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Environmentally Extended Input-Output Analysis:
Application to India

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Abstract: As the world witnesses a record level of greenhouse gas emission and associated environmental crises in the form of global warming and climate change, it is the need of the hour for all countries to be diligent and innovative in their economic and environmental policy. Policy discourse in climate action is bound to take separate paths for developed and developing countries due to a difference in their economic expansion trajectory. India, a rapidly expanding economy faces critical challenge to strike a balance between its economic and environmental targets to provide for its vast population and its ever growing consumption demands. In this context, I analyze the structure of carbon emissions in India from a demand and supply multiplier perspective to draw insights on key emission multiplier sectors using 2011 data. Among other sectors in India, electricity sector has high supply and demand side multipliers. Concentrating on the supply side of electricity sector, it becomes imperative to analyze the highly electricity intensive agriculture sector. I analyze emission saving potential of hypothetical scenarios of electricity subsidy elimination first as a whole, and next from agriculture alone. I find about 12 million tons reduction in carbon emission following a subsidy elimination policy shock. I also find that about a sixth of this emission saving potential can alternately be achieved through subsidy elimination for electricity use in agriculture. Appropriate policy implications from these results are discussed.

Keywords: Input-output analysis, demand and supply multipliers, key sectors in emission, electricity subsidy, CO_2 emission

JEL: D57, P28, P18, Q43

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Any errors are mine alone.

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1. Introduction

1.1 *Background*

One of the most pressing concerns in recent years is the unprecedented growth in greenhouse gas emission all over the world. Near exponentially increasing levels of greenhouse gas concentration in the atmosphere causes surface temperature to rise, which is the phenomena of global warming. Global warming in turn causes climate patterns to change over time. Climate change is one of the major challenges faced by all governments as average temperatures are on the rise. The alarming rates of rising temperature and climate change pose a risk of adversely impacting economic activity (Burke et al., 2015). Some of the most observed ramification of climate change are delayed monsoons, frequent draughts, wildfires, and flooding which impact agricultural and primary production in many countries. Coupled with the cost of mitigating the impacts of climate change, the discourse of integrating environmental effects with economic activity has increasingly gained popularity.

While a number of gases constitute greenhouse gas, like Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Chlorofluorocarbons (CFC's), among these, Carbon Dioxide (CO_2) emission contributes to over eighty percent of global greenhouse gas emission (EPA) and has been a major focus of policy discussion and mitigation efforts as it is emitted from the direct combustion of fossil fuels. Fossil fuels (coal, oil, and natural gas), which remain by far the chief energy source for industrial production, is the dominant anthropological activity that drives climate change. Other human activities that drive climate change are deforestation, land use change, waste burning etc. Fossil fuel CO_2 emission is often used synonymously with carbon emissions as CO_2 emission is directly linked with the carbon content of a fuel. Carbon emission related with fossil fuel is regarded as the primary cause of global climate change. Carbon emissions have increased by about ninety percent since 1970 (IPCC 2014).

Important landmarks in the global joint actions toward climate change mitigation and to stabilize greenhouse gas concentration are the 1992 United Nations Framework Convention on Climate Change, the Kyoto Protocol, 1997 and the recently concluded Conference of Parties (COP) in Paris, 2015. International conventions toward climate change stress the need for joint as well as individual action from developed and developing countries.

Global discussions around action toward climate change often tend to suggest different policy focus for developed and developing countries. While industrial activities of developed nations have contributed significantly in the past to the current state of emission concentration, the saturation of growth and higher income levels have simultaneously improved production technology and awareness toward the environment. On the other hand, developing and growing nations at present face the need for rapid industrial expansion that leads to high pollution combined with lesser capability to control emissions in light of their growing production and consumption needs. The differential commitment of countries toward climate action in the Kyoto Protocol is widely believed to be a reason for its failure. There is a need for countries to adopt policies that are most suitable to their domestic needs as well as act responsibly concerning its global impacts. Therefore, judging the suitability of action plans of countries is of essence.

As incomes rise, citizens grow more concerned about the environmental quality and the carbon footprint of their activities. This in turn calls for better accountability and transparency in measuring carbon footprints of economic activities as well as wider policy measures to control and reduce the emission associated with all actors in the economic system. Accuracy in accounting for emission is central to effective policymaking toward regulating emissions and mitigation efforts. In this context it is essential for policy-makers to use effective tools to better identify the structure of economic activity that leads to emission, so that the policies can target the most effective areas of emissions saving.

The individual sections of an economy are inherently linked to each other. The same holds true for carbon emission intensity of economic activities. Emission analysis of any economic section cannot be conducted in isolation to other sections. It is therefore crucial to study the linkage and inter dependence of one economic activity with other related activities to optimize the impact of policy.

An important macroeconomic tool that utilizes the interdependence of different sectors of an economy is the input-output analysis methodology. The work in input-output analysis was pioneered by the economist Wassily Leontief, as early as in the 1930's. His analysis of interdependence of industries and sectors of the American economy (Leontief 1936) provided a powerful model to conduct detailed study and estimation of sectoral linkages using the input and output shares of each industry to all other industries. Augmenting this method of input-output analysis with environmental implication of industrial production was later carried out by Leontief himself in the seventies (Leontief 1970). Since then the so called environmentally extended input-output analysis has been widely used and built on by several scholars. Numerous modifications of the basic input-output model have been implemented to study the structural composition of the economy, energy, and emissions using matrix data of sectoral transactions.

The concept of forward and backward linkages developed by Rasmussen (1956) and Hirschman (1958) are among numerous applications of Leontief's input-output model that measure structural dependence of industries. The linkage analysis serves to link structural change in industrial sectors with economic development, and have been used widely to identify key impact sectors of the economy. Using the linkage analysis, those sectors of the economy could be identified which have the maximum potential to amplify the entire economic production, through small changes in their production structure that ultimately impact the economy. The interpretation of linkage analysis has been criticized on many contexts (Drejer 2003); however, their selective and careful application serves as an important descriptive tool (Lenzen, 2003).

Though apparently too simple to appeal as an analytical tool, input-output methodology can provide important information on full range of inputs for a process and a coherent method to account for the entire supply-chain in the production process.

1.2 *Case of India*

India is home to almost a fifth of the world's poor. Pulling out a vast population out of poverty has taken priority in its economic policy. Industrial revolution is a major tool to achieve a high growth rate. Amidst the focus on growth through increased production and exports, environmental action had taken a back stage until recently. Rapid industrial production growth has resulted in high level of environmental degradation and resource depletion to its current worrisome level. India at present is the fourth largest carbon emitter and has remained among top five carbon emitting countries for a long time. When considered at per capita level of emission, India ranks relatively low and well below the global average. However, a huge population of over a billion makes the absolute picture much worse. Four Indian cities ranked among the worlds most polluted cities in 2015.

While governments have expressed concerns about the impacts of climate change, in the international platform, before the 2015 Paris summit, India had refused to limit its emission to prioritize growth. In the Kyoto agreement, India had taken a similar stand of not limiting its emission as it is a developing country. India had maintained that the current pressing need is to expand access to energy for a growing population and serious commitment to reduce emission would compromise with the growth prospects. At a time when a large proportion of rural as well as urban population do not have access to electricity, the argument to not let emission reduction commitments hinder economic growth does not lie on baseless grounds. However, environmental degradation has accelerated and its adverse effects have become more and more visible. Continued lack of focus on integrating environmental resources with economic development has proven to be unsustainable. The argument to not commit to reduce emissions to expand national income has ultimately led to increased costs in term of climate change mitigation. This is likely to have adverse impacts on growth and development as well, unless a balance is struck between growth and environmental resource use.

With growing instances of environment degradation led crisis, Indian government has recently spiked up focus toward better environmental management and resource planning. In the recently concluded Paris conference on climate change, India has pledged to reduce emission intensity of GDP by about thirty percent by 2030 from 2005 levels and create carbon sinks. Under this backdrop, it is interesting to decompose the environmental burden of production activities transmitted to the economy. Insights into contribution of key emission sectors and the structure of their contribution are important to assess efficacy of policies.

1.3 Purpose and structure

This study attempts to examine the emission structure of the Indian economy from latest available data, 2011. Forward and backward linkage analysis is applied to Indian input-output tables in conjunction with carbon emission data to analyze the structure of carbon emissions in India. Following the results from linkage analysis, relevant sectors are discussed and policy scenarios are studied for the electricity and agriculture sectors.

The rest of the paper is structured as follows: Section 2 discusses the methodology (input-output table structure, Leontief's model, Ghosh's model, forward and backward linkages, and environmentally extended analyses), Section 3 reviews relevant literature, Section 4 cites the data source, Section 5 presents initial results and Section 6 discusses these results briefly. Based on the discussion of results from linkage analysis, Section 7 discusses the electricity sector in detail with a focus on subsidies, Section 8 analyzes hypothetical policy scenarios, Section 9 sheds light on policy discourse, Section 9 discusses strengths and limitations of the study and finally Section 10 concludes.

2. Methodology

In this study I analyze the sectoral emissions and their relative significance based on input-output methodology. The input-output technique is a macroeconomic tool that can be utilized to analyze industrial production linkages in an economy and to map the changes brought about by a demand shift in a particular sector of the economy. The basic framework of input-output analysis method, developed by Leontief (1936) serves as the basis to analyze technical and industrial relationships in demand and supply of different sectors in an economy. The basic seminal input-output technique has been widely applied in economic analyses to study inter-industrial linkages. Many scholars have since contributed to Leontief's static version of input-output in several other analyses and expanded the scientific applicability of input-output methodology.

2.1 Structure of input-output table

The input-output table for an economy essentially lays down the flow of industrial goods and services within all sectors. Each horizontal row lays down how an industry's total monetary product is divided among various production processes and final consumption. Each vertical column describes the combination or input mix of all other industrial and primary resources used in the production of one industry.

The upper left corner of the table represents the flow of intermediate goods required in production. This is also called the transactions table as it highlights the inter-industry transactions of inputs and outputs. Transaction table gives a picture of flow of products from a producing sector (in the row) to a purchasing sector (in the column). Every column in this part represents, for a specific sector, the input share of all sectors in the production of that sector. Every row represents the distribution of output of the corresponding sector that is used for production in all other sectors. The rows are complemented by primary input value added in each sector in the corresponding column. Each column together with inputs from all sectors and value added totals up its entire input. Typically, value added is comprised of labor income generated through employee compensation, profits, capital allowances, and net taxes, though the exact specification varies in table computation by countries. The columns, on the other hand are complemented by the final consumption demand for each sector in the corresponding row. Each row similarly sums up for a sector its intermediate demand from other sectors and final consumption demand, to give the total output for that sector. Final consumption is typically divided into private consumption, government consumption, capital formation, and trade (exports-imports).

All values in the input-output table are reported in monetary units and are usually measured for a particular time period. The table as a whole illustrates the interdependence of each industry on products of all the other industries. It is a snapshot of the structure of sectoral linkages in an economy in a particular year. Table 1 below represents an example input-output table structure.

Table 1: An example input-output table structure

	Primary industries		Manufacturing industries		Tertiary Industries		Final demand				Total output
	ind 1	ind 2	…	ind j	…	ind n	Pvt. Cons	Govt. cons	GCF	Net export	
industry 1	x_{11}	x_{12}	…	x_{1j}		x_{1n}	y_1				X_1
industry 2	.	…					.				.
…	.						.				.
industry i	x_{i1}	…		x_{ij}		x_{in}	y_i				X_i
…	.						.				.
industry n	x_{n1}	…		x_{nj}		x_{nn}	y_n				X_n
Compensation											
Net taxes											
Gross surplus	V_1	..	…	V_j	…	V_n					
Total Input	X_1			X_j		X_n					

X_i is the total production turned out by sector i.

Y_i is the final consumption demand for sector i products by different demand groups.

x_{ij} is the amount of output of sector i that is purchased by sector j for the production of sector j. In other words, it is the amount of products sold from sector i to sector j. It can be used to obtain the input share of sector i in the production of sector j as well as the output share of sector i consumed by sector j.

V_j is the gross value added by sector j.

In each row i, the sum of x_{ij} over all sector j's in that row along with the final consumption demand for the products of sector, Y_i equals the total output of sector i. Similarly, in each column, the sum of x_{ij} over all sector i's in that column along with the gross value added by sector, V_j gives the total input requirements of sector j. In a balanced input-output table, the total inputs should be equal to the total outputs for all sectors. Alternately total sales proceeds and total purchases of all sectors should be equal.

2.2 The Leontief Model

The model and its utility can be represented by the following equations. Along each row, the sum of a sector's sales to all other sectors and sales to final consumption demand equals it total production sales:

$$x_{11} + x_{12} + x_{13} + \cdots + x_{1n} + Y_1 = X_1$$

$$x_{21} + x_{22} + x_{23} + \cdots + x_{2n} + Y_2 = X_2 \quad \text{and so on}$$

Alternately,

$$\sum_{j=1}^{n} x_{ij} + Y_i = X_i \tag{1}$$

In the model of Leontief, a_{ij} is the technical coefficient that represents the proportion of inputs from sector i consumed in the production of sector j. It is obtained by dividing each element of the transaction table x_{ij} by the total input requirement of the consuming sector, X_j.

$$a_{ij} = \frac{x_{ij}}{X_j} \tag{2}$$

Substituting this coefficient in the previous equation gives:

$$\sum_{i=1}^{n} a_{ij} X_j + Y_i = X_i \tag{3}$$

The above equation can be written in the matrix form as

$$AX + Y = X \tag{4}$$

Or alternately,

$$X = (I - A)^{-1} Y = BY \tag{5}$$

Thus the input-output table can be used to compute the multiplier effect of final demand of industrial products on the entire output of an economy. While the characteristic elements of matrix A, as mentioned earlier, represents the direct requirement coefficients, the characteristic element of the inverse matrix, $(I-A)^{-1}$ or the matrix B, comprised of b_{ij} represent the coefficient of output from sector i required to meet a unit increase in the exogenous final demand of sector j.

2.3 The Ghosh Model

Ghosh (1958) formulated an alternative formulation of the input-output theory. While the Leontief method is known as the demand driven input-output model, the Ghosh's model is known as the supply driven alternate. In Ghosh's model, he defines matrix D whose characteristic elements d_{ij} are the proportion of production output of sector i that is consumed by sector j, also defined as direct sales coefficients i.e.,

$$d_{ij} = \frac{x_{ij}}{X_i} \tag{6}$$

The skeleton equation for this model is synonymous to equation (1) of Leontief's model with the difference being in considering the sum along each column instead of row sums. Along a column, the input purchases from all sectors along with purchases of primary inputs equal the total input or purchase value of that sector. The summation along each column can therefore be seen as:

$$\sum_{i=1}^{n} x_{ij} + V_j = X_j \tag{7}$$

Using equation (7), equation (8) can be expressed as:

$$\sum_{i=1}^{n} d_{ij} X_j + V_j = X_j \tag{8}$$

In the matrix form this comes out as:

$$X = V(I - D)^{-1} = VE \tag{9}$$

The inverse matrix $(I\text{-}D)^{-1}$ or matrix E, known as Ghosh's inverse matrix, represents the transformation of primary inputs in the production of a sector to the total output through the above equation.

2.4 Forward and backward linkages

The now vast literature in industrial linkage was first conceptualized by Hirschman (1958). The focus of this analysis was to measure the dependence and therefore the importance of sectoral development in the context of economic development. Hirschman's linkage concept forms the basis of studying the demand and supply relations of industries with other industries to identify key sectors that are likely to have large multiplier effect in stimulating the demand of the economy and in reducing the supply bottlenecks in economic production. Backward linkages essentially indicate the increase in output activity of the whole economy induced by a unit change in in a sector. For example, when the production of electricity expands, it induces intermediate inputs like fuel, machinery, and construction services. This demand then stimulates production in other sectors to supply these intermediate goods (Shumilkina et al., 2015). Forward linkages on the other hand account for the increased supply of inputs to upstream industries. For example, when electricity production expands, it can supply more power to the economy, which stimulates production in all the sectors which use power (Shumilkina et al.,2015).

An equally seminal work by Rasmussen's "Studies In Inter-Sectoral Relations" (1956) developed indices to measure Hirschman's linkage effects. Analogous with backward linkages is the power index of dispersion based on Leontief's inverse, defined as the ratio of column averages and the global average of the inverse matrix.

$$U_j^b = \frac{\sum_{i=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \tag{10}$$

Similarly, sensitivity index of dispersion is a measure of forward linkage defined as the ratio of row averages and the global average of the inverse matrix.

$$U_i^f = \frac{\sum_{j=1}^{n} b_{ij}}{\frac{i}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \tag{11}$$

The use of sensitivity index of dispersion as a measure for forward linkage was questioned by Jones (1976). It is argued that the sensitivity index of dispersion does not have a valid economic interpretation. Instead Ghosh's inverse is suggested as a more useful technique to measure forward linkage. A detailed summary of Jones' criticism of the sensitivity index of dispersion can be found in Drejer (2002) and Lenzen (2003). Ghosh's inverse matrix E can be utilized to define forward linkage as the ratio of row average and the global average:

$$\widehat{U_i^f} = \frac{\sum_{j=1}^{n} e_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}} \tag{12}$$

Hirschman (1958) and Jones (1976) point out that linkages could have a high value due to either many small elements in the row or column adding up to a high summed up value or a few large elements. Therefore it is important to add weights to each sector while calculating the forward and backward linkages. Accordingly, weights of sectoral final demand $\widetilde{y_i} = y_i / \sum y_i$ can be added to the backward linkage and expressed as:

$$U_w^b = \sum_{i=1}^{n} b_{ij}\widetilde{y_i} \tag{13}$$

For calculating the weighted forward linkages, weights of sectoral value added $\widetilde{v_j} = v_j / \sum v_j$ can be used and the weighted forward linkage can be expressed as:

$$U_w^f = \sum_{j=1}^{n} \widetilde{v_j} e_{ij} \tag{14}$$

While the unweighted linkages describe response to a unit change in sectoral final demand, the weighted linkages describe response to a fractional change in the final demand.

2.5 Environmentally extended input-output and linkage analysis

The forward and backward linkages calculated in the section above give us a picture of sectoral interdependence in the entire economic structure. In the context of pressing environmental impact of industrial production, Lenzen (2003) formulated the linkage analysis to include pollutant emission associated with production activities. The external factors like physical quantities of emissions and energy use can be added to the general input-output transactions to compute the structure of emissions and link it to the production chain.

With the data on direct carbon emissions in physical units per monetary unit of output for each sector augmented in the input-output table, the direct emission coefficient c_i for each sector can be obtained as a ratio of emission to output. The computations in the above sections can accordingly be augmented with sectoral emission coefficients.

The demand side emission multiplier is given by

$$\sum_{i=1}^{n} c_i b_{ij} \tag{15}$$

The supply side emission multiplier is given by

$$\sum_{j=1}^{n} c_j e_{ij} \tag{16}$$

The weighted demand side emission multiplier is given by

$$\sum_{i=1}^{n} c_i b_{ij} \widetilde{y}_j \tag{17}$$

The weighted supply side emission multiplier is given by

$$\sum_{j=1}^{n} \widetilde{v}_i \, e_{ij} c_j \tag{18}$$

The weighted multipliers can be normalized by dividing all the multipliers with the average of all multipliers. The normalized multipliers are represented as μ_y *and* μ_v for demand and supply side respectively. These normalized multipliers can used to identify key sectors for carbon emissions within the linkage analysis. The classification of sectors can be carried out as categorized in Table 2:

Table 2: Sector classification scheme

	μ_v>1	**μ_v<1**
μ_y>1	Determinant emission sectors	Demand push sectors
μ_y<1	Supply push sectors	Remaining sectors

The first part of this study is based on direct and indirect emission analysis on a sectoral level followed by forward and backward linkage analysis. Based on insights derived from these analyses, two hypothetical policy scenarios of subsidy removal are analyzed with input-output framework.

3. Review of relevant literature

Leontief's paper titled "Environmental Repercussions And The Economic Structure" (1970), followed by Leontief and Ford (1972), are some of the first studies to use input-output analysis for environmental impacts resulting from industrial activity, though some earlier works are known to have conducted similar analysis before, for example Ayres and Kneese (1969), Daly (1968), and Isard et al. (1967) (as cited in Wood, 2009). Numerous studies have since analyzed the association of emission and energy consumption with economic activity using input-output methodology (for example, Proops 1993). Lenzen (1998) decomposed direct and indirect energy and greenhouse gas embedded in final consumption of Australia using input-output analysis. A recent study in this field is by Alcántara (2011) that determines key sectors for carbon emissions in Spain, based on which Alcántara and Padilla (2006, 2008) extend the analysis for retail trade and services sector examination. More examples of prominent studies include Chang and Lin (1998) that studies structural decomposition of carbon emissions in Taiwan, Wood (2009) studies Australian greenhouse gas emission structural decomposition. In the Indian context Parikh et al. (2009) contrast direct and indirect carbon emissions by sector using input-output analysis. Parikh et al. (1993) shed light on key emitting sectors and analyze different emission saving policy scenarios. Murthy et al. (1997) analyze direct and indirect emission content of different consumption baskets in India for 1990 and predict emission intensities for 2020 under different growth scenarios.

4. Data

For this analysis, I use input-output table for India for the year 2011 provided by Global Trade Analysis Project database. The emissions are in kilo tons of CO_2 and all monetary values in million US dollars. The sectors have been aggregated to a 34 sector level for convenience. The emission data corresponds to each sector's direct emission of CO_2 due to combustion of domestically produced fossil fuels only. It therefore does not account for imported emissions and facilitates the reflection of domestic carbon footprint of industrial activities.

The Central Statistical Office of India computes input-output tables for certain years. It maintains to publish input-output tables with an interval of ten years. However, at present the latest input-output table is available for the year 2003. Moreover, the Indian input-output tables do not provide information regarding physical quantities of industries from the point of view of environmental analysis like emissions or energy use data. Researchers who have conducted environmentally extended input-output analysis for India have used physical energy or emission values from external sources like the International Energy Agency (IEA), or Organization for Economic Co-operation and Development (OECD) databases.

5. Results

From the demand side carbon emissions multiplier given by equation (15), we can compute the consumption based (total direct and indirect) emissions of a sector by multiplying it with the final demands of each sector. Direct or production based emissions account for the emissions generated to produce for a sector itself, including its production that goes into others sectors as inputs. Total emissions on the other hand account for the emissions generated in response to final consumption demand. It includes embedded emissions in the production of a sector's inputs which are required to meet the sector's final consumption demand. The direct and total emissions for all thirty-four sectors of India along with the percentage share of sectors in direct and total emissions are presented in Annex 1, some highlights are presented below. Figure 1 compares the top ten direct carbon emitting sectors with their total emissions and Figure 2 compares the top ten total emitters with their direct emissions.

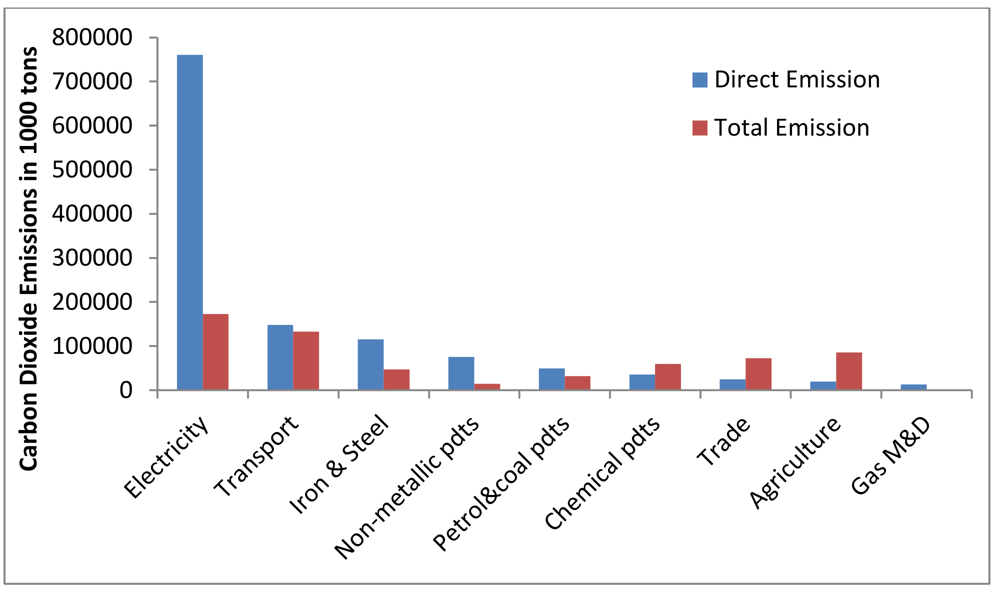

Figure 1: Top ten direct emission sectors and their total emissions
Source: own calculations

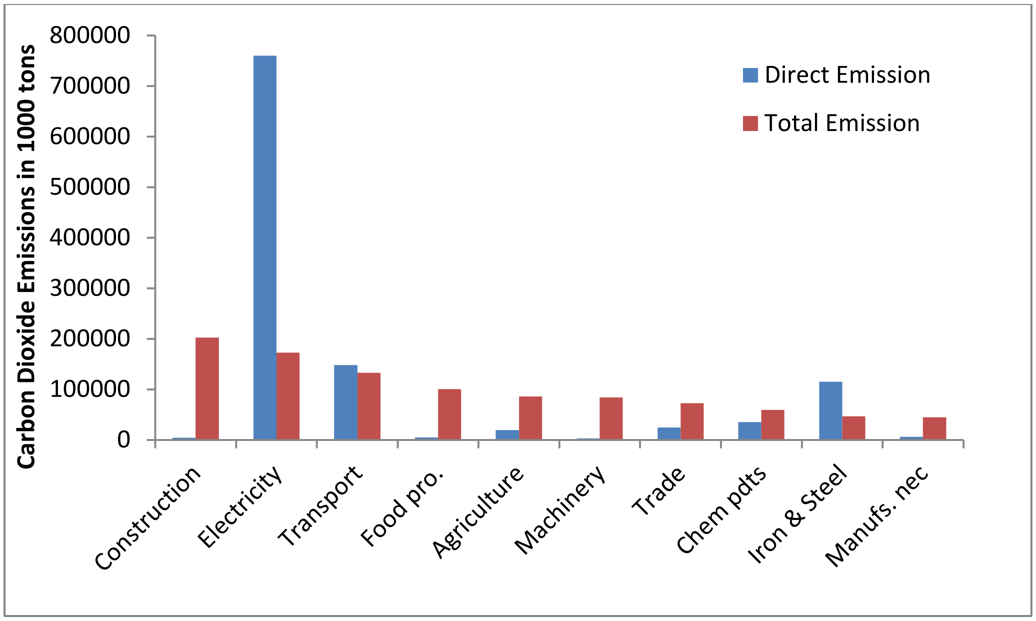

Figure 2: Top ten total emission sectors and their direct emissions
Source: own calculations

As can be seen from Figure 1 and Figure 2, sectors vary greatly in terms of their direct and total emissions. Some sectors like electricity are highly emission intensive in terms of direct emissions, but a large part of this emission may arise due to supply of electricity to other productive sectors. Additionally, some sectors like construction have low direct emissions but large indirect emission which implies that construction itself does not generate a large amount of emissions for its production but consumes emission intensive inputs like cement and electricity, which increases its total emissions embedded in production.

Next, I compute the emission multipliers of the productive sectors based on the computation methods described in methodology, Section 2.5. The weighted and unweighted demand and supply multipliers of all sectors are represented in Annex 2.

Using the information about emission multipliers from Annex 2, the sectors have been classified as per the description in Table 2. The sector classification illustrates the determinant sectors with pollution potential with respect to demand and supply side multipliers. The results from sector classification are presented in Table 3 below and a scatter plot representation follows in Figure 3.

Table 3: Classification by sector taking into account weighted carbon emission multipliers.

		Demand		Supply	
Group A: Determinant sectors	Direct emission	Total emission (direct+indirect)	demand impact index	Total emission (direct+indirect)	supply impact index
Electricity	760276.8	172670.7	4.468	409697.9	10.600
Transport	148329.5	133003.1	3.441	127952.6	3.311
Trade and retail sales	24514.32	72573.38	1.878	110915.6	2.870
Iron and Steel	115130.4	46878.33	1.213	66423.0	1.719
total	1048251	425125.5		714989.1	
%	79.77	32.35		54.41	
Group B: Demand determinant sectors					
Construction	4183.269	202576.9	5.241	16377.69	0.424
Food processing	4953.293	100551.8	2.602	2891.051	0.075
Agriculture	19675.24	85745.43	2.219	29554.47	0.765
Machine equipment	3349.441	83881.12	2.170	22991.84	0.595
Chemical products	35318.9	59665.89	1.544	38333.53	0.992
Manufacturing nec*	6531.955	44606.91	1.154	10255.58	0.265
total	74012.1	577028		120404.2	
%	5.63	43.91		9.16	
Group C: Supply determinant sectors					
Petroleum & coal products	49054.97	31691.78	0.820	163385.8	4.227
Mining	12889.75	8210.398	0.212	88715.13	2.295
Financial services	2059.342	12289.13	0.318	72639.97	1.879
Non-metallic minerals	75818.24	14200.28	0.367	38893.29	1.006
total	139822.3	66391.59		363634.2	
%	10.64	5.05		27.67	

*nec: not elsewhere classified

Source: own calculations

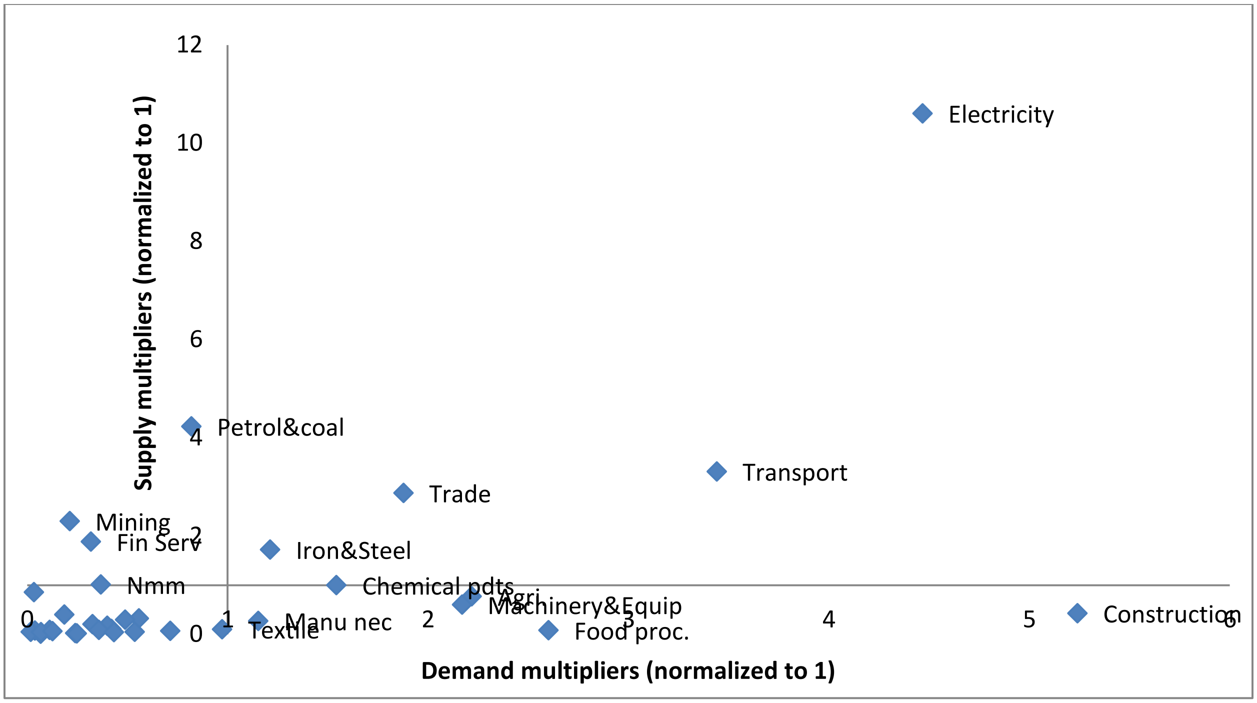

Figure 3: Scatter plot representation of sector classifications.
Source: own calculations

The top right section of the Figure 3 represents determinant emission sectors from both supply and demand side as both their multipliers are greater than one. The top left section represents supply determinant emission sectors as for these sectors, the supply multiplier is greater than one but demand multiplier is less than one. The lower right section represents demand determinant emission sectors with a demand multiplier greater than one but supply multipliers lower than one. The lower left section comprises remaining sectors that are not significant in the context of multiplier effect on emissions.

6. Discussion of sectoral classification

From Table 3, we can see the sectors that have the highest pollution potential in terms of demand pull and supply push capacity. As can be seen, the most important sectors from both supply and demand perspective of pollution are electricity, transport, retail sales and wholesale trade, and production of ferrous metals (iron and steel). These determinant emission sectors that constitute Group A, represent close to 80 percent of direct emission from production activities. Moreover, these determinant sectors represent 32.4 percent of emission from demand point of view and 54.4 percent of emission from supply point of view.

The significance of this huge difference arising from different emission accounting methods is in that a substantial amount of polluting potential of these determinant sectors is generated to provide for other sectors, especially in the case of electricity, as has been alluded to in the preceding section. Accordingly the supply side emission potential of electricity has a larger multiplier than the demand side. Similar conclusion can be drawn for the supply side emission potential for transport sector as it is a major input in the production process of other sectors. Being highly intensive in fossil fuel inputs, it contributes significantly to indirect emission of other sectors. However, the difference between the supply and demand emissions is not as huge as electricity sector. This is due to the sector's own emission intensity explained by its input structure.

The sectors next in importance in terms of emission potential from both supply and demand side are retail sale and wholesale trade activities, and the iron and steel sector. An interesting point to be made here is that a seemingly innocuous sector retail trade, with a low share in direct emissions turns out to be one of the most important sectors in determining emissions when forward and backward linkages are taken into account. It is therefore necessary to consider emission potential of sectors from all perspectives to formulate effective policies to curb emissions.

Coming to group B, which comprises the determinant sectors from a demand perspective, represents a 5.63 percent, a relatively small percentage of direct emissions of the production sectors. As can be expected, they have a small emission share from a supply perspective (9.16 percent). However, the emission share of group B from demand perspective is 43.91 percent, which is higher than the demand side pollution share of group A. Thus, while group A sectors justify attention from both demand and supply side emission management, group B calls for attention due to its demand side pollution potential alone.

Of the sectors worth highlighting in group B, the construction sector is of major importance as it is the highest contributor of demand induced emission from this group. It has a very low direct emission share (0.32 percent) but is the highest emitter with a share of 15.42 percent when both direct and indirect emissions are considered (see Figure 2 and Annex 1). This large share in demand side emission indicates that policy measure to control emissions targeted at the construction sector should aim to make it less intensive in inputs that are in turn highly carbon intensive, or aim at reducing the carbon emission of its major inputs like cement.

Similar conclusion can be drawn about agriculture, the food processing sector and other manufactures, with low contribution to direct carbon emission but a significantly high demand multiplier. In this context, it is worth noting that the agriculture sector not only contributes significantly to demand induced emissions, but also has high a direct emission. Although the difference between its supply and demand side emissions is high, the supply side emissions are also significant. This implies that agricultural activities in India not only use emission intensive inputs but are also highly emission intensive. Chemical products sector has similar characteristics in terms of high emissions from all perspectives but of course has a greater importance in terms of demand side emissions.

In group C, the significance of petroleum and coal products, the mining sector as well as other minerals is obvious from the supply perspective. Since these sectors are major constituents of inputs in production of other sectors, their pollution potential is significant from the supply standpoint. An interesting thing to note in group C is the occurrence of financial services sector as a supply determinant emission sector. While further study is necessary to shed light on the supply side importance of services sector in determining emissions, it appeals intuitively that financial services are required in almost every other sectors. Financial services sectors are heavily dependent on computing and electronic devices which are energy intensive. This might be a possible explanation of the channel through which the financial services sector contributes to supply side determination of emissions in the economic production system.

The above discussion reflects the importance of framing appropriate policies for emission control keeping in view the polluting potential of productive sectors from all accounting techniques. While direct emissions can be informative about the structure of overall emissions, the policies can be effective only if they consider the forward and backward emission linkages of sectors. Demand determinant sectors require policies that target their input intensity of carbon intense components whereas effective policies in the supply determinant sectors should address their input intensity and efficiency in sectors that consume the former sectors in their production.

In light of the above discussion, the electricity sector can be examined from the supply and demand perspective as it has a very high multiplier from both perspectives. Breaking down the components of the backward and forward linkages of the electricity sector highlights the demand and supply relationship of electricity with other sectors. The top ten sectors with which the electricity sector has highest forward linkages and the top ten sectors that constitute the highest backward linkages of the electricity sector are presented in Table 4.

Table 4: Sectors with highest and lowest backward linkages to electricity sector

Rank	Forward linkage	Backward linkage
1	Iron & Steel	Gas distribution
2	Non-metallic minerals	Transport
3	Transport	Petroleum & coal products
4	Chemical products	Mining
5	Agriculture	Iron & Steel
6	Paper & Paper products	Trade
7	Trade	Non-metallic minerals
8	Non-ferrous metals	Chemical products
9	Metal Products nec*	Paper & Paper products
10	Mining	Financial services

*nec: Not Elsewhere Classified

The first column in the table above lists the sectors whose high emissions result from a relatively high share of electricity use in their production. The second column reflects the highest contributors to the embedded emission of electricity sector.

All in all, we conclude from the above discussion that in the context of carbon emissions in the production system of the Indian economy, the electricity sector makes an intriguing case for further analysis. More importantly, its supply to other sectors as input calls for a greater attention with respect to policy reform regarding industrial emissions. Electricity efficiency in technology employed by industries consuming a heavy amount of power could have significant emission reducing capacity.

7. Background on energy subsidy and insights into electricity subsidies in India

Taking a glimpse of the global discussions around energy subsidies, governments in both advanced and transition economies have used energy subsidy as a policy to achieve a range of economic goals. These economic goals have ranged from employment objectives when subsidy is provided for energy production, expanding energy access to end use consumers when subsidy is provided for energy consumption, or to provide cheap energy for industrial use. Subsidy for energy production is typically common among industrialized economies, like the OECD countries whereas consumption subsidy is more common among developing and transition economies (Moor, 2001). The government in return bears the financial burden of these subsidies. The discussion around the distortionary effects of energy subsidies have stemmed since 1990 (Willams and Ghanadan, 2006). Subsidies distort the price signals and fail to reflect the true economic cost of energy supply, leading to inefficient levels of production and consumption of energy (Saunders and Shneider, 2000). This has huge implication on pollution as energy is the major cause of environmental pollution. Therefore the environmental consequences of inefficient subsidy policy could be significant. Moor and Calamai (1997) conduct a worldwide analysis of energy subsidies and report that a majority of the subsidy schemes fail to achieve the desired results. Many scholars have demonstrated and argued that energy consumption subsidy policies have outlived their aim and become unsustainable in the context of transition economies (Gulati and Sharma 1995; Saboohi, 2001; Mourougane, 2010; Dube 2003). Moreover studies from international agencies like OECD, World Bank, and the International Energy Agency (IEA) stressing the adverse impacts on environmental pollution and energy use from energy subsidies have further added traction to debates around economic inefficiency of subsidy policy (OECD 1997, 1998; World Bank, 1997; IEA, 1999). World Bank's lending policy for energy sector reforms laid down criteria such as commitments to commercialization, privatization, competitive structures, tariff increases, and subsidy elimination as a condition of new loans (World Bank, 1997; Moor, 2001). A study of literature around energy sector reforms thus confirms a unanimous call for subsidy elimination in energy, and especially electricity sectors. Recent studies have identified energy subsidies as one of the greatest barriers to sustainable development. Consumer subsidies through low energy prices encourage overuse and waste, hence stimulating pollution. Underpricing also hurts energy producers, whose revenues and profits are insufficient for replacing and modernizing existing equipment. The existence of old vintage energy equipment, as for instance in many former centrally planned economies, causes enormous waste of energy between production and consumption points (Moor, 2001).

As the analysis in the previous section confirms the critical role of electricity in carbon emissions in India, it is important to gain insights into the electricity sector to analyze the drivers of its high consumption. Electricity consumers in India are divided into five broad categories: residential or domestic consumers, agriculture consumers, commercial consumers, industrial consumers and railways. Each of these sectors is provided electricity at different tariff rates decided by the governments of each state. The tariffs are decided based on sales forecast, revenue required, and the consumption category specifications. The government regulation of electricity prices for different consumers implies an implicit subsidy in the form of transfers made to the power utilities to provide electricity at the desired prices. This is very much in accordance with the general trend among transition economies in providing consumption subsidies for energy. The aim of providing subsidy is to make electricity easily accessible to the citizens, and more importantly, to the poor. To facilitate the objective of development through easy access to energy, the government subsidizes not only electricity but other energy sources, but bears a high burden for these subsidies. Additionally, the power utilities are often not paid the full amount of subsidy to cover the cost of providing electricity at government stipulated prices. A Power Finance Corporation study (PFC, 2015) reports less than eighty percent cost recovery by the power utilities. While the average cost of electricity in 2011 was about Rupees 4.5 (about 0.7 US dollars) per unit, the selling price averaged at Rupees 3.30 (PFC 2015).

Electricity is heavily subsidized for agricultural use which has led to not only over use of electricity for irrigation, but also stealing from other rural users for domestic use (Swain 2012). A whopping 70 percent of the entire uncovered electricity subsidy is attributed to agriculture sector. Many states like Punjab and Andhra Pradesh provide free electricity for agriculture use while many others have near zero tariff rates. This has raised concerns about massive misuse of electricity in agriculture as well as non-agriculture users. Agriculture has consistently consumed somewhere around 18 to 23 percent of total electricity supply in India (Gulati et al., 2012). Subsidized electricity in agriculture is cited as the cause for uncontrolled over use of electricity for irrigation and ground water extraction. This has aggravated groundwater depletion to record low levels, adding significantly to the debate of sustainability of Indian agriculture. Moreover, free electricity is stolen by non-agricultural consumers as most of the farm connections are not metered (IISD 2012). This is aggravated by the difficulty in accounting for different form of electricity consumption in the same rural location. This leads to criticism of the subsidy policy as the benefits do not really accrue to poor farmers as is intended.

In the short term electricity subsidy provides cheap access to electricity to consumers and plays an important role in social and economic development. In the long run, energy (including electricity) subsidy has been criticized on several grounds such as contributing heavily to financial burden of states, being used as a populist measure by governments to lure voters, and most importantly, induces misuse, overuse and stealing by non-target consumers. A Power Finance Corporation study estimates that more than half of subsidy payments for electricity benefit above poverty line consumers rather than the poorest (PFC 2015). The misuse of electricity by non-target consumers, induced by huge electricity subsidy has triggered debates on environmental consequences of electricity subsidy. Moreover, as subsidies are not fully recovered by the power companies, they have little incentive to invest in improving their efficiency and employing sophisticated technology. Inefficient production systems induced by financial losses by power utilities add to the environmental impacts of power generation.

Owing to the debate and criticism around subsidized electricity, it is critical to examine the impacts of a possible elimination of subsidy in electricity. In the following sub sections, I analyze the environmental impact of a hypothetical subsidy elimination within the framework of input-output methodology for elimination of subsidy as a whole and for elimination of electricity subsidy from agriculture.

8. Hypothetical subsidy elimination scenario

In the remaining part of this study, I attempt to compute the environmental impacts of a hypothetical subsidy removal from the electricity sector in India. For the purpose of this computation within the framework of input-output methodology, I follow the computational framework adopted in Ogarenko and Hubacek (2012) that estimates the impacts of a hypothetical indirect energy subsidy removal in Ukraine. The study applies a demand driven input-output approach to compute relative price changes occurring from a subsidy removal and finds a three percent reduction in greenhouse gas emissions. I follow a similar approach for only electricity subsidies in India. The computational framework is briefly described below followed by the implications.

8.1 Computational framework

The computation framework as adopted from Ogarenko and Hubacek (2012) follows a price input-output approach. In this approach, an indirect subsidy, given out to power generating companies as a lump sum transfer, can be accounted as value added component of electricity production. To incorporate this into the input-output model, this hypothetical removal of subsidy can be added up in the value added component of the electricity sector to reflect increased cost of production.

To capture the impact of a change in value added, the well-known price input-output model developed by Leontief (1936) is used. This model was developed as a dual version of the regular input-output model to simulate cost push inflationary processes (Oosterhaven 1996). The price input-output model can be used to estimate change in relative prices due to elimination of electricity subsidies. The basic equation of the price model is expressed as:

$$p' = v'(I - A)^{-1} = v'B \tag{19}$$

where p' is a row vector of price indices for each sector and v' is the row vector of primary inputs per unit monetary input for a sector. B, as described before, is the Leontief inverse matrix. While accounting for the base year, the price indices are standardized at one. The elimination of subsidies will accordingly lead to a change in relative price indices. This change in prices due to subsidy elimination can be estimated by the equation:

$$\Delta p' = \Delta v'(I - A)^{-1} = \Delta v'B \tag{20}$$

where Δp' and Δv' are vectors of changes in value added and price indices respectively.

A change in value added in any one sector, due to industrial interdependence, will lead to price rise in all other sectors due to increased input prices for those sectors. After the relative change in price due to subsidy elimination is determined, it is assumed that the price changes in all sectors due to electricity subsidy elimination will reflect in their final demand. This assumption is made in keeping with the limitations of input-output model where technical coefficients of production do not change. In the demand driven input-output model, final demand can be the only exogenous variable. Therefore, the input-output model cannot capture the changes in intermediate demand of a sector due to a price rise. This might seem as a major limitation, but in the short term, it might be logical to assume that industries cannot change their production structure immediately in response to a price change. Therefore, the price rise resulting from subsidy elimination is assumed to be passed on completely to final consumers as they are more likely to respond to price changes in the short run.

For the purpose of computing demand changes due to a change in relative prices, a partial equilibrium approach is used. Price elasticity of demand is used to estimate the demand response of final consumers. The relation of price and quantity changes can be expressed with the help of price elasticity as:

$$\varepsilon = \frac{\Delta Q}{Q} / \frac{\Delta P}{P} \tag{21}$$

where ε is the price elasticity of demand, Q and P are initial demand and price respectively, and ΔQ and ΔP are changes in quantity demand and price respectively.

The demand change in response to price changes can therefore be expressed as:

$$\Delta Q = \varepsilon Q \Delta P / P \tag{22}$$

As the initial price indices in the price model are standardized to one, P=1 in the above equation. In alternate terminology, the equation above can be also expressed as:

$$\Delta y = \varepsilon . \Delta p . y \tag{23}$$

To correspond with matrix notation of input-output model, the equation can be represented in the matrix form as:

$$\Delta \boldsymbol{y} = \Delta \widehat{\boldsymbol{p}} \hat{\varepsilon} \boldsymbol{y} \tag{24}$$

where y is the initial demand matrix, Δy is the matrix of demand change in response to relative price changes, Δp. A hat in the notation implies a diagonal matrix. The relative price changes are obtained from equation (20). Substituting these price change values with the initial demand vector y and a diagonal vector of price elasticities, the demand change can be computed.

After estimating the demand response from the above equation, the familiar demand driven input-output model can be applied to estimate the resulting changes in carbon emissions from the equation:

$$\Delta E = \hat{c}(I - A)^{-1}\Delta y \tag{25}$$

As has been discussed briefly before, agriculture accounts for a major share of the entire electricity subsidies as it faces three to four times lower tariff than domestic consumers. Keeping the computational framework unchanged, it is important to study the implication of electricity subsidy removal from agriculture sector alone. However, since the subsidy is provided in the form of very low flat tariff rates to farmers, the actual subsidy is transferred to the electricity sector, but cannot be subtracted directly from agriculture sector. To achieve the objective of analyzing the impact resulting from increased electricity prices in the agricultural sector alone, the above computational framework is slightly modified as described below.

According to equation (20), a subsidy elimination in electricity reflects in the price changes of all other sectors due to increased electricity input prices. For any sector j, the increased value added in electricity, Δv_i (i=electricity) is transformed into price changes through multiplication with coefficient b_{ij} (characteristic element of the Leontief inverse matrix B, which is the coefficient of electricity input required for a unit output of sector j). For this hypothetical scenario, agriculture sector is allowed to face price change due to an electricity subsidy through its electricity input coefficient b_{ij} (i=electricity, j=agriculture). However, for all other sectors, the price change is computed in proportion of their agriculture input coefficient b_{ij} (i=agriculture) and not electricity input coefficient. In essence this captures a price rise in agriculture input due to a subsidy removal in agricultural electricity alone, while allowing other sectors to respond to a hypothetical price change in their agricultural inputs. In other words, agriculture sector faces a price rise due to more expensive electricity input in production but all other sectors face price rise due to more expensive agricultural inputs in production. A detailed matrix representation of these calculations can be found in the appendix.

8.2 Subsidy and price elasticity values

There are several ways of computing subsidies, the most widely used being a price-gap approach. Some other approaches are effective rate of resistance and producer subsidy equivalent (see Lin and Jiang 2011). However, the aim of this paper is not to determine the amount of subsidy but to study the impacts of its hypothetical removal. A discussion on strength and benefit of methods to compute subsidy therefore is beyond the scope of this paper. For an estimate of the electricity subsidy, I use information from an annual report of the Power and Energy Division of the Planning Commission in India (2014). It estimates the gross electricity subsidy at Rs. 85811 crores, or 18411 million US dollars for 2011, of which Rs. 57901 crores or 12423 million US dollars are from agriculture sector (PC 2014, Table 4.2). These two values are used for the two respective policy scenario analyses. The estimation approach for subsidy adopted in the Planning Commission report is that of the reported losses of power generating companies as a result of selling electricity at government mandated prices.

For the price elasticity values, unfortunately, consistent estimates for all commodities are not available. To obtain accurate values of price elasticities corresponding to all thirty four sectors in the input-output table could be a tedious exercise in itself, with little measures to ensure their accuracy. Ogarenko and Hubacek (2012) compiled existing estimates for some commodities in the literature from a number of country studies (for example Andrikopoulos et al., 1987, Nahata et al., 2007; Russo et al., 2008; Wohlgemuth, 1997; Ho et al., 2008; and Choi et al., 2010) for their study. In the Indian context, some studies have carried out estimation of elasticities for a few commodities like energy, food products (Kumar et al., 2011) and services (Kothe, 2014). Energy and food commodities are relatively inelastic in the short term due to lack of substitutes, while services are found to be relatively more elastic. However, these estimates are likely to be different for different income sections of the population. Also, elasticity estimates vary in short and long terms.

Due to limited availability of consistent elasticity estimates for all commodities, this study adopts similar elasticity values as Ogarenko and Hubacek (2012). As the estimates are derived from studies in different contexts, it can be assumed that they are reasonable to the extent allowed from existing literature. They make an additional assumption that similar sectors have the same price elasticities. Elasticity values are very likely to differ not only within income groups and sectors, but also within countries. The use of elasticity values from other countries could therefore be questioned as to its usability within India. The values have therefore been verified with the few studies on elasticity conducted within India (Kumar et al., 2011 and Kothe 2014). However, not many estimates were found that could ensure the robustness of these assumed values. The estimates are generous approximations based on available evidence, made to simplify the computations and obtain a conditional analysis of the problem at hand. As these estimates are obtained from studies in different countries like Greece, Russia, and United States, they can be assumed to reflect an approximate value. Price elasticity values used for this analysis can be found in Annex 3.

8.3 Results from subsidy elimination

Using the above computation method from Section 8.1, this study estimates the total saving in emissions due to a demand reduction following electricity subsidy elimination comes out to be approximately over 12 million tones. The subsidy value of 18411 US dollars for the first scenario as mentioned in the previous section, gives changes in relative prices using equation (20). The elasticity values are then utilized to compute change in sectoral final demand, which can be further multiplied by sectoral emission coefficients to obtain change in sectoral carbon emissions (equations (21) to (25) lay out the computation procedure). In relative terms it depicts a small percentage of the total national emissions. However it is more than total sectoral emissions of many individual sectors and implies a significant emission saving potential. Figure 4 shows the emission saving of major sectors following a hypothetical electricity subsidy elimination. Since the sector classification of electricity includes electricity production as well as distribution, we observe the highest saving in the electricity sector itself since electricity distribution uses electricity as its major input. Among other sectors, large emission saving occur from manufacturing industries, agriculture, and transport sectors as anticipated from the demand multiplier composition of electricity sector.

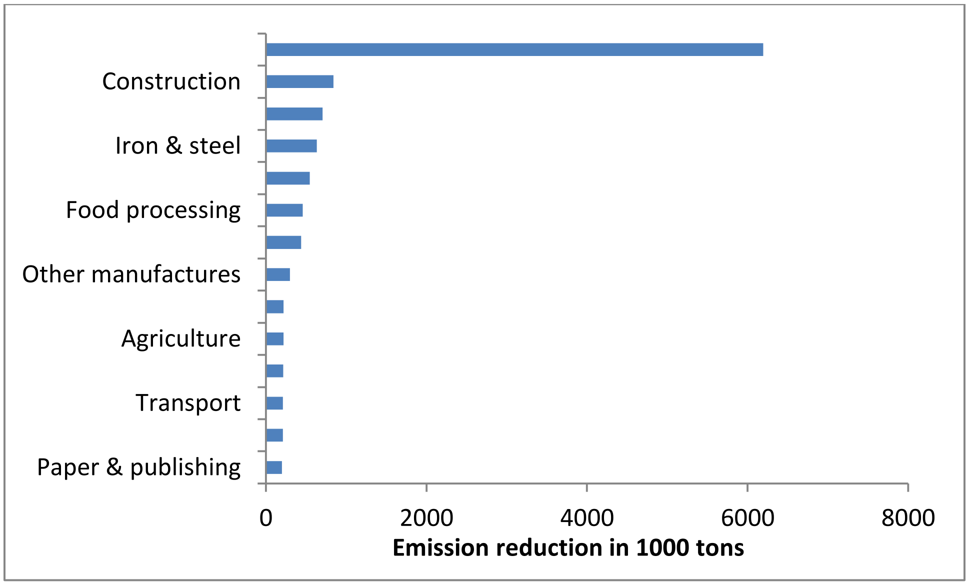

Figure 4: Major emission saving sectors in scenario 1
Source: own computation

In the second hypothetical electricity subsidy removal scenario of electricity subsidy removal alone, the emission saving estimated in this scenario amounts to approximately 2 million tons of CO_2. The subsidy amount of 12423 million US dollars is used for the second policy scenario. This result implies that a sixth of the emission saving potential of electricity subsidy could be achieved from electricity subsidy elimination in the agriculture sector alone. In this scenario, food processing contributes to a major share of emission saved (971,000 tons). This is intuitively appealing as food processing is highly intensive in agricultural inputs. Other sectors save emission via their consumption of agricultural inputs. Sectors that are relatively less intensive in their use of agricultural produce therefore do not contribute significantly to emission saving.

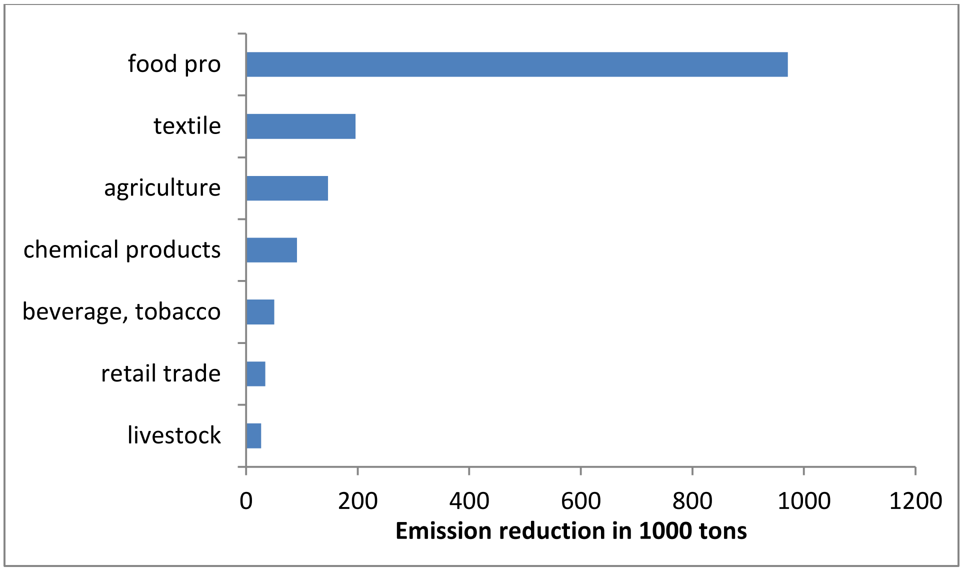

Figure 5: Major emission saving sectors in scenario 2
Source: own computation

9. Policy discussion

The above scenario analyses reveal a reasonable potential to save carbon emissions via a hypothetical subsidy removal. However, as the input-output framework facilitates a short term exogenous policy shock, a subsidy removal should not be interpreted as an immediate policy recommendation from this study. Rather this is an indicative attempt to quantify the emission saving potential of subsidy policy. A short term analysis relies on dampening of demand in response to price increase. However, a removal of subsidy would result in reducing financial stress of the state governments which could be potentially channelized for socioeconomic reforms and mitigating the welfare losses arising from subsidy elimination. Power utilities that presently suffer losses as a result of uncovered subsidy will have the capacity and incentive to invest in production efficiency. A subsidy removal could therefore correct the distortions that result from a price regulation in electricity use and discourage wasteful use. Moreover, this study does not take into consideration the technical changes in input structure of industrial production. A carefully planned gradual phase out of electricity should take into the account the restructuring of industrial production so that a demand damp is not in the form of increased prices passed on to end users but in the form of efficient resource use in production. For subsidy removal to be effective, the financial savings must be channelized in an efficient and transparent manner to control welfare losses arising from such a policy shock (Williams and Ghanadan, 2006).

Arguments against removing subsidy to agriculture are mostly concerned with increased input cost of farmers translating to increased food prices. This might have potential harmful impacts concerning the food security in India as it is burdened with the responsibility of feeding a huge population. Food inflation has been a major policy concern, especially in the last five years when it crossed double digit. While these might seem reasonable concern for subsidies to remain, multiple studies and analyses have proven that poor farmers hardly benefit from low electricity tariffs. A deregulation of electricity price would check stealing agricultural electricity from non-agricultural users. Price deregulation combined with efforts for better targeting among farm consumers, for example installing electricity meters in rural locations could be an effective policy step.

Some state governments have responded to the agriculture sector electricity overuse by implementing programs to improve efficiency of pump sets used for groundwater irrigation. At the onset, it appeals as an action measure to economize electricity use, this alone does not address environmental concerns around agriculture. As long as electricity tariffs remain low, farmers do not have incentive to reduce excessive groundwater extraction. This as a standalone policy might increase speed of water table depletion in areas already burdened with water stress (Swain, 2012). This strengthens the case for tariff reform, and the need to invest in irrigation technologies like soil humidity indicating devices, surface irrigation and other irrigation technologies.

As far as a rise in prices of agricultural produce is concerned, substantial evidence have emerged to disprove the positive impact of input prices to increased product price. The farmers are reported to not receive fair prices of their products due to existence to middlemen in the agriculture market. The presence and role of middlemen in agriculture market has been highly criticized for inflationary trends in farm produce as well as for farmers not realizing full value of their produce. Farmer distress is attributed not to expensive input prices but unfair compensation brought about by exorbitant profit margins extracted by middlemen. Vagaries of nature like delayed monsoons, draught, and floods are more pressing causes for a high instance of farmer suicide across India. This furthers the need for better irrigation technologies as well as effort to mitigate impacts of climate change. Food shortages in India have been long attributed to inefficient distribution schemes and insufficient storage facilities. In fact, lack of storage facilities has been extensively cited as a major avenue for policy actions to focus on. Therefore, sufficient evidence in literature and policy discourse exists to decouple the impact of increased electricity input prices on food prices.

Since the Paris climate conference, India has pledged to reduce its emission intensity of GDP by 30 percent below 2005 levels by 2030 (Climate Action Tracker). A major pathway to achieve this target is through heavy encouragement for non-fossil fuel electricity generation, especially a massive increase in solar power generation. A significant portion of solar energy is supposed to be harnessed for rural electrification. As of 2011, 80 percent of electricity is generated using fossil fuels. A transition to cleaner fuels is very likely to result in emission saving. However, it is important for accurate targeting of clean versus conventional electricity. In other words, clean electricity generated should be targeted for use in the sectors that use up relatively large amounts of electricity. Results in Table 3, from an analysis of supply side composition of electricity sector provide a list of sectors that could result in most amount of emission saving from clean electricity use. Further decomposition of these sectors could provide important insight for efficient policy design.

Adding to the importance of supply and demand side analysis of carbon emissions, sectors that stand to save most in terms of emissions resulting from energy efficiency from sources other than electricity can be accordingly targeted for fuel efficiency plans. For example, the transport sector, that has high demand as well as supply multipliers could transmit a high emission saving potential. Low emission intensity fuel use in transport sector as well as emission efficiency of vehicles would result in lower carbon footprint of not only the transport sector itself, but for all sectors using transport services, as explained by its multipliers. From the demand side management of transport sector implemented through improved public transport infrastructure could also result in less environment pollution by a significant amount, apparent from its high demand multiplier.

10. Strengths and limitations

This section highlights some limitations of input-output analysis, and how it affects this particular study. A discussion regarding other assumptions in this study follows and the overall performance of input-output methodology in achieving the purpose of this study is highlighted.

In an input-output methodology, the technical coefficients or the amount of inputs required for a unit of output are assumed to be constant. The implication of this is that this methodology assumes constant returns to scale (Sousa e Silva, 2001). This limits the impact of an exogenous policy change to changes in demand and does not consider price effects on input composition. As a consequence, production functions are assumed to be linear in inputs. A proportional change in inputs is always assumed to accompany a change in output. For this study, this limitation has an implication that the model does not accommodate adjustments in input structure of other productive sectors of the economy. The model transforms any price changes to increased cost of production and therefore dampens the final demand. Practical ramification of a subsidy removal from electricity is likely to witness productive sectors reducing their electricity consumption using superior production techniques. These effects are not captured in a static input-output analysis. However, the assumptions of this model might not seem too unreasonable for short term policy analysis as technical changes take time to adjust to policy shocks. In the short run, it is reasonable to assume that input structure of production is not likely to change immediately following a policy shock. Therefore the short term energy saving estimates derived from this model are likely to be exceeded if technical adjustments follow a policy shock.

Though input-output analysis is capable of tracing down the impacts of a change in any one area of the economic system to all other areas, it does not allow analyses of complex relations to the extent facilitated by a Computable General Equilibrium (CGE). The flexibility afforded by a CGE model in the production function facilitates a short and long term policy analysis that encompasses structural changes that are likely to happen along the way. The CGE is undoubtedly a more sophisticated tool to analyze policy implications in an economy. For example, Lin and Jiang (2011) use a CGE model to analyze environmental impacts of energy subsidy elimination in China. However the trade-off lies in additional information in terms of data, parameters, and computational complexity. For this particular study, to achieve the environmental impacts of electricity subsidy removal, the use of CGE requires a Social Accounting Matrix (SAM) instead of an input-output table. Although an input-output table lies at the core of a social accounting matrix, its computation are a lot more tedious as it includes more information as compared to an input-output table in terms of employment generated, and decomposition of economic value into other input factors. Due to its computational difficulty, a social accounting matrix for India is not computed by central accounting authorities. Even with the availability of a social accounting matrix, the parameters of the model are subject to assumptions.

The strength of the input-output analysis as compared to a CGE model lies in the short term focus of this study. For a short term analysis, this study considers the interaction of sectors without the requirement for assumptions for any value. As far as price elasticity values are concerned, which are subject to assumption in this study, also need to be assumed in a CGE framework. Thus, a major weakness of this study arising due to generous estimates of price elasticity values are not likely to be completely addressed with the use of a CGE model.

However there is of course a scope for further research to obtain better policy impact estimates using a CGE model that does not put assumptions on the production technology and can deliver long run impacts.

Another serious limitation of input-output analysis is in that it neglects heterogeneity within sectors. While input-output tables compiled for an economy considers each sector in its entirety, in practical scenario, a sector might produce multiple products, or by-products. Another implication of sectoral aggregation is that this neglects different production structure employed by different firms within one industry. Although this might seem a limitation, input-output model facilitates a sufficiently disaggregated analysis of the production system. Considering deeper variations within sectors comes with additional data requirements and such a disaggregated dataset is hardly available. Input-output analysis makes use of as much data as is economically feasible to compile and made available in the highest form of disaggregation.

Input-output data can be time-consuming to compile and is therefore available only with considerable time lags. At present, the latest available input-output data, even for advanced economies, are those from 2011. This time lag in compilation of data restricts analysis to an ex-post study of the economy in a particular year. Due to this restriction, this study limits itself to an analysis based 2011 economy scenario. The technical coefficients are very likely to have undergone significant changes given the dynamic nature of the Indian economy. The conclusions of this study are therefore conditional on information from 2011. The veracity of attempts to estimate the changes that might have ensued after 2011 would be questionable and are therefore not addressed.

Despite the above limitations and its simple appeal, the input-output methodology has its major strength in that it encompasses the economic activities in their entirety. This tool has the capability to account for a large amount of information on disaggregated economic data on a sectoral level, delivering results in a consistent manner. In this capacity, it can exploit interconnections within industries and consumers to deliver direct and indirect impacts of a change in any one section of the economy.

The impacts of a postulated policy shock can not only be traced along the entire economic system, but the magnitude of change can also be decomposed for deriving crucial policy insights. An input-output table augmented with physical quantities of resource use can be an effective analytical tool to study resource use optimization. Finally, a relatively simple computation effort adds to the attractiveness of this tool.

To sum up the justification of using input-output analysis, it can be stressed that the assumptions regarding short term rigidity in production structures are not too unreasonable, given the time lag in structural adjustments, and its ability to exploit sectoral linkages and interactions.

11. Conclusion

This study applies forward and backward linkage analysis to analyze the structural composition of carbon emissions in India for the year 2011, which is a manifestation of environmental input-output analysis. The direct sectoral carbon emission of thirty four sectors in India is analyzed for implication from demand and supply perspectives. For demand perspective, Leontief's inverse matrix is used and for supply perspective, Ghosh's inverse matrix is used. Based on demand and supply multipliers obtained from the linkage analysis, sectors are classified as emission determinant sectors, demand emission determinant sectors, and supply emission determinant sectors. Among determinant sectors are electricity, transport, retail trade, and iron and steel. Major demand side emission determinant sectors are construction, food processing, and agriculture whereas major supply side emission determinant sectors are petroleum and coal products, mining, and financial services.

Drawing upon these findings, the electricity sector is examined in greater detail. As the electricity is heavily subsidized in India especially for the agriculture sector, two hypothetical policy scenarios are analyzed. A hypothetical subsidy elimination in the electricity sector is considered, with the assumption that the only demand response this can generate is with the final consumption demand, in keeping the constraints of input-output framework. Using Leontief's price model and assumed price elasticity values from literature, carbon emission saving potentials are derived. The conclusion of this thesis remains that it is necessary to analyze the structural composition of carbon emissions and focus on areas that have the maximum emission saving potential. This would lead to optimal energy use and reduction in carbon emissions. Especially, this thesis supports the policy discussion behind phasing out electricity subsidy for agriculture, which has facilitated unaccounted and overuse of electricity. The ideal policy action should be a gradual phasing out of such subsidies coupled with supportive measures to regulate the potential short term negative impacts to enhance the sustainability of industrial productivity through optimization of energy use and reduced carbon emission.

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Appendix

Annex1: Direct and total emissions and percentage shares for all sectors.

Code	Sectors	Direct Emission	%	Indirect Emission	%
1	Agriculture	19,675.24	1.50	85,745.43	6.53
2	Livestock	52.06	0.00	16,229.29	1.24
3	Forestry	880.38	0.07	1,496.28	0.11
4	Fishing	3,720.15	0.28	4,367.92	0.33
5	Mining	12,889.75	0.98	8,210.40	0.62
6	Food processing	4,953.29	0.38	100,551.77	7.65
7	Beverage, Tobacco	886.06	0.07	9,280.00	0.71
8	Textile	6,164.88	0.47	37,615.06	2.86
9	Apparel	543.89	0.04	9,594.03	0.73
10	Leather products	192.48	0.01	2,594.41	0.20
11	Woods Products	652.10	0.05	684.20	0.05
12	Paper products	7,584.30	0.58	12,637.34	0.96
13	Petrol & coal products	49,054.97	3.73	31,691.78	2.41
14	Chemical products	35,318.90	2.69	59,665.89	4.54
15	Non-metallic mineral products	75,818.24	5.77	14,200.28	1.08
16	Iron & Steel	115,130.40	8.76	46,878.33	3.57
17	Non-ferrous metal products	3,847.80	0.29	15,446.53	1.18
18	Metal products nec	8,997.87	0.68	21,584.95	1.64
19	Motor Vehicles	530.33	0.04	27,622.65	2.10
20	Transport equipment other	695.62	0.05	13,833.07	1.05
21	Electronic equipment	325.89	0.02	16,764.99	1.28
22	Machinery and equipment nec	3,349.44	0.25	83,881.12	6.38
23	Manufactures nec	6,531.96	0.50	44,606.91	3.39
24	Electricity	760,276.80	57.86	172,670.69	13.14
25	Gas manufacture, distribution	13,265.20	1.01	1,327.71	0.10
26	Water	335.21	0.03	2,664.20	0.20
27	Construction	4,183.27	0.32	202,576.87	15.42
28	Trade	24,514.32	1.87	72,573.38	5.52
29	Transport	148,329.50	11.29	133,003.10	10.12
30	Communication	744.68	0.06	7,199.59	0.55
31	Financial Services	2,059.34	0.16	12,289.13	0.94
32	Business Services	1,195.11	0.09	18,913.42	1.44
33	Other services	219.50	0.02	4,908.04	0.37
34	Administration, Education, Health	1,177.86	0.09	20,787.85	1.58
	Total	1,314,097	100.00	1,314,097	100.00

Source: own calculations

Annex 2: Unweighted and weighted demand and supply multipliers of all sectors

		Total emissions multiplier			
		Unweighted		Weighted	
Code	Sectors	Demand	Supply	Demand	Supply
1	Agriculture	0.660	0.148	0.039	0.014
2	Livestock	0.187	0.047	0.007	0.002
3	Forestry	0.137	0.176	0.001	0.001
4	Fishing	0.294	0.223	0.002	0.002
5	Mining	0.620	2.023	0.004	0.041
6	Food processing	0.538	0.050	0.046	0.001
7	Beverage, Tobacco	0.453	0.075	0.004	0.000
8	Textile	0.576	0.112	0.017	0.002
9	Apparel	0.420	0.033	0.004	0.000
10	Leather products	0.300	0.047	0.001	0.000
11	Woods Products	0.592	0.312	0.000	0.001
12	Paper products	1.455	0.756	0.006	0.004
13	Chemical products	0.385	1.082	0.015	0.075
14	Chemical products	0.915	0.466	0.027	0.018
15	Non-metallic mineral products	2.506	1.828	0.007	0.018
16	Iron & Steel	2.579	1.812	0.021	0.030
17	Non-ferrous metal products	2.017	0.621	0.007	0.003
18	Metal products nec	1.041	0.352	0.010	0.006
19	Motor Vehicles	0.699	0.127	0.013	0.001
20	Transport equipment other	0.719	0.259	0.006	0.001
21	Electronic equipment	0.715	0.110	0.008	0.001
22	Machinery and equipment nec	0.840	0.341	0.038	0.011
23	Manufactures nec	0.635	0.215	0.020	0.005
24	Electricity	7.601	7.722	0.079	0.188
25	Gas manufacture, distribution	1.876	5.268	0.001	0.015
26	Water	0.800	0.386	0.001	0.001
27	Construction	0.649	0.094	0.093	0.008
28	Trade	0.410	0.434	0.033	0.051
29	Transport	0.855	0.898	0.061	0.059
30	Communication	0.513	0.484	0.003	0.007
31	Financial Services	0.315	0.632	0.006	0.033
32	Business Services	0.191	0.108	0.009	0.005
33	Other services	0.052	0.024	0.002	0.001
34	Administration, Education, Health	0.086	0.007	0.010	0.001

Source: own calculations

Annex 3: Price elasticities of final consumption demand

Sector	Elasticities
Agriculture	0.2
Livestock	0.2
Forestry	0.5
Fishing	0.2
Mining	0.2
Food processing	0.5
Beverage, Tobacco	0.7
Textile	0.7
Apparel	0.7
Leather products	0.7
Woods Products	0.7
Paper products	0.7
Chemical products	0.7
Chemical products	0.7
Non-metallic mineral products	0.7
Iron & Steel	0.7
Non-ferrous metal products	0.7
Metal products nec	0.7
Motor Vehicles	0.7
Transport equipment other	0.7
Electronic equipment	0.7
Machinery and equipment nec	0.7
Manufactures nec	0.7
Electricity	0.2
Gas manufacture, distribution	0.2
Water	0.2
Construction	0.7
Trade	0.2
Transport	0.2
Communication	0.2
Financial Services	0.8
Business Services	0.8
Other services	0.8
Administration, Education, Health	0.5

Source: estimates based on literature

Policy scenario computations

Equation (20) can be used in its transposed format to represent the remaining calculations. The transpose of equation (20) is:

$$\Delta p = B^T \Delta v \tag{A.1}$$

A matrix representation of the above equation looks like:

$$\Delta p = \begin{bmatrix} b_{11} & \cdots & b_{24,1} \\ \vdots & \ddots & \vdots \\ b_{1,24} & \cdots & b_{24,24} \end{bmatrix} . \begin{bmatrix} \Delta v_1 \\ \Delta v_2 \\ \vdots \\ \Delta v_{24} \end{bmatrix}$$

A matrix multiplication operation of the above equation gives:

$$\Delta p = \begin{bmatrix} \Delta v_1 b_{11} + \Delta v_2 b_{21} + \cdots + \Delta v_{24} b_{24,1} \\ \Delta v_1 b_{12} + \Delta v_2 b_{22} + \cdots + \Delta v_{24} b_{24,2} \\ \vdots \end{bmatrix}$$

In the first policy scenario, the subsidy amount of 18411 (see Section 8.1) is divided by the total output of the electricity sector represent the fraction of value added. In this scenario, the only change in value added (Δv) is for the electricity sector. Assuming that the index 24 represents the electricity sector, only Δv_{24} has a positive value. All other Δv's are zero in this case. A sector n faces price changes in proportion with Δv_{24} and the coefficient $b_{24,n}$.

The rest of the calculation, as explained in the text, can be obtained from equation (21) to (25).

For the second policy scenario the subsidy amount of 12423 US dollars (see Section 8.1) is used. This value is divided by total output of electricity to reflect reduction of value added in electricity (Δv_{24}). However, for other sectors, this subsidy amount is divided by the total output of agriculture (Δv_1). All other sectors have zero change in value added as usual. In essence, in this scenario, electricity, as an input becomes more expensive for agriculture, and for all other sectors, the agricultural input becomes more expensive. So in this scenario the price change computation looks like:

$$\Delta p = \begin{bmatrix} 0 + 0 + \cdots + \Delta v_{24} b_{24,1} \\ \Delta v_1 b_{1,2} + 0 + \cdots + 0 \\ \vdots \end{bmatrix}$$

The rest of the calculation, as explained before, can be obtained from equation (21) to (25).