Journal of Global Environment Engineering, Vol. 6, pp. 103-116, 2000

LIFE CYCLE ESTIMATION OF CO_2 EMISSION FROM URBAN DISTRICTS AND ITS APPLICATION FOR URBAN ENVIRONMENTAL MANAGEMENT

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Abstract

Environmental impacts from urban renewal process are caused either through urban activities or construction of urban structures. By utilizing the life cycle estimation methodology, this paper focuses on both flow-type and stock-type environmental loads. Strategic environmental improvement methods are devised and their implemented effects are analyzed through a case study in Nakanoshima West District, a downtown area of Osaka City. An estimation method of environmental emission, such as CO_2 and solid wastes from urban renewal process is discussed. The method is applied by utilizing Life Cycle Assessment (LCA) methodology for buildings, urban and metabolism infrastructures. Various policy tools for environmental improvement are estimated for their effects to reduce life cycle impacts by presuming several urban renewal patterns and policy scenarios are planned as the combinations of multiple environmental improvement methods to investigate comparative effects. The scenarios are composed of various calculation assumptions which contemplate future growth of building floors and renewal process of the specified area. As a result, the following are found: (1) environmental impacts attributed to urban activities are much larger than those to accumulation of urban stocks, and those from the outside of the district are much larger than those from the inside of it; (2) spatial management and utility management policies are found as effective as building-scale management methods; and (3) life cycle CO_2 estimations for different scenarios indicate spatial adjustment by all at once renewal schedules would be an effective management alternatives if the district accepts additional floor area developments under current pro-growth land use policies.

KEYWORDS: *Urban Development, Life Cycle Assessment, CO_2 Emission, Environmental Impact Reduction Method, Osaka City*

1. Introduction

As growing activities keep moving into metropolitan areas all over the world, one important challenge for the society is to reduce the impact of urban renewal process on local, regional, and

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global environment. Urban development causes various types of environmental impacts, such as CO_2, solid waste generation, and resource consumption. While a life cycle assessment method is applied in several empirical studies, the interactive linkage of the estimation results with the strategy of societal policies has been seldom investigated so far. In this paper, strategic policy alternatives are planned from wide range of policy standpoints such as building management, utility management and spatial management. Reduction effects of environmental impacts by different management tools are estimated and their effects are compared from a life cycle viewpoint.

Environmental impacts from urban renewal process are caused either through changing urban activities or reconstruction of aged urban structures. Flow type environmental impacts attributed to urban services and activities are focused in this paper as well as those attributed to the accumulation of physical structures by applying the life cycle estimation methodology. Strategic environmental improvement methods are prepared and their effects are estimated in a case study in Nakanoshima West District, Central Business District of Osaka City, which is the second largest metropolitan region in Japan. First, estimation system for urban renewal process of environmental impact such as CO_2 and solid wastes is discussed. Second, the system is applied to estimate environmental impacts from urban renewal stages in a downtown of Osaka City. Life Cycle Assessment (LCA) methodology is used for buildings, urban infrastructures, and metabolism infrastructures. Material inventory estimation subsystem is combined with quantitative estimation sub-system for environmental impacts. Third, several policy methods from district-scale to city or region-wide scale for environmental improvement are estimated for their effects to reduce life cycle impacts. Finally policy scenarios are planned as the combinations of multiple environmental improvement methods and their comparative effects are investigated. The scenarios are composed of those of various calculation presumption of future growth of building floors and renewal process of the area.

2. Methodology

2.1 Life Cycle Estimation System for Urban Renewal Area

LCA method is applied to estimate material inventory and environmental impacts through the urban renewal. Estimation consists of seven stages, namely, material production, material transportation, field construction, facility operation, maintenance, facility renewal, and demolition. In case of buildings, they are classified into twelve calculation units based on their uses and structural patterns. Material inventory matrices are prepared for seven stages of each unit. Material consumption and energy consumption are given from data of actual buildings of last decade. The parameters for environmental impacts are obtained by converting material inventory and other factors. As parameters of CO_2 emission attributed to each material, the data of Japan Society of Civil Engineers are utilized. These values were derived from the Industries Input-Output Tables as basic data and partially using a linear accumulation method to include spreading effects among different industries. Further, the unit generation of waste materials at time of major materials production was calculated as shown in Table 1 with the use of the Fiscal 1990 Trade-by-Trade Industrial Wastes Discharge Data and fiscal 1990 Industries Input-Output Tables. In this paper, standard calculation parameters are used so that parameter matrices can be easily replaced for the other calculation conditions. Fig.1 shows conceptual process to calculate material inventory and environmental impacts. The inventory composition is shown in Fig.2 and the data are arranged accordingly. Fig.3 diagrammatically shows the LCA calculation processes. In order to calculate the material consumption, energy consumption, carbon dioxide emission and construction wastes quantities at each of the seven stages from the material production stage to the demolition stage in the life cycle, the unit consumptions, the unit emissions and the unit generations were investigated as shown in Tables 2 and 3.

Table 1 Carbon dioxide unit emission, energy unit consumption and wastes unit generation, at time of production, of major construction materials

Classification	CO_2 emissions units* (kg-C/kg)	Energy consumption units(kJ/kg)	Wastes discharge units(kg/t)
Gravel & quarried stone	0.00154	13	0.074
Crushed stone	0.00189	29	
Swan lumber	0.0297	502	-
Plywood	0.0519	4,974	-
Portland cement	0.228	4,987	37.75
45% slug mixed cement	0.135	3,256	
New steel	0.411	15,136	154.2
Recycle steel	0.128	8,544	
Aluminum (sash)	2.03	8,410	-
Glass (plate)	0.486	20,482	-
Plastics	0.492	14,617	-
Mixture for asphalt pavement	0.0113	418	-
Gas oil	0.779 (kg-C/l)	-	-
LNG	0.669 (kg-C/m^3)	-	-
LPG	0.868	-	-
Electric power	0.129 (kg-C/kWh)	-	-
Transportation	0.093 (kg-C/t·km)	4,590(kJ/t·km)	-

*recommended value of Japan Society of Civil Engineers

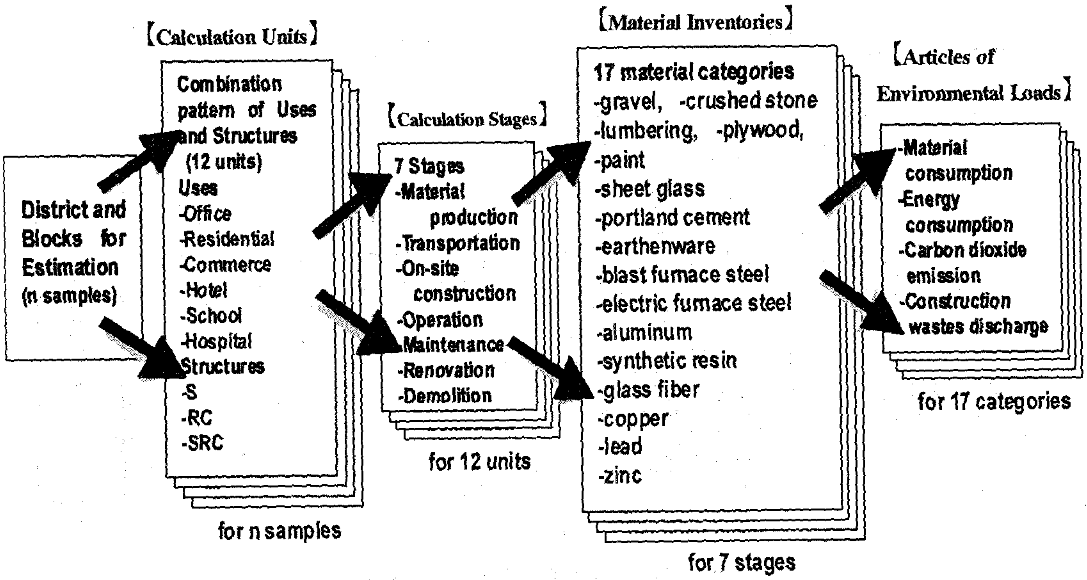


Fig.1 Calculation process on environmental impacts of urban structures

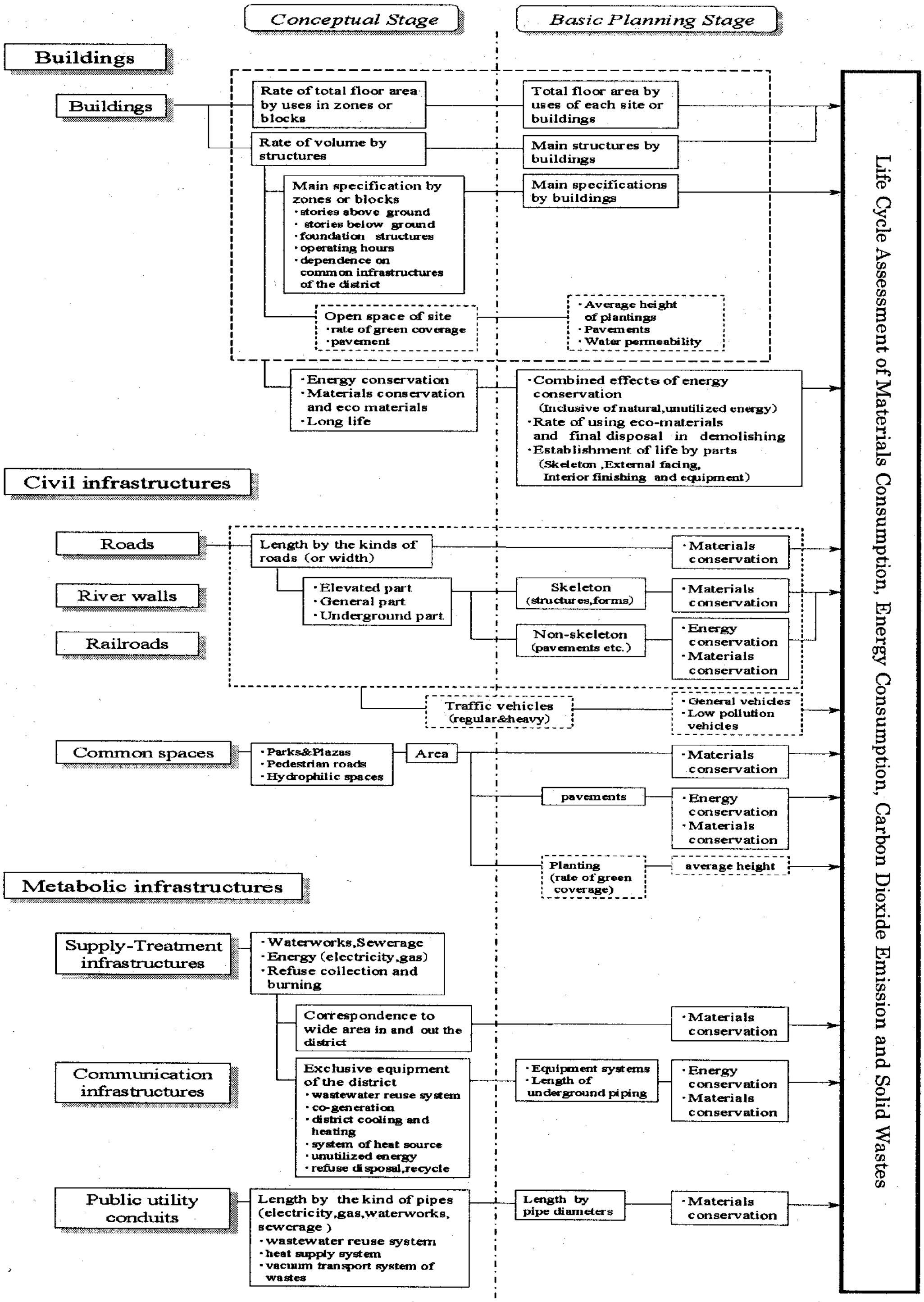


Fig. 2 Outline of urban structure inventory

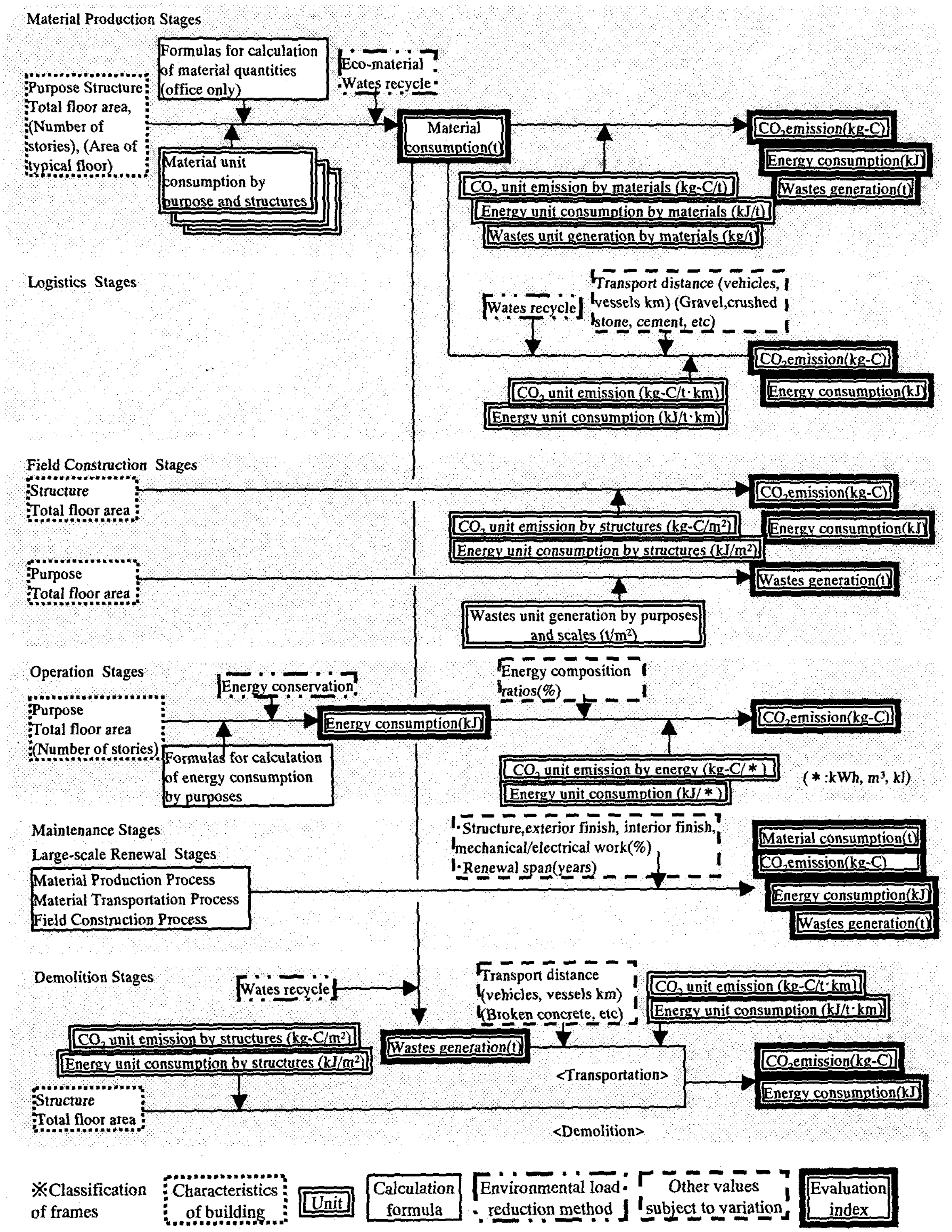


Fig. 3 Life cycle estimation process for building

Table 2 Unit consumption, unit emission and unit generation in building construction

	Materials Consumption	Energy Consumption / Carbon Dioxide Emission	Wastes Generation
Materials Production Stage	Building and mechanical-electrical materials consumption by structure and per total floor area	Energy consumption and carbon dioxide emission at time of materials production	Wastes generation at time of materials production
Logistics Stage	—	Energy consumption and carbon dioxide emission per full loading capacity transport distance	—
Field Construction Stage	—	Energy consumption and carbon dioxide emission per construction floor area	Wastes generation per construction floor area
Management/Operation Stage	—	Energy consumption and carbon dioxide emission by purpose and scale	Trash generation per total floor area
Maintenance Stage*	Materials consumption by type of frame, exterior / interior finish and mechanical-electrical work	Energy consumption and carbon dioxide emission at time of materials production, transport and construction	Wastes generation at time of materials production and construction
Large-scale Renewal Stage*	Materials consumption by exterior / interior finish and mechanical-electrical work	Energy consumption and carbon dioxide emission at time of materials production, transport, construction and wastes transport	Wastes generation at time of materials production and construction
Demolition Stage**	—	Energy consumption and carbon dioxide emission at time of demolition and wastes transport	Materials consumption at time of construction

* Transportation and construction at the maintenance and large-scale reformation stages are to be calculated separately.
** Transportation at the demolition stage is to be calculated separately.

Table 3 Unit consumption, unit emission and unit generation in construction of civil structures and metabolic infrastructures

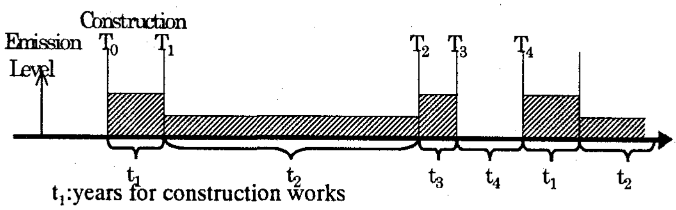
	Materials Consumption	Energy Consumption / Carbon Dioxide Emission	Wastes Generation
Materials Production Stage	Materials consumption by subject works	Energy consumption and carbon dioxide emission at time of materials production	Wastes generation at time of materials production
Logistics Stage	—	Energy consumption and carbon dioxide emission at time of full loading capacity transport distance	—
Field Construction Stage	—	Energy consumption and carbon dioxide emission by subject works	Wastes generation by subject works
Management/Operation Stage	—	Energy consumption and carbon dioxide emission at time of operation by subject works	—
Large-scale Renewal Stage*	Materials consumption by subject works	Energy consumption and carbon dioxide emission at time of materials production, transport, construction and wastes transport	Wastes generation at time of materials production and construction
Demolition Stage**	—	Energy consumption and carbon dioxide emission at time of demolition and wastes transport	Materials consumption at time of construction

* Transportation and construction at the large-scale reformation stage are to be calculated separately.
** Transportation at the demolition stage is to be calculated separately.

2.2 Urban Renewal Schedule

To simulate building renewal situation in the future decades, several growth schedules need to be considered and the results should be compared, since development of urban structures is hard to forecast due to changeful external factors of urban systems, such as socio-economical conditions of cities and regions. Two growth schedules are prepared, that is, current level renewal schedule, and pro-growth schedule or higher density CBD development schedule which allows as many as legislatively designated floor area ratio (Fig. 4). In the former schedule, a building which has identical floor area with currently located one will be constructed and unused land site will be kept vacant. The average floor area ratio of the district is consequently controlled as the current condition of around three hundred percent. In the latter schedule, denser land use than current level is allowed in the district as many as six hundred percent of floor area ratio which double the current land use pattern.

Calculation variables are set as follows; a duration period of a building is exogenously determined and it is applied for buildings of the same use and structural characteristics uniformly. Duration periods for other urban infrastructures such as roads and subway lines are exogenously inputted likewise. Buildings are presumed to be in operation during the duration periods, while consuming several urban services and products such as energy and transportation. Construction periods as well as other time variables are determined and modified as operational values.



t_1:years for construction works

$t_1=f(x_1,x_2,x_3)$ x_1:floor area x_2:hights x_3:type

t_2: years for operation(exogeous variable)

t_3: years for demolition works (2 years)

t_4: years for preparation

○Current Level Renewal Schedule : After Product Life
Building ・Redevelopment As they are same floor area(Ave.300%), Office
Vacant land ・keep unused

○Higher Density CBD Development Schedule
Building →Redevelopment of 600% FAR, Office
Vacant land →Developed with Legitimate FAR(600%)

Fig.4 Urban renewal schedules

2.3 Strategic Planning Alternatives

Since the environmental impacts from urban accumulations affect surrounding out-side areas or global atmosphere as well as the district itself, city-scale and regional scale urban environmental improvement methods in addition to building scale methods should be contemplated and compared to attain socially rational urban environmental policies. Environmental improvement methods are categorized as follows; (1)building management methods which control material stock and flow of urban buildings and structures include environmentally efficient resource utilization or recycle of construction wastes. (2)Urban utility management methods which improve the efficiency of urban utility facilities and network include energy generation and distribution facilities and creating more environmentally sound mobility system. (3)Spatial management methods which manage urban renewal patterns or spatial distribution patterns of urban structures include planned urban development projects, growth control, and restrictive zoning codes. Urban environmental improvement methods are to be adopted in practical urban environmental policies as of internal district-scale and as of external city and regional scale. Table4 shows a list of strategic environmental improvement methods categorized as mentioned above.

Table 4 Strategic environmental improvement methods

		Systems Boundary	
		Building/District Scale	City Scale
Building Management	Efficient Resource Use	・Ecological material use ・Resource-saving construction methods	・Material procurement from neighboring regions
Utility Management	Efficient Energy System	・District-scale energy supply systems with innovative advanced technological devices	・Efficiency improvement in regional energy supply
		・Reusing waste heat from rivers,sewage,etc.	・Renewable energy resource
	Environmentally Sound Mobility System	・Public transportation services for intra-district mobility ・Pedestrian network development ・Collaborative-cargo distribution system	・Modal shift of cargo traffic for city-scale public transit
	Solid Waste Management System	・On-site closed system of construction wastes	・Region-wide construction material recycle network
Spatial Management (Zoning, Land Use Planning)		・Planned urban renewal management ・District-scale redevelopment plan ・Restrictive physical construction code	・Eco-material production complex ・Growth control of city and region scale

3. Result

3.1 Environmental Impact Analysis in Pilot Study Site

The Life Cycle Estimation system is used to analyze the peculiarities of environmental emission, namely CO_2, solid waste discharge, in Nakanoshima West District(Fig.5). The district, which has been known as the national commercial center for centuries, neighboring the central business district of Osaka City, consists of as many as one hundred buildings with the total floor area of 778,000 square meter in 33 hectare area, as of 1996. Most blocks in the district are designated as commercial zones and dense development incentive zones with as many as 800 % planned floor area ratio. While a good amount of vacant land lots are left undeveloped or under low

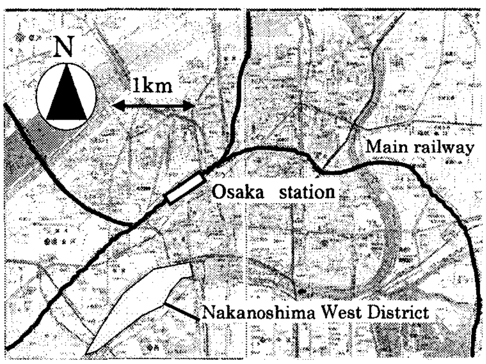


Fig.5 Nakanoshima West District, Osaka City

density with wooden housings, due to current economical depression, a number of large-scale projects with high density are under planning, which might additionally increase future emission increase from construction related activities and additional urban activities.

The result of the analysis of current structures shows a large quantity of CO_2 emissions arise from buildings, particularly from its operation stage. Life cycle CO_2 emissions thorough urban renewal process of buildings and infrastructures are estimated. The emission is classified into four categories, such as internal structure-oriented, external structure-oriented, internal activity-oriented, and external activity-oriented as are shown in Fig.6. Areas of boxes and widths of arrows indicate the proportion of the quantity of life cycle CO_2 emissions. For example, the emission from the stage of field construction is categorized into internal structure-oriented, that from the stage of material production into external structure-oriented, that from the use of electric power into external activity-oriented, that from the use of gas into internal activity-oriented, that from passenger traffic which runs inside the district into internal activity-oriented.

Activities supported by the buildings and infrastructure cause five times as many life cycle CO_2 emission as those caused by stock accumulation. Among them, emission from transportation and energy consumption on building operation stages provides as many as 83% of the total life cycle CO_2 emission. More than 90% of the emissions are, in the meantime, generated outside of the district, which imply the fact that urban activities are supported largely by off-site emission in terms of life cycle CO_2 emission.

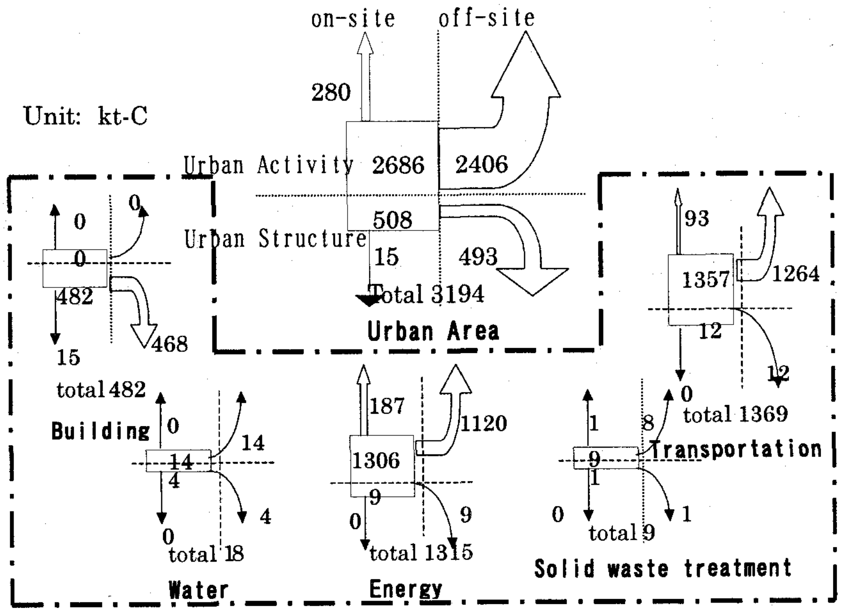


Fig.6 CO_2 Emission from urban area in 50 years from 2000 (600%Renewal)

3.2 Comparison of Life Cycle CO_2 Emission in Different Renewal Schedules

All at once renewal schedule, presuming all the buildings in the district are simultaneously demolished and rebuilt to enable fundamental reform of spatial pattern, is estimated for its effect to reduce life cycle CO_2 emission. It is compared with the schedule of continuous individual renewal schedule, which is common in usual downtown renewal process of Japanese cities. In both schedules, the average floor area ratio of 600% is presumed with additional 300% floor space construction to the current accumulation. Effects of several environmental improvement methods are estimated in Fig.7. The estimated amounts include life cycle CO_2 emission from buildings and other infrastructure. In the schedule considering present building locations, only half of life cycle CO_2 are emitted compared with "all at once renewal schedule", since the latter schedule, the additional building construction up to 600% floor area ratio would instantly start from the first year of estimation, while the former schedule, buildings would be renewed only after the duration periods complete. While assuming application of environmental improvement methods with building management and energy saving, additional buildings cause as many as 757kt-carbon, while in all at once renewal schedule larger-scale additional buildings generate 863kt-carbon by applying both utility management and spatial management methods as well as material management. Table 5 shows the definition of environmental improvement methods set up in estimation.

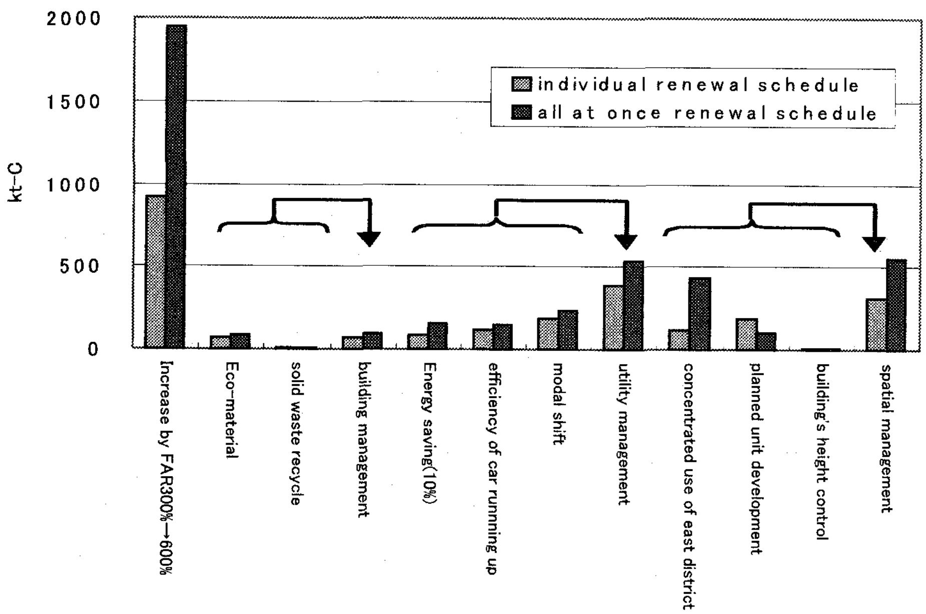


Fig. 7 Reduction of CO_2 by environmental improvement methods (50 years from 2000)

Table 5 Definition of environmental improvement methods

Method Category	Method	Content
Building Management	Eco-material	Materials, such as cement and steel, used in building's construction and maintenance are transfered into evironmentally sound material.
	Solid waste recycle	Waste concrete from building's demolition is recycled to be used as crushed stone in building's construction and maintenance.
Utility Management	Energy saving	Energy Efficiency is improved as many as 10% better by building or infrastructure improvement
	Efficiency of car	Fuels used in car runnning are saved by efficiency 10% up.
	Modal shift	Trips of car are shift to those of train by 5% of all trips.
Spatial Management	Concentrated use of district near station	Floor area is distrubuted mainly to eastern area located near the station, 1000% FAR in the eastern area 300% FAR in the western area.
	Planned unit development	Buildings are renovated by one building per one block. One block includes about 5 buildings.
	Building's height control	Building's height is controlled to 10F , while keeping floor area level by changing of building coverage

3.3 Estimations of Environmantal Improvement Scenarios

Life cycle CO_2 emissions are estimated for scenarios in two growth patterns of floor area scale and two renewal schedules. In Table 6, the scenario group 1a implies the current level of 300% floor area with individual renewal schedule and the 1b implies the current floor area level with all at once renewal schedule which enables the strategic adjustment of locational patterns of buildings and infrastructures. The scenario group 2a implies additional building construction up to 300 % floor area ratio with individual building renewal schedules and the 2b consists of scenarios of 600% ratio and all at once renewal schedules. Each scenario is estimated by introducing different combination patterns of environmental improvement methods of building management, utility management, and spatial management. In individual renewal schedules, unlike all at once renewal schedules, district-scale policies such as modal shift and spatial rearrangement are not adopted.

Table 6 Composition of each scenario

Method Category	Method	1a-1	1a-2	1a-3	1a-4	1a-5	1b-1	1b-2	1b-3	1b-4	1b-5	1b-6
Building Management	Eco-material	O				O	O					O
	Solid waste recycle	O				O	O					O
Utility Management	Energy saving		O			O		O				O
	Efficiency of car runnning up			O		O			O	O		O
	Modal shift									O		O
Spatial Management	Planned unit development				O	O					O	O
	Concentrated use of east district										O	O

Method Category	Method	2a-1	2a-2	2a-3	2a-4	2a-5	2b-1	2b-2	2b-3	2b-4	2b-5	2b-6
Building Management	Eco-material	O				O	O					O
	Solid waste recycle	O				O	O					O
Utility Management	Energy saving		O			O		O				O
	Efficiency of car runnning up			O		O			O	O		O
	Modal shift									O		O
Spatial Management	Planned unit development				O	O					O	O
	Concentrated use of east district										O	O

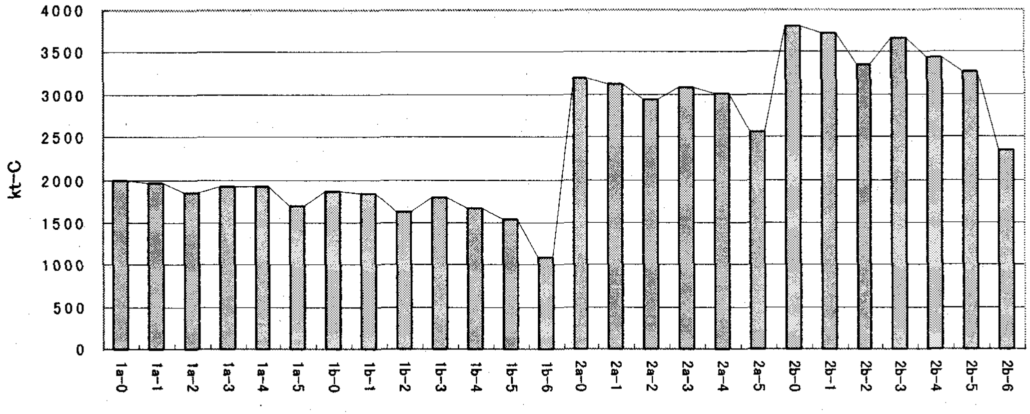


Fig.8 $LCCO_2$ emission for each scenario (50 years from 2000))

The estimation of each scenario is shown in Fig.8. Scenario 1a-0 indicates the present emission scale, while scenario 2a-0 indicates the possible CO_2 increase under current zoning regulations, which implies as many as 60% more CO_2 would be emitted from the urban accumulation of the district in 50 years. Scenario 1a-5 and 1b-6 indicate that as many as 15% of current emission level can be reduced by introducing acceptable environmental methods while 45% reduction is possible, even in calculation, if the locational patterns of structures are adjusted by simultaneous district-scale renewal schedule. In 600% floor area ratio develop scenarios, more than 15% life cycle CO_2 from current level would arise even if all the possible methods are adopted.

Life cycle CO_2 per unit floor area could be reduced as many as 40 % by adjusting the spatial distribution pattern and by adopting all the possible environmental policies. These estimation results suggest that either district-scale or city-scale growth control such as down zoning are required to control under the current CO_2 emission level.

3.4 Application for Urban Environmental Policy

Under the "Extended urban activity subject responsibility principal" which is an extensive idea from Extended Producer's Responsibility in manufacturing sectors, firms and residents located in urban central area should take upon the responsibility for environmental impacts from construction's renewal and outer area supporting urban activity in order to take the social benefits from urban accumulation. In this paper it is targeted to estimate the probability toward reduction of environmental emission of internal factors in urban area. So the influence of changeful external factors such as the change of the nuclear power's share and of the efficiency increase of power plants is ignored.

Under this principle, if keeping life cycle CO_2 emissions in the first half of 21st century as 1990's level, urban renewal need to be controlled under for present pattern only 307% FAR (Fig.5). This figure shows that 603% FAR can be allowed if the district is renovated all at once and high level eco-efficiency society come true. If 6% reduction from 1990' level which is the target of Japan in Kyoto Protocol is used as target level, present renewal pattern allows only less than 290% FAR, while

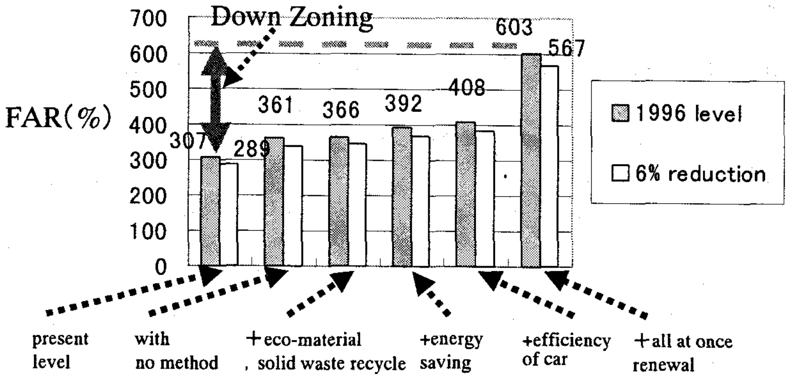


Fig.9 FAR allowance from the view point of CO_2

environmentally sound renewal pattern allows as many as 560% FAR. These numbers should be considered as a tentative estimation by taking national target of Kyoto Protocol as a local target for emission reduction, while the local target level need to be determined through social cost-benefit comparison and responsibility sharing among industrial sectors and municipal planning authorities and other related sectors. CO_2 proportion in the total green house gas reduction targets also needs to be investigated. This estimation implies that strategic land use control is as effective for the environmental emission CO_2 as well as product chain management policies for manufacturing products and food products, which multiple social systems have been already planned and legislated.

4. Conclusions

Life cycle estimation of CO_2 from urban structures and related activities brings several policy findings as follows; (1) CO_2 emissions attributed to urban activities rather than accumulation of urban stocks account for as many as 85% of the total amount. Emissions caused by transportation and energy consumption among service-oriented impacts have the largest parts. Only less than 10% of the life cycle CO_2 are emitted inside of the district. (2) Spatial management and utility management policies are found as effective as building-scale management methods such as eco-material utilization. (3) Life cycle CO_2 estimations for different scenarios indicate spatial adjustment by all at once renewal schedules would be an effective management alternatives if the district accepts additional floor area developments under current growth regulation policies.

Acknowledgement

This paper was written as a part of the research project of 'Construction of the reCycle-oriented Industrial Complex System', a research project toward sustainable society in Core Research for Evolutional Science and Technology (CREST) supported by Japan Science and Technology Corporation.

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