, power generation warrants a deeper investigation. A sensitivity analysis is performed by reducing at varying rates the kg CO_2 per kWh of energy from the current level of 0.458 to about half of it. Reductions may be realized by adjusting the power mix towards greater reliance on non-carbon-emitting renewable sources such as geothermal in lieu of coal-fired power sources for the base load and wind farms and hydro power to replace diesel-run power plants, or resorting to nuclear power, among others. A representative scenario is one where oil's share is almost halved, coal's share is reduced to a third, natural gas use is held constant, and utilization of renewable sources is less than doubled that of the 2000 to 2006 mix. The study estimates a potential of as much as USD 641 million worth of carbon dioxide emissions avoided in a year by switching to renewable sources of power generation. See Figure 2

The estimates are based on the use of the 2006 emissions data of 21.5 million tons of carbon dioxide as the reference case and on the

Figure 2. *Power generation sensitivity analysis.*



kg of CO2/kWh	0.46	0.45	0.40	0.35	0.30	0.25
Total Effect	0.413	0.410	0.389	0.365	0.338	0.306
Distributive Effect	0.526	0.522	0.492	0.459	0.421	0.377
Market Value (million USD)	0	19	146	289	453	641

assumptions that power generation via oil produces 0.8 kg CO_2/kWh, coal emits 1 kg CO_2/kWh, natural gas creates 0.5 kg CO_2/kWh, and renewable sources such as geothermal, wind, hydro, and solar do not produce any carbon dioxide. The Philippine growth rate is 5%, and the current contract price of carbon dioxide per ton of EUR 25 or USD 40 holds. Although the market for emissions trading does not exist in the Philippines, the country is a party to a number of Kyoto Protocol's Clean Development Mechanism (CDM) projects that allow exchange of carbon credits to Annex I developed countries. Hence, the valuation of carbon dioxide in this study may be interpreted in terms of the country's involvement with CDM projects.

CONCLUDING REMARKS

Using input-output analysis from a production perspective, this study finds power generation as the primary key sector and cement manufacture, wholesale/retail trade, mining, road and water transport, and private services as the secondary key sectors in Philippine carbon dioxide emissions. Jointly, the secondary sectors are responsible for 0.25% total increase in emissions of the Philippines from a 1% increase in their value-added while a 1% increase in the income of the economy entails 0.23% increase in total emissions accountable to these sectors. Combining their impact with power generation, the elasticities increase to 0.66 total effect and 0.75 distributive effect. Appendix B shows the breakdown of the emissions impact of income generation for each of the sectors together with other pertinent details.

Mining and private services are key sectors due to their significant total effect on overall emissions from their income generation growth. The dominance of the indirect effects brought in by the user sectors implies that user sector-focused policies are most appropriate for carbon mitigation on mining and private services. On the other hand, road transport and water transport are key sectors for exhibiting relevant distributive effects. Likewise, cement manufacture, albeit with significant total effect, has greater distributive effect. Since these sectors not only have significant magnitudes of emissions but majority of the emissions impact of these sectors' income growth are directly or self-generated, then production side regulatory measures are suggested to be suitable for cement, road transport and water transport. Wholesale/retail trade sector's extensive upstream and downstream linkages justify its relevance and imply that a combination of production side and demand side regulations should be explored.

Power generation, as expected, is identified as the primary key sector in Philippine carbon dioxide emissions. A closer examination of the sector in the form of a sensitivity analysis yields an estimate of as much as USD 641 million worth of carbon dioxide emissions avoided in a year when kg CO_2/kWh is reduced from the current level of 0.458 to about half of it by switching to renewable sources of power generation.

The findings of the study lend support to initiatives that are beginning to be phased in the Philippines such as the use of renewable and alternative energy in power generation and transport, and adoption of measures to improve energy efficiency and conservation as promoted by DOE, in general. Some specific emissions mitigation measures that can be pursued are provision of incentives for clean coal technologies, improvement of efficiency of biomass fuel use, use of nuclear energy, and serious consideration of collecting carbon tax in the Philippines.

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Appendix A
Data Descriptions and Computations

Variable/ Matrix	Description	Characteristic Element	Dimension	Computation	Data Source(s)
	CO2 from Petroleum per sector			$\sum_{fueltype}$ Petroleum demand per fuel type in barrels x kg CO2 per barrel of the fuel where	DOE's report on Petroleum Demand by Industry, by Sub-Sector and Fuel Type in Barrels, 2000-2006
	kg CO2 per barrel of petroleum fuel type			Fuel density in grams/gal x 3,780 (to convert to kg/liter) x 200 (to convert to kg/ barrel) x Carbon (C) ratio (to compute kg C/barrel) x 44/ 12 molar mass ratio (to convert from C to CO2 based on molar mass of 12 g/mol for C and 16 g/mol for O, i.e., 1 C (12) + 2 O (32) = 44)	Argonne National Laboratory (ANL)
	CO2 from Coal per sector except Power Generation			Coal consumption in MT x 1,000 (to convert to kg) x 60% C ratio of coal (to compute the Carbon content of coal) x 44/12 molar mass ratio	DOE's report on Coal and Natural Gas Consumption, 2000-2006 and ANL
	CO2 from Coal of Power Generation			Power generation from coal in GWh x 3.6 (to convert to million MJ) x100,000 (to convert to kg of coal consumption since burning 1 kg of coal produces 10 MJ of electricity) x 60% C ratio of coal x 44/12 molar mass ratio	DOE's report on Power Generation by Source (in GWh) and ANL
	CO2 from Natural Gas			Natural gas consumption in MMSCF x 55,623.33 kg CO2 per MMSCF of natural gas	DOE's report on Coal and Natural Gas Consumption, 2000-2006; and see

Variable/ Matrix	Description	Characteristic Element	Dimension	Computation	Data Source(s)
				where	Computation of kg CO2 per MMSCF of natural gas
	kg CO2 per MMSCF of Natural Gas			20.5 natural gas density in grams/SCF / 1,000 (to convert to kg/SCF) x 1,000,000 (to convert to kg/ MMSCF) x 74% C ratio of natural gas (to convert to kg C per MMSCF) x 44/12 molar mass ratio	ANL
C	Vector of sectoral direct CO2 emissions	c_i	33 x 1	c_i = CO2 from Petroleum$_i$ + CO2 from Coal$_i$ + CO2 from Natural gas$_i$, i=1, 2, … 33 for the 33 sectors	See computation of each component above
C	Total carbon dioxide emissions		Scalar	$C=\sum_{i=1}^{33} c_i$ for i sectors	**C**
G	33-Sector Transactions Table	g_i	33 x 1	$g_i=\frac{c_i}{C}$ where $\sum_{i=1}^{33} g_i = 1$ for i	**c** and **C**
	33-Sector Transactions Table			From the highest resolution 240-Sector I-O Transactions Table, each sector is mapped to one of the 33 sectors detailed in the fuel demand report of the DOE and reclassified accordingly with a new code, then row and column entries of like codes are summed	2000 I-O Accounts of NSCB
	33-Sector Technical Coefficients Table			Each element of the 33-Sector Transactions Table is divided by the row sum or row column, i.e., total output vector, **x**	33-Sector Transactions Table
A	Technical coefficients matrix	a_{ij}	33 x 33		First 33 x 33 elements of the 33-Sector Technical Coefficients Table

Variable/ Matrix	Description	Characteristic Element	Dimension	Computation	Data Source(s)
$(\mathbf{I}-\mathbf{A}')^{-1}$	Transpose of the Leontief Inverse	β_{ji}	33 x 33	Transpose of $(\mathbf{I}-\mathbf{A})^{-1}$ Leontief Inverse $=\left((\mathbf{I}-\mathbf{A})^{-1}\right)'=\left((\mathbf{I}-\mathbf{A})'\right)^{-1}$ $=(\mathbf{I}-\mathbf{A}')^{-1}$ where the characteristic element of $(\mathbf{I}-\mathbf{A})^{-1}$ is β_{ij} for the i^th supplier sector and j^th user sector, and $i, j = 1, 2, \ldots, 33$ for the 33 sectors	**A**
V	Value-added vector	v_j	33 x 1		Total primary inputs row of the 33-Sector Transactions Table
X	Output vector	x_j	33 x 1		Last column or last row of the 33-Sector Transactions Table
S	Vector of sectoral value-added coefficients	s_j	33 x 1	$g_j = \frac{v_j}{x_j}$ where $j = 1, 2, \ldots, 33$ for j sectors	Total primary inputs row of the 33-Sector Technical Coefficients Table, **v** and **x**
$\mathbf{E}^{\mathbf{V}}$	Matrix of income elasticities of emissions	E_{ij}^{V}	33 x 1	$\hat{\mathbf{g}}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{s}}$	**g** , $(\mathbf{I}-\mathbf{A})^{-1}$, and **S**

Appendix B
Summary of Results

Key Sectors: Primary and Secondary	CO2 in million Kg	Total Effect	Distributive Effect	Dominant Effect, i.e., T= Total Effect and D= Distributive Effect	User sectors that indirectly produce CO2 emissions of the Key and Other Relevant Sectors	Supplier sectors that induce CO2 emissions from the Key and Other Relevant Sectors
Power Generation	166.3	0.41**	0.53**		10, 14, 19, 22, 27, 28, 33	1, 3, 4, 6, 7, 12, 13, 14, 16, 22, 23, 24, 27, 30-33
Cement	27.7	0.035*	0.088*	D		1, 6, 13, 14, 16, 20-25, 30-33
Wholesale/ Retail Trade	14.8	0.62*	0.047*		7, 10, 12, 14, 16, 19, 22, 23, 25, 27, 28, 29, 33	1, 6, 7, 16, 23, 27, 28, 31, 32, 33
Water Transport	16.3	0.026	0.052*	D	30	1, 3, 6, 7, 12, 13, 16, 22, 23, 25, 30-33
Road Transport	11.2	0.022	0.036*	D	25, 30	6, 16, 22, 23, 25, 30-33
Mining	1.3	0.66*	0.004	T	19, 24, 25, 27-30, 33	
Private Services	0.7	0.027*	0.002	T	16, 19, 22, 25, 27-30, 33	
Total	**238.2**	**0.66**	**0.75**			
Other (Non-Key) Sectors	**77.9**	**0.34**	**0.25**			

**Extremely relevant, identifier of the primary key sector

*Relevant with scaled elasticity over 100