Review on investment schemes of urban underground utility tunnels in multiple energy systems

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Abstract. As a part of multiple energy systems, the urban underground utility tunnel plays an important role in improving the utilization efficiency of urban underground space. However, single investor and difficult financing problem make the construction of urban underground utility tunnels more and more difficult. Thus, it is very important to study a reasonable and effective investment scheme for investing the utility tunnels in multiple energy systems. In this paper, a review on investment schemes of urban underground utility tunnels is presented. The basic properties and related subjects of the utility tunnels are summarized and analyzed. The investment schemes are divided into three types according to the different investment subjects: government direct investment scheme, government and companies joint investment scheme, and public-private partnerships investment scheme. Moreover, the three schemes are introduced and analyzed in detail according to the actual investment cases.

1. Introduction

With the ever-increasing capacities and the restructuring of the power industry \cite{1}, the research of power system extends to the multi-energy system. Urban underground utility tunnels in multiple energy systems have developed rapidly as intensive and modern municipal pipeline channels in the process of urbanization. It is the general trend for power pipelines to enter the urban underground utility tunnels. Utility tunnel is the public tunnel in which power, communication, water supply, gas and other municipal pipelines are laid \cite{2}. In recent years, multiple energy system, which is an energy system with coupling and interaction of natural gas, electricity, heat, cold and other energy carriers, has received considerable attention worldwide \cite{3}. The interdependence of various energy infrastructure has increased significantly. Therefore, a comprehensive analysis of various energy systems is essential for the short-term operation and long-term planning of sustainable energy supply. As an important part of multiple energy systems \cite{4}, the utility tunnel is an effective way to improve the utilization efficiency of urban underground space and can produce high social economy benefits \cite{5}-\cite{6} and environmental benefits \cite{7}. In addition, the maintenance of various municipal pipelines is...
greatly facilitated by the utility tunnels and the maintenance costs could be reduced. Up to April, 2018, the mileage of the utility tunnels planned to be built in China has exceeded 7800 kilometers.

The development of urban underground utility tunnels started in Paris in 1855. From then on, the utility tunnels have been widely used in the world. The researches on utility tunnels in Europe focus on the internal pipeline design, facilities planning, and construction technology and so on. Some scholars point out that the construction and operation technology level of the utility tunnels have become mature and reliable after nearly 150 years of exploration and development [8]. The main obstacle for the utility tunnels’ development is the financial problem. As for the investment schemes of the utility tunnels, European and American governments invest in building utility tunnels [9]. Japanese government has enacted the most complete schemes and laws for the utility tunnels, in which the funds management has been defined clearly [10]. In [11], the composition of utility tunnels’ construction cost is discussed, which could be used as a reference for calculating the cost of the investment schemes. In [12], the problems existing in the construction of urban underground utility tunnels are pointed out, single investor and difficult financing are the problems in the utility tunnel’s construction in Guangzhou University Town, China. In [13], the investment schemes of the utility tunnels are discussed with the economic attributes of the utility tunnel and Chinese policy environment considered. In [14], the characteristics of the utility tunnel projects and the public-private partnerships investment scheme are analyzed, and seven public-private partnerships investment schemes are proposed, which are suitable for the construction of the utility tunnels in multiple energy systems.

To sum up, it is more and more difficult to sustain the construction of urban underground utility tunnels by a single source of funds. Exploring the investment schemes of utility tunnels and realizing the transformation of government functions have become the key to the large-scale development of utility tunnels in China. Therefore, this paper introduces the basic properties and related subjects of the utility tunnels, and sorts out the existing investment schemes of utility tunnels. Considering the basic properties of the utility tunnels, the investment schemes are divided into three types according to the different investment subjects: government direct investment scheme, government and companies’ joint investment scheme and public-private partnerships investment scheme. Meanwhile, the characteristics, advantages and disadvantages of different investment schemes are analyzed.

2. Urban underground utility tunnels

2.1 Basic properties of utility tunnels

The basic properties of utility tunnels are the most fundamental basis for deciding the investment scheme. The utility tunnels have the building property as pipeline spaces for accommodating municipal pipelines in cities. However, there are some differences between the properties of utility tunnels and the conventional building. The main difference is that the costs of utility tunnels are difficult to be transferred through the price changes, which makes the investment in utility tunnels difficult. Because the prices of pipeline service products (such as electricity price and water price) are related to the daily life of the public, and their change would lead to significant impacts on society and economy. At the same time, because of the land policy and related laws, the utility tunnels could only be owned by the local government, and the social capitals could obtain the use and management rights only after investing and constructing the utility tunnels. Hence, the enthusiasm of the social capitals’ owners to participate in the utility tunnels’ investment and construction are inhibited to some extent.

The utility tunnels in multiple energy systems are essentially urban infrastructures that provide services to the public and they are monopolized, up to a point. A large part of the benefits produced by the utility tunnels are external benefits such as reducing road excavation, improving urban landscape, avoiding traffic jams and so on. Therefore, it has the property of public goods. However, the number of pipelines that could be accommodated by the utility tunnels is limited and the owner of the utility tunnels can charge the pipeline companies to cover the costs, which is the property of private goods. Thus, the utility tunnels have the property of mixed goods.
The utility tunnels in multiple energy systems are quasi-public goods between public goods and private goods. If the government agencies invest the construction funds entirely at one time like other public goods, it would cause a heavy financial burden on the government and affect the sustainable development of the utility tunnels. However, it is also unreasonable to allocate the utility tunnels by the market completely, which would lead to the deterioration of the service quality. Thus, the shortage of funds faced by the government in the construction process of the utility tunnels projects can be solved by inducting social capitals. However, it should be avoided the circumstance that the utility tunnels are completely controlled by the private subjects. The reason is that the interests of the public would be damaged if the government were unable to control the price of the services in the later operation process of the utility tunnels.

2.2 Analysis of related subjects of utility tunnels
Due to the large investment cost in the urban underground utility tunnels construction and many related subjects involved, it is necessary to analyze the related interest subjects before studying the investment scheme of utility tunnels. Generally, the related subjects of utility tunnels mainly include the government, social capitals, pipeline companies and the public. In order to improve the urban environment and enhance the level of urban construction, the government plans and constructs the utility tunnel project. The social capitals are introduced to participate in the construction due to the large investment cost in the early stage of the utility tunnels construction and the limited financial funds of the government. The power, communication, water supply, gas and other pipeline companies needed by urban operation should enter into the utility tunnel after it is built. The pipeline companies should pay an amount of fees to subsidize the construction, operation and maintenance expenses of the utility tunnels. However, the public is the ultimate beneficiary, enjoying the environmental and social benefits brought by the utility tunnels.

2.3 Existing problems in utility tunnels
- The roles of utility tunnels in multiple energy systems are unclear: there are many disputes in the process of the investment, construction and operation.
- The relevant laws and regulations are not complete: such as the ownership of underground space, cost allocation among different subjects and other issues which are not clearly defined.
- The investors' understanding of utility tunnels is not comprehensive: the social benefits brought by the utility tunnels have not been fully recognized by the public and the relevant subjects, so there is no effective investment, construction, operation and management scheme accepted by people.
- Lack of stable sources of funds: the investment cost of urban underground utility tunnel is relatively large. At present, the existing utility tunnels are mainly invested by local governments, which is not conducive to the long-term and sustainable development of the utility tunnels.
- Operation and management fees are difficult to collect: the costs of utility tunnels mainly include construction costs and management costs. The annual management fees would bring a heavy burden to the pipeline companies.

3. Investment scheme analysis of urban underground utility tunnels
According to the different investment subjects, there are three main investment schemes in the existing urban underground utility tunnels projects, i.e., government direct investment scheme [15], government and companies joint investment scheme [16] and public-private partnerships investment scheme [17]. As shown in table 1, different schemes have their own characteristics and they have been applied in different countries or cities.
Table 1. Different investment schemes used by areas in different countries or cities.

| Investment Schemes                        | Areas in Different Countries/Cities                                                                 |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------|
| Government direct investment scheme       | Beijing Zhongguancun, Shanghai Zhangyang Road, Guangzhou University Town, Qingdao High-tech Zone,   |
|                                          | Anting New Town, Foshan Dongping New Town and Suzhou Industrial Park in China, Some European countries|
|                                          | such as France, Britain, Germany, etc.                                                             |
| Government and companies joint investment | Taiwan, Baoshan and Shanghai World Expo in China, Japan, etc.                                     |
| investment scheme                         |                                                                                                     |
| Public-private partnerships investment    | Kunming, Gui’an New Zone, Yanji, Hengshui, Zigong, Leshan and Sanya in China, etc.                  |
| scheme                                    |                                                                                                     |

3.1 Government direct investment scheme

In the government direct investment scheme, the government takes total responsibility for the construction funds of utility tunnels. The main sources of funds include government direct financial allocation, bank loan, discount fund and the utilization of the above three kinds comprehensively. The government’s ability to repay loan is mainly supported by the development and operation income of lands, and the local government financial subsidy and so on. At the same time, the pipeline companies need to pay operation and management expenses for using the utility tunnels in multiple energy systems, ensuring that the utility tunnels can obtain a stable cash flow and operation normally, as shown in figure 1. This kind of investment scheme is most common in the early period of the construction of urban underground utility tunnels.

![Figure 1](image_url)

Figure 1. The government direct investment scheme for utility tunnels.

Next, the utility tunnels in Europe are taken as an example for demonstrating the government direct investment scheme. In the 19th century, France, Germany and other European countries began to construct urban underground utility tunnels. Up to now, many European cities have formed a relatively complete network of utility tunnels with a total distance of more than 600 kilometers. The main reason for constructing and forming the large scale utility tunnels in European countries is that the government direct investment scheme are adopted. European governments have good financial capacity and are able to undertake the large financial burdens of the investment of the utility tunnels.

The utility tunnels in multiple energy systems, which are important guarantees for the normal production and lives of the city, are important infrastructure projects with prominent external effect. The process of the project construction and the government’s control to the project can be ensured
effectively by adopting the government direct investment scheme. In addition, it is difficult to attract social capitals because of the large investment cost, not obvious short-term benefits and low return rate of utility tunnels construction. Government funding can avoid these financial difficulties. This investment scheme is generally applied in areas with good financial conditions.

Due to the large investment cost, the government would face the shortage of funds and the increased financial burden in a short period if this investment scheme is adopted. The government should invest a large sum of money at one time, which aggravates the precipitation of assets in public utilities, and is not conducive to the development of investment channels and the use of private capitals. In addition, the utility tunnels built under this investment scheme are often met with difficulties that pipeline companies are reluctant to enter into the utility tunnels in multiple energy systems in the later operation and lease process, which would cause a waste of public resources.

3.2 Government and companies joint investment scheme

In the government and companies joint investment scheme, the government and companies (mainly pipeline companies) jointly invest in the construction of urban underground utility tunnels in multiple energy systems. This scheme, which is the most mature investment scheme, has been widely applied in Japan. The government and companies joint investment scheme for utility tunnels is shown in figure 2. The key point of this scheme is how to determine the investment amount of government agencies and pipeline companies scientifically and reasonably to balance the profits of all subjects. This scheme could be divided into two types: proportional apportionment scheme and companies investment and government complemented scheme.

![Diagram of government and companies joint investment scheme for utility tunnels.](Diagram)

In the proportional apportionment scheme, the government invests a certain proportion of the funds needed by the utility tunnels construction and the rest is shared by the pipeline companies. This scheme was first applied in Taiwan, where the government agencies afford 1/3 of the construction costs of urban underground utility tunnels and the pipeline companies afford the rest construction costs. The rest costs are allocated to the pipeline companies according to the space occupied by different pipelines, and the traditional direct-buried cost and so on. While in the companies' investment and government complemented scheme, the difference between the utility tunnels construction costs and the total funds supported by all pipeline companies is filled by the government. Among them, the funds supported by each pipeline company are determined comprehensively on basis of the traditional direct-buried cost, the space occupied by different pipelines, the economic strength of the pipeline companies themselves and so on.

Next, the utility tunnels in Japan are taken as an example for demonstrating the government and companies joint investment scheme. The construction costs of urban underground utility tunnels are
mainly afforded by the government. The pipeline companies, which can obtain loans to relieve the financial pressure, invest the rest costs according to the traditional direct burial cost of pipelines. The investment scheme could be effective in Japan because the costs of pipeline companies after entering into the utility tunnels have not been increased when compared with the traditional direct-buried cost. That is, the pipeline companies enjoy the benefits of the urban underground utility tunnels. Moreover, pipeline companies need to pay road usage fees when they lay pipelines underground directly, so this cost could be saved if the pipeline companies participate in investment of the utility tunnels. At the same time, a perfect legal system about the use of road and underground space has established by the government, which can restrict pipeline companies from entering utility tunnels and road excavation through legal effect.

To sum up, in the government and companies joint investment scheme, the large-scale construction costs are shared by all subjects, which is conducive to the raising of funds and reduce the government’s financial pressure. There is no lease risk after the utility tunnels are built, because the pipeline companies participate in the construction as the main investors, which guarantees the utilization efficiency of the urban underground utility tunnels. On the other hand, because the utility tunnels construction costs are higher than that of the traditional pipeline direct-buried costs, the pipeline companies may prefer to adopt the traditional direct-buried method. Moreover, it is difficult to determine the investment proportion that is approved by all subjects. Although it is generally considered that the ownership of the utility tunnels in multiple energy systems should be owned by the government after the completion of the utility tunnels construction, the boundary of property right is vague for the absence of a clear definition of the relevant laws and regulations. Thus, the complete supporting laws and regulations are required. However, there are no relevant complete supporting law and regulation in Chinese Mainland presently.

3.3 Public-private partnerships investment scheme

In the public-private partnerships investment scheme, government agencies and private companies sign franchise agreements, and the government agencies hand over part of the utility tunnels’ management and revenue rights to private companies for a long time. Both of them share the responsibility and possible risks. The government and private subjects can complement each other in this scheme. The government plays a coordinating role in supporting the project and supervising the implementation by using its identity and rights. The private companies, acting as the main executors of the project, provide services to the public sectors and obtain reasonable investment return through schemes such as user charge and government charge. This process is subject to the supervision of the public. Because the classifications of public-private partnerships investment scheme are different in different countries and international organizations, this investment scheme is classified considering Chinese actual situation and the World Bank’s classification, as shown in table 2.

Table 2. Classification of public-private partnerships investment scheme.

| Top Category | Sub Category | Three-stage Category |
|--------------|--------------|---------------------|
| Outsourcing  | Component Outsourcing | Management contract; Service contract; Design-Build (DB); Design-Build-Major-Maintenance (DBMM); Operation & Maintenance (O&M); Design-Build-Operation (DBO); |
|              | Turnkey      |                      |
| Concession   | Transfer-Operate-Transfer (TOT) [18] | Rehabilitate-Operate-Transfer (ROT); Purchase-Upgrade-Operate-Transfer (PUOT); Lease-Upgrade-Operate-Transfer (LUOT); |
In practice, the specific public-private partnerships investment scheme for urban underground utility tunnels in multiple energy systems should be selected with investment scope, operation scheme, pricing mechanism and management mechanism considered comprehensively. Not only the benefits of government and private companies, but also the relationship between the costs and profits of construction should be considered. So far, the fees charged from users cannot completely cover the construction costs of the utility tunnels, so a large amount of subsidize funds from the government and other relevant departments are still needed for the public-private partnerships investment scheme for utility tunnels. The public-private partnerships investment schemes that are suitable for utility tunnels could be divided into two types with the characteristics of the utility tunnels projects in China considered. One is divided according to the different subjects of property rights, which is typically represented by BOT and Build-Own-Operate (BOO). The other is divided according to the different funding support stages of the government, which is typically represented by Subsidize in Building, Operate and Transfer (SBOT), and Build, Subsidize in Operate and Transfer (BSOT). In the SBOT scheme, the construction period of utility tunnels is divided into the basic part and the operation part. The government departments mainly invest in the basic part, and the private investors invest in the operation part because the operation part is the main source of income after the completion of the utility tunnel construction.

In the public-private partnerships investment scheme, the government becomes a supervisor in the urban underground utility tunnels construction in multiple energy systems, achieving functional transformation. The government’s financial burden is lightened and the utilization ratio of funds is raised. Meanwhile, the government and social capitals share project risks in this scheme. It gives full play to the management advantages of social capitals and reduces the risks of the government. In addition, it can also improve the quality of construction and operation of the utility tunnels in multiple energy systems. Therefore, this scheme is more suitable for urban underground utility tunnels in the future.

4. Future Work
Based on the analysis of the existing investment schemes of urban underground utility tunnels in multiple energy systems, the cost and benefit sharing mechanism of urban underground utility tunnels for multi-stakeholders and the comprehensive benefit assessment of utility tunnels should be studied in the future research.

To determine the cost and benefit sharing mechanism, the influence of construction type, duty cycle, service intensity, operation cost and maintenance cost of urban underground utility tunnels should be analyzed first to identify the cost source. Then, economic returns, social benefits and comprehensive utilization of urban underground utility tunnels should be quantified. Differential pricing model of various pipelines including power pipelines that merge into utility tunnels should be proposed, considering public attributes of utility tunnels, benefit balance between supply and demand units, traditional laying cost and so on.

To assess the comprehensive benefit of urban underground utility tunnels, the different demands of various pipelines that merge into the utility tunnels should also be analyzed. Then, the guiding principles and technical principles of urban underground utility tunnels should be determined. The comprehensive evaluation system of utility tunnels would be constructed by choosing all-round
evaluation indexes of the benefit of the utility tunnels. The result of the comprehensive benefit of urban underground utility tunnels could be obtained by the comprehensive evaluation system.

5. Conclusion
In this paper, the existing investment schemes of utility tunnels in multiple energy systems are divided into three types according to the different investment subjects: government direct investment scheme, government and pipeline company joint investment scheme and public-private partnerships investment scheme. The characteristics, advantages and disadvantages of different investment schemes are analyzed in detail according to the actual investment cases, which could provide references for the future urban underground utility tunnels investments.

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