Optimization of Underground Energy Infrastructures

Kobayashi, Ryusuke
JGC Corporation

Nishikawa, Masabumi
Department of Advanced Energy Engineering Science, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

https://doi.org/10.15017/16594

出版情報：九州大学大学院総合理工学報告. 22 (2), pp.193-202, 2000-09. 九州大学大学院総合理工学府
バージョン：
権利関係：

九州大学大学院総合理工学報告
第22巻 第2号 193 - 202頁 平成12年 9 月

Engineering Sciences Reports, Kyushu University
(KYUSHU DAIGAKU SOGORIKOGAKU HOKOKU)
Vol. 22, No. 2 pp. 193 - 202 SEPT. 2000

Optimization of Underground Energy Infrastructures

Ryusuke KOBAYASHI* and Masabumi NISHIKAWA**

(Received May 30, 2000)

In order to maximize the efficiency of newly proposed underground energy infrastructures, it is significant to conduct a simulation analysis considering the size of the area to be covered and the construction timeframe of the network. An expansion plan of the underground network, maintaining a proper combination with the existing aboveground infrastructures can be optimized by the analysis. For this purpose, a new evaluation index that includes environment or safety aspect as well as initial and operation cost is required. Also, energy flow management, including valuable energy or exergy evaluation, will be one of significant factors in further improving the network efficiency. Five cases discussed in this paper show various features of the existing aboveground infrastructures and the newly planned underground infrastructures, in the timeframe from 2005 through 2080. As a result, although the discussed evaluation is mainly based on the energy flow management, it is shown that the proposed evaluation index is useful in finding out the optimized network plan among the proposed cases, comparing construction cost and long-term operation cost.

1. Introduction

Optimization of underground energy infrastructures should include a discussion on long-term flexibility of the infrastructures in terms of new energy utilization, taking into account a proper evaluation index of energy use efficiency. New energy resources as an alternate to the existing energy resources need to be discussed during the long-term construction and utilization period of the proposed systems. This paper describes a necessity of the new evaluation index for energy use efficiency and proposes an optimization approach.

Utilization of underground spaces provides more flexibility for us to connect each energy facility in an optimized manner, as shown in this paper with several representative data and analysis results [1)-6)]. However, the energy network size needs to be carefully discussed prior to the determination of the long-term plan, based on the energy demand and supply amount. It is essential to establish and maintain sustainable energy network systems also valuable in the future.

This paper discusses a newly proposed evaluation index for the underground energy infrastructures, taking into account proper energy flow management, reduction of environmental influences, and improvement of the economics. Exergy, or valuable energy, evaluation approach is also discussed in this paper, as one of significant factors in establishing a new optimizing approach for the underground infrastructures. Showing the evaluation results on several representative network cases, this paper describes the significance of environmental consideration on the final decision of the long-term planning.

As a conclusion, this paper shows the effect of the new index as an optimizing evaluation to find out the properly planned network systems among four network patterns in terms of overall energy use efficiencies, based on the analysis and discussion of the network case studies. Also, this paper adds, as another conclusion, a further possibility to expand the exergy evaluation, which this paper describes as an optimizing approach for the future energy network systems.

*JGC Corporation, 2-3-1 Minato Mirai, Nishi-ku, Yokohama, 220-6001
**Department of Advanced Energy Engineering Science

2. Network size and long-term plan

2.1 Network size

As discussed in the paper entitled "Energy Infrastructures and Underground Space Utilization," the underground network could be effective energy infrastructures to balance energy demand and supply profile in metropolitan areas. The evaluated network in the paper has a 700km length consisting of five different routes based on the areas to be covered and transfer load estimation. In this paper, we discuss the size of networks and its effects on the efficiency and profitability of the network plan. In other words, it is important for the network planner to find out an appropriate size of the network in terms of economics and construction flexibility. Therefore, we introduce a network expansion concept referring to the discussed network plan in the previous paper. **Fig. 1** shows four patterns of the network, Network pattern Ⅰ — Ⅳ and their expansion plan.

Network Pattern I :

As discussed previously, the most active route among the network route is D2-D4. We selected this route as the first network, Network Pattern- Ⅰ. This network will be scheduled to start construction as the first network because of its immediate necessity for networking. The network length is 19km in total. This route is a part of the bay-area circulation route D.

Network Pattern II :

Network Pattern Ⅱ consists of Routes A1 — A6 (Metropolitan circulation route) and Routes E1 — E4 (Radiation-shaped routes), in addition to Network Pattern Ⅰ. After completion of the Network Pattern Ⅱ, the total network length will be 78km. Network Pattern Ⅱ covers the center of the assumed metropolitan area and the bay area.

Network Pattern III :

Routes B1 — B7 and related radiation-shaped routes E5 — E9 will be jointed to the Network Pattern Ⅲ to cover the larger metropolitan area, consisting of a 182km network length. Compared to Network Pattern Ⅱ, transfer loads of wastes and commercial packages are high, and converting the ground transportation to the underground network could significantly improve transfer efficiency and environmental conditions of the area covered by this network pattern. Many waste incineration plants exist within this network, therefore, it is expected that interconnections of each plant allow flexibility for the operation and maintenance mode of the plant as well as a back-up function.

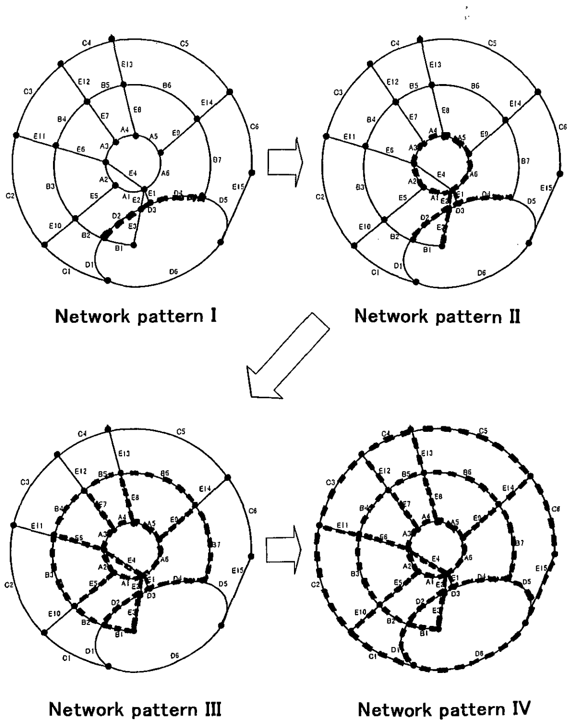
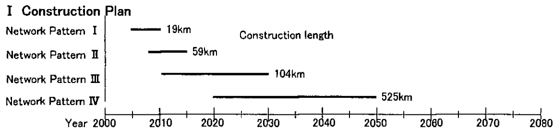


Fig. 1 NetworK pattern Ⅰ — Ⅳ

Network Pattern IV :

This Network Pattern shows the final shape of the network. It enables much allowance for the metropolitan areas to expand their functions to outer areas of the center of the metropolitan. This route shows many possibilities as to how the 21st century-city could improve and sustain its functions, balancing with surrounding environment. However, because of the total length of the network will be 700km, a careful study is



II Utilization

(1) Network Pattern

Pattern	I	II	III	IV
Length	19km	78km	182km	707km
Crossing	4	11	19	28

(2) Local Station

Total	(10)	(54)	(92)	(101)
Waste Treatment	2	5	15	17
Water Supply	2	4	9	9
Indst. Water Treatment	2	33	42	42
Sewage Water Treatment	4	6	15	18
Ultra-High V. Transformer	-	6	11	13
Thermal Power	-	-	-	2

Fig. 2 Construction and utilization schedule of underground networks

required prior to the decision of this network from the viewpoint of construction technologies, construction period, legislations, land use or entity to manage this plan, etc. In this paper, assuming that this network can be realized technically in the 21st century, the effect and profitability of the network will be evaluated and compared with other three network patterns.

2.2 Long-term plan

The purpose to prepare four network patterns is to evaluate the flexibility of this network plan in terms of construction period and utilization plan. Since we assume that the center of the metropolitan area needs more immediate improvement by underground networks and shows high effects of the networks, the explained network patterns will expand from the center of the metropolitan towards outer areas, where many city-functions could be located in the 21st century if the larger network, such as Network Pattern IV is realized in the future. **Fig. 2** illustrates construction plan of Network Pattern I - IV, starting in 2005 (Network Plan I) until completion in 2050 (Network IV). Also we assumed that the utilization of Network Pattern I would be started in 2010. According to the construction work schedule, Network II, III and IV also will be available in 2015, 2030 and 2050 respectively. **Fig. 2** also shows the number of local energy stations within the network patterns. This is a typical long-term plan for the metropolitan areas assumed in this paper. In the following sections, we discuss the evaluation index and optimization approach referring to this long-term plan.

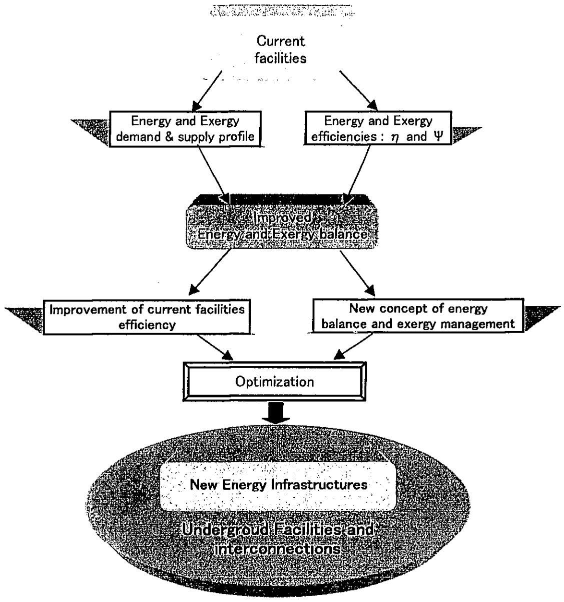


Fig. 3 Optimization of energy balance and exergy management for new energy infrastructures

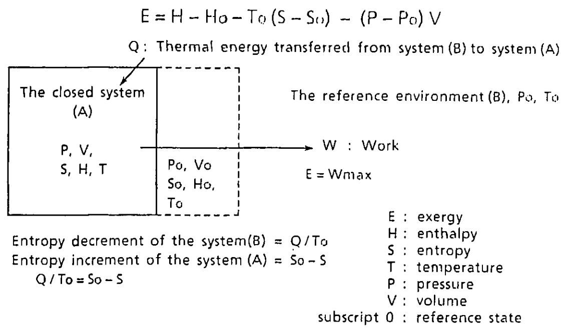


Fig. 4 Exergy between system (A) and (B)

3. Evaluation index for optimization

3.1 Influence factors

In order to optimize the underground network patterns, taking into account their construction and utilization schedule, the following three factors will be discussed. Exergy, or valuable energy, is one of key factors in evaluating the efficiency of the network. The purpose of this discussion includes proposing application of the exergy evaluation to the network-wide evaluation. Various kinds of energy sources need to be analyzed in the network plan.

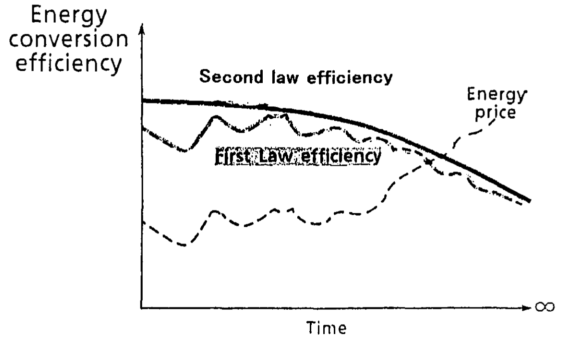


Fig. 5 Energy conversion efficiency and 1st and 2nd law of thermodynamics

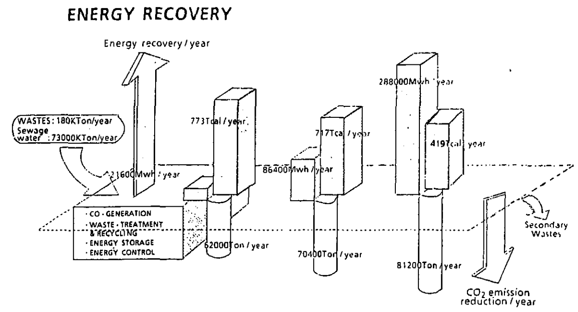


Fig. 6 Energy recovery and CO_2 emission reduction

Therefore, establishment of the evaluation methodology will be very useful in showing how the network improves the energy demand and supply balances. Quality of energy needs to de included in the planning analysis.

a. Energy balance and exergy management

Fig. 3 shows a flow of energy balance and exergy management. Optimum analysis of energy flow and exergy efficiency is essential to have the maximized efficiency of the energy network. For that purpose, it is necessary to understand where and how the recovered energy or exergy will be utilized. Exergy is defined as the maximum work that could be obtained from the system (A) that is surrounded by a reference environment (B), as shown in **Fig. 4**. It is well known that the 2nd law of thermodynamics forecasts an increment of entropy, bringing the system to an equilibrium status to the surrounding reference system. **Fig. 5** schematically shows that the efficiency of energy utilization will be decreased with time if the reference environmental system shows entropy increment with time, causing increment in energy source price. It is also understood that recent global problems in environmental conditions, such as CO_2 concentration increment may be one of these phenomena. Since we are focusing on the metropolitan area in terms of energy use efficiency without major impact on the surrounding environment, and also because the underground space where the network is constructed in a closed space, energy and exergy evaluations are both essential, in order to evaluate the remaining level of value of the energy after utilized in the network systems.

As an example of energy recovery case study, we assumed an energy recovery from a waste incineration plant and sewage water treatment system covering residence areas with population of 400,000. The treatment capacity of the underground incineration plant is assumed to be 180 K tons/year (600 tons/day) and the capacity of the sewage water treatment system, to be 73,000K tons/year (200,000 tons/year). **Table 1** shows four cases of energy recovery plan, showing recovered energy and the amount of secondary waste. **Fig. 6** illustrates the calculated results.

Case 1 : Thermal energy recovery plan:

Energy is recovered and delivered mainly as thermal energy. Only 3% of the recovered energy at the incineration plant is converted to electricity, in order to use the electricity for the plant operation. Energy is also recovered from the sewage water treatment system already existing above ground. 21,600MWh/year of electricity and 773 Tcal/year of thermal energy are recovered in this plan. Required underground spaces for the incineration plant and a thermal energy storage facility are to be approximately 250,000m^3 and 90,000m^3, respectively.

Case 2 : Electricity recovery plan at the incineration plan:

Recovered energy at the incineration plant is mainly converted to electricity with an efficiency of 15%. The rest is delivered as thermal energy in combination with recovered thermal energy from the sewage water treatment system. 86,400MWh/year of electricity and

Table 1 Energy recovery plan from waste treatment facilities

Model	Energy recovery Plan	Results	Resources Savings*	CO_2 emission reduction per underground space volume for the Facilities
Population : 400.000 Wastes : 180K ton/year Sewage water : 73,000 K ton/year	—Underground incineration and electricity generation with heat deliverry —Heat recovery from sewage water treatment system —Thermal exergy storage system —Interconnections of the facilities	(Case 1) Electricity : 21,600MWh/year Heat : 773Tcal/year Secondary wastes : 73,800m³/year	81,900 ton/year	0.19 ton/m³/year
		(Case 2) Electricity : 86,400MWh/year Heat : 717Tcal/year Secondary wastes : 73,800m³/year	90,300 ton/year	0.22 ton/m³/year
		(Case 3) Electricity : 288,000MWh/year Heat : 419Tcal/year Secondary wastes : 73,800m³/year	103,800 ton/year	0.28 ton/m³/year
		(Case 4) Electricity : 86,400MWh/year Heat : 717Tcal/year Secondary wastes : 5,700m³/year	90,300 ton/year	0.20 ton/m³/year

*Calculated as oil equivalent with electricity generation efficiency of 40% and heat content of 10 Gcal/ton.

Table 2 Energy and exergy efficiency η and ϕ for the Residential-Commercial Sector in Canada

Device	Product temperature (K)		Energy and exergy efficiencies (%)			
	Electrical heating	Fuel heating	Electrical heating		Fuel heating	
			η	ϕ	η	ϕ
Space hearters	328	328	100.0	17.1	65.0	11.1
Water heaters	350	374	93.0	25.4	62.0	14.0
Cooking appliances	394	—	80.0	22.5	—	—
Clothes dryers	350	350	50.0	9.6	50.0	10.3

717 Tcal/year of thermal energy are recovered. Underground volume of 70,000m³ is estimated for the thermal energy storage facility.

Case 3 : Highly efficient power generation plan:

Efficiency of power generation at the incineration plant is assumed to be as high as 45%. The obtained electricity is to be 288,000MWh/year and 419 Tcal/year of thermal energy is recovered. Underground space for thermal energy storage is estimated to be 50,000m³.

Case 4 : Volume reduction with highly efficient power generation plan :

A volume reduction system such as a slagging system is applied to the incineration ash generated at the incineration plant and dewatered cakes generated at the sewage waste treatment system, in order to reduce volumes of the secondary waste generation amount.

It is obvious that Case 3 could save approximately 27% more energy resources than Case 1. However, both the balance of electricity and thermal energy required in the region and the investment cost for the newly planned energy facilities should be examined to determine the most preferable Case.

Table 2 shows an example of exergy efficiency evaluation performed for residential-commercial sectors in Canada, aiming at comparison with energy efficiency. Exergy efficiency is defined as a ratio of exergy in products and total exergy input. Also, energy efficiency is defined as a ratio of energy in products and total energy input. Large differences between energy and exergy efficiency of electricity in **Table 2** indicate that electricity looses more valuable energy in heating of this case. We should recognize a proper energy source to be applied in order to save energy resources.

b. Environment

Underground network enables bringing more open spaces within the metropolitan areas where green belts or parks can be located. Solar panels can also be installed on the open spaces. Such well-planned urban infrastructures will satisfy required quality of urban life. In the 21st century, an underground energy network could be a significant part of the city design, because it provides a beautiful landscape on the surface of the city. It is rather difficult to count this kind of advantage, however we should note that a comfortable space realized on the surface of the ground is a key factor in the evaluation as well as such a direct environmental factor as reduction in NO_x, SO_x or CO_2 emission, etc.

c. Safety

By separating transporting activities to aboveground and underground, current situation that causes traffic accidents will be significantly lowered. Also, it is believed that underground shows more safety features than aboveground against earthquakes in some cases. City functions can be compensated both aboveground and underground. On the other hand, when people need to go into deep underground, safety simulation or evacuation routes in case of accidents need to be secured. These factors also should be considered when an underground network is optimized.

d. Economics

Underground space has such an advantage that it enables a straight connection route. This means distance between two locations can be minimized compared with the route aboveground. It saves transporting time and energy. Automated transporting system saves labor cost and an integrated network where various kinds of items share a large network line, as shown in the previous paper, enables less maintenance cost. Final determination of the network size or route will be evaluated based on the economic case study, including cost factors derived from the above a through c. Overall feasibility study is required.

3.2 Evaluation index

Taking influence factors into account, we propose the following evaluation index to optimize the underground network.

$$P = I + O \tag{1}$$

P : Evaluation Index

I : Intial Cost (Capital Cost, Construction Cost, etc.)

O : Operation Cost

$$O = \sum_{i=1}^{n} \left[O' \times \left[\frac{1+e}{1+d} \right]^n \right]$$

O′ : Fuel cost
Labor cost
Maintenance cost
Emission compensate cost (CO_2, NO_x, SO_x, etc.)
Insurance cost (Vehicle, labor, etc.)
Environmental cost
Highway toolgate cost
Others

n : Operation period
e : escalation rate
d : discount rate

4. Evaluation results

4.1 Network patterns and evaluation

In this section, several case studies are shown in terms of influence factors explained above. Although all four factors are desired to be included numerically into the evaluation equation (1), this study mainly focuses on 1) energy flow management, 2) environmental cost and 3) overall economics of the network including 1) and 2) throughout the construction and utilization period. Exergy evaluation should provide more precise evaluation results and suggestions when it is properly included into the evaluation scheme. Further data acquisition on both energy sources and utilization plan will help this approach. Within the scope of this study, we performed investigations to find out profitability of the four network plans based on the three factors mentioned above.

a. Network models

Evaluation indexes of four network patterns described in this paper have been evaluated using equation (1). Details of the network patterns and construction and utilization schedule were explained in **Table 2**. The evaluation period is from 2005 through 2080. During this period, we compared the four network patterns with the current situation case (no underground network is planned).

b. Results and discussion

Fig. 7 shows a result of the evaluation. Case 1 represents the current situation case, and Case 2－5 represent Network patterns Ⅰ－Ⅳ, respectively. The obtained index in billion US$ indicates the necessary cost to maintain transferring activities of targeted items in the areas covered by Network Ⅰ－Ⅳ. In order to have an equal transfer load for the evaluation, the same area and transport load were used in all five cases. It should be noted that though the absolute value of the index result is based on the many assumed data and models to represent the typical metropolitan area of Japan, it is not indicating any specific idea on the actual construction or operation cost for any specific area.

As shown in the figure, because of the construction cost of the network, the effect of the network appears in terms of some time delays. For instance, Case 2 that represents Network pattern Ⅰ utilizing Routes D2, 3, and 4, shows an introduction advantage after 2015, five years from its utilization start of 2010. Same observation can be found on Case 3 and 4. Case3 became the most profitable case among five cases in 2024 (9 years after utilization start) and 2038 (8 years after utilization start) for Case4 respectively. However, during the evaluation until 2080, Case 5 that represents Network pattern Ⅳ (all network routes are utilized) does not become the best case, even though Case 5 becomes the second profitable case next to Case 4 (Network pattern Ⅲ) after 2064 (14 years after utilization start). This is because of the less transport load along with Route C that characterizes Network pattern Ⅳ.

This less load comes from current distribution profiles of urban functions in the assumed metropolitan areas. According to the gradual slope of evaluation index with time of Case 5 compare with that of Case 4, it is expected that this case will be the best case in the future. In case where more transport loads are delivered using this network route C, the city functions can be expanded smoothly from the center of the metropolitan area towards the outer areas. As described in the previous paper, this Network pattern Ⅳ that includes Route C has allowances in its transport capacity compared with current transport demands. In other words, this network

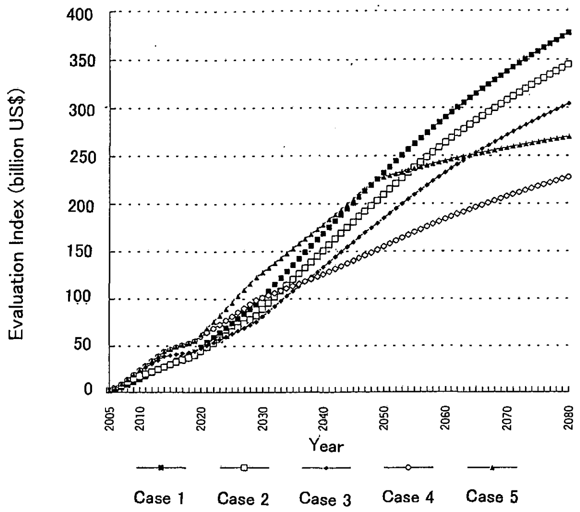


Fig. 7　Evaluation index (Case 1—5)

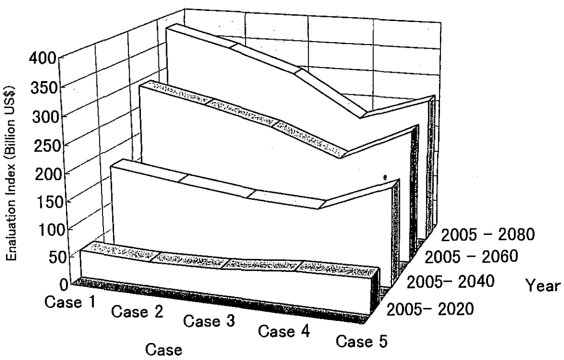


Fig. 8　Evaluation index for Case 1—5

pattern covers the area where an immediate improvement need is observed. Therefore, we can understand that this result is reasonably expected.

Fig. 8 shows features of each case until 2020, 2040, 2060 and 2080. As explained, Case 4 (Network pattern Ⅲ) demonstrates advantages all through the evaluation period until 2080.

Here, we discuss the ratio of capital cost and operation cost of each case. **Fig. 9** (**A**), (**B**), (**C**) and (**D**) show a breakdown of the evaluation index of the cases as of 2020, 2040, 2060 and 2080. In 2020, Network pattern Ⅵ starts its construction. Compared with high construction cost of wider network patterns, the operation cost (transportation cost) shows less amounts because of improved efficiency. You can clearly see the improvement effect of the network on the transportation activities.

Fig. 10 show accumulated operation cost comparison among these five cases from 2005 through 2020, 2040, 2060 and 2080, respectively. Each case has two indexes that represent the operation cost with environmental cost and without environmental cost. The results without environmental cost exclude the environmental cost such as NO_x, SO_x or CO_2 emissions, etc., from the evaluation. From this figure, we can see that Case 5 shows the most profitable performance in terms of transportation activities. The difference of Case 1 and Case 5 are 220 billion US$ in the case with environmental cost, and 141 billion US$ in the case without environmental cost. These amounts are comparable with the total assumed construction cost of the network pattern Ⅳ of 210 billion US$ shown in **Fig. 9**(**C**) and **9**(**D**). Also, Case 1 shows much discrepancy (30% of the case with environmental cost) between the case with and without environmental cost. This means that this case will have many uncertainties for future environmental policy to be applied, and its operation cost will be impacted by this uncertainty. On the other hand, the operation cost of Case 5 shows only a 10% difference. The differences in assumed absolute value in Case 1 and 5 with and without environmental cost are 85 billion US$ for Case 1 and 6 billion US$ for Case 3.

Another observation of **Fig. 10** is that the index result of Case 3 (Network pattern II) with environmental cost is already less than the index result of Case 1 without environmental cost. This means, Route D2—4, and Route A (the center of metropolitan circulation route) that cover the most active areas in the urban areas feature fewer operation cost even when no environmental costs are added on the transportation activities through 2080 in the current situation. Case 1, the case using the Network pattern Ⅱ shows an operational advantage in both with and without environmental cost. This fact is significant because this network construction is providing a stable operation performances for the covered metropolitan areas not influenced by the future environmental policy. Again, we should note that the environmental cost is already included

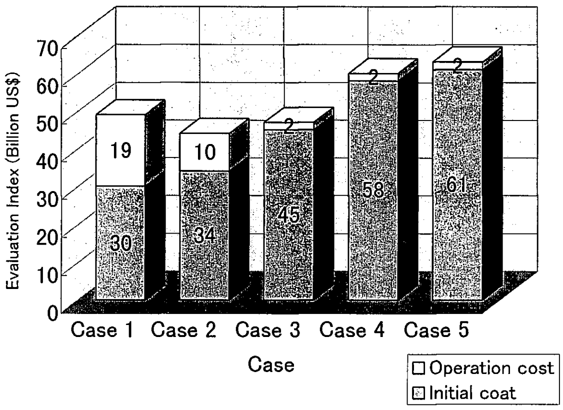


Fig. 9 (A) Intial cost and operation cost (2005—2020)

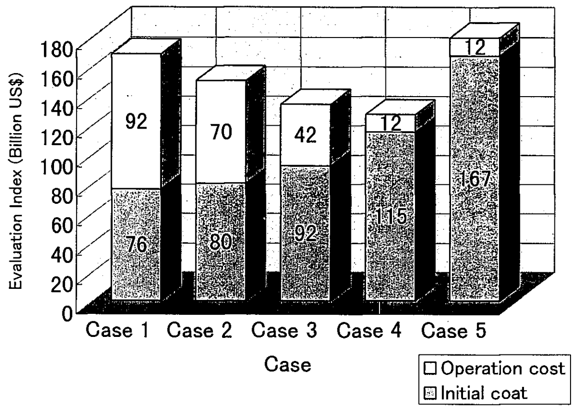


Fig. 9 (B) Intial cost and operation cost (2005—2040)

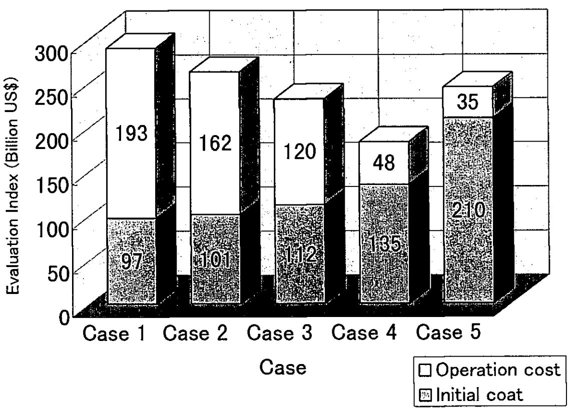


Fig. 9 (C) Intial cost and operation cost (2005—2060)

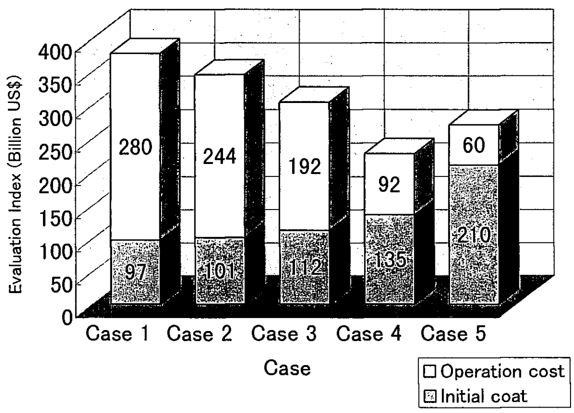


Fig. 9 (D) Intial cost and operation cost (2005—2080)

in the evaluation results shown in **Fig. 9 (A)** – **9 (D)**.

4.2 Optimization approach

Fig. 11 shows schematic concept where we should aim to reach in terms of energy use improvement. In the figures, a configuration of the discussed energy system regarding the amount of primary energy consumption, alternate energy consumption and also the energy conversion efficiency can be plotted. We assume that as time goes, we would improve energy conversion efficiency. Therefore, a vertical axis can be understood as time, or in other woods, as an improvement steps of the energy related system in the area with time, such as demonstrated in this paper as Network pattern Ⅰ - Ⅳ. This figure conceptually explains that an area given on the surface of a plane made by the axis of primary energy consumption and the axis of alternative energy consumption indicates the amount of total

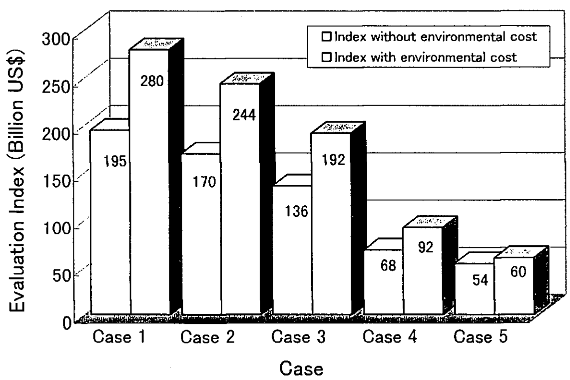


Fig. 10 Operation cost with and without environmental cost (2005—2080)

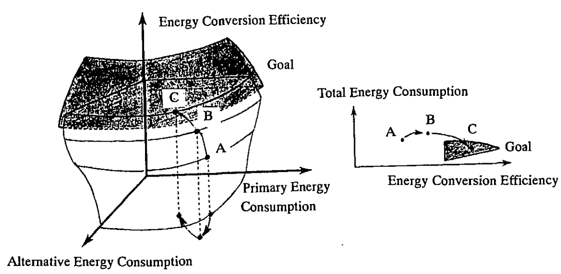


Fig. 11 Energy Conversion Efficiency and Energy Consumption

energy consumption consisting of primary energy and alternative energy at a certain time during the evaluation period.

On the figure, point A shows that a relatively larger amount of primary energy is consumed than alternative energy, followed by point B where a ratio of the alternative energy becomes larger than primary energy. Point B also indicates that total energy consumption is greater than that of point A as shown on the plane made by the axis of primary energy consumption and alternative energy consumption, although energy conversion efficiency is improved. This means social functions of the area are requiring much energy than the time of point A. Exceeding point B, the goal we should reach is point C where further energy conversion improvement is achieved and total energy consumption is less than that of A and B. Energy configuration of Point C has various options in addition to primary energy of point A. An optimization approach of the underground energy network should include such a philosophy. We proposed a new evaluation index to optimize the network system, where this approach can be combined numerically based on the broad data acquisition on the targeted area and a specific goal of the energy system.

5. Conclusion

The network patterns Ⅰ — Ⅳ shown in this paper have been evaluated in terms of influence factors such as energy balance, environmental impacts and overall economics, using the proposed evaluation index. Among the network patterns, Network pattern Ⅲ gives the most advantages during the evaluation period from 2005 through 2080, compared with smaller network patterns Ⅰ or Ⅱ, and larger network pattern Ⅳ. This brings as a conclusion that a proper size of network, in other words, proper size of the urban area that the network can cover exists. Also, the conclusion shows that the proposed index can be utilized to find out such an appropriate size based on the quantitative data that influence on the network features. The importance is the planning of the wider network should take into account a longer-time frame where construction and utilization modes are simultaneously considered, and also new energy systems need to be included as alternate energy options to achieve further improvement of the network. Flexibility of the planning is another key factor in the future network planning. Underground space utilization for the future energy infrastructures can be discussed and optimized by the planning approach and the evaluation indexes proposed and described in this paper.

Acknowledgement

The authors acknowledge the support of the Engineering Advancement Association of Japan (ENAA), Kajima Corporation, Shimizu Corporation, Taisei Corporation, Obayashi Corporation, Kumagai Gumi Co., Ltd., Hazama Corporation, NKK Corporation, Kawasaki Steel Corporation, Tokyo Electric Power Company and Tokyo Gas Co., Ltd. for the data used in this study.

References

1) R. Kobayashi, et al., "Underground Distributed-Type Energy Supply and Recycling Facilities in Urban Area," Proceeding of the 5th International Conference on Underground Space and Earth Sheltered Structures, Delft, the Netherlands (1992)
2) R. Kobayashi et al., "Utilization of Underground Space for Distributed-Type Energy Supply and Industrial Facilities," Proceeding of Underground Space Utilization Symposium, Tokyo, Japan (1989)
3) R. Kobayashi et al., "Exergy Evaluation for Urban Underground Space Utilization," Proceedings of the 4th International Conference on Underground Space and Earth Sheltered Structures, Tokyo, Japan (1991)
4) R. Kobayashi, et al., "Development and Actual Application of High Temperature Incineration System," Proceeding of International EPRI Low-Level Waste Conference and Exhibit Show, New Orleans, U.S.A. (1996)
5) "Study Report on Underground Network Concept in Urban Area," ENAA (1993)
6) "Study Report on Underground Network Concept in Urban Area," ENAA (1992)