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Full-length article

Supply modes for renewable-based distributed energy systems and their applications: case studies in China

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Abstract: Distributed energy systems (DES), as an integrated energy system with coupled distributed energy resources, have great potential in reducing carbon dioxide emissions and improving energy efficiencies. Considering the background of urbanization and the energy revolution in China, the study investigates the renewable-based DESs supply modes and their application in China. A new method is proposed to classify DESs supply modes into three categories considering the renewable resource in domination, and their application domains are discussed. A comprehensive model is given for economic and environmental evaluation. Typical case studies show that the renewable-based DES systems can supply the energy in a cost-effective and environment-friendly way. Among them, the biomass waste dominated supply mode can not only achieve "zero" carbon emissions but also "zero" energy consumption, even though not yet economically attractive under the present policy and market conditions. Thus, recommendations are given to promote the further deployment of renewable-based DESs, regarding their supply modes, policy requirements, and issues to be addressed.

Keywords: Distributed Energy Resources, Distributed Energy System, Supply Mode, Biogas, New-type Village, Agricultural Resource Recycling.

1 Introduction

A distributed energy system (DES) is an integrated energy system with coupled distributed energy resources (DERs) [1–4]. It breaks the independent supply mode of electricity, cooling, heat, and gas, and helps build an integrated energy generation and consumption mode with improved energy efficiency [5].

Although new low-carbon technologies, including negative-emission technologies, and new concepts of micro energy grid and Energy Internet are becoming increasingly prevalent in China [6], it is difficult to present the differences between these technologies and concepts from the application perspective. Moreover, some cross-sector technology applications that couple energy with agricultural, environmental, chemical, and biological products are not considered as typical DESs. Although these coupled DESs are beneficial, they have not been studied adequately [7–8]. For example, agricultural and livestock wastes and

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household garbage can be utilized as distributed energy resources as well; however, this could cause environmental pollution and pose safety concerns if not handled well [9– 11].

Because DERs depend on the resource condition and application requirements, they are significantly restricted by the application scenarios of DESs. Considering the various application scenarios in China and its trend of regional economic integration development, it is of strategic significance to investigate and find the appropriate energy supply mode according to the scenarios [12–16]. Research on the distributed energy supply mode would provide not only a theoretical basis for optimal configuration but also a solid foundation for investigating the value and potential of different supply modes based on various application scenarios. Such research would further provide a guidance and policy advice on the application of DES for the enhancement of its financial viability and social and environmental benefits based on resource distribution. Therefore, a better connection must be established between the DER application scenarios and the supply modes.

However, the current studies mainly focus on economic analysis, optimal operation, or configuration of DES according to a specified application scenario [17–23], and only a few attempts have been made toward comparing different scenarios. For example, [24] analyzes the influence of applying integrated cooling, heating, and power systems in two types of buildings, i.e., residential and office buildings, in China. Although the methods of economic value evaluation of DESs have been established in [25,26] to address the optimization problem under different energy use scenarios, they are applicable only for industrial parks. Reference [27] developed a classified evaluation model of scenario competitiveness for the DES; however, it lacks a quantitative method for investment planning and economic evaluation. The concept of multi-scenario planning has been discussed in [28,29] to promote the local accommodation of renewable energy resources and enhance the comprehensive energy efficiency of the system. However, these studies do not show the correspondence between the energy supply modes and application scenarios.

A few studies have been conducted for investigating different energy supply modes for a specified scenario. Several typical supply modes of DERs are summarized in [30] but only for rural areas. Reference [31] proposed three energy supply modes for a typical DES in Tianjin through an economic analysis. This reference, however, did not investigate the method of determining an energy supply mode according to different scenarios.

Therefore, we first analyze three key application domains, followed by a discussion of typical DES supply modes in section 2. Then, an economic and environmental analysis model is introduced in section 3. In section 4, practical project cases are analyzed with a detailed discussion on the environmental benefits of biomass energy dominated DES. Finally, conclusions and recommendations are given to promote the development of these renewable-based DES in section 5.

2 Distributed energy system: application domains and supply modes

2.1 Main application domains in China

Distributed energy systems have developed rapidly since 2017. The development of DES is fundamentally inspired by many factors such as policy and energy environment. Taking these factors into account, a schematic of the main application domains in China is shown in Fig. 1.

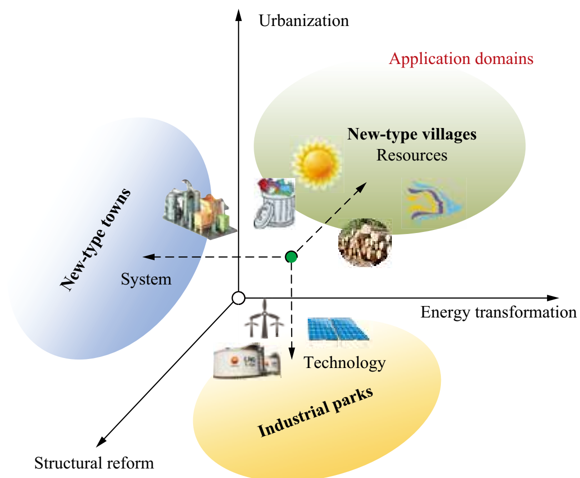

Fig. 1 Applications of DER in three domains

2.1.1 Background

(1) Urbanization offers an excellent opportunity for the development of DESs.

China's urbanization process has accelerated significantly in the past decade, and the urbanization rate is expected to reach 75% in 2030 from 60% in 2019 [36,37]. Urbanization with Chinese characteristics can be viewed from two sides [38–41]: 1) construction of new types of towns (new-type towns) to address the resource and environmental problems caused by the burgeoning population density and energy demand in urban areas; 2) construction of new types of villages (new-type villages) to achieve agricultural modernization and improve the living standards of farmers by concentrating the resources in rural areas.

With this background, China will face a huge energy demand in the future. And studies show that 80 million tons of standard coal will be consumed for an increase in every percentage point in urbanization, which would cause severe environmental issues if not handled well. Therefore, the energy system needs to be upgraded for the circular economy through energy transformation and structural reforms to ensure effective energy supply.

(2) Development of renewable energy is a reasonable alternative for energy transformation.

The energy transformation, characterized by the deep integration of renewable energy, power industry, and information technology, brings new opportunities and challenges.

Renewable-based DESs would be an alternative for a green and low-carbon energy system in the future, which would bring prosperity to the power industry and change the mode of energy production and consumption in a revolutionary way. However, there are still problems such as unreasonable energy consumption structure, low-efficient, and environmentally unfriendly ways of energy utilization, which brings challenges to energy transformation particularly in rural areas.

(3) Structural reform of the power system encourages the development of DESs according to the local conditions.

The market will become the main driving force if not the only one, partially due to the fast subsidy decline for renewables around 2020. It is always the important substance of structural reform for DESs to participate in electricity sales and market transactions and be competitive with little or no subsidy.

2.1.2 Application

China has abundant renewable resources, such as solar, wind, geothermal, and biomass energy [42–44], which would help achieve a high-quality urbanization, energy transformation, and structural reform. And waste recycling and utilization should be paid more attention to considering the development of circular economy. For example, the potential for biomass energy development in rural areas is tremendous. Theoretically, the bioenergy potential in China is approximately equivalent to 46 million tons of standard coal [45]. This potential could help meet the local energy demand as well as the ecological and environmental requirements.

In new-type villages, the problems of resource waste and environmental pollution in the process of urbanization should not be ignored. In the city of Bazhong, for example, 183 villages and towns with a population of 301,000 generate more than 300 tons of household garbage a day. More than 70% of the household garbage is untreated and transferred to nearby landfills. The Chinese government started to build resource recycling and utilization bases since 2017, and many enterprises are actively developing and applying various technologies of waste treatment. The positive effects of DESs characterized by the environment-friendly utilization of waste resources are significant, and the biomass resources in the surrounding rural areas can also be utilized for combined heat and power generation.

In industrial parks that are characterized by the industry cluster zone economy, there is a large space for DESs application [36,37] since the structural reform of the power system primarily focuses on industrial parks. Moreover, according to the latest statistics from the China Electricity Council, China’s industrial electricity consumption accounted for 68% in the first half of 2019, of which industrial parks were the major consumers [32–35].

In new-type towns, the increase in the amount of garbage is a big problem. The supply mode dominated by utilization of waste as resources will draw more attention. In new-type villages, the problems of resource waste and environmental pollution caused by improper disposal of rural waste, and the challenge of utilizing the large amount of biomass energy resources, remain to be addressed. For those industrial parks whose energy network has not been built yet or is under planning and renewable energy is abundant, DES can be established to reduce the construction demand of the energy network, which could additionally play an important role in energy transformation.

2.2 Typical supply modes

The supply modes of DESs are closely related to the application scenarios of DESs. To establish a connection between DERs application scenarios and their supply modes of DESs, we need to classify the DESs. A simple way is to consider the demand types (electricity, heating, and cooling, or a combination of these) or the application scenarios (such as community, hotel, or hospital) of DES; however, it is difficult to elucidate the relationship of DES and the application scenarios with these classifications [46,47]. Therefore, we propose a new method of DES mode classification based on the resource domination which depends on the application to a great extent [48].

Three types of supply modes are categorized in this study: 1) wind and solar energy dominated, 2) biomass energy dominated, and 3) utilization of waste resources dominated. Here, “dominated” is a relative concept that refers to the dominant resource in the system energy supply and, to some extent, indicates the conditions and energy requirements of the application scenarios.

To describe the composition and structural characteristics of DESs clearly, a unified energy bus model proposed in [21] is used to describe the system based on different energy forms, including electricity, gas, and heat. Fig. 2 shows a bus-based structure for the three supply modes of DES, which includes various energy resources (such as electricity, natural gas, and renewable energy sources) and load. And the energy storage system and energy management system are also included.

(1) Wind and solar energy dominated supply mode

As China has increased its deployment of renewable energy over the past decade, wind and solar energy dominated supply mode is relatively mature and widely used in urban and rural areas. Since investment in rural power grids is relatively low, it is an ideal application domain for renewable-based DESs.

Generally speaking, this mode is of great potential in the eastern and central parts of China. The development potential of DERs like distributed PV and wind power in these areas accounts for more than half of the total in China. Owing to the intermittent characteristic of its DERs, an energy storage or other dispatchable generators are always added to cope with power fluctuations and improve the reliability of supply in this mode [49,50].

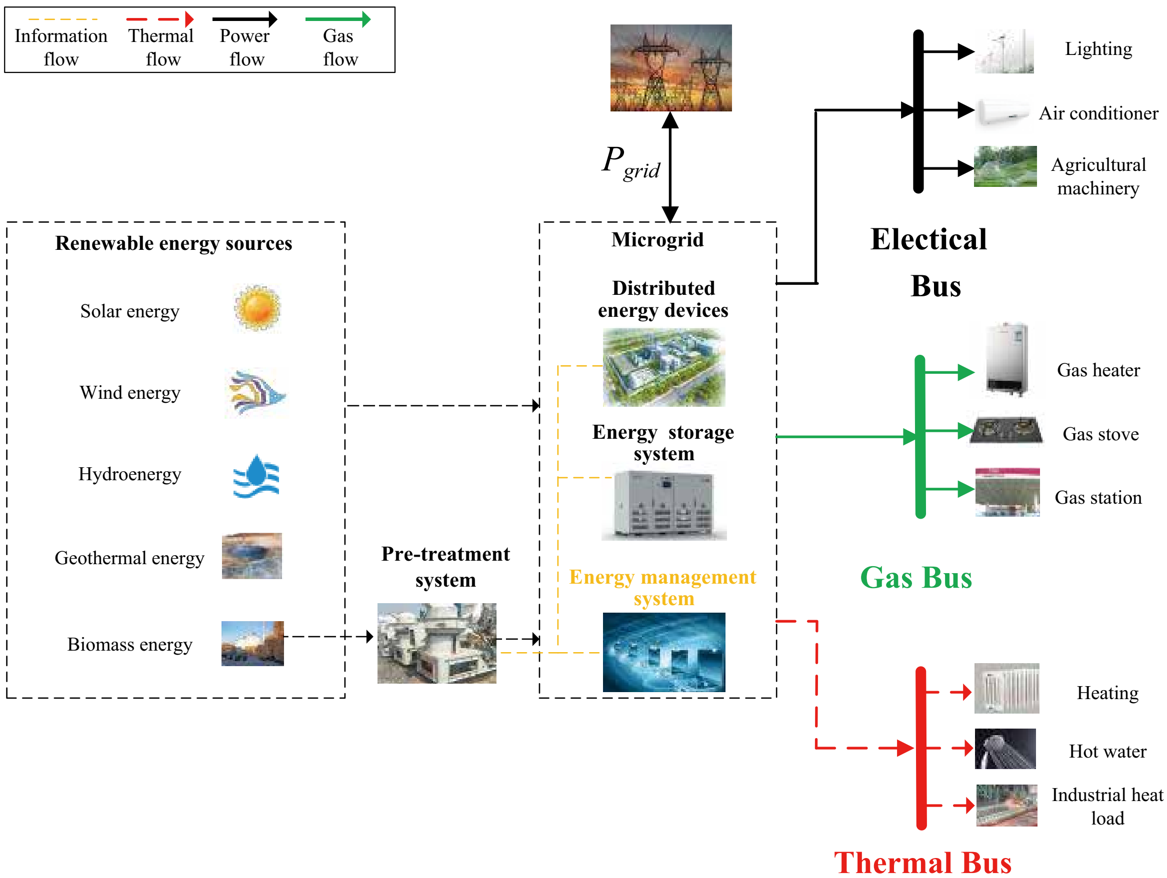

Fig. 2 Three typical supply modes of DES

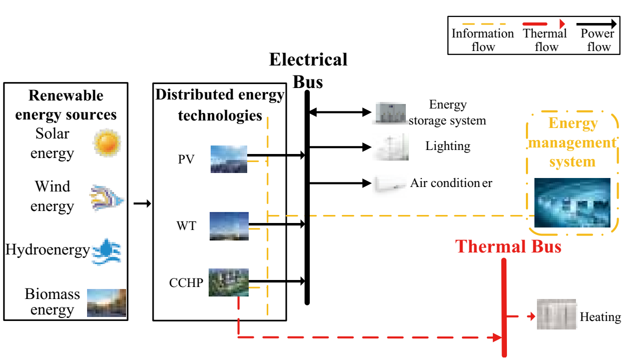

Fig. 3 Structure of wind and solar energy dominated DES

In the 13th five-year plan (2016–2020), the government has reduced the Feed-in Tariff (FIT) to respond to technology maturation and production cost decrease [59]. With the increasing economies of scale and further technological improvements, the costs of wind and solar power would continue to decline.

(2) Biomass energy dominated supply mode

China produces 1 billion tons of straw every year. As the most stable renewable energy with multiple types of output (such as natural gas, fertilizer, and electricity), the development of biomass energy is of great significance to the rural and suburb areas in China [54].

The use of energy is different from region to region. The utilization ratio of coal, straw and firewood accounts for more than 90% of the total domestic energy utilization in rural areas of northeastern China, and the utilization ratio of straw ranks first in China. Since straw and firewood resources are rich in northwest and northeast China, the biogas power generation and its cogeneration can be developed

The biomass energy dominated DES shown in Fig. 4 is composed of renewable energy technologies, energy management systems, and load. The system is mainly based on biomass power generation or gasification technology, and it usually has a relatively stable output. Based on the biomass gas fermentation technology, the system achieves a comprehensive utilization of biomass energy resources, such as crop straw, human and animal manure, and household garbage. The biogas residue, as an important medium of ecological circulation, can be used as a fertilizer in farms or orchards. The full use of biomass resources and flexible operation can promote distributed production and consumption of biogas.

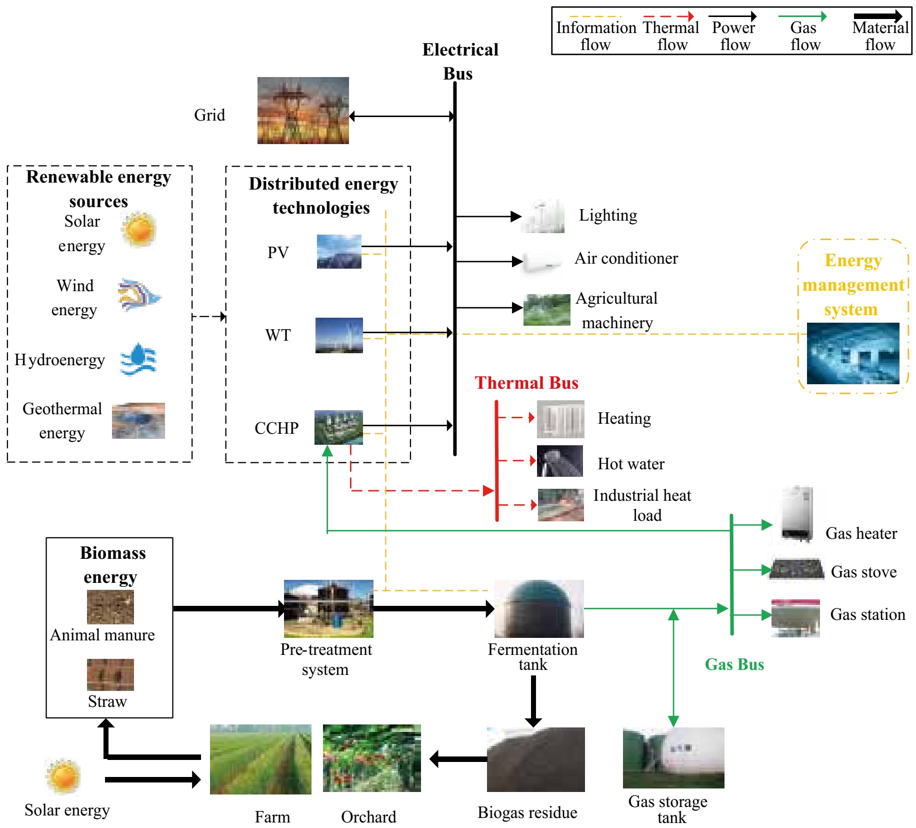

Fig. 4 Structure of biomass energy dominated DES

(3) Supply mode dominated by utilization of wastes as resources

Recovering energy from waste is a practice that is widely followed in many countries [56]. In 2015, the Opinions on Accelerating the Construction of Ecological Civilization and the Overall Plan for the Reform of Ecological Civilization System issued by the State Council clearly required to strengthen the effective connection between “classified household garbage recycling” and “renewable resource recycling” [36]. Efforts should be made towards reducing consumption and pollution, and improving the supply and industrialization of ecological technologies, to provide an impetus for transforming the economy and society green ones [58]. The DES dominated by utilization of wastes as resources emerged in new-type towns because of their highly centralized disposal rate of waste dumps.

This type of DES is usually found in new-type towns that have abundant power resources (such as hydro energy, wind energy, solar energy, geothermal energy, or natural gas) and power grids of high quality and reliability; furthermore, the high utilization efficiency of renewable energy makes the system more economical. The output products of the system differ significantly in the use of household waste, residues of industrial wastewater, and lowgrade heating sources for power and heat generation. These systems are usually restricted by the utilization conditions of heat resources.

This study attempts to classify the supply modes of DERs in a general way considering the domination of resources rather than by technology. Since the fossil fuel dominated mode is excluded in this paper, combined heat and power technologies using natural gas or diesel are not considered even though they are high efficient. This is based on the idea that DES will be renewable energy dominated in the future.

3 Analysis model

To analyze the relationship between supply modes and application domains, the economic and environmental evaluation models considering the project life cycle are discussed in this section.

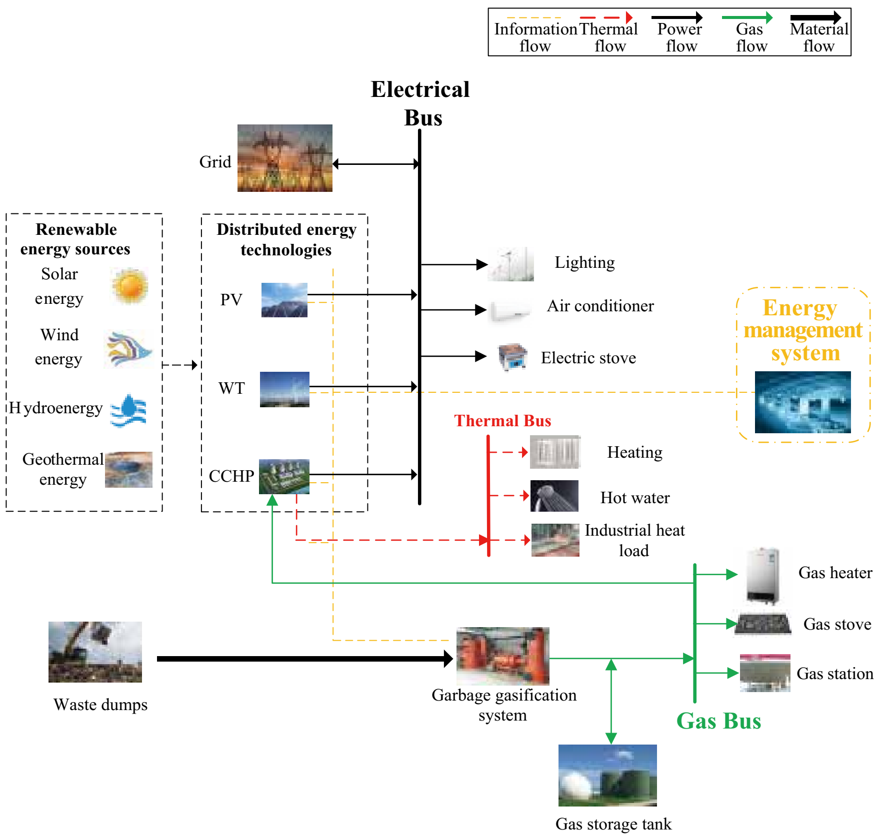

Fig. 5 Structure of utilization of waste resources dominated DES

3.1 Economic analysis model

(1) Net present value

When investing in a project, the net present value is generally used to measure the benefit of the investment. The smaller the total cost of the investment plan in the life cycle of the project, the better the scheme is. The net present value of total cost is calculated as follows:

$$C_{NPV}=\frac{C_{ann,t}}{K_{CRF}(r,T_{Pro})} \tag{1}$$

where C_{NPV} represents the net present value for the total project cost, CNY; $C_{ann,t}$ is the total annual cash flow, CNY; and $K_{CRF}(r,T_{Pro})$ is the capital recovery factor for the project period, which is used to calculate the present value of average annual cash flow, where r is the interest rate and T_{Pro} is the project period, year. K_{CRF} is given by

$$K_{CRF}(r,T_{Pro})=\frac{r(1+r)^{T_{Pro}}}{(1+r)^{T_{Pro}}-1} \tag{2}$$

(2) Total annual cash flow

The total annual cash flow is calculated by Eq (3).

$$\begin{aligned}C_{ann,t}&=C_{ann,cap}+C_{ann,rep}+C_{ann,om}\\&+C_{ann,ele}+C_{ann,bas}-B_{sel}-B_{sub}\end{aligned} \tag{3}$$

where $C_{ann,cap}$, $C_{ann,rep}$, $C_{ann,om}$, $C_{ann,ele}$, and $C_{ann,bas}$ represent the annual capital cost, annual replacement cost, annual cost of maintenance, annual cost of electricity, and annual basic cost of electricity, respectively, CNY; B_{sel} represents the annual income of selling electricity, gas, and heating, and B_{sub} represents the subsidy income, CNY. Among them, $C_{ann,om}$, $C_{ann,ele}$, B_{sel}, and B_{sub} are related to the 8760 h operation of the system

(3) Financial internal rate of return

The financial internal rate of return (FIRR) can be expressed as

$$\sum_{t=0}^{n}\left(C_{ann,t}-C_{ann,cap}\right)\frac{1}{\left(1+FIRR\right)^{t}}=C_{cap} \tag{4}$$

where $FIRR$ represents the FIRR of DES.

3.2 Environmental analysis model

(1) Greenhouse gas emission

The greenhouse gas emission of a project is calculated as follows [62–64]:

$$E_g=\sum_k F_k\times EF_{kg} \tag{5}$$

where E_g, F_k, and EF_{kg} represent the emission of greenhouse gas type g, consumption of energy type k, and emission factor, respectively, kg.

(2) Equivalent carbon dioxide emission

For the convenience of comparison, the total greenhouse gas emission of the project is described by the equivalent carbon dioxide emission of the project:

$$E_{\mathrm{eq}}=\sum_g E_g\times GWP_g \tag{6}$$

where E_{eq} is the equivalent carbon dioxide emission, kg; GWP_g is the global warming potential of greenhouse gas g.

The GWP of several greenhouse gases are listed in Table 1 [65–67].

Table 1 GWP of several greenhouse gases

	CO_2	CH_4	N_2O	SF_6
GWP	1	25	298	22800

(3) Carbon dioxide emission reduction

The emission reduction of a project is given by,

$$ER=BE-E \tag{7}$$

where ER is the carbon dioxide emission reduction, BE is the carbon dioxide emissions generated by alternative energy (power from the grid in this study), and E represents the carbon dioxide emissions generated by the DES.

4 Case study

Economic analysis of the three typical supply modes in China is discussed in this section. For comparison of different supply modes, the FIRR and carbon dioxide emission reduction of each DES is calculated. The emphasis is on the environmental benefits of bioenergy dominated DES, because the biomass industry currently leads the transformation of the type of energy consumption.

4.1 Economic analysis of typical supply modes

(1) Case description and parameters

Case 1: industrial park micro-grid

Industrial parks are generally dominated by production-oriented companies with large and stable loads. The utilization rate of wind and solar energy is significantly improved when the load is stable and large. Therefore, wind and solar energy dominated supply modes are widely used in the industrial parks in China where adequate resources are available.

Case 1 analyzes a typical industrial park DES. The system combination is shown in Fig. 6. The DES mainly consists of PV, wind turbine (WT), CHP, ground source heat pump, and various types of energy storage. It can be observed that PV and wind turbines supply the most power in this case. The annual energy consumption of this park is approximately 6.7 GWh, and clean energy generation supplies~30% of the total load demand. More details are given in Table 2.

Table 2 Investment cost, utilization hours, and feed-in tariff of renewable energy technologies

	Investment cost (CNY/kW)	Utilization hours	Feed-in tariff (CNY/kWh)
WT	8000	1642	0.77
PV	6500	1000	1.02
MT	15000	4500	0.77

Case 2: urban solid waste treatment + distributed energy

Ecological towns are an inevitable direction of urbanization in China. In developing new-type towns, a huge requirement for effective garbage disposal exists. Therefore, the garbage disposal industry is a key point of the 13th five-year plan, which is strongly supported by the government. Compared with traditional composting and landfill techniques, garbage gasification has high efficiency and its environmental impact is relatively small. Combined with garbage disposal, DES can be more economical and environmentally friendly; however, very little research has

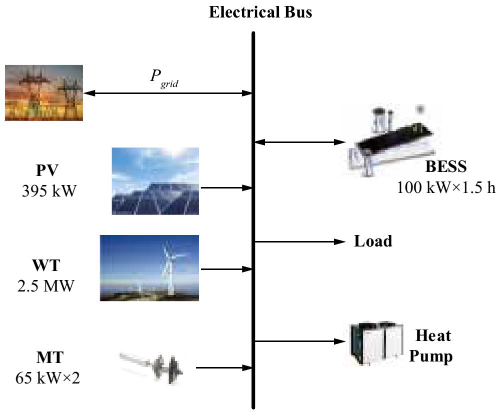

Fig. 6 System configuration of a typical industrial park DES in Beijing

been conducted on this perspective.

A municipal solid waste (MSW) system with a daily disposal capacity of 50 tons (Fig. 7) is taken as an example; it can be applied to ordinary towns with a population of ~50,000. According to the National Development and Reform Commission, each ton of MSW is converted to 280 kWh of electricity. The economic parameters and the daily operation data are shown in Tables 3 and 4, respectively.

The system runs for 10 h per day, consuming 1.5 tons of MSW and producing 500 cubic meters of gas per hour. The system itself is made of combustible gases from organic materials, which can be used for self-production or external use. The revenue of waste-to-energy power generation projects includes electricity generation income and garbage disposal subsidy.

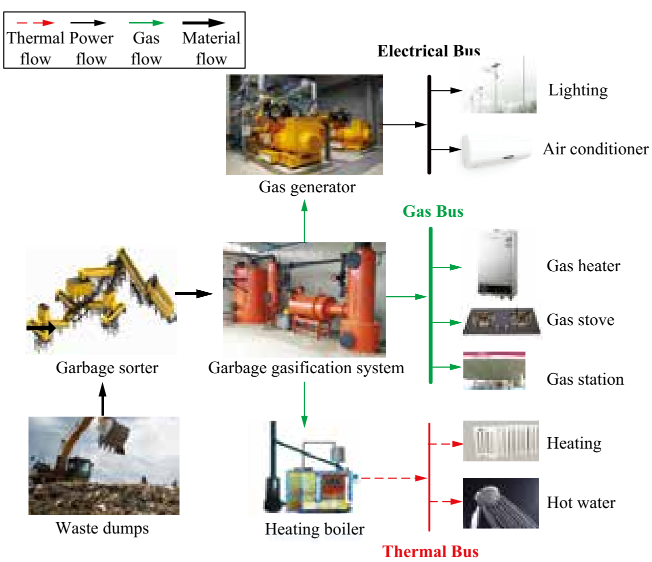

Fig. 7 System flow chart of the garbage disposal process

Table 3 Economic parameters of utilization of wastes dominated supply mode system

Investment cost (CNY/kW)	Disposal subsidy (CNY/ton)	Feed-in tariff (CNY/kWh)
17,763	0.2	0.65

Table 4 Daily operation data of utilization of wastes dominated supply mode system

Run time (h)	MSW consumed (ton)	Gas production (m^3)
10	15	5000

Case 3: agricultural resource recycling + distributed energy

Table 5 Economic parameters of the system

Investment cost (CNY/kW)	Straw (CNY/ton)	Feed-in tariff (CNY/kWh)
10,140	170	0.75

In recent years, the biogas industry has been sprouting in China. Taking livestock and poultry manure, crop straw, urban household waste, industrial organic waste, among others, as raw materials, the biomass gas fermentation technology is environment-friendly (Fig. 8). The guidelines on promoting the industrialization of biomass gas specify that the annual output of biomass gas will be higher than 10 billion cubic meters by 2025 and the amount will be double by 2030 [60].

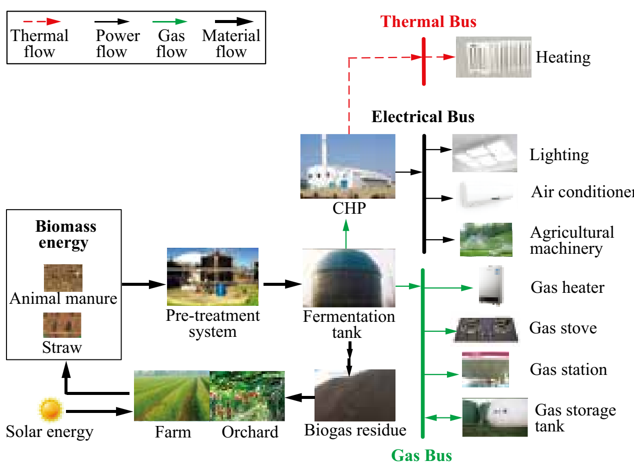

Fig. 8 Agricultural resource recycling-based DES

The economic parameter of the agricultural resource recycling-based DES is shown in Table 5.

(2) Results and analysis

The results of the three case studies are given in Table 6.

In Case 1, the FIRR is approximately 8.0%, which is generally taken as the fiducial FIRR of a conventional power plant in China when the interest rate of loans is 3.2%. In this case, approximately 1558.8 tons of carbon dioxide emissions can be cut.

The FIRR of the MSW power generation project in Case 2 can reach 13.3%, which can attain a normal profit level. This system will effectively reduce carbon dioxide emissions by 5791 tons, which is equal to the emissions of 1300 large-sized cars.

The FIRR of Case 3 is calculated to be 6.6%, which fails to attain the ideal profit level. It has not reached its full economic potential, which could be attributed to many reasons. For example, the technology and the industry chain of biomass technology are not mature. Given that the biomass technology is progressing rapidly and becoming increasingly cost-effective, it is believed that its economic indices will improve with the maturing technology and lowering costs.

Although the FIRR of biomass energy dominated DES is currently relatively low, biomass dominated DES projects are supported strongly by the government because of their great environmental benefits and broad application prospects.

Under the current electricity price policy, most biomass power generation projects maintain a tiny profit level. Moreover, in the near future, there is no room for a significant reduction in the cost of biomass power generation. Traditional agricultural and forestry straw power generation is mainly pure power generation, with energy efficiency below 30%, while that of biomass cogeneration can reach as high as 90%, which is of a promising future.

Table 6 Comparison of DESs in different application domains

	Application domain	Supply mode	FIRR	Social or environmental benefits
Case 1	Industry parks	Wind and solar power dominated	~8%	Emission reduction
Case 2	New-type towns	Waste resources dominated	>8%	Negative emission
Case 3	New-type villages	Biomass energy dominated	<8%	Environmental and agricultural benefits

4.2 Environmental benefits of biomass energy dominated DES

In this section, the environmental benefits of the agricultural resource recycling-based DES (Fig. 8) are discussed in detail, even though its economic profit is not so good on current policy and market conditions.

(1) Environmental benefits

The biomass gas fermentation technology can be combined with agriculture, fishery, and processing industries to achieve the integrated development of rural biomass energy technology and agricultural production, rural development, and ecological protection. Based on the biomass gas fermentation technology, the system shown in Fig. 8 achieves comprehensive utilization of biomass energy resources. The biological 'natural gas' produced by the gasifier and purification technology is used for power generation, and the biogas residue is used as fertilizer in farms or orchards. The environmental benefits of the system shown in Fig. 6 are outstanding.

Here, straw is taken as an example. A ton of straw can produce approximately 270 m^3 of biogas, the products of which, when used in a CHP unit, are shown in Table 7 [61]. The project has no carbon emissions for its participation in the global carbon cycle in nature.

Table 7 Energy products of 1 ton of straw

Electricity (kWh)	Heat produced (kWh)	Fertilizer (kg)
494.91	907.34	35.83

If this 1 ton of straw is not used in agricultural resource recycling DES, the equivalent carbon emissions and coal consumption for the straw treatment and energy demand are calculated as followed.

For straw treatment, a comparison is made with bury 1 ton of straw in field, because about 43% of straws are addressed in this manner nowadays. The energy produced by 1 ton of straw is supplied by electricity from coal. The results show that burying 1 ton of straw in field will produce 40.5 kg of methane and 0.058 kg of nitrous oxide, which are potent greenhouse gases and cannot participate in the global carbon circulation [62,63]. To supply the equivalent energy by electricity from coal, 419.19 kg of CO_2 is produced for electricity demand and 784.20 kg for electric heating; in this process, approximately 0.56 tons of standard coal is consumed.

The equivalent carbon emissions and standard coal of these two systems for consuming 1 ton of straw and supply equivalent loads are shown in Table 8.

Table 8 Equivalent carbon emissions and coal consumption of two systems

	$CO_{2\text{-}eq}$ (ton)	Coal (ton)
Agricultural resource recycling+ distributed energy	0	0
Straw burying in field+grid	2.35	0.56

As the biomass waste such as straw is part of the global carbon circulation in the ecosphere, the CO_2 emission impact of biomass utilization is usually not considered. However, landfill gas such as CH_4 leakage into the atmosphere not only fails to participate in global carbon circulation, but also brings a greenhouse effect 26 times that of CO_2, thus causing greater harm to the environment. As shown in Table 8, the agricultural resource recycling-based DES can reach "zero" carbon emission and "zero" energy consumption compared with the straw burying in field and purchasing electricity from the grid mode.

(2) Analysis

The potential environmental benefits and enhanced efficiency of bioenergy dominated DES deserve more attention. The biomass energy dominated DES, combined with agricultural resource recycling, can achieve 100% emission reduction compared with the conventional energy supply mode, according to the results in subsection 4.2.

Biomass energy resources are convenient to use because of their lower environmental impact; additionally, they have higher efficiency. Accordingly, the 13th five-year plan emphasizes the importance of developing biomass heating and power generation.

5 Conclusion

With better renewable energy consumption and lower benchmark lending rates, the economic benefits of DES projects are improving steadily in China. In the case of industrial parks, it is appropriate to promote the wind and solar energy dominated supply mode, with a focus on coordinating the grid and the DES. A DES, combined with an MSW system or biomass gas fermentation technology, is suitable for new-type towns because it is clean and environment-friendly. Furthermore, it is suitable to promote the supply mode dominated by the utilization of wastes as energy resources, and the wind and solar energy dominated supply mode in new-type villages and remote areas with abundant resources. Other major conclusions drawn from this study are as follows:

(1) Recycling of waste materials should be strengthened.

Urban wastes, including waste papers and kitchen garbage, are good energy resources that provide great opportunities for developing DES and achieving green and sustainable development based on resource recycling. Biomass energy can be converted into a variety of energy products and improve the local environment by processing wastes, which play an important role in developing a circular economy.

However, utilizing waste materials could sometimes be disadvantageous as well. For example, straw and animal manure, which could be used as biogas resources and organic fertilizers, will cause severe air pollution when burnt directly.

However, it is possible to reduce the wastage of resources and environmental pollution, and protect the climate and ecological environment, through waste recycling and utilization.

(2) Policy and technology must be improved.

It is expected that the 14th five-year plan will continue to propose more requirements from the perspectives of ensuring energy supply, accelerating the adjustment of energy structure, promoting energy conservation, and emission reduction. This indicates that the renewable-based DES will play a more important role in the 14th five-year plan period. Therefore, the policy support for projects across sectors and industries must be strengthened.

A clear policy framework and a predictable market environment are required to promote the development of cost-effective energy sources, especially biomass. The government could offer more policy support for developing abundant renewable energy resources to meet the local energy demand. Furthermore, establishing a demonstration and training facility for advanced renewable energy systems could scale-up the utilization of renewables at the local level. Policy interventions and market may be required to support the establishment of supply chains and proper pricing of biomass and waste. What is more, with the emergence of new technologies for comprehensive utilization of resources and waste, formulating and improving the technical and environmental standards are very important.

This paper focuses on the analysis and discussion of the supply modes and their applications in China. Future study will focus on the application potential assessment of typical supply modes in the key applications and the optimization design of supply modes of DESs in the regional subdivision.

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