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EVALUATION OF ENIVIRONMENTAL IMPCAT IN CIVIL INFRASTRUCTURE SYSTEMS WITH RESPECT TO SUSTAINABLE INDUSTRIAL TRANSFORMATION

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Abstract

This paper aims to evaluate environmental impacts from resource dissipation to global warming in civil infrastructure systems as a basis of discussion on sustainable industrial transformation for the industrial society. Civil infrastructure systems give considerable impacts both directly and indirectly through various product chains and supply of related societal services. From this aspects, first, the content of environmental impacts were divided into several categories according to its repercussive characteristics. Second, specific environmental impacts were analyzed using life cycle inventory approach including input-output analysis. As a result, the followings were examined : 1) various product chains were observed with relation to release of carbon dioxide and industrial waste, and steel consumption due to construction activities; 2) machinery and utility - derived impacts were recognized to some extent as well as cumulative stock impacts of the infrastructure bodies; 3) considerable environmental impacts due to societal services supported by civil infrastructure indicated the necessity of further discussion on the allocation of responsibility for reducing the impacts.

KEYWORDS: *Civil Infrastructure Systems, Industrial Transformation, Life Cycle Assessment,, Product-Chain Analysis*

1. Introduction

This research attempts to evaluate life cycle environmental impacts of civil infrastructure systems as a basis of the response to the sustainable industrial transformation. Civil capital formation activities have great impacts on environment with nearly 40% of all carbon dioxide emission in Japan (Sakai, et al., 1997). After the COP3, therefore actual response is required to reduce carbon dioxide emission and also to increase environmental performance such as eco-efficiency (Schmidheiny /BCSD, 1992). Civil infrastructures give great impact not only by construction through various life cycle industrial chains from procurement of construction materials to services on the infrastructure. From this points of view, here both direct and indirect environmental impacts are examined by means

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of input-output analysis and estimation by summing up environmental loads for divided several environmental impact categories, which especially spread the system boundary more widely than that of existing product life cycle assessment by estimating the "category 4" environmental load which is to be defined at the chapter 2. The same categorization is applied also for designing environmentally sound urban renovation (Fujita et al., 1998)

2. Methodology

Direct and indirect release of environmental loads are evaluated by means of life cycle inventory analysis for the following environmental impacts (loads) categories:

Category 1: Direct release in construction stage.

Category 2: Indirect release associated with production and waste of construction materials.

Category 3: Direct release due to consumption of goods and services derived from business and other sectors activities on civil infrastructures.

Category 4: Indirect release due to production and waste associated with goods and services in category 3.

First, environmental impacts due to domestic annual construction activities are evaluated using input-output analysis. Direct and indirect carbon dioxide release, steel consumption, final disposal of industrial and commercial waste (as the mount of landfill or reclamation) are calculated by the construction sector–specific I-O tables 1990 with general 91 sectors and construction 68 sectors (Ministry of Construction, 1995), Butsuryo table (Management and Coordination Agency, 1994), industrial waste statistics and the intensity data (Tsurumaki and Noike, 1997) corresponding to these environmental loads and I-O 91 sectors aggregation. Here $(I-A)^{-1}$ type Leontief's inverse matrix are applied in consideration of imported goods (assuming that imported goods are also produced in the same industrial structure as that in case of domestics goods). Second, the following typical civil infrastructures are selected such as a) buildings, b) dams, c) roads, d) sewage treatment facilities. Then, direct and indirect carbon dioxide release is calculated for the above-mentioned four environmental impact categories. Table 1 explains detailed methodologies for the four civil

Table 1 Environmental Impact categories and estimation methodologies for each infrastructure

Infrastructure	Categories of environmental impacts	Methodologies for estimation
Buildings	C1: Direct release in construction of buildings C2: Indirect release due to production of construction materials C3: Direct release in operation C4: Indirect release due to production of business equipment	Floor area data multiplied by environmental load intensities per area (C1, C2). Estimate based on energy statistics (C3). Estimation by duration time and statistical data (C4).
Dams	C1: Direct release in construction of dams C2: Indirect release due to production of construction materials C3: Direct release in construction of water supply system C4: Indirect release due to water supply	Dam volume data multiplied by life cycle CO_2 intensity per volume (C1, C2).Water volume multiplied life cycle environmental load intensities per volume (C3, C4).
Roads	C1: Direct release in construction of roads C2: Indirect release due to production of construction materials C3: Direct release due to fuel consumption for driving C4: Indirect release due to car production	Data of length (roads, bridges, tunnels) multiplied by environmental load intensity (C1, C2). Energy statistics (C3). Registered car number multiplied by intensity (C4).
Sewage	C1: Direct release in construction of sewage C2: Indirect release due to production of construction materials C3: Direct release in operation C4: Indirect release due to chemicals use and sludge disposal	Data of water treatment volume. Planned max water treatment capacity volume multiplied by environmental load intensity (C1, C2, C3, C4)

infrastructures. The construction sectors of the four civil infrastructures give great contribution to construction-associated gross domestic output with the share of 78% (1990).

3. Direct and indirect environmental impact in civil construction activities

3.1 Environmental impact of annual domestic civil construction activities

Investment to civil construction in Japan continuously has a great share of nearly 20% of GNP since 1970 through rapid economic growth. It is broadly known that construction sectors have close industry-wide relations with various sectors. These economical connections also give various material-product chains (Vellinga et al., 1997) which have significant relations with environmental impacts. Fig. 1 shows up-stream industrial chains of carbon dioxide, steel and industrial waste due to annual final demand of civil construction sectors. The above carbon dioxide emission is 57MtC. This amount is as nearly 16 times as the direct release in construction stage, referred as category 1. Direct emission due to energy consumption in various activities on civil infrastructures (category 3) reaches to 34 MtC. Total emissions occupy about 40% of 340MtC, the whole carbon dioxide release in Japan. Cement and ceramic industries give the greatest contribution. Steel, electricity and transport sectors have nearly half the share of that of cement and ceramic industry respectively. As for construction materials-related sectors, there are 3.4% of total carbon dioxide in chemical sectors (plastics), 1.7%

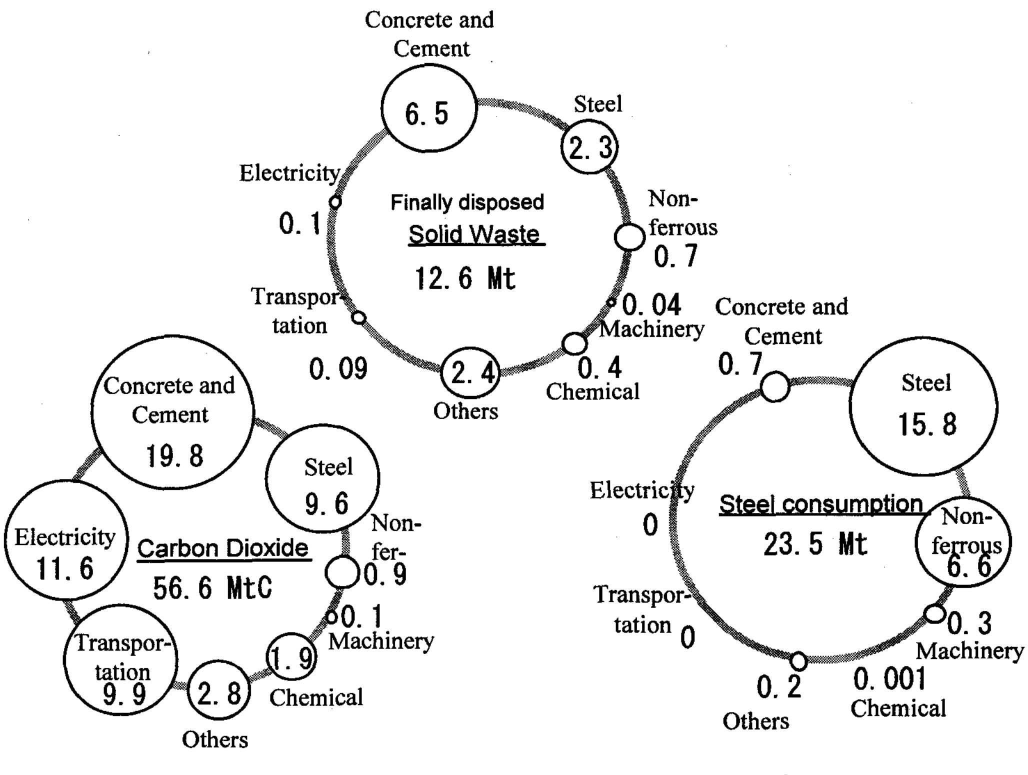

Fig. 1 Industrial chains of annual final demand of civil construction sectors

in non-ferrous metals (construction metals) and 0.2% in machinery (building equipment). The finally disposed solid wastes in the industrial linkages associated with annual production and delivery of construction materials and equipment amount to 12.5Mt. This indirectly generated waste is nearly 32% of the directly disposed construction waste which totals about 39Mt. Cement and ceramic industries have greater share (52%) of the finally disposed industrial and commercial waste. Steel and non-ferrous industry has a share of 10% and 6% of the finally disposed waste respectively. As for steel consumption, non-ferrous industry has a share of 28%. This means that considerable steel is used in construction metal products together with non-ferrous metals. It is interesting that even a non-ferrous metal sectors use a lot of steels in production and delivery of their own (non-ferrous) products due to installing refinery equipment and so on. In this context inter-industrial collaboration to increase eco-efficiency, for example by recycling steels, also should be taken into consideration among construction-associated industrial chains.

Industrial or product chains in various civil construction activities were shown in Fig. 2. While Dwelling (7.0MtC), Office (5.2MtC), Factory (3.9MtC) and Road (3.9MtC) sectors indirectly release considerable carbon dioxide through demand for materials sectors by the amount, Erosion control (67%), Sanitary facilities (62%), Railway (62%), Road (62%) has a great share of material sectors by the ratio in their indirect carbon dioxide releases. Through machinery sectors, carbon dioxide is induced by Power plants (0.4%) and Offices (0.3%). Higher share of transport sectors was recognized in Coastal projects (22%) and Airports (22%) because of long transportation of construction materials to the construction sites.

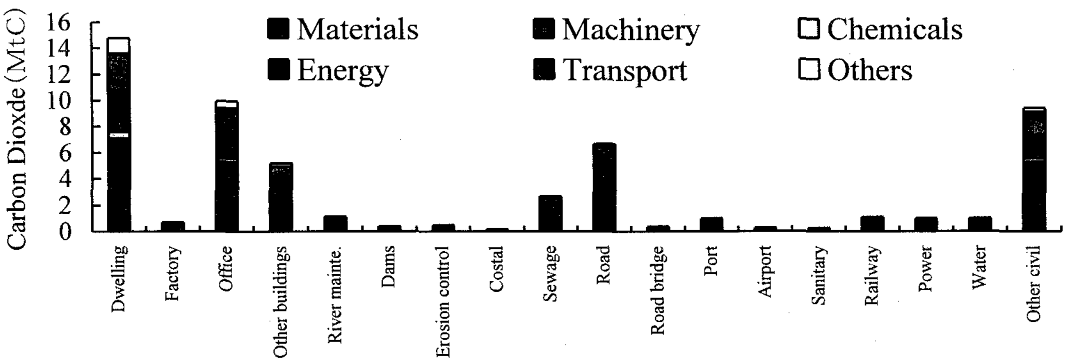

Fig. 2 Carbon dioxide-related industrial chains in civil construction activities

3.2 Direct and indirect carbon dioxide emission in four civil infrastructures

Based on the four environmental impact categories, direct and indirect carbon dioxide emissions were calculated for buildings, dams, roads, and sewage treatment facilities.

(1) Buildings

Buildings provide various goods and services which differ from metabolic time scales. Environmental impacts due to renovation are considerably great in Japan which have rapidly constructed buildings through highly development period since 1960's as well as newly industrialized countries. Business-related resources and energy use also give influences in addition to environmental impacts derived from renovation of industrial equipment such as pumps with shorter

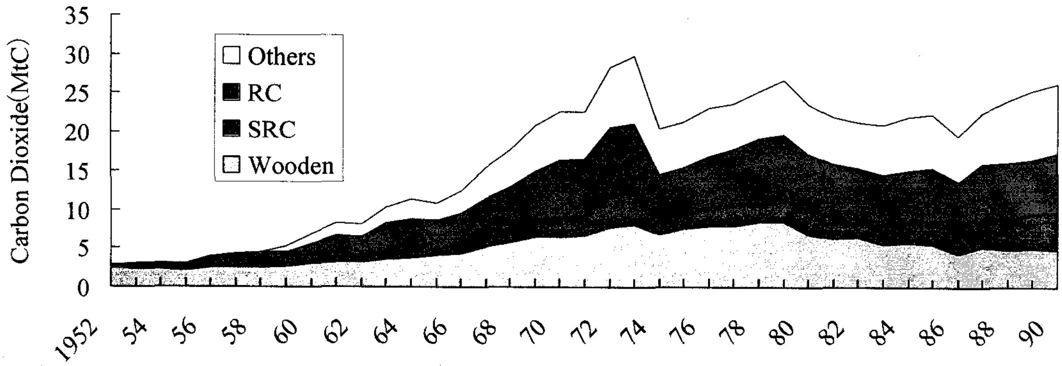

Fig. 3 Yearly trend of carbon dioxide emission due to construction of buildings

product lives than buildings. Fig. 3 shows the estimate of yearly trend of carbon dioxide emission due to construction of buildings based on building construction statistic yearbook. 616MtC of carbon dioxide has been released due to construction of the present stock of building floor area (6180Mm^2) which equals to gross floor area installed since 1952 to 1990 (6146Mm^2, 651MtC) adding to the existed building floor area up to 1952 (1572Mm^2) minus the demolished building floor area since 1952 to 1990 (1538Mm^2, 35MtC). Annually discarded building materials due to renovation has become nearly 10Mt waste since 1976. In 1990, 11Mt of building materials are released and this has a share of 15% in total domestic construction waste (76Mt). On the other hand, 68.7MtC of carbon dioxide is released through consumption of energy and resources in business activities (category3). Specifically power consumption due to transfer of liquid gives great contribution. In the case of water, 2-3 m^3 of water are consumed annually per floor area (m^2). This means that annual water flow is twice as large as present building stock.

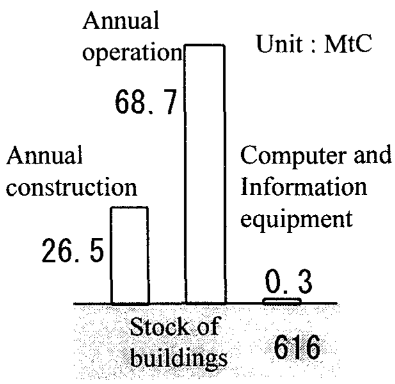

Fig. 4 Direct and indirect carbon dioxide emission due to buildings and related services

(2) Dams

Dams have been constructed as socially important infrastructures since more than 300 years ago. Fig. 5 shows carbon dioxide emission due to construction of 3128 dams, which have available data of the volume or can be estimated, in all dams constructed until 1995 (Japan Dam Association, 1997).

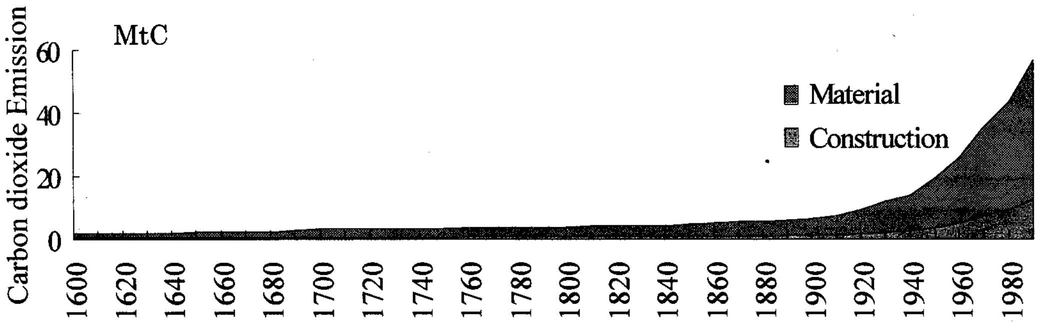

Fig. 5 Yearly trend of carbon dioxide emission due to construction of dams

The emission were estimated by multiplying the emission intensity per unit dam volume, 15.37tC/m^3 for fill dams and 114.73tC/m^3 for concrete dams (Koizumi et al., 1996). The total carbon dioxide emission is 52.5MtC. The construction-associated emission amounts to 14.7MtC (28%) in total emission. While activities of dam construction have given great impact on natural environment in addition to global environment, it has followed natural stream or gravity-oriented water supply which reduces considerable environmental impacts accompanied by pumping up water. As shown in Fig. 6, carbon dioxide emission due to construction of stocks of dams is 52.5MtC. Carbon dioxide due to annual construction is twice as that due to annual operation. This figure deals with only dam construction and excludes construction of related equipment such as gates for extracting water, pipes for delivery, etc.. Carbon dioxide associated with drinking water supply of 7.59Mm^3 (Japan Water Association, 1994) is estimated about as 0.3MtC. This include power consumption in delivery and purification of water and incineration of sludge cakes (category 3). Moreover, indirectly induced carbon dioxide emission due to consumption of chemicals and production of equipment is nearly 0.03MtC (category 4).

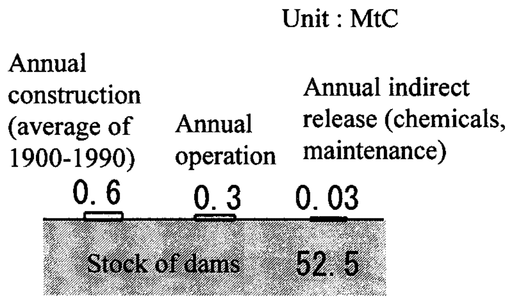

Fig. 6 Carbon dioxide emission due to stock of dams and water supply services

(3) Roads

Roads have relatively frequent renovation and maintenance, and also provide vehicle transport services which cause large amount of direct carbon dioxide release. Although various economic and industrial sectors have close relationships with automobile transport and associated social systems such as ITS, local car sharing etc., yet response or responsibility is not obviously defined among these sectors. Because of the limitation of statistical data, specifically yearly road construction for material-oriented road types, only accumulated carbon dioxide release was estimated comparing with automobile stock and fuel consumption for driving. Fig. 7 presents that service-associated carbon dioxide is dominant in road infrastructure systems.

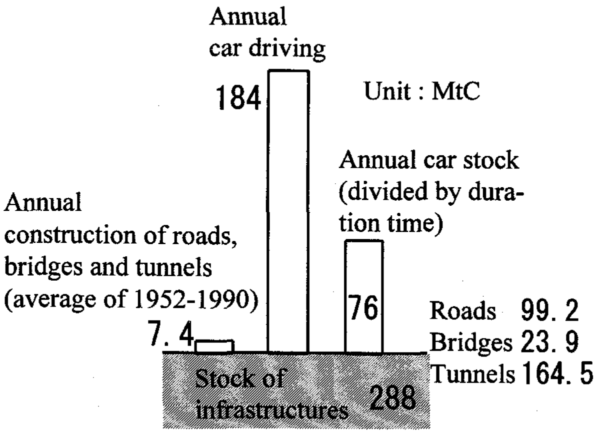

Fig. 7 Carbon dioxide emission due to car-related services and infrastructures

(4) Sewage

Sewage represents the infrastructures where operation-associated consumption of power, chemicals, etc. gives greater contribution than construction of sewage facilities and related material use. Yearly trend of carbon dioxide emission due to construction of sewage plants is shown in Fig. 8. Total amount of construction-related carbon dioxide emission by 1990 is 12.9MtC. Moreover, carbon dioxide due to stock of sewage treatment is compared with that due to annual consumption of fuel and chemicals in Fig. 9. The volume of annual operation-associated carbon dioxide emission is estimated to be as 1.5 times as the annual construction-related emission and nearly one twentieth of the whole stock-related carbon dioxide. For reference, the volume of final disposal for sewage sludge amounts to 930 thousand ton for landfill and 460 thousand ton for sea reclamation in 1990. In considering these burdens, indirect environmental impacts due to water treatment services will increase.

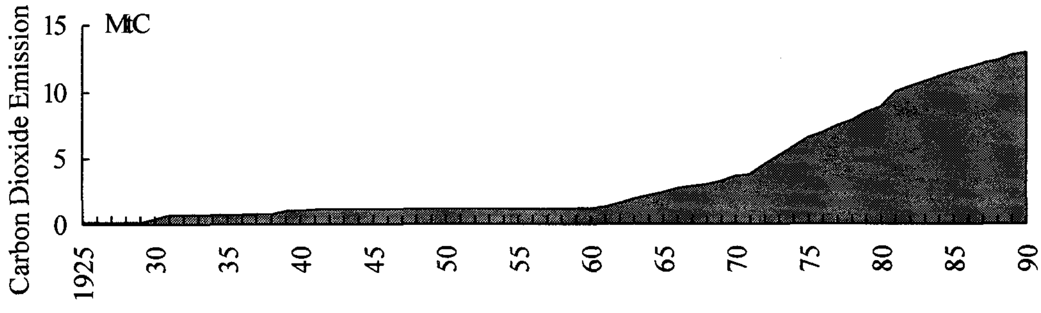

Fig. 8 Yearly trend of carbon dioxide emission due to construction of sewage facilities

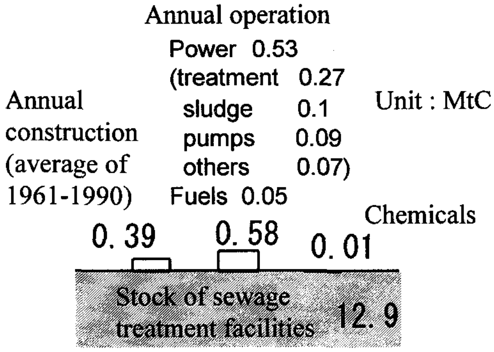

Fig. 9 Carbon dioxide emission associated with sewage construction and operation

4. Conclusions

In this paper we attempted to estimate life cycle and product chain-related environmental impacts due to civil construction activities and the derived goods and services. The paper especially focused on the indirect environmental impact through life cycle and product-industrial chains. The analysis revealed that there are considerable amount of indirect and service-associated environmental impact compared with direct construction-related impact. Japan and also Asian developing countries have now constructed civil infrastructures toward 21st century. The outcome of this analysis would suggest the importance of product-chain management for construction activities in order to reconstruct eco-efficient industrial society after the COP3. In detail, the followings were highlighted:

(1) Various patterns of environmental load repercussions were recognized through construction-related industrial by using I – O tables. The figures suggested that inter-industrial collaboration to increase eco-efficiency , for example by recycling steels, should be taken into consideration among construction-associated industrial chains.

(2) Greater carbon dioxide emissions in operation phase were recognized in building systems. The annual service-associated emission reached to more than twice as annual construction-associated emission and nearly one twentieth of capital stock-related carbon dioxide.

(3) Dams reduce carbon dioxide emission in water supply while they give great impact both on natural and global environment. Material recycle should be considered as material-associated carbon dioxide emission has been increased accompanied by yearly increasing concrete dams construction.

(4) Car-related carbon dioxide emissions are dominant in road and mobility systems. Environmentally conscious road designs are required in addition to eco-design for cars.

(5) Sewage systems release greater carbon dioxide emission in operation and maintenance phase, particularly energy use for liquid operation. Response to liquid operation-associated carbon dioxide should be considered across over civil infrastructure systems.

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