

Title	Application of the input-output approach in environmental analysis in LCA
Sub Title	
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Publisher	慶應義塾大学産業研究所
Publication year	1996
Jtitle	Keio Economic Observatory review No.No.8 (1996. 4) ,p.106- 113
JaLC DOI	
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Notes	
Genre	Journal Article
URL	<a href="https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AN00390376-00000008-0106">https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AN00390376-00000008-0106</a>

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## Application of the Input-Output Approach in Environmental Analysis in LCA\*

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### Abstract

Life cycle assessment evaluates the total burden on the environment in the life cycles of goods and services. However, to obtain the cumulative effects attributed by each material inputs necessary involved high cost. As the quality of the analysis results are not positively related to the amount of time and cost spent on the estimation, this undermines the incentive to carry out LCA investigation. Hence, in this paper, we make use of the input-output tables that have been extended for environmental analysis in LCA analysis. For the production of automobiles, we found that the indirect effect it contributed is greater than the direct effect, and the total CO<sub>2</sub> emission from general inputs such as wholesale trade and advertising are in fact greater than that from the production of the car body.

### 1. LCA and Input-Output Analysis

Recently, there has been an attempt to capture the impact of the production of goods and services on the environment using the concept of Life Cycle Assessment(LCA). LCA is an attempt to evaluate the burden effect caused by the production of a good on the environment, and it involves the retrospective accumulation of effects on the environment produced by energy and materials required directly and indirectly in the production of a particular good. The accumulation of these effects involves firstly, measuring the impact of energy consumption on the environment (e.g. CO<sub>2</sub> emission), secondly, measuring the impact on the environment from energy consumption occurs during the production of the various energies and materials required in the production process, and so on, retrospectively.

However, it is almost impossible for an individual firm to know the effect its products exert on the environment as its products pass through many hands. While it may not be difficult to calculate the burden to the environment generated by the production process within the firm, it is difficult for the firm to know the burden on the environment produced in the manufacturing of parts and components and raw materials that are supplied by other firms. Even if it is possible to obtain these information, the range is extremely limited considering the human effort put into it and we may also be forced to calculate the effect of the burden arbitrarily in actual circumstances. Moreover, if the linkage effects of the retrospective accumulation are omitted, this will result in an underestimation of the burden to the environment. As the greater the amount of time and cost spent, the worse the results obtained, this undermines the incentives to carry out the investigation.

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\*Reprinted and corrected from *Keio Economic Observatory Occasional Paper* E.No.19(May 1995).

On the other hand, in the case of input-output analysis in economics, while it only takes into account the national average, arbitrariness is reduced if the tables from a particular year is used as a base, as the retrospective accumulation of the burden effect on the environment and its linkages could be calculated till the very final stage. Hence, in this paper, we introduce the LCA analysis using the input-output table that has been extended for environmental analysis.

Although we only consider CO<sub>2</sub> as the burden to the environment in this paper, similar calculations could also be applied to NO<sub>x</sub> and SO<sub>x</sub>. Further, due to the limitation in products data, we only consider products manufactured domestically. However, as this method of analysis could be easily extended to other kinds of burden on the environment and linkage effects abroad, it could be considered as a useful prototype for analysis along this line of approach.

## 2. Calculating the burden on the environment based on input-output analysis

We assumed that  $n$  types of goods and services are produced in the economy. These goods and services are used in the production of other goods and services, and they are also consumed as final demand or used as investment goods. The relationship in the quantities of these inputs and outputs are illustrated in matrix forms which constitute the input-output tables.

The quantity of input requires in the production of 1 unit of the various components of the matrices in the input-output tables are written as  $a_{ij}$ , i.e. the input coefficient. The value of  $a_{ij}$  refers to the quantity of the  $i$ th good required in the production of 1 unit of the  $j$ th good. Here, both the values of  $i$  and  $j$ , which represent the number of goods and services, take values from 1 to  $n$ . The input coefficients could also be rewritten in the following form,

$$\mathbf{A} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} : \text{Input coefficient matrix} \quad (1)$$

Further, we let the burden on the environment generated by the production of 1 unit of the  $j$ th good as  $e_j$ . For convenience in calculation, it is written in the following diagonal matrix form,

$$\mathbf{e} = \begin{pmatrix} e_1 & & 0 \\ & \ddots & \\ 0 & & e_n \end{pmatrix} : \text{Environmental burden diagonal matrix} \quad (2)$$

Let  $\mathbf{f} = \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix}$  be the demand on various goods for the production of a particular good. Here, the direct burden on the environment arises from the production of vector  $\mathbf{f}$  of goods and services inputs is  $\mathbf{e} \cdot \mathbf{f}$ .

For example, the burden on the environment generated by the production of 1 unit (1 million yen unit in 1985 fixed prices) of automobile ( $k$ th good) is written as follows,

<Direct effect>

<1st indirect effect>

<2nd indirect effect>

	211101 Petroleum refinery products (inc. greas):3kg	073101 Natural gas:2kg
	221101 Plastic products:4kg	181201 Foreign paper and Japanes
	231101 Tyres and inner tubes:4kg	202101 Industrial soda chemicals:2
	251101 Sheet glass and safety glass:33kg	202902 Inorganic pigment:3kg
	272101 Electric wires and cables:2kg	202909 Other industrial inorganic
	321101 Electric audio equipment:1kg	203101 Petrochemical basic produ
	342103 Batteries:3kg	203201 Aliphatic intermediates:2kg
	342104 Electric bulbs:1kg	203202 Cyclic intermediates:1kg
	342106 Electrical equipment for internal comb:3kg	203301 Synthetic rubber:10kg
	354101 Motor vehicle bodies:41kg	203909 Other industrial organic ch
	354102 Internal combustion engine for motor v:26kg	204101 Thermo setting resin:2kg
	354103 Motor vehicle parts and access.:54kg	204102 Thermoplastics resin:9kg
	511100 Electric power:122kg	204109 Other resin:2kg
	511104 Self power generation:3kg	207909 Other final chemical produ
	512101 Gas supply:2kg	211101 Petroleum refinery produc (inc. greas):10kg
	521202 Other sanitary services (industrial):8kg	212101 Coal products:1kg
	611101 Wholesale trade:6kg	221101 Plastic products:5kg
	712201 Road freight transport:18kg	231909 Other rubber products:3kg
	713101 Self passenger transport by private motor:3kg	251101 Sheet glass and safety glas
	713201 Self freight transport by private motor:2kg	251909 Other glass and glass prod
	714201 Coastal and inland water trans.:2kg	259909 Miscellaneous ceramic, s and clay:14kg
	715101 Air transport:7kg	262101 Hot rolled steel:9kg
	822201 Self research:10kg	262301 Cold finished steel:26kg
	851909 Other business services:5kg	262302 Coated steel:4kg
	900000 :1kg	263101 Cast and forged steel:5kg
		263103 Cast and forged materials
		263104 Top and steel shearing
		263109 Other steel products:1kg
		271101 Copper:4kg
		271102 Lead(inc. regenerated lead
		271109 Other non ferrous metals:
		272202 Rolled aluminium product
		272203 Non ferrous metal casting and forgings:6kg
		272209 Other non ferrous metal p
		289909 Other metal products:2kg
		303102 Bearings:2kg
		342106 Electrical equipment for internal combustion engine for motor vehicles:8kg
		354102 Internal combustion engine for motor vehicles:8kg
		354103 Motor vehicle parts and accessories:4kg
		511100 Electric power:208kg
		511104 Self power generation:2kg
		521202 Other sanitary services (industrial):5kg
		611101 Wholesale trade:4kg
		712101 Bus transport:1kg
		712102 Hird car and taxi transpo
		712201 Road freight transport:14
		713101 Self passenger transport by private motor:12kg
		713201 Self freight transport by private motor:12kg
		714201 Coastal and inland water
		715101 Air transport:5kg
		822201 Self research:8kg
		851909 Other business services:3kg
		900000 :17kg

351101 Passenger cars:105kg

CO <sub>2</sub> Total	105kg	383kg	571kg
CO <sub>2</sub> Cummulative Total	105kg	488kg	1059kg

Figure 1: CO<sub>2</sub> Emission from per unit production

# <1st indirect effect>

01 Natural gas:2kg  
 01 Foreign paper and Japanese paper:2kg  
 01 Industrial soda chemicals:2kg  
 02 Inorganic pigment:3kg  
 09 Other industrial inorganic chem.:3kg  
 01 Petrochemical basic products:1kg  
 01 Aliphatic intermediates:2kg  
 02 Cyclic intermediates:1kg  
 01 Synthetic rubber:10kg  
 09 Other industrial organic chem.:1kg  
 01 Thermo setting resin:2kg  
 02 Thermoplastics resin:9kg  
 09 Other resin:2kg  
 09 Other final chemical products:2kg  
 01 Petroleum refinery products (inc. greas):10kg  
 01 Coal products:1kg  
 01 Plastic products:5kg  
 09 Other rubber products:3kg  
 01 Sheet glass and safety glass:6kg  
 09 Other glass and glass products:2kg  
 09 Miscellaneous ceramic, stone and clay:1kg  
 01 Hot rolled steel:9kg  
 01 Cold finished steel:26kg  
 02 Coated steel:4kg  
 01 Cast and forged steel:5kg  
 03 Cast and forged materials(iron):91kg  
 04 Iron and steel shearing  
 09 Other steel products:1kg  
 01 Copper:4kg  
 02 Lead(inc.ragenerated lead):6kg  
 09 Other non ferrous metals:5kg  
 02 Rolled aluminium products:2kg  
 03 Non ferrous metal casting and forgings:6kg  
 09 Other non ferrous metal prod.:1kg  
 09 Other metal products:2kg  
 02 Bearings:2kg  
 06 Electrical equipment for internal comb.:5kg  
 02 Internal combustion engine for motor vehicles:8kg  
 03 Motor vehicle parts and accessories:4kg  
 00 Electric power:208kg  
 04 Self power generation:2kg  
 02 Other sanitary services (industrial):3kg  
 01 Wholesale trade:4kg  
 01 Bus transport:1kg  
 02 Hird car and taxi transport:2kg  
 01 Road freight transport:14kg  
 01 Self passenger transport by private motor:12kg  
 01 Self freight transport by private motor:12kg  
 01 Coastal and inland water trans.:4kg  
 01 Air transport:5kg  
 01 Self research:8kg  
 09 Other business services:3kg  
 00 :17kg

# <3rd indirect effect>

072101 Crude petroleum:7kg  
 073101 Natural gas:2kg  
 151401 Yarn and fabric dyeing and finishing :2kg  
 181101 Pulp:2kg  
 181201 Foreign paper and Japanese paper:8kg  
 181301 Paperboard:2kg  
 202101 Industrial soda chemicals:3kg  
 202902 Inorganic pigment:1kg  
 202909 Other industrial inorganic chemical:4kg  
 203101 Petrochemical basic products:6kg  
 203102 Petrochemical aromatic products:1kg  
 203201 Aliphatic intermediates:6kg  
 203202 Cyclic intermediates:4kg  
 203301 Synthetic rubber:4kg  
 203909 Oth. industrial organic chem.:1kg  
 204101 Thermo setting resin:3kg  
 204102 Thermoplastics resin:8kg  
 204109 Other resin:2kg  
 205102 Synthetic fibers:1kg  
 207909 Other final chemical products:1kg  
 211101 Petroleum refinery products:11kg  
 212101 Coal products:5kg  
 221101 Plastic products:2kg  
 231909 Other rubber products:1kg  
 251101 Sheet glass and safety glass:1kg  
 252101 Cement:3kg  
 259909 Misc. ceramic, stone & clay:18kg  
 261101 Pig iron:45kg  
 261103 Crude steel:7kg  
 262101 Hot rolled steel:22kg  
 262301 Cold finished steel:11kg  
 262302 Coated steel:3kg  
 263101 Cast and forged steel:2kg  
 263103 Cast and forged materials(iron):38kg  
 271101 Copper:2kg  
 271102 Lead(inc.ragenerated lead):2kg  
 271103 Zinc(inc.ragenerated zinc):4kg  
 271104 Aluminium:7kg  
 271109 Other non ferrous metals:5kg  
 272203 Non ferrous metal casting etc.:2kg  
 342106 Elec. equip. for internal comb.:1kg  
 354102 Int. combustion engine for motor:3kg  
 354103 Motor vehicle parts and access.:7kg  
 511100 Electric power:179kg  
 511104 Self power generation:22kg  
 521202 Other sanitary services (ind.):4kg  
 611101 Wholesale trade:2kg  
 712102 Hird car and taxi transport:1kg  
 712201 Road freight transport:11kg  
 713101 Self pass. transport by private:11kg  
 713201 Self freight trans. by private:11kg  
 714201 Coastal and inland water trans.:5kg  
 715101 Air transport:4kg  
 822201 Self research:3kg  
 851909 Other business services:2kg  
 900000 :13kg

# <4th indirect effect>

072101 Crude petroleum:7kg  
 073101 Natural gas:2kg  
 181101 Pulp:8kg  
 181201 Foreign paper and Japanese paper:7kg  
 181301 Paperboard:3kg  
 202101 Industrial soda chemicals:3kg  
 202909 Other industrial inorganic chem.:3kg  
 203101 Petrochemical basic products:7kg  
 203102 Petrochemical aromatic products:2kg  
 203201 Aliphatic intermediates:6kg  
 203202 Cyclic intermediates:5kg  
 203301 Synthetic rubber:1kg  
 204101 Thermo setting resin:1kg  
 204102 Thermoplastics resin:4kg  
 211101 Petroleum refinery products:11kg  
 212101 Coal products:12kg  
 221101 Plastic products:1kg  
 252101 Cement:3kg  
 259909 Misc. ceramic, stone and cla:10kg  
 261101 Pig iron:90kg  
 261102 ferro alloy:4kg  
 261103 Crude steel:16kg  
 262101 Hot rolled steel:9kg  
 262301 Cold finished steel:5kg  
 263103 Cast and forged materials(iron):12kg  
 271101 Copper:1kg  
 271102 Lead(inc.ragenerated lead):1kg  
 271103 Zinc(inc.ragenerated zinc):2kg  
 271104 Aluminium:5kg  
 271109 Other non ferrous metals:3kg  
 354103 Motor vehicle parts and access.:2kg  
 511100 Electric power:134kg  
 511104 Self power generation:42kg  
 521202 Other sanitary services(ind.):4kg  
 611101 Wholesale trade:1kg  
 712201 Road freight transport:8kg  
 713101 Self pass. trans. by private:9kg  
 713201 Self freight trans. by private:9kg  
 714201 Coastal and inland water trans.:4kg  
 715101 Air transport:3kg  
 822201 Self research:1kg  
 851909 Other business services:1kg  
 900000 :8kg

# <5th indirect effect>

061201 Non ferrous metal ores:2kg  
 071101 Coal mining:1kg  
 072101 Crude petroleum:7kg  
 073101 Natural gas:2kg  
 181101 Pulp:8kg  
 181201 Foreign paper and Japanese  
 181301 Paperboard:3kg  
 202101 Industrial soda chemicals:2kg  
 202909 Other industrial inorganic c  
 203101 Petrochemical basic product  
 203102 Petrochemical aromatic prod  
 203201 Aliphatic intermediates:4kg  
 203202 Cyclic intermediates:3kg  
 204102 Thermoplastics resin:2kg  
 211101 Petroleum refinery products  
 212101 Coal products:14kg  
 252101 Cement:2kg  
 259909 Miscell. ceramic, stone and  
 261101 Pig iron:185kg  
 261102 ferro alloy:8kg  
 261103 Crude steel:7kg  
 262101 Hot rolled steel:4kg  
 262301 Cold finished steel:2kg  
 263103 Cast and forged materials(i  
 271104 Aluminium:2kg  
 271109 Other non ferrous metals:2kg  
 511100 Electric power:94kg  
 511104 Self power generation:41kg  
 521202 Other sanitary services (ind  
 712201 Road freight transport:5kg  
 713101 Self passenger trans. by pri  
 713201 Self freight trans. by privat  
 714201 Coastal and inland water tr  
 715101 Air transport:2kg  
 900000 :5kg

571kg

1059kg

576kg

1635kg

507kg

2142kg

484kg

2626kg

ton per unit production of automobile

# 5th indirect effect>

001 Non ferrous metal ores:2kg  
 101 Coal mining:1kg  
 101 Crude petroleum:7kg  
 101 Natural gas:2kg  
 101 Pulp:8kg  
 201 Foreign paper and Japanese paper:5kg  
 301 Paperboard:3kg  
 101 Industrial soda chemicals:2kg  
 909 Other industrial inorganic chem.:2kg  
 101 Petrochemical basic products:5kg  
 102 Petrochemical aromatic products:2kg  
 201 Aliphatic intermediates:4kg  
 202 Cyclic intermediates:3kg  
 102 Thermoplastics resin:2kg  
 101 Petroleum refinery products:9kg  
 101 Coal products:14kg  
 101 Cement:2kg  
 909 Miscell. ceramic, stone and cla:8kg  
 101 Pig iron:185kg  
 102 ferro alloy:8kg  
 103 Crude steel:7kg  
 101 Hot rolled steel:4kg  
 301 Cold finished steel:2kg  
 103 Cast and forged materials(iron):4kg  
 104 Aluminium:2kg  
 109 Other non ferrous metals:2kg  
 100 Electric power:94kg  
 104 Self power generation:41kg  
 202 Other sanitary services (ind.):3kg  
 201 Road freight transport:5kg  
 101 Self passenger trans by private:6kg  
 201 Self freight trans. by private:7kg  
 201 Coastal and inland water trans.:3kg  
 101 Air transport:2kg  
 000 :5kg

# <6th indirect effect>

071101 Coal mining:2kg  
 072101 Crude petroleum:6kg  
 073101 Natural gas:1kg  
 181101 Pulp:5kg  
 181201 Foreign paper and Japanese paper:3kg  
 181301 Paperboard:2kg  
 202101 Industrial soda chemicals:1kg  
 202909 Other industrial inorganic chem.:1kg  
 203101 Petrochemical basic products:3kg  
 203102 Petrochemical aromatic products:1kg  
 203201 Aliphatic intermediates:2kg  
 203202 Cyclic intermediates:1kg  
 211101 Petroleum refinery products:7kg  
212101 Coal products:21kg  
 252101 Cement:2kg  
 259909 Miscell. ceramic, stone and clay:4kg  
 261101 Pig iron:78kg  
 261102 ferro alloy:4kg  
 261103 Crude steel:3kg  
 262101 Hot rolled steel:2kg  
 263103 Cast and forged materials(iron):1kg  
 271104 Aluminium:1kg  
511100 Electric power:63kg  
 511104 Self power generation:30kg  
 521202 Other sanitary services (ind.):2kg  
 712201 Road freight transport:3kg  
 713101 Self passenger trans by private:4kg  
 713201 Self freight trans. by private:5kg  
 714201 Coastal and inland water trans.:2kg  
 715101 Air transport:1kg  
 900000 :3kg

# <7th indirect effect>

072101 Crude petroleum:4kg  
 181101 Pulp:3kg  
 181201 Foreign paper and Japanese paper:2kg  
 203101 Petrochemical basic products:1kg  
 203201 Aliphatic intermediates:1kg  
 211101 Petroleum refinery products:4kg  
 212101 Coal products:11kg  
 252101 Cement:1kg  
 259909 Miscell. ceramic, stone and clay:2kg  
 261101 Pig iron:34kg  
 261102 ferro alloy:2kg  
 261103 Crude steel:1kg  
511100 Electric power:39kg  
 511104 Self power generation:18kg  
 521202 Other sanitary services (ind.):1kg  
 712201 Road freight transport:2kg  
 713101 Self passenger trans. by private:3kg  
 713201 Self freight trans by private:3kg  
 714201 Coastal and inland water trans.:1kg  
 900000 :2kg

# <8th indirect effect>

072101 Crude petroleum:3kg  
 181101 Pulp:2kg  
 211101 Petroleum refinery product  
 212101 Coal products:5kg  
 259909 Miscell. ceramic, stone and  
 261101 Pig iron:14kg  
511100 Electric power:22kg  
 511104 Self power generation:12kg  
 712201 Road freight transport:1kg  
 713101 Self passenger trans. by pr  
 713201 Self freight trans. by priva  
 900000 :1kg

484kg

2626kg

282kg

2907kg

156kg

3063kg

83kg

3146kg

Figure 1: CO<sub>2</sub> Emission from per unit production of automobile(Continued)

## &lt;Direct effect&gt;

Crude petroleum:4kg

3kg

Foreign paper and Japanese paper:2kg

Petrochemical basic products:1kg

Aromatic intermediates:1kg

Petroleum refinery products:4kg

Products:11kg

Cement:1kg

Miscell. ceramic, stone and clay:2kg

Iron:34kg

Alloy:2kg

Steel:1kg

Electric power:39kg

Power generation:18kg

Other sanitary services (ind.):1kg

Road freight transport:2kg

Self passenger trans. by private:3kg

Self freight trans. by private:3kg

Coastal and inland water trans.:1kg

## &lt;8th indirect effect&gt;

072101 Crude petroleum:3kg

181101 Pulp:2kg

211101 Petroleum refinery products:3kg

212101 Coal products:5kg

259909 Miscell. ceramic, stone and clay:1kg

261101 Pig iron:14kg

511100 Electric power:22kg

511104 Self power generation:12kg

712201 Road freight transport:1kg

713101 Self passenger trans. by private:2kg

713201 Self freight trans. by private:2kg

900000 :1kg

## &lt;Total effect&gt;

071101 Coal mining:9kg

072101 Crude petroleum:41kg

073101 Natural gas:11kg

111901 Salt:4kg

151401 Yarn, fabric dyeing, finishing:4kg

181101 Pulp:31kg

181201 Foreign and Japanese paper:28kg

181301 Paperboard:13kg

202101 Industrial soda chemicals:13kg

202902 Inorganic pigment:5kg

202909 Other ind. inorganic chem.:15kg

203101 Petrochemical basic products:24kg

203102 Petrochemical aromatic products:9kg

203201 Aliphatic intermediates:22kg

203202 Cyclic intermediates:15kg

203301 Synthetic rubber:16kg

204101 Thermo setting resin:8kg

204102 Thermoplastics resin:27kg

211101 Petroleum refinery products:61kg

212101 Coal products:74kg

221101 Plastic products:13kg

231101 Tyres and inner tubes:5kg

251101 Sheet glass and safety glass:41kg

252101 Cement:14kg

259909 Miscell. ceramic, stone &amp; clay:60kg

261101 Pig iron:421kg

261102 Ferro alloy:19kg

261103 Crude steel:36kg

262101 Hot rolled steel:48kg

262301 Cold finished steel:47kg

262302 Coated steel:8kg

263101 Cast &amp; forged steel:9kg

263103 Cast &amp; forged materials(iron):148kg

271101 Copper:9kg

271102 Lead(inc. regenerated lead):10kg

271103 Zinc(inc. regenerated zinc):8kg

271104 Aluminium:17kg

271109 Other non ferrous metals:16kg

272203 Non ferrous metal casting etc.:9kg

342106 Elec. equip. for internal comb:7kg

351101 Passenger cars:105kg

354101 Motor vehicle bodies:42kg

354102 Internal combustion engine:38kg

354103 Motor vehicle parts and access.:88kg

511100 Electric power:888kg

511104 Self power generation:183kg

521202 Other sanitary services (ind.):29kg

611101 Wholesale trade:16kg

712101 Bus transport:4kg

712102 Hire car and taxi transport:6kg

712201 Road freight transport:64kg

713101 Self pass. trans. by private:52kg

713201 Self freight trans. by private:54kg

714201 Coastal &amp; inland water trans.:24kg

715101 Air transport:23kg

822201 Self research:23kg

851909 Other business services:13kg

900000 :52kg

kg

83kg

3241kg

3kg

3146kg

3241kg

Production of automobile(Continued)

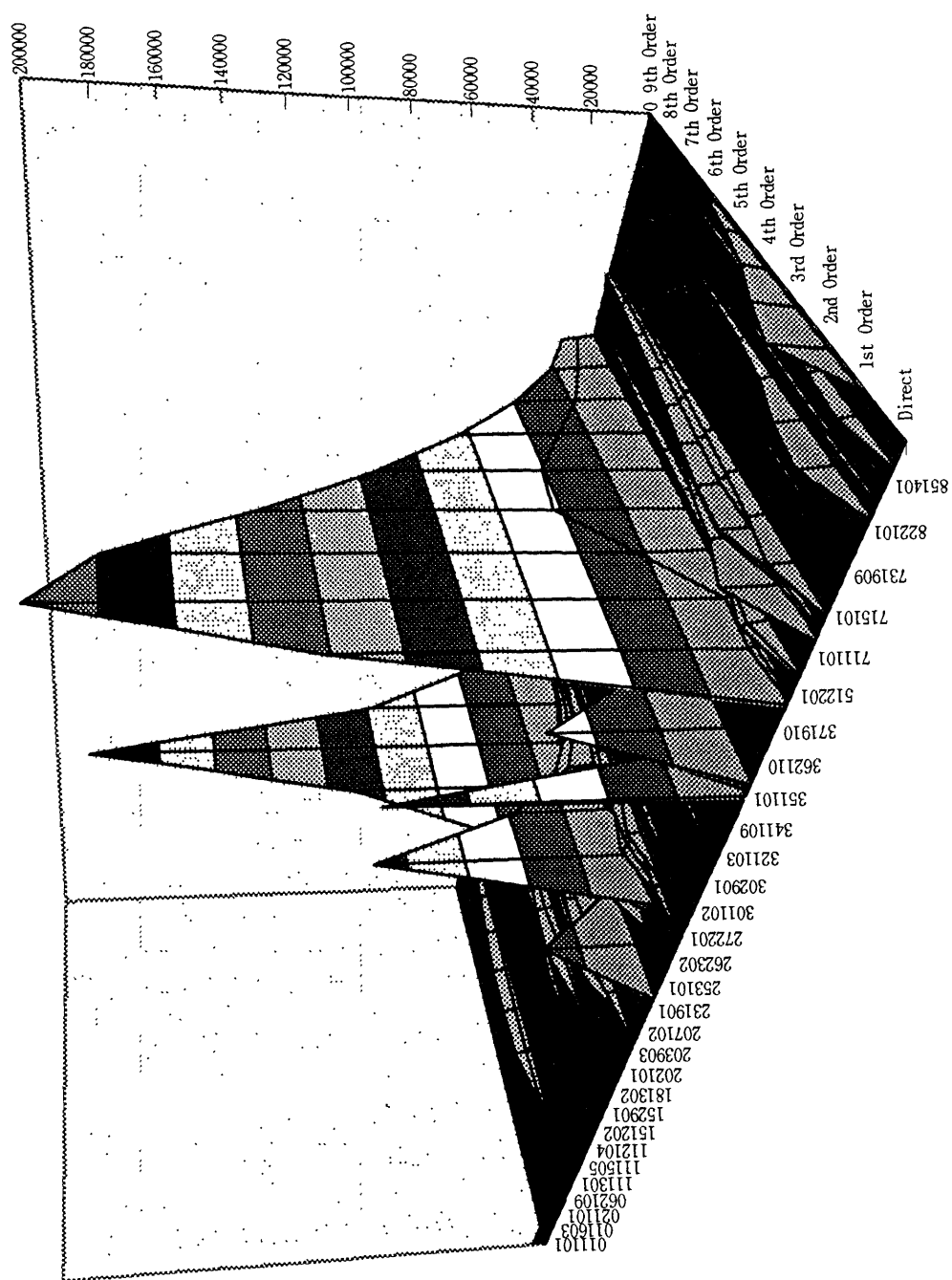


Figure2.: Process of CO<sub>2</sub> emission induced from per unit production of automobile



$$\mathbf{e}_k = \begin{pmatrix} e_1 & & \\ & \ddots & \\ 0 & & e_n \end{pmatrix} \begin{pmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{pmatrix} \quad (3)$$

This is the direct burden effect on the environment.

Next, for the first order indirect effect, the production of demand  $\mathbf{f}$  requires addition production  $\mathbf{A}\mathbf{f}$ , which is used as intermediate good. Therefore, the first order indirect burden effect on the environment amounts to  $\mathbf{e} \cdot \mathbf{A}\mathbf{f}$ . Within which, its linkage effect on intermediate goods is again linked to the second order indirect effect. As the production of  $\mathbf{A}\mathbf{f}$ , in turns requires intermediate good,  $\mathbf{A}\mathbf{A}\mathbf{f} = \mathbf{A}^2\mathbf{f}$ , the second order indirect effect on the environment amounts to  $\mathbf{e} \cdot \mathbf{A}^2\mathbf{f}$ .

The above effects could be summarized as follows,

$$\mathbf{x} = \mathbf{f} + \mathbf{A}\mathbf{f} + \mathbf{A}^2\mathbf{f} + \cdots = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \quad (4)$$

where  $\mathbf{x}$  is called the total production inducement vector. The total burden on the environment is thus written as

$$\mathbf{e} \cdot \mathbf{x} = \mathbf{e} \cdot \mathbf{f} + \mathbf{e} \cdot \mathbf{A}\mathbf{f} + \mathbf{e} \cdot \mathbf{A}^2\mathbf{f} + \cdots = \mathbf{e} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \quad (5)$$

where  $(\mathbf{I} - \mathbf{A})^{-1}$  is the Leontief inverse matrix. The Leontief inverse matrix, being the sum of an unlimited number of columns, is equivalent to the retrospective accumulation of the linkage effects of the intermediate goods to the very last stage. It is worth noting that due to the unlimited number of items to be included in the summation, accumulation could only be carried out within a small range. Further, it could also be proved that the inverse matrix exists under normal conditions.

### 3. The production of automobile: an example

Given the demand  $\mathbf{f}$  of the various goods, the burden on the environment generated directly and indirectly by the intermediate goods could be calculated by  $\mathbf{e} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$ . In the following section, we use the production of 1 unit (1 million yen) of automobile as an illustration (The details are based on the 440 sectors table in the 1985 Input-output Tables for Environmental Analysis which we compiled<sup>1</sup>. Figure 1 and 2 shows the calculation results of the CO<sub>2</sub> emission from per unit production of automobile. Due to the limits of space, Figure 1 focuses on items which their indirect effects have an emission of more than 1kg and total effects that exceed 4kg.

Firstly, for the direct effect, the production activities of a 1 million yen unit of automobile induced a CO<sub>2</sub> emission of 105kg. Various types of parts and components, and energy are used in the production of automobiles. From the perspective of the emission of CO<sub>2</sub>, the production of plastic, tyres and inner tube, sheet glass, motor vehicle bodies, internal combustion engine for motor vehicles induce a larger emission comparatively. In addition, high CO<sub>2</sub> emission is induced from electric power generation and road freight transport. The total first order indirect effect induces a CO<sub>2</sub> emission of 383kg.

<sup>1</sup> See Yoshioka et al.(1992a) and Hayami et al.(1993).

In the next round of the linkage effect, intermediate goods are again required in the production of the goods in the first order indirect effect. Here, a high level of CO<sub>2</sub> is emitted in the production of cold finished steel and cast iron. Moreover, electric power generation, as a general input, has a CO<sub>2</sub> emission of 208kg. Hence, a total of 571kg of CO<sub>2</sub> is emitted in the second order indirect effect. It should be noted that the peaks in CO<sub>2</sub> emission for the various intermediate goods are different. For instance, the peak of CO<sub>2</sub> emission for electric power generation occurs in the second order effect whereas the peak for road freight transport occurs in the first order effect. While it is relatively easy to estimate the peaks for car body or internal combustion engine, it is difficult to estimate the required production of inputs used in the manufacturing of the various kinds of intermediate goods demanded simultaneously. In the calculation process of the second order indirect effect, in trying to know the quantity of the *i*th good required in the production of the *j*th good, we have to aggregate the derived demand in the production of the *i*th good due to *j*th good, through the linkage effect on the *k*th good. In other words, the calculation involves  $\sum_{k=1}^{440} a_{ik}a_{kj}$  ( $440 \times 440 = 193,600$  items in total), to obtain the CO<sub>2</sub> emission induced in the production of the *j*th good. While the retrospective accumulation method is simple, it is clear that an enormous amount of calculation is involved in the estimation of the second order indirect effect alone.

Further, as for the third order indirect effect, items such as crude oil, pulp, dyeing and finishing, cement, crude steel, zinc, and aluminum induced an emission of more than 1kg, and cold finished steel and cast iron required in the second order indirect effect have great inducement effect on the production of pig iron and hot rolled steel. While the CO<sub>2</sub> emission from electric power generation remains large at 179kg, it is on a decreasing trend. On the contrary, emission from self-power generation is on the increase. The total emission of CO<sub>2</sub> in the third order effect amounts to 576kg, the highest level of emission within the different stages considered.

For the fourth order indirect effect, CO<sub>2</sub> emissions from crude petroleum, coal products, pig iron and crude steel increased. Emission peaks are located for pulp, crude steel and self-power generation. The quantity of CO<sub>2</sub> emission from transport related activities should not be neglected, although it is on a decreasing trend.

For the inducement effect after the fourth order, the emission peak of pig iron occurs at the fifth order indirect effect, whereas the emission peak of coal products (coke) is found to occur at the sixth order. Besides, the peak of ferro alloy (8kg) also occurs at the fifth order. The total CO<sub>2</sub> emission amount to 484kg and 282kg at the fifth and the six order effect, respectively, while declining thereafter. The cumulative total upto the sixth order effect amount to 2,907kg, which is equivalent to about 90% of total cumulative emission of 3,421kg obtained through the inverse matrix. However, the emission of CO<sub>2</sub> continues until the very last stage for the case of petroleum related products, pulp, pig iron, power generation and transport related sectors.

#### 4. An evaluation of the total effect

It is found that in terms of the total cumulative effect, 3.2 tons of CO<sub>2</sub> is emitted in the production of per unit of automobile. The characteristics of the total cumulative effect could be summarized as follows. Firstly, electric power generation has the highest level, 888kg of CO<sub>2</sub> emission, follow by pig iron (421kg), self-power generation (183kg), and cast iron (148kg). Secondly, as the direct effect contributed by automobile amount to only 105kg, the indirect effect it generated is much larger. Thirdly, CO<sub>2</sub> emission from the transport sector is large, as the total emission from bus transport, hired car & taxi

transport, road freight transport, self-passenger transport and self-freight transport by private motor car, coastal and inland water transport, and air transport amount to 227kg. The CO<sub>2</sub> emission from these sectors are rather constant at all stages. Moreover, we should not ignore electric power generation and other general inputs that are required in all the manufacturing processes of various products. Fourthly, the accumulation of CO<sub>2</sub> emission from production activities such as salt, dyeing and finishing, inorganic pigment, wholesale trade and advertising, which we are likely to neglect could also sum up to a considerable amount. In fact, the total emission from these activities is about the same magnitude as the emission from the production of the car body, and wholesale trade and advertising could be considered as general inputs.

With regards to efficiency in production processes which consume a large amount of energy, Japan is quite advance among the industrial countries. However, it should be noted that transport, distribution and services are general inputs, just as the case of electricity or iron, required in the production of all types of goods. Therefore, it is a characteristic of general inputs that they are induced largely by the production of other goods. As it is also shown in our calculation, their effects should not be ignored. However, the efficiency of these services related sectors have not received much attention in Japan.

## 5. Towards LCA

For other goods and services, we have also calculated the CO<sub>2</sub> emission from the production of intermediate goods required in their production<sup>2</sup>. In this paper, we have illustrated using the example of automobile, analysis involving the retrospective accumulation method based on input-output analysis.

However, problems regarding the use of LCA remain. First, as we have used Japan's input-output table, CO<sub>2</sub> emission from the production and transport of raw materials and energy from abroad have not been included in the calculation. However, CO<sub>2</sub> emission effects induced abroad could be captured using the international input-output tables. Moreover, in this paper we have assumed that imports from abroad are produced using the same technology as that in Japan, while the transport of imports has been ignored in the study.

Second, we are still in the process of extending the input-output tables to include the effects of recycling and the absorption of CO<sub>2</sub> by plants.

The third point is that, we have also ignored the CO<sub>2</sub> emission induced from the production of manufacturing facilities. However, as seen in case of electricity, CO<sub>2</sub> emissions induced from the construction of manufacturing facilities are relatively small compared to that induced from production activities<sup>3</sup>.

As the concept of LCA is based on the accumulation of all the burden which the products of individual firms exert on the environment. It is necessary to single out the effects each product exerts on the environment.

As the results of the input-output tables are available, there should be incentives to carry out detailed survey so as to differentiate the data contain in both. Further, with the information provided in the input-output table, they help to reduce the omissions that may occur in the accumulation process. Therefore, the introduction of input-output tables in LCA is important from both the point of view of calculation efficiency and comprehensive coverage.

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<sup>2</sup>Yoshioka et al.(1992b)

<sup>3</sup>Yoshioka et al.(1994)

Nevertheless, there is a limit individual firm could claim about the burden its product exerts on the environment. For instance, even if the burden one's product exerts on the environment is small, but the reason behind being that electricity input is obtained from nuclear power instead of coal-fired power, then the evaluation will become rather difficult.

## References

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