1.1.1. Direct & Indirect Energy Consumption Analysis

(1) Introduction

It is note-worthy that all of the researches with focus on generating CO_2 emission inventories or projecting future emissions in this project have been done within the territory of each mega-city itself. In this approach emissions from manufacturing and transportation of commercial goods are assigned at the point where they are finally released to the atmosphere, no matter where the goods are consumed.

Generally speaking, as pointed out by Muradian (2002), the assessment of the environmental performance of any selected economic system requires us to specify the relevant spatial scales of analysis. How to design this kind of "spatial scale" may depend on assumptions mainly (1) the interrelationship between the different ecological systems transformed by economic activity; (2) the agents and institutions where environmental liability has to be assigned; (3) the economic driving forces of environmental transformation; and (4) the envisaged mechanisms of environmental policy. Dominating work in our Mega-city project has followed the traditional way of thinking in setting the boundaries of research object, which is to refer to the political boundaries but not the ecological ones.

However, we never intended to ignore the close relationship between the objective cities and the outside world, not only in terms of "international trade" or "internal trade", but also in terms of "trans-boundary environmental issues". Considering the hierarchy of dependency on outside world, city may be much more complicated than country. By analogy with country scale, city has similar boundary as country between itself and the world. However, additionally it has another boundary that can not be omitted: the boundary between the city and the country. Actually, tracing back to the boundary setting, we can easily find that the economic dependency on outside world makes the city an absolute open system and correspondingly extending beyond the political territory becomes necessary.

In addition to reconsidering the specification of territories in meaning of socioeconomic dependency, another point of view widely used in industrial ecology also attracts our concern. This is "metabolism", or specifically speaking, the "socioeconomic metabolism". In analogy to the biological notion of metabolism, the concept of socioeconomic metabolism describes physical exchange processes (i.e. material and energy flows) between human societies and their natural environment as well as the internal material and energy flows of human societies (Ayres and Simonis, 1994; Fischer-Kowalski, 1998). Robert Ayres (1976) firstly developed a kind of "industrial metabolism" analysis, which traces materials and energy flows from initial extraction of resources through industrial and consumer systems to the final disposal waste. Nowadays, the international standards to be used in accounting for socioeconomic metabolism are being developed. In the metabolism approach, socioeconomic systems are conceived as systems depending upon a continuous throughput of material and energy. Socioeconomic systems extract raw materials from their natural environment and subsequently transform these materials as part of the economic process. Materials are accumulated for a certain period of time (forming material stocks) or they are more or less readily released into the ecosystems as waste and emissions (Krausmann and Habert, 2002). So in virtue of the concept of "social metabolism", we can address two types of environmental problems: resources scarcity on the input side and the pollution or emission on the output side.

This action of boundary rethinking makes us treat the city as an ecological open system, which is located on an approximate close loop and interact with outside world through material and energy flows. Such kind of regional application of the concept of "social metabolism" can provide valuable insight into the sustainability of each sector in the city scale. The information from this kind of study makes it possible to map the resources, to replay the process of transformation and to clarify the emission burden.

It is obvious that the metabolism of a city can only be clarified if both the energy and material flow are considered. Considering the ultimate objective of this project, here we will focus on analyzing the energy flow and correspondingly CO_2 emission flow. One concept of “embodied energy” or “embodied emission” will be employed in our research. The term “embodied” or “indirect” energy use or emissions has been used by several authors to distinguish the indirect energy use for the production of goods in contrast to the direct energy uses (e.g. Van ENGELENBURG,1994; COLEY, 1997, SUBAK 1995). The indirect energy uses and emissions can imply the economic dependency of the city on the outside region and especially highlight the “environmental load displacement” of the highly developed mage-cities to the outside region. Additionally, the ratio of direct energy use or emission or indirect energy use or emission can also provide information about the economic structure change within the city. To simulate the energy flow emphasized in the socioeconomic metabolism, we try to make use of the IO technique to recur the energy related economic activities. In the late 1960s, some specialists brought IO analysis from economics to energy and environmental fields (Daly 1968; Leontief, 1970). The application of IO techniques to these fields allows one to trace, through an economy, the direct and indirect energy /environmental impacts of changes in the final demand.

Considering the characteristics of mega-cities itself, this research tries to highlight the exact role of mage-cities by extending the targeting scope from city itself to a broader space. To realize this objective, we developed the traditional concept of direct and indirect energy use and build up a set of indicators to serve for our ultimate goal. This will be discussed in detail in section 2.

(2) Basic model for “ indirect energy consumption ” and “ indirect energy supply ” basing on the concept of “ embodied energy ”

(2)-1 theoretical discussions about the concept of “indirect energy consumption” and “indirect energy supply”

No violating with the thermodynamic law, there should be an “energy balance” for each production sector or say system. This can be simply expressed as following.

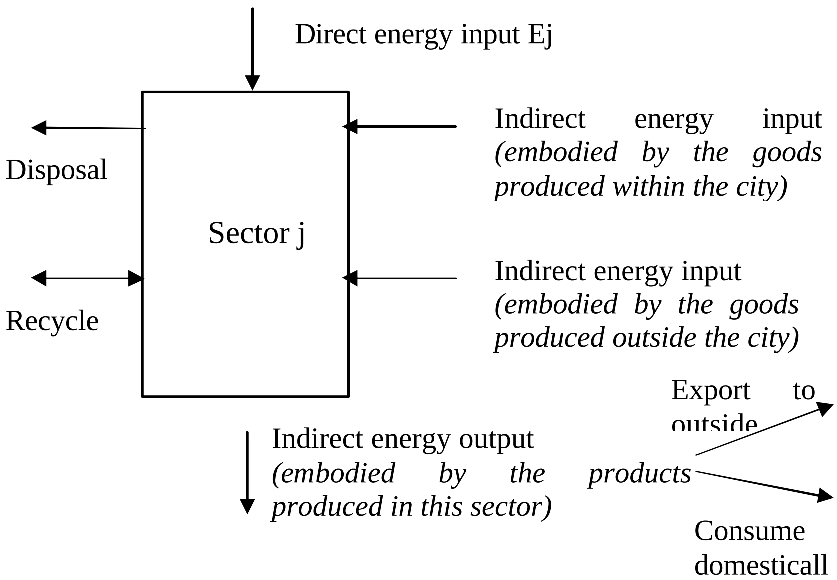

Figure 4-4-5-1: Energy balance for sector *j* on a city scale

Due to data availability, this research will neglect the disposal part and recycle part and then the "energy balance" can be expressed in the following way

$$\boldsymbol{E}_j + \sum_{i=1}^{n} e_i C_{ij} + \sum_{i=1}^{n} x_i \overline{C}_{ij} = e_j \boldsymbol{Q}_j \qquad \textbf{(1)}$$

Where Ej is the direct energy input into sector j, ej is the embodied energy per unit production of industry j within the city; ?j is the embodied energy per unit production of imported goods; ? ij is the goods and services flow from industry i to industry j within that city, is the flow of imported goods and services from industry i to industry j.

Actually, goods and services consumed in a city can be clarified as 1. Local goods produced in the city, 2. Goods imported from other areas in the country, and 3. Goods imported from other countries. This makes it necessary to establish a model with not only boundaries between the city and the country but also between the country and the world. Data restriction, however, make it difficult to calculate the embodied energy of goods imported from other countries. So in this study, we assume that embodied energy of goods imported from other areas in the country were equal with those imported from other countries if they were in the same industry, but different between local and imported goods.

The essence of the "embodied energy" is a kind of indirect reflection on the behavior followed after the energy direct consumption. We try to emphasize the following two points: a). "indirect energy consumption" or say "indirect energy demand". That means that where the good is finally consumed, where the energy embodied in that good should be accounted as a kind of "indirect energy consumption" or "indirect energy demand". So in terms of "indirect energy consumption", the end-user should somehow take some responsibility for the energy consumption, and correspondingly the CO_2 emission. b). "indirect energy supply". Goods produced within the city can be divided into two parts: consumed domestically or exported to the outside, correspondingly, energy embodied in those goods which are exported to the outside should be a "indirect energy supply" to outside and also correspondingly the CO_2 emission from this part should not be simply accounted to the city itself, even though city really consumed this part of energy (directly or indirectly).

To highlight the contribution of "indirect energy consumption or demand" and "indirect energy supply", we can make clear how city "rely on outside" or "is relied on by outside". Of course, the direct energy consumption can be taken as an indicator on how city "rely on outside" beyond all doubts (assume that the energy extraction is outside the city). However, as kinds of proxy indicators, "indirect energy consumption" and "indirect energy supply" may provide some very interesting information which we can not easily draw from the "direct energy consumption" in the city", like:

1) Generally speaking, they are material-related indicator. To clarify the dependency on outside, the direct energy consumption of each sector, as a pure energy-related indicator, can give us little information about the material reliance on outside of the city. But these two indicators can contribute to this query in some sense, even though our ultimate objective is to show the energy embodied by the material but not the material itself.

2).They are directly related to the characteristics of the sectors themselves. So we can easily clarify the sectoral difference and characteristics in terms of energy or material reliance on outside, and consequently, easily draw some implications about the industry structure transition.

3) Since they are the mirror of the industry structure of the city itself, comparison among cities in different development stages can indicate how the evolution of industry influence the energy reliance of the city. And

4) To show how city rely on outside or is relied on by outside, is to clarify the role of city in the sense of energy consumption and CO_2 emission beyond the geographical

scope of the city itself. This may shed some light on the “urban sustainable development”, since one objective of it is to “reduce the city’s use of natural resources and energy”. In addition to the dominating way of aiming at controlling the direct energy consumption, our point of view may highlight the real role the city played beyond the scope of city itself and broaden the view of any urban development planner. This may be very significant for planning sustainable development on national scale or even on global scale.

(2)-2 Model specification

The proposed model can be applied to a competitive-imports type input-output table that clearly distinguishes between local and imported goods but not to a noncompetitive-imports type input-output table that does not distinguish between local and imported goods. City-level input-output tables in China as well as in Japan are usually of the competitive-imports type and rarely of the noncompetitive-imports type. Therefore, the degree of self - sufficiency of each industry is used in this study to distinguish between local and imported products. In this case, the formula for the energy balance is as follows:

$$\boldsymbol{E}_{\boldsymbol{j}} + \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} e_{\boldsymbol{i}} g_{\boldsymbol{i}} \mathrm{C}_{\boldsymbol{ij}} + \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} x_{\boldsymbol{i}} (\mathbf{1} - g_{\boldsymbol{i}}) \mathrm{C}_{\boldsymbol{ij}} = e_{\boldsymbol{j}} \boldsymbol{Q}_{\boldsymbol{j}} \qquad \mathbf{(2)}$$

Where ?i is the degree of self-sufficiency of product i, which can be expressed as follows:

$$g_{\boldsymbol{i}} = \frac{\boldsymbol{Q}_{\boldsymbol{i}}}{\boldsymbol{Q}_{\boldsymbol{i}} + \boldsymbol{M}_{\boldsymbol{i}}}$$

In the above formula, Mi indexes the imports of product i. Qi indexes the local amount of product i.

(3) Data specification

Featuring with great data-intensiveness, basic model discussed above needs material flow and energy flow information of each detailed industry sector. The material flow data, as we discussed above, will be extracted from the input-output table of targeted cities. In our research, we employed the input-output tables of Tokyo 1990, 1995, Beijing 1992, 1997 and Shanghai 1992, 1997. The national input-output table is also employed if necessary. Comparing with the material flow data, the energy consumption data for each detailed industry is much more difficult to obtain, which are not always available for each specific industry sector, especially on city level. So if the detailed energy data is not available on city level, we will turn to the national data and assume that the marginal transaction price cost may remain constant within the whole country for all industry sectors. Detailed information for each city are summarized in **Table 4-4-5-1**

Basing on energy data, CO_2 emission will be obtained by multiplying the energy consumption of each fuel type with the corresponding carbon emission factors. Special attention should be paid to the electricity and heat since the consumption of which has no CO_2 emission.

Table 4-4-5-1: Data specification

	year	Sector aggregation of Input-output table	Energy consumption data
Tokyo	1990		Detailed data on city level
	1995	484‡ 599	Detailed data on city level
Beijing	1992		Detailed data on national level
	1997	124‡ 128	Detailed data on city level
Shanghai	1992	128‡ 128	Detailed data on national level
	1997		Detailed data on city level

(4) Analysis result and discussion

(4)-1 direct energy demand and indirect energy demand- "how city rely on outside"

(4)-1-1 Direct and indirect energy demand in the targeted cities

Figure 4-4-5-2 shows the direct and indirect energy demand of targeted cities. For Tokyo and Shanghai, indirect energy demand is more significant than direct energy demand, though the ratio of indirect to direct energy demand decreases during the period of 1990-1995 in Tokyo and also of 1992-1997 in Shanghai. During 1990-1995, total amount of energy demand in Tokyo decreased by 6.34%, among which, indirect energy demand decreased by 10.74% and direct energy demand increased by 9.36%. During 1992-1997, total amount of energy demand of Shanghai increased about 1.66%, among which, the direct energy demand increased by 25.37% and indirect energy demand decreased by 11.94%. For Beijing case, direct energy demand is more significant. During the period of 1992-1995, total amount of energy demand increased about 25.77%, among which, the direct energy demand increased by 33.57% and simultaneously the indirect energy demand increased by 14.89%.

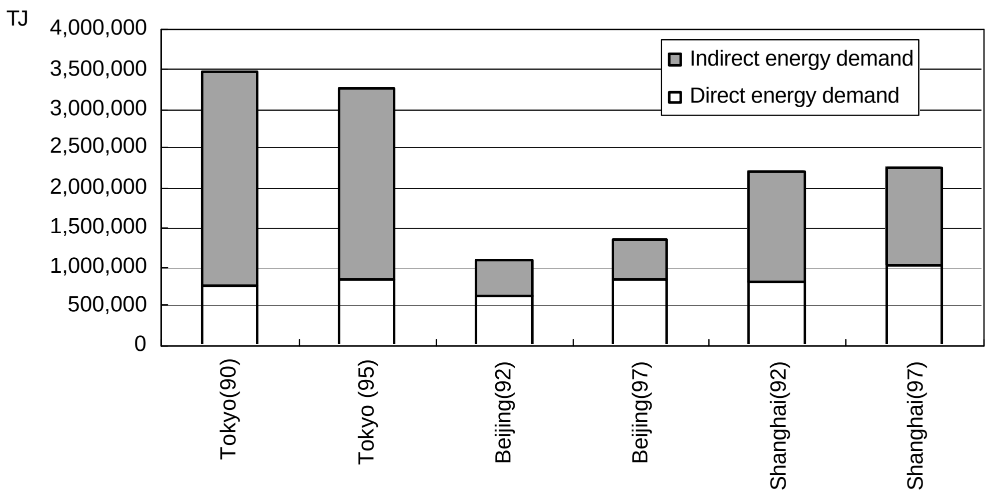

Figure 4-4-5-2: Direct and indirect energy demand of the targeted cities

(4)-1-2 Sectoral distribution of the direct and indirect energy demand

Taking a glance at the industrial structure transition of each targeted cities (**Figure 4-4-5-3**), we can easily find that for each city, during the shooting period the proportion of economic output of secondary industry decreased and at the same time the proportion of tertiary industry increased.

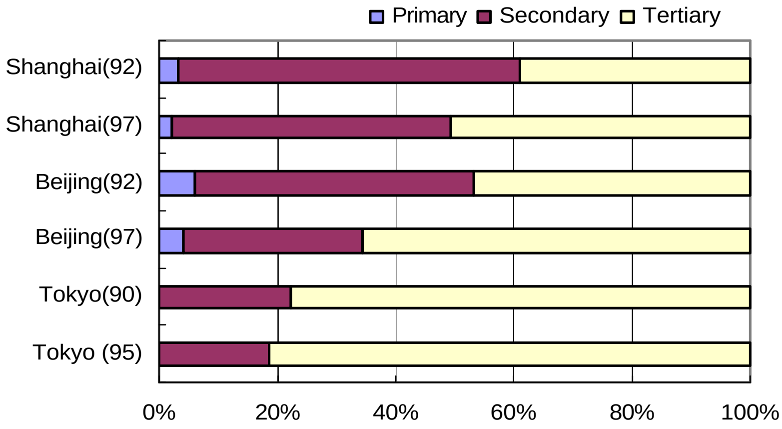

Figure 4-4-5-3: Industry structure transition of the targeted cities

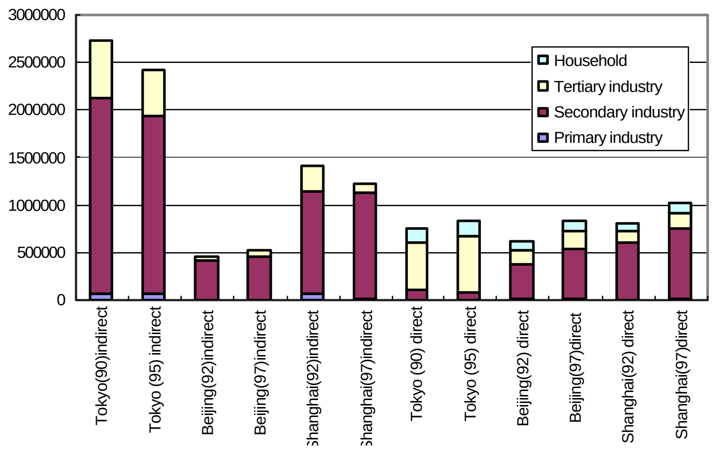

Figure 4-4-5-4: Sectoral contribution for direct and indirect energy demand of targeted cities

How these kinds of industrial structure transition contribute to the change of direct and indirect energy demand can be showed in **Figure 4-4-5-4**. For Tokyo case, during the period of 1990-1995, direct energy demand increased about 9.36 %, which should be mainly attributed to the increase of tertiary industry (increased by 14.5%) and household (increased by 9.7%). On the other hand the absolute amount of direct energy demand in primary and secondary industry has decreased (primary industry: -19.6%, secondary industry -15.5%). For Shanghai case, during the period of 1992-1997, each sector’s direct energy demand increased greatly (primary industry: 267%, secondary industry: 19.0%, tertiary industry 50.1% and household 20.4%). As for Beijing case, during the same period, except primary industry, all of the other three sectors’ absolute contribution also increased greatly, which lead to the increase of total direct energy demand.

As for indirect energy demand, as we discussed before, the total amount in Tokyo and Shanghai decreased during the targeting period. For Tokyo case, each sector's indirect energy demand decreased during 1990-1995, among which, primary industry decreased by 22.1%, secondary industry decreased by 8.9% and tertiary industry decreased by 16.0%. For Shanghai case, the drop of total indirect energy demand should be mainly due to the contribution of tertiary industry (-53.2%) and of primary industry (-58.8%). Differing from other cities, Beijing shows an increase in indirect energy demand during 1992-1997, which should be attributed to the great increase of indirect energy demand of tertiary industry (increased by 53 %.).

Basing on the discussion of the absolute level in each sector, we ulteriorly summarize the fluctuation of the proportion of each sector in total direct and indirect energy demand in the targeted cities (see **Figure 4-4-5-5** and **4-4-5-6**).

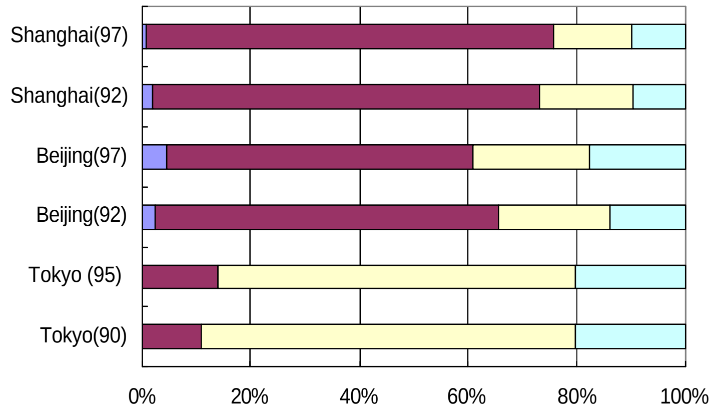

Figure 4-4-5-5: Promotion of each sector in the total direct energy demand in the targeted cities

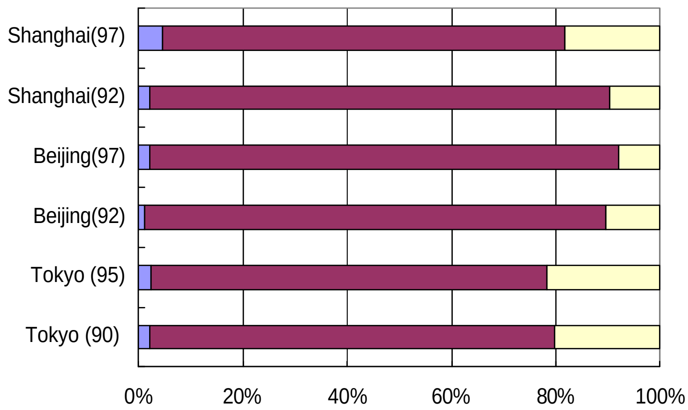

Figure 4-4-5-6: Promotion of each sector in the total indirect energy demand in the targeted cities

Tertiary industry plays a dominating role in direct energy demand in Tokyo, since which accounts for almost 70% of the total amount. On the other hand, the secondary industry is most significant in indirect energy demand, which also occupy above 75% of the total amount. For Beijing and Shanghai case, same as Tokyo, the secondary industry plays dominating role in the indirect energy demand but greatly different from Tokyo, the secondary industry is most important for direct energy demand.

(4)-2 Direct energy supply and indirect energy supply-how the city is relied on by outside

As we discussed in previous section, in addition to direct and indirect energy demand, we try to define the other two concepts "direct energy supply" and "indirect energy supply" to indicate the to what extent city meet the local demand or contribute to the outside demand. The analysis is showed in **Figure 4-4-5-7**.

It is noticing that the proportion of indirect energy supply of Shanghai is highest among these three cities. Though this proportion has decreased from 58% to 42% from 1992 to 1997 in Shanghai, it still reflect that shanghai is strongly relied by outside and in terms of embodied energy, half of it has been transferred to outside world. Remaining at a level of around 30%, the outside reliance on Tokyo is very stable. For Beijing case, the proportion increased greatly during the period 1992-1997, indicating an ascending tendency of Beijing in terms of material export.

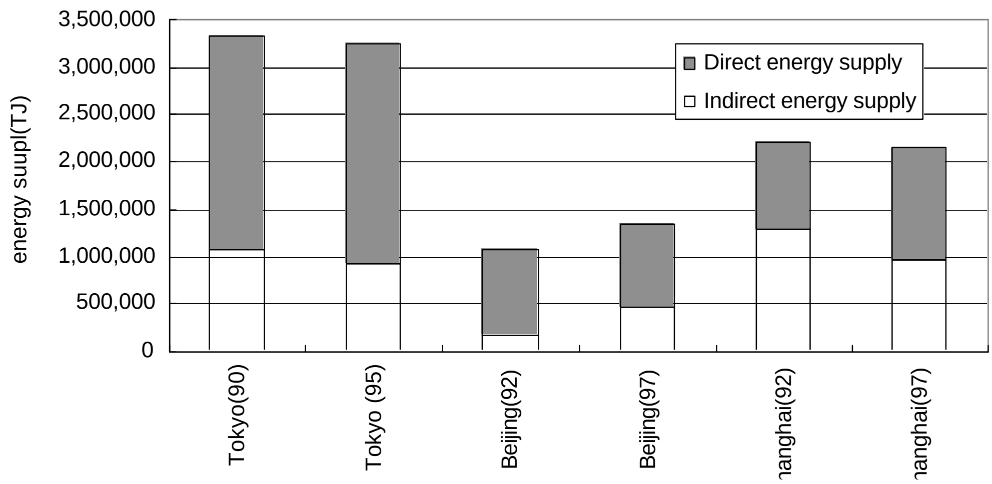

Figure 4-4-5-7: Direct and indirect energy supply of the targeted cities

(4)-3 CO_2 emission: trace back the origin and clarify the responsibility

Basing on the discussion of "indirect energy demand" and "indirect energy supply", we try to trace back to the sources of CO_2 emissions and re-define the role who should take responsibility for the CO_2 emission, no matter embodied or direct.

Here we define the "direct CO_2 emission" and "indirect CO_2 emission" as the counter-parts of "direct energy demand" and "indirect energy demand". To distinguish the embodied CO_2 emission coming from the materials consumed for local demand from the embodied CO_2 emission coming from materials exported to outside, we define the "internal CO_2 supply" and "external CO_2 supply" correspondingly. **Figure 4-4-5-8** indicates the performance of "direct CO_2 emission" and "indirect CO_2 emission". **Figure 4-4-5-9 and 10** is the share of each sector in total amount. **Figure 4-4-5-11** shows the "internal CO_2 supply" and "external CO_2 supply". Why here we give up the terminologies of “direct CO_2 supply” and “indirect CO_2 supply” but to emphasize the “internal indirect CO_2 supply” and “external indirect CO_2 supply” is to clarify the following point. All of CO_2 here talked is basing on the concept of embodied CO_2 emission, that means it is from the product side. So some proportion of this part of CO_2 was emitted directly, but some part is embodied by other materials. So to avoid some misunderstanding, we use “internal CO_2 supply” and “external CO_2 supply” under this situation.

Figure 4-4-5-8 clearly show that indirect CO_2 emission in Tokyo is much lager than direct CO_2 emission (above 2.5 times), which indicate that in terms of indirect CO_2 emission, Tokyo may take much more responsibility in addition to the apparent direct CO_2 emission. As to say Shanghai and Beijing, we find that the indirect CO_2 emission decreased during the period of 1992-1997.Especially for Shanghai case, the indirect CO_2 emission decreased from 1.9 times of direct CO_2 emission to 0.9 times of it. Which means that the transferring of indirect CO_2 emission in Shanghai and Beijing is not so great as Tokyo. Sectoral contribution figure (**Figure 4-4-5-9 and 10**) shows that secondary industry should take major responsibility for indirect CO_2 emission for all of the cities. As for direct CO_2 emission, Tokyo case show that tertiary industry plays the dominating role and Shanghai and Beijing cases indicate a more important or at least equal role for secondary industry.

Considering the CO_2 emission embodied in the products, we can find from **Figure 4-4-5-11** that mega-city should take major responsibility for the embodied CO_2 emission since the dominating part of which is consumed to meet the domestic demand.

Combining with the analysis of the “direct CO_2 emission” and “indirect CO_2 emission”, we can safely say that mega-city should take much more responsibility than it is assigned by the direct energy consumption and correspondingly direct CO_2 emission. In the meaning of “indirect CO_2 emission” mega-cities show great reliance on outside and should be responsible for the part consumed within its territory. On the other hand, in terms of “external CO_2 supply”, mega-cities transfer little to outside to relief its own burden. These two aspects beyond all doubts highlight the role of mega-city in CO_2 mitigation.

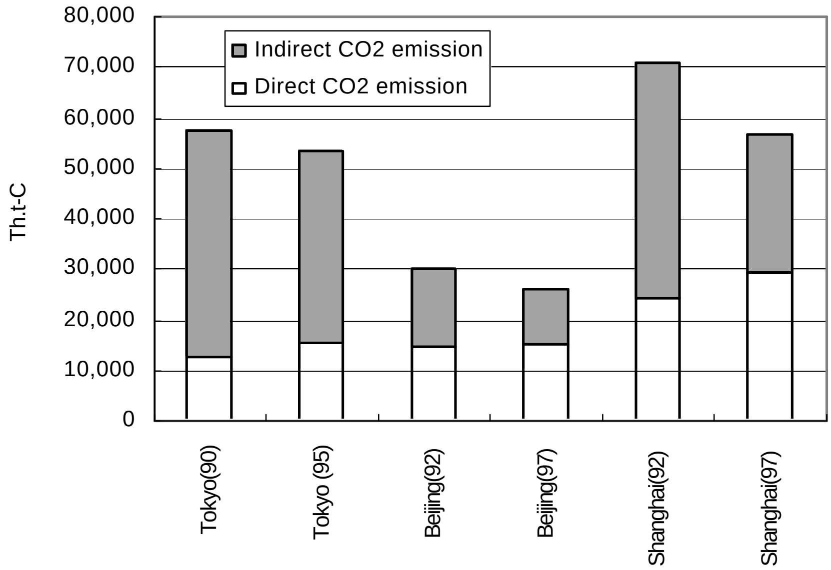

Figure 4-4-5-8: Direct and indirect CO_2 emsission

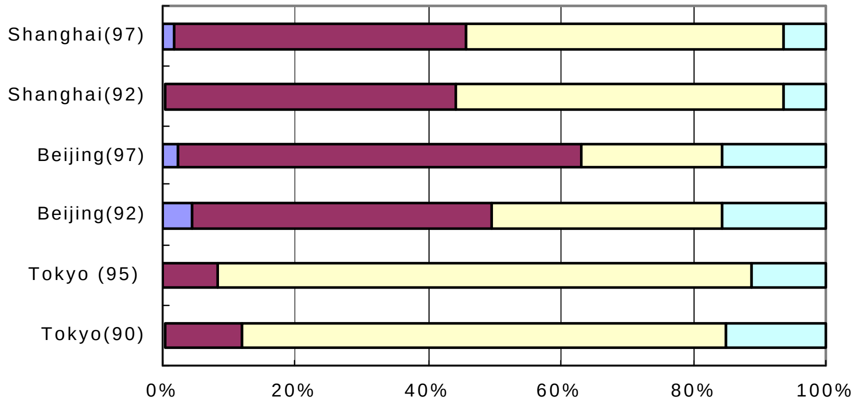

Figure 4-4-5-9: Share of each sector in the total direct CO_2 emission in the targeted cities

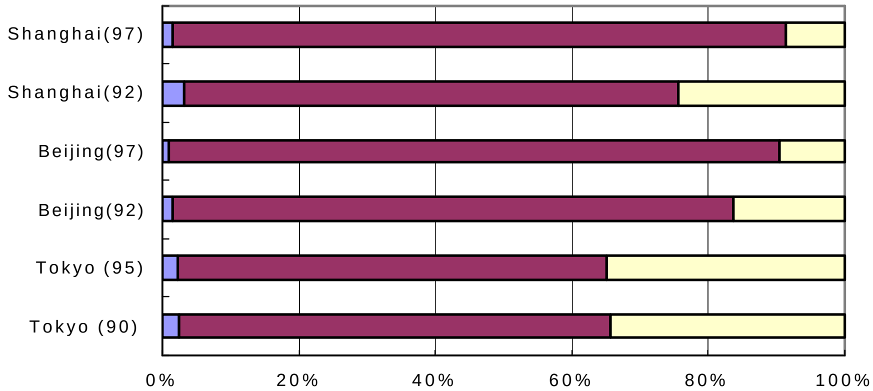

Figure 4-4-5-10: Share of each sector in the total indirect CO_2 emission in the targeted cities

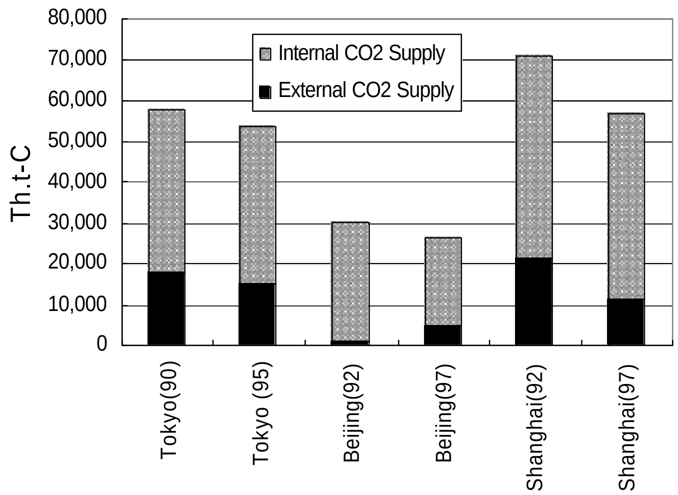

Figure 4-4-5-11: Internal and external indirect CO_2 supply

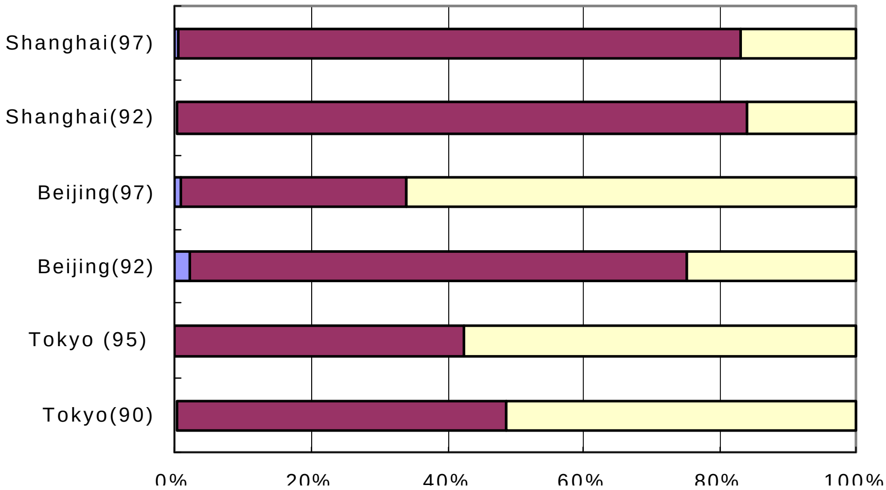

Figure 4-4-5-12: Share of each sector in the total internal indirect CO_2 supply in the targeted cities

Primary Secondary Tertiary Household

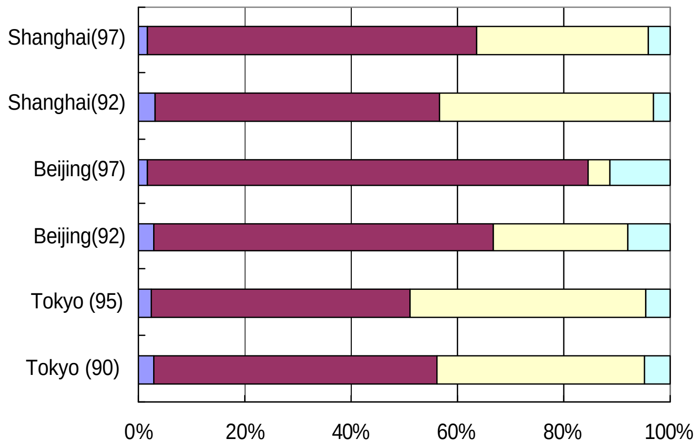

Figure 4-4-5-13: Share of each sector in the total external indirect CO_2 supply in the targeted cities

Primary Secondary Tertiary Household

(5) Conclusion and implications

Considering that major attention has been paid to the direct energy consumption and CO_2 emission in mega-cities, this research try to highlight the exact role of mage-cities by extending the targeting scope: from the city itself to the city and outside together. In virtue of the concept of "embodied energy", this research clarifies four types of indicators for the performance of energy and CO_2 emission.

" Direct and indirect energy demand "emphasize the reliance of the mega-cities on outside. Our research show that indirect energy demand in Tokyo and Shanghai is much more significant than direct energy demand, which indicates that these two cities have great reliance on outside in terms of energy demand. Contrarily, direct energy demand in Beijing plays a more important role.

Tertiary industry plays a dominating role in direct energy demand in Tokyo, since which accounts for almost 70% of the total amount. On the other hand, the secondary industry is most significant in indirect energy demand, which also occupy above 75% of the total amount. For Beijing and Shanghai case, same as Tokyo, the secondary industry plays dominating role in the indirect energy demand but greatly different from Tokyo, the secondary industry is most important for direct energy demand.

It is noticing that the proportion of indirect energy supply of Shanghai is highest among these three cities. Though this proportion has decreased from 58% to 42% from 1992 to 1997 in Shanghai, it still reflect that shanghai is strongly relied by outside and in terms of embodied energy, half of it has been transferred to outside world. Remaining at a level of around 30%, the outside reliance on Tokyo is very stable. For Beijing case, the proportion increased greatly during the period 1992-1997, indicating an ascending tendency of Beijing in terms of material export.

indirect CO_2 emission in Tokyo is much lager than direct CO_2 emission (above 2.5 times), which indicate that, in terms of indirect CO_2 emission Tokyo may take much more responsibility in addition to the apparent direct CO_2 emission. As to say Shanghai and Beijing, we find that the indirect CO_2 emission decreased during the period of 1992-1997.Especially for Shanghai case, the indirect CO_2 emission decreased from 1.9 times of direct CO_2 emission to 0.9 times of it. Which means that the transferring of indirect CO_2 emission in Shanghai and Beijing is not so great as Tokyo. Sectoral contribution shows that secondary industry should take major responsibility for indirect CO_2 emission for all of the cities. As for direct CO_2 emission, Tokyo case show that tertiary industry plays the dominating role and Shanghai and Beijing cases indicate a more important or at least equal role for secondary industry.

All in all, we may tentatively draw a conclusion that mega-city should take much more responsibility than it is assigned by the direct energy consumption and correspondingly direct CO_2 emission. In the meaning of "indirect CO_2 emission" mega-cities show great reliance on outside and should be responsible for the part consumed within its territory. On the other hand, in terms of "external CO_2 supply", mega-cities transfer little to outside to relief its own burden. These two aspects beyond all doubts highlight the role of mega-city in CO_2 mitigation.

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