IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received January 22, 2021, accepted February 16, 2021, date of publication February 19, 2021, date of current version March 2, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3060421

Urban Waste Disposal Capacity and Its Energy Supply Performance Optimal Model Based on Multi-Energy System Coordinated Operation

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This work was supported in part by the National Key Research and Development Program of China under Grant 2017YFB0902100.

ABSTRACT In the world with Zero Waste City and Energy Internet construction is promoting to meet waste reduction and power grid regulation flexibility improvement. Based on the waste stockpile and disposal demands, the waste disposal facilities multi-time scale model of energy supply and demand is proposed. On these premises, This paper presents the Multi-energy Waste Disposal System (MEWDS) topology and its optimal model based on coordinated operation of multi-energy system and waste disposal facilities to maximize economic benefits. Through simulation, the case studies are performed for the waste stockpile and multi-energy operation data of a Chinese city from different waste disposal scenarios to demonstrate. The proposed MEWDS optimal model can make the waste reduced and the economic benefits best. Meanwhile, it can also improve the flexibility of power grid regulation effectively.

INDEX TERMS Waste disposal facilities, multi-energy waste disposal system, zero waste city, power grid regulation.

I. INTRODUCTION

With the development of society and waste management across the globe, Zero Waste City has become the goal of more and more countries or cities. Cappanori, Italy, as the leader of European zero waste cities, which established the first zero waste research center in Europe and joined the Zero Waste Europe Union. European cities have moved towards a zero waste management network [1]. Kitakyushu, Japan, is a typical environmental governance city recognized by the United Nations, which the promotion of 3R (Reduce, Reuse, Recycle) waste management and Zero Waste City make its international influence enhanced significantly in environmental governance [2]. In 2019, Sydney, Australia, implemented a plan called *Leave Nothing to Waste*, which opened up a zero waste road and proposed to achieve the goal of no waste by 2050 [3]. The Chinese government have developed pilot work of Zero Waste City in 2019 and forming a systematic criterion construction in 2020 [4]. With the development and promotion of Zero Waste City in the world, the energy system of Zero Waste City still need to research in depth.

In the process of Zero Waste City construction, the urban waste disposed by the large-scale waste disposal facilities, which can supply the energy such as electricity, thermal and gas, is as the same important as that of solid waste source reduction, garbage classification, waste filling and transfer. Considering the characteristics of energy supply and demand from garbage disposal, there will be a great change in the architecture of urban energy system with the large-scale waste disposal facilities connected to the urban energy system. Waste incineration power plant is the main way to deal with waste in the world. In China, the scale of environment friendly waste incineration power plant is increasing. According to the data of National Bureau of statistics, the incineration capacity of urban domestic waste in China is about 1×10^8t, and the capacity is 38×10^4t per day by 2018. According to current trends, China's waste incineration capacity will reach 600,000 tons per day by 2020, and its installed capacity will reach 12×10^6kW. Furthermore, as the

The associate editor coordinating the review of this manuscript and approving it for publication was Eklas Hossain.

waste incineration capacity continues to increase, the waste incineration power plant will become an important link in Zero Waste City energy supplement [5]. For faeces treatment, a 6 kW rated power faeces treatment facility can treat 1.2 t faeces waste and produce $5 \times 10^6 m^3$ biogas in a day. Furthermore, a city can produce $940 \times 10^4 t$ feces in a year, which the natural gas obtained from biogas purification by faeces treatment is equivalent to 6% of the annual natural gas consumption with Tian Jin, China as an example [6]. So, natural gas obtained from faeces treatment is one of the key links in Zero Waste City energy supplement.

With development of high proportion of renewable energy [7]–[9] and the integration of large-scale waste disposal facilities into the urban multi-energy network, the architecture and morphological characteristics of the multi-energy system will change radically, which have higher challenges for its flexibility, economy and regulation.

Considerable research work has been done with respect to the modeling, optimal planning and operation of multi-energy systems. For example, reference [10] proposed an object-oriented modeling methodology for planning and operations control of the multi-energy system to support the balancing of fluctuating renewable generation based on nodal analysis. In order to increase renewable energy penetration in power systems, an optimal design and operation method of regional multi-energy system that considers system reliability constraints under different-level renewable energy penetrations was presented in [11]. To improve the energy efficiency, flexible operation condition of multi-energy system, reference [12] proposed an optimal planning method for the multi-energy system that considers the thermal storage capacity of the heating network and the heat load. Reference [13] proposed a coordinated optimization model of electricity heat hydrogen multi-energy storage system to improve the flexibility of power grid. For increasing energy utilization efficiency and renewable energy accommodation, reference [14] proposed a two-stage mixed-integer linear programming approach for district level multi-energy system planning considering distributed renewable energy integration. For the nonlinearity and modeling complexity of the internal energy, reference [15] proposed a robust operational optimization framework for smart districts with multi-energy devices and integrated energy networks,which have ability to capture network limits and uncertainty. Reference [16] explored interaction patterns for multi-energy demand management and proposed an integrated demand response mechanism for the industrial integrated energy system, which the total dispatch cost and consumers' energy procurement cost are both reduced. Reference [17] proposed a coordinated optimization model of the multiple energy systems in consideration of demand response based on the uncertainty of photovoltaic output to the optimal operation of the system. Reference [18] paper proposed a new optimization scheduling method basedon the environment and economy, which can achieve a balanced decision-making results by taking environmental protection and economic objectives into account. In order to achieve coordinated and efficient operation of multi-energies, an integrated energy system was presented based on the analysis of scheduling elasticity of different types of loads in reference [19].

With the development of Zero Waste City and multi energy system, the waste disposal facilities in the Zero Waste City multi-energy system should be eco-friendly and have a high ability to coordinate and optimize various energy sources. At present, there is no previous research paper about the optimization model of urban waste disposal capacity and its energy supplement considering the coordinated operation of waste disposal facilities and multi-energy system.

Consequently, Main purpose of the paper is to realize the optimal operation of waste disposal facilities with multi-energy-system, which make large-scale reduction of city's waste in the most economical operating mode and improve the flexibility of power grid regulation. More concretely, main contributions of this paper are listed as follows:

1) The Multi-energy Waste Disposal System is established. Furthermore, the energy supply and demand model of multi time scale waste disposal is proposed in detail, which can realize the waste disposal to participate in the operation of multi-energy system.

2) The coordination and optimization model with the largest total profit during the operation of MEWDS is presented. And MEWDS optimization operation strategy is developed. The proposed MEWDS optimal model can reduce the large-scale waste effectively and provide a certain regulation capacity for power grid concurrently.

3) Through comparison to the current operation scenario of waste disposal facilities, impacts of the economy, waste disposal ability and the flexibility of power grid regulation are discussed. The proposed MEWDS optimal model can get more economic benefits to reduce operating costs from energy supply and storage and waste reduction, and it will also improve eco-environmental quality effectively.

The paper is structured as follows. Section II describes the main features of MEWDS and multi-time scale waste disposal facilities energy supplement modelling. Section III discusses the optimal operation model and the optimal operation strategy for MEWDS put forward. Section IV illustrates case study and discusses simulation results in detail. Conclusions are given in Section V.

II. THE MULTI-ENERGY WASTE DISPOSAL SYSTEM MODELLING

A. THE STRUCTURE OF MEWDS

For the daily waste and large-scale livestock and poultry excrement, the waste incineration power plants and faeces treatment facilities are mainly used to transform waste into energy. Then, considering the energy conversion and storage device, such as electrolyzer, electric boiler, heat storage, gas storage, hydrogen storage, and fuel cell *et al.*, the Multi-energy Waste Disposal System powered by high proportion of renewable energy is illustrated in Fig. 1.

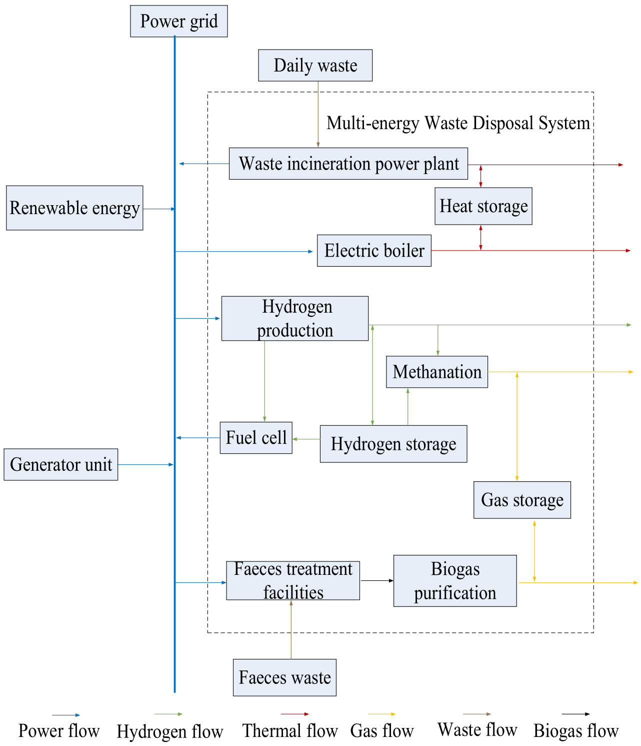


FIGURE 1. The multi-energy waste disposal system.

B. WASTE INCINERATION POWER PLANT MODELLING

The external characteristics of waste incineration power plant can be regarded as an energy supply device during waste incineration. Furthermore, for the time delay dynamic characteristics of heat storage, heat network and heat area, the dynamic transmission process is different between electricity and heat supply. The multi-time scale energy supply model of waste incineration power plant considering the supply cycle and start-stop control of electricity and heat supply is given by

$$\begin{cases} W_{WIPP-E} = \sum_{t=1}^{T_E} P_{WIPP-E} \cdot \Delta t_E \\ P_{WIPP-E}(t) = x_{WIPP-E}(t) P_{WIPP-E} \\ \sum_{n \in N} \Delta t_{En} = T_E \end{cases} \tag{1}$$

$$\begin{cases} W_{WIPP-H} = \sum_{t=1}^{T_H} P_{WIPP-H} \cdot \Delta t_H \\ P_{WIPP-H}(t) = x_{WIPP-H} P_{WIPP-H} \\ \sum_{n \in N} \Delta t_{Hn} = T_H \end{cases} \tag{2}$$

where P_{WIPP-E} and P_{WIPP-H} are the equivalent electricity and heat output of waste incineration power plant, Δt_E and Δt_H are the waste incineration power plant operation time of power and heat supply, T_E and T_H are the dispatching period of power and heat supply, $x_{WIPP-E}(t)$ and $x_{WIPP-H}(t)$ are the state of power and heat supply of waste incineration power plant at a given time and the value is 0 or 1, while 0 means stop and 1 means start-up.

C. FAECES TREATMENT FACILITY MODELLING

The process of faeces treatment consumes a lot of electricity, and the natural gas can be purified by the biogas produced from faeces treatment, which can sell and supply gas by coordinate gas networks for economic payoff. In order to achieve the coordinated operation of faeces treatment facilities and multi-energy systems and meet the demand of power grid regulation. the start-stop control and energy supply cycle of the faeces treatment facility should be considered. Then, the external characteristics of faeces treatment facility can be regarded as an electricity to gas conversion device and the multi-time scale energy supply model of it is given by

$$\begin{cases} P_{FTF-G}(t) = \eta_{FTF} \cdot P_{FTF-E}(t) \\ W_{FTF-G} = P_{FTF-G}(t) \Delta T_G / H_C \\ P_{FTF-E}(t) = x_{FTF-E}(t) P_{FTF-E} \\ \sum_{n \in N} \Delta t_{Gn} = T_G \end{cases} \tag{3}$$

where η_{FTF} is the operating efficiency of faeces treatment facility, $P_{FTF-E}(t)$ and $P_{FTF-G}(t)$ are the electricity consumption power and gas production power during the operation of waste treatment facilities at a given time, $W_{FTF-G}(t)$ is the gas supply flow of faeces treatment facility, Δt_G is the faeces treatment facility operation time of gas supply, T_G is the dispatching period of gas supply, H_C is the low calorific value of gas, $x_{FTF-E}(t)$ is the state of faeces treatment facilities at a given time and the value is 0 or 1, while 0 means stop and 1 means start-up.

D. ENERGY CONVERSION AND STORAGE DEVICE MODELLING

The optimization analysis of MEWDS in this paper mainly considers the power flow. For the energy conversion and storage device models of MEWDS such as electricity to hydrogen production, electric boiler, heat storage, gas storage, hydrogen storage, methanation, and fuel cell have been established in relevant literatures, In the following, the models are established from reference [13], [20]–[22].

1) ENERGY CONVERSION DEVICE MODELLING

The energy conversion device includes hydrogen production, methanation, electric boiler and fuel cell. The model of hydrogen production, methanation electric boiler and fuel cell are given by

$$\begin{cases} P_{H_2}(t) = \eta_{H_2} P_{H_2-E}(t) \\ P_{Gas}(t) = \eta_M P_{H_2-M}(t) \\ P_{EB-H}(t) = \eta_{EB} P_{EB-E}(t) \\ P_{FC}(t) = \eta_{FC} P_{H_2-FC}(t) \end{cases} \tag{4}$$

where $P_{H_2-E}(t)$, $P_{H_2}(t)$ and η_{H_2} are the power consumption, hydrogen supply power and conversion efficiency of hydrogen production at a given time, $P_{H_2-all}(t)$, $P_{Gas}(t)$ and η_M are the hydrogen consumption, gas supply power and conversion efficiency of methanation at a given time. $P_{EB-E}(t)$, $P_{EB-H}(t)$ and η_{EB} are the power consumption, heat supply power and conversion efficiency of electric boiler at a given time. $P_{H_2-FC}(t)$, $P_{FC}(t)$ and η_{FC} are the hydrogen consumption, electricity power supply and conversion efficiency of fuel cell at a given time.

2) ENERGY STORAGE DEVICE MODELLING

The energy storage device includes heat storage, gas storage and hydrogen storage. The model of heat storage, gas storage and hydrogen storage are given by

$$\begin{cases} E_{HEAT}(t) = E_{HEAT}(t-1) + [\eta_{HS-s}P_{HS-s}(t) \\ \qquad - \frac{P_{HS-r}(t)}{\eta_{HS-r}}]\Delta t \\ E_{GAS}(t) = E_{GAS}(t-1) + [\frac{\eta_{GS-s}P_{GS-s}(t)}{H_{LCV-Gas}} \\ \qquad - \frac{P_{GS-r}(t)}{H_{LCV-Gas}\eta_{GS-r}}]\Delta t \\ E_{H_2}(t) = E_{H_2}(t-1) + [\frac{\eta_{H_2S-s}P_{H_2S-s}(t)}{H_{LCV-H_2}} \\ \qquad - \frac{P_{H_2S-r}(t)}{H_{LCV-H_2}\eta_{H_2S-r}}]\Delta t \end{cases} \tag{5}$$

where $E_{HEAT}(t)$, $E_{GAS}(t)$ and $E_{H_2}(t)$ are the storage capacity of heat, gas and gas storage at a given time respectively. $P_{HS-s}(t)$, $P_{HS-r}(t)$, η_{HS-s} and η_{HS-r} are the power of heat storage and release and the efficiency of heat storage and release, $P_{GS-s}(t)$, $P_{GS-r}(t)$, η_{GS-s}, η_{GS-r} and $H_{LCV-Gas}$ are the power of gas storage and release and the efficiency of gas storage and release and the low calorific value of gas, $P_{H_2S-s}(t)$, $P_{H_2S-r}(t)$, η_{H_2S-s}, η_{H_2S-r} and H_{LCV-H_2} are the power of hydrogen storage and release and the efficiency of hydrogen storage and release and the low calorific value of hydrogen.

III. OPTIMAL OPERATION MODEL AMD STRATEGY OF MEWDS

In China, the government has some policies support for the construction of Zero Waste City, for example, if achieve waste reduction, some economic subsidies will be given. Then, for the largest total profit objective and the environmental, waste stockpile constraints *et al.* Achieving waste reduction and coordinated operation of MEWDS.

A. OBJECTIVE FUNCTION

Considering the government economic subsidies for large-scale waste disposal f_1, the energy storage benefits f_2 and supply benefits f_3 for power grid regulation from waste disposal facilities and the energy conversion and storage devices coordinated operation, and the maintenance costs f_4 of MEWDS. The optimization objective function aiming at maximize economic benefits of MEWDS is given by

$$\max F = f_1 + f_2 + f_3 - f_4 \tag{6}$$

$$f_1 = \sum_{t=1}^{T} C_W W_W(t) \tag{7}$$

$$f_2 = \sum_{t=1}^{T} [C_{H_2-E}P_{H_2-E}(t) + C_{FTF-E}P_{FTF-E}(t) + C_{EB-E}P_{EB-E}(t)] \tag{8}$$

$$f_3 = \sum_{t=1}^{T} [C_{H_2}P_{H_2}(t) + C_{FC}P_{FC}(t) + C_{Gas}P_{Gas}(t) + C_{FTF-G}P_{FTG-G}(t) + C_{WIPP-E}P_{WIPP-E}(t) + C_{WIPP-H}P_{WIPP-H}(t) + C_{EB-H}P_{EB-H}(t)] \tag{9}$$

$$f_4 = \sum_{k\in\Omega} C_{MC,k} \tag{10}$$

where C_W is the unit subsidy of waste disposal, $W_W(t)$ is the waste disposal capacity at a given time, C_{H_2-E}, C_{FTF-E} and C_{EB-E} are the energy storage benefits of electricity to hydrogen, faeces treatment facilities and electric boiler respectively, $P_{H_2-E}(t)$, $P_{FTF-E}(t)$ and $P_{EB-E}(t)$ are the energy storage power of electricity to hydrogen production, faeces treatment facilities and electric boiler respectively, C_{H_2}, C_{FC}, C_{Gas}, C_{FTF-G}, C_{WIPP-E}, C_{WIPP-H} and C_{EB-H} are the energy supply benefits of electricity to hydrogen, fuel cell, hydrogen to gas, faeces treatment facilities, waste incineration power plant and electric boiler respectively, $P_{FTF-G}(t)$, $P_{WIPP-E}(t)P_{WIPP-H}(t)$ and are the energy supply power of faeces treatment facilities, and waste incineration power plant respectively, $C_{MC,k}$ is the maintenance costs of device k, Ω is the set of devices includes electricity to hydrogen, fuel cell, hydrogen to gas, faeces treatment facilities, waste incineration power plant and electric boiler *et al.*

1) OPERATING POWER BALANCE CONSTRAINTS

According to the demand of urban multi-energy load, MEWDS needs to coordinated operation with urban energy supply system when dispose of waste, which can meet the power balance of both sides of supply and demand at any time. Correspondingly, the operating power balance constraints are

$$P_{E-Load}(t) = P_{RE}(t) + P_{GU-E}(t) + P_{WIPP-E}(t) + P_{FC}(t) - P_{H_2-E}(t) - P_{FTF-E}(t) - P_{EB-E}(t) \tag{11}$$

$$P_{H-Load}(t) = P_{WIPP-H}(t) + P_{EB-H}(t) + P_{GU-H}(t) \tag{12}$$

$$P_{G-Load}(t) = P_{FTF-G}(t) + P_{Gas}(t) \tag{13}$$

$$P_{H_2-Load}(t) = P_{H_2}(t) \tag{14}$$

where $P_{E-Load}(t)$, $P_{H-Load}(t)$, $P_{G-Load}(t)$ and $P_{H_2-Load}(t)$ are the demand of electricity, heat, hydrogen and gas load at a given time respectively, $P_{RE}(t)$, $P_{GU}(t)$ are the power supply of renewable energy and generator units.

2) WASTE STOCKPILE CONSTRAINTS

According to supply and demand characteristics of the urban multi-energy system and the waste disposal efficiency, the MEWDS can maximize economic benefits. However, Considering the environment and waste capacity of the city, waste stockpile needs to be within the acceptable range. Furthermore, the waste stockpile constraints are

$$S_{DW,\min} \le S_{DW}(t) \le S_{DW,\max} \tag{15}$$

$$S_{FW,\min} \le S_{FW}(t) \le S_{FW,\max} \tag{16}$$

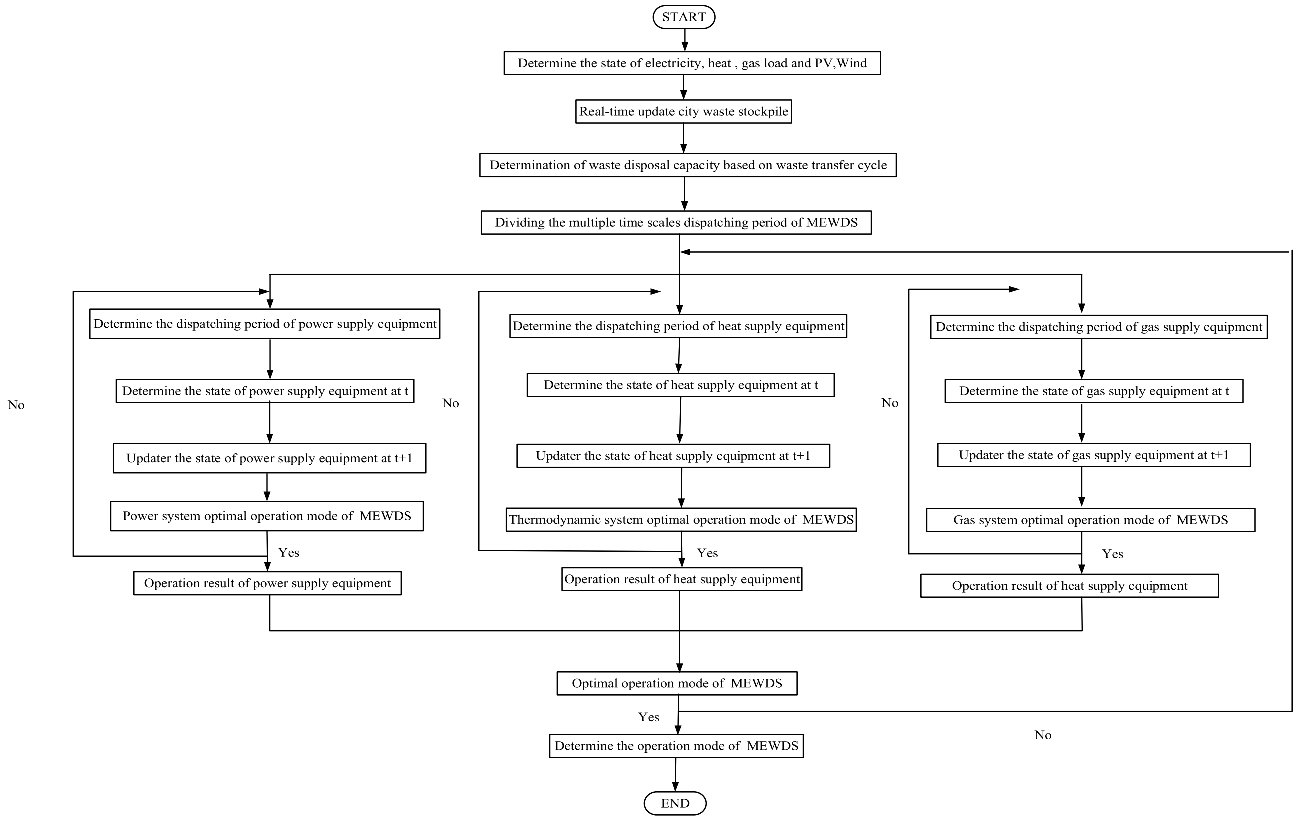


FIGURE 2. Flow chart of the MEWDS optimal operation strategy.

where $S_{DW}(t)$ and $S_{FW}(t)$ are the stockpile of daily and faeces waste, $S_{DW,\min}$, $S_{DW,\max}$, $S_{FW,\min}$ and $S_{FW,\max}$ are the minimum and maximum limits of daily and faeces waste stockpile respectively.

3) OPERATING POWER CONSTRAINTS

For the waste disposal facilities and energy conversion and storage devices in MEWDS, the operating power need to meet the minimum and maximum limits. Furthermore, the operating power constraints is

$$P_{k,\min} \le P_k(t) \le P_{k,\max}, k \in \Omega \tag{17}$$

where $P_k(t)$ is the operating power of device k, $P_{k,\min}$ and $P_{k,\max}$ are the minimum and maximum limits operating power of device k.

For the system uses a high proportion of renewable energy for energy supply,the energy conversion and storage devices have uncertainty in MEWDS. So, the waste disposal facilities and energy conversion and storage devices ramping up and down limits considering uncertainty is established refer to the method of references [23], [24].

$$\begin{cases} P_{k,t}(S) - P_{k,t-1}(S) \le UR_k \cdot IA_{k,t-1} + \\ P_{k,\min}(IA_{k,t} - IA_{k,t-1}) + P_{k,\max}(1 - IA_{k,t}) \\ P_{k,t-1}(S) - P_{k,t}(S) \le DR_k \cdot IA_{k,t-1} + \\ P_{k,\min}(IA_{k,t-1} - IA_{k,t}) + P_{k,\max}(1 - IA_{k,t-1}) \end{cases} \tag{18}$$

where $P_{k,t}(S)$ is the operating power of device k at a given time in an uncertain scenario, UR_k and DR_k are ramp up and down rate limits of device k, $IA_{k,t}$ is auxiliary binary variable.

4) ENERGY STORAGE CAPACITY CONSTRAINTS

According to the storage capacity of gas, heat and gas storage, the energy storage capacity constraints are

$$\begin{cases} E_{GAS,\min} \le E_{GAS}(t) \le E_{GAS,\max} \\ E_{HEAT,\min} \le E_{HEAT}(t) \le E_{HEAT,\max} \\ E_{H_2,\min} \le E_{H_2}(t) \le E_{H_2,\max} \end{cases} \tag{19}$$

where $E_{GAS,\min}$, $E_{GAS,\max}$, $E_{HEAT,\min}$, $E_{HEAT,\max}$, $E_{H_2,\min}$ and $E_{H_2,\max}$ are the minimum and maximum limits storage capacity of gas, heat and gas storage respectively.

5) TIE-LINE POWER CONSTRAINT

According to the energy interaction between MEWDS, and power grid, the tie-line power constraint is

$$0 \le P_{TL}(t) \le P_{TL,\max} \tag{20}$$

where $P_{TL}(t)$ is the tie-line power at a given time, $P_{TL,\max}$ is the maximum limits of tie-line power.

B. MEWDS OPTIMAL OPERATION STRATEGY

For the differences of regulation and operation characteristics of waste disposal facilities, energy conversion and storage

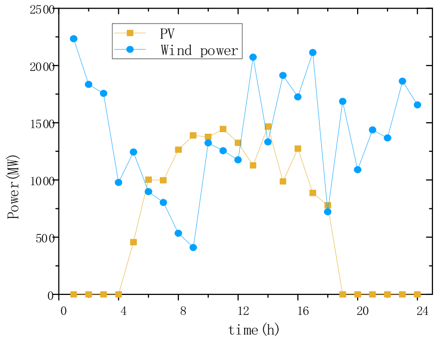


FIGURE 3. Renewable energy output of typical day.

devices and other types of equipment in the electricity heat and gas subsystem, it will increase the difficulty of optimal operation in MEWDS. Furthermore, The waste disposal process needs to be collaboratively optimized with multi energy system for the existence of waste disposal facilities.

Consequently, The MEWDS optimal operation strategy is proposed. Firstly, the daily waste production and transfer volume of the city should be determined in addition to the determination the state of electricity, heat, gas load and PV and wind power in the city. Then, according to the real-time update of waste disposal capacity and waste stockpile, the energy supply and energy consumption characteristics of waste disposal facilities are analyzed. Furthermore, the operation mode of different kinds of energy supply, conversion and storage facilities in MEWDS is determined for the demand of various energy sources in the whole city. Finally, the operation mode of MEWDS is optimized, and determine the its operation mode. The MEWDS optimal operation strategy is shown in Figure 2.

IV. CASE STUDIES

A. BASIC DATA

The optimization model established in this paper is a typical mixed integer linear programming problem, which is solved by CPLEX in MATLAB. The iterations in the calculation process is 115 times, and the average calculation time is 403.3 seconds

This paper takes the energy data of a city in China's northeast for simulation verification The capacity of generator unit is 6500 MW included combined heat and power units 2000 MW and condensing steam turbines 4500 MW for electricity and heat supply. The gas distribution station with 700 MW capacity is installed for gas supply. The capacity of renewable energy is 4000 MW included PV1500MW and wind power 2500 MW, and the maximum electric, heat, gas and hydrogen power loads are 8000 MW, 1200 MW, 800 MW and 500 MW. The renewable energy output and electric, heat, gas, and hydrogen power loads of a typical day are selected for validation are shown in Figure 3 and Figure 4.

TABLE 1. Key parameters of energy conversion devices.

Name	Efficiency(%)	Life(year)	Maximum output
Electrolyzer	80	30	300MW
Electric boiler	95	15	450MW
Fuel cell	65	5	200MW

TABLE 2. KEY parameters of energy storage devices.

Name	Efficiency(%)	Life(year)	Capacity
Heat storage	90	10	1200MWh
Hydrogen storage	95	35	4000m^3
Gas storage	95	30	5000m^3

TABLE 3. KEY parameters of waste incineration power plant.

Name	Average daily waste disposal	Installed capacity
Waste incineration power plant	3000t	200MW

TABLE 4. KEY parameters of faeces treatment facility.

Name	Average daily Faeces disposal	Average daily biogas production	Rating power
Faeces treatment facility	1.2t	$5\times10^6m^3$	6KW

The key parameters and capacity of energy conversion and storage devices, a waste incineration power plant and a faeces treatment facility are shown in table I-IV.

B. SCENARIOS DIVISION

Waste incineration power plant is only in coordination with the power grid and faeces treatment facility is mostly used to make gas for personal demand in traditional operation mode of waste disposal facilities, which will cause some waste considering the uncertainty of waste disposal and energy utilization. However, Waste disposal facilities operate in coordination with multi-energy systems by optimal operation strategy in MEWDS presented in this paper. Then, more waste disposal facilities can be placed for waste reduced massively and obtain more economic benefits from energy storage and release according to power grid regulation demand. Consequently, two scenarios are divided for comparative analysis of this paper.

Scenario 1 is traditional operation mode of waste treatment facilities, which don't consider operating in coordination with multi-energy system. Waste incineration power plant only considers coordination with power grid, and users of faeces treatment facilities only consider their personal needs, natural gas can use or sell directly by purified from the biogas produced, then there are one waste incineration power plant with a daily treatment capacity of 3000 tons and fifteen thousand

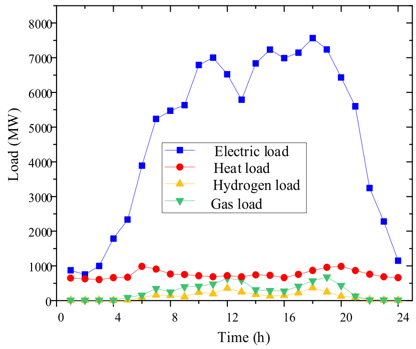


FIGURE 4. Electric, heat, gas, and hydrogen power loads of a typical day.

TABLE 5. ENERGY storage benefit of MEWDS.

Name	Price ($/kW·h)
Electricity to heat storage in MEWDS	0.11
Electricity to gas storage in MEWDS	0.14
Electricity to hydrogen storage in MEWDS	0.12

faeces treatment facilities are installed in the energy supply system.

Scenario 2 is coordinated operation of multi-energy system and waste disposal facilities. Considering the maximization of waste disposal and the demand of power grid regulation, three waste incineration power plants are placed. Users of faeces treatment facilities not only consider their personal needs, but also consider waste reduction, the demand of power grid regulation and gas supply, twenty-five thousand faeces treatment facilities are Installed.

C. COMPARISON ANALYSIS

When the power of renewable energy supply exceeds the demand of electric load, the curtailment of wind and PV will happen. In order to eliminate the curtailment of wind and PV, the energy conversion and storage devices can make electricity storage, and faeces treatment facilities can make electricity to gas when it works for faeces reduction. the average payoff of the electricity being converted to heat, gas and hydrogen to store in MEWDS are shown in table V.

The energy conversion and storage devices and waste disposal facilities can coordinately supply energy in MEWDS, When electricity, heat, gas and hydrogen loads are at different peak and valley period, and obtain its payoff. the average payoff of the electricity heat, gas and hydrogen supply are shown in table VI.

According to the data of renewable energy output and electric, heat, gas, and hydrogen power loads in Figure 3 and Figure 4, the waste disposal facilities operation curve of scenario 1 is shown in Figure 5. Then, based on the multi-time scale optimal operation strategy, the MEWDS optimal operation curve of scenario 2 is shown in Figure 6.

TABLE 6. Energy supply benefit of MEWDS.

Type	Electricity supply price ($/kW·h)	Heat supply price ($/kW·h)	Gas supply price ($/m^3)	Hydrogen supply price ($/kg)
Peak value of electricity heat gas and hydrogen load	0.24	0.12	0.62	9.30
Peak value of electricity heat and hydrogen load	0.23	0.09	0.42	9.28
Peak value of electricity heat and gas load	0.19	0.11	0.59	7.42
Peak value of electricity and heat load	0.98	0.07	0.41	7.45
Peak value of electricity and hydrogen load	0.21	0.05	0.39	9.24
Peak value of electricity and gas load	0.18	0.04	0.58	7.39
Peak value of electricity gas and hydrogen load	0.11	0.05	0.60	7.51
Peak value of heat and hydrogen load	0.09	0.08	0.37	9.18
Peak value of heat and gas load	0.08	0.09	0.56	7.52
Peak value of heat gas and hydrogen load	0.10	0.08	0.57	9.23
Peak value of gas and hydrogen load	0.07	0.04	0.61	9.15

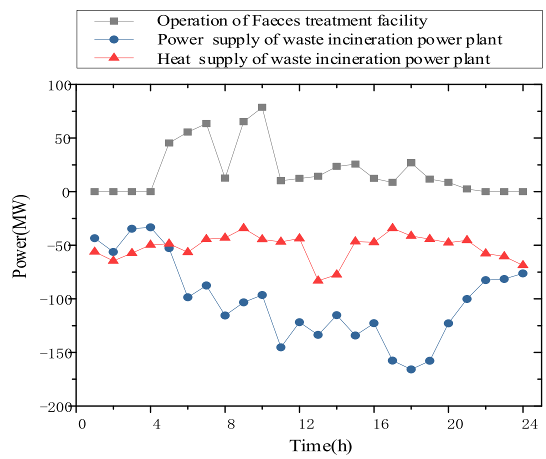
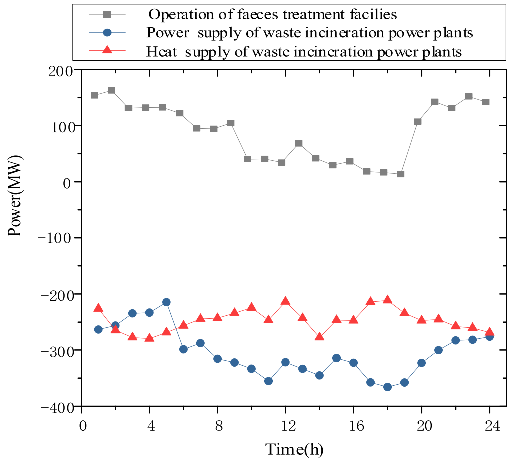
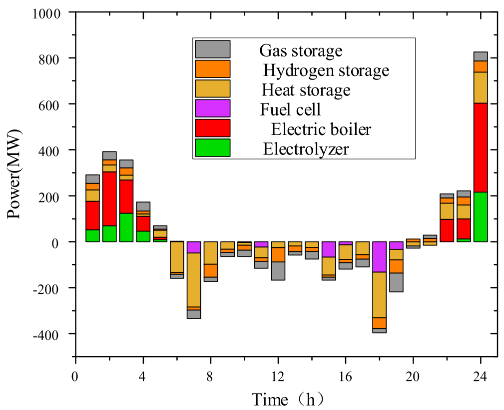


FIGURE 5. The waste disposal facilities operation curve of scenario 1.

For scenario 1, The installed capacity of waste disposal facilities doesn't consider multi-energy system, and for the cost and the demand of waste disposal process, the small capacity waste disposal facilities lead to its weak waste disposal. Especially in the process of faeces treatment, At 6:00-22:00, faeces treatment facilities operate continuously and large power consumption leads to high operation cost. Meanwhile, waste incineration power plant also has limited regulation scope for power grid as shown in figure 5. However, in the MEWDS optimal operation process of scenario 2 as shown in figure 6, As the multi-energy system has better compatibility for waste disposal facilities, which can install waste disposal facilities with larger capacity and achieve large-scale waste reduction, gain more government economic



(a)The waste disposal facilities optimal operation curve of scenario 2

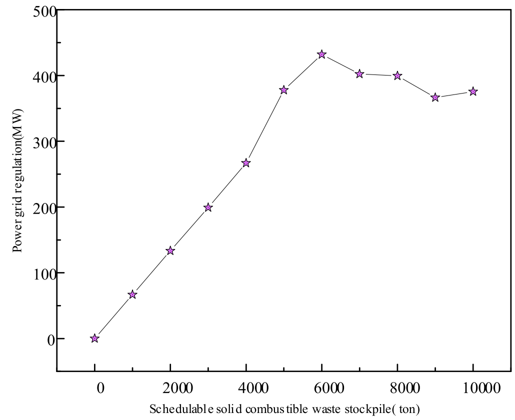


(b)The energy conversion and storage devices optimal operation curve of scenario 2

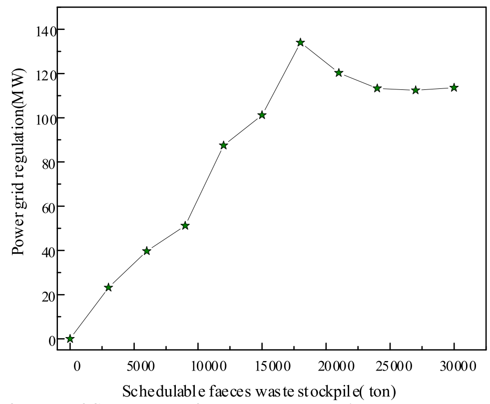
FIGURE 6. The optimal operation curve of MEWDS.

TABLE 7. Optimal comparison of different scenario.

Name	Economic benefits($)	Daily waste reduction(t)
scenario 1	65321.23	16000
scenario 2	300563.42	43000



(a)The influence of schedulable solid combustible waste stockpile to the demand of power grid regulation



(b)The influence of Schedulable faeces waste stockpile to the demand of power grid regulation

FIGURE 7. The influence of MEWDS and waste stockpile to power grid regulation.

subsidies. Furthermore, MEWDS has better grid regulation capability and gain more the energy storage and supply benefits. At 1:00-6:00, 22:00-24:00 have the curtailment of wind and PV in electricity load peak period, the faeces treatment facilities and energy conversion and storage devices can coordinated energy storage. Meanwhile, MEWDS can gain energy storage benefits from electricity storage for power grid and faeces treatment facilities can operate in high power and gain government economic subsidies from waste reduction. At 10:00-12:00, 14:00-20:00 in electricity load peak period, faeces treatment facilities reduce operating and waste incineration power plant operate in high power form waste reduction, and the energy conversion and storage devices can also coordinated energy supply to reduce power grid pressure. Meanwhile, MEWDS can gain energy supply benefits and government economic subsidies. The optimal comparison between scenario 1 and scenario 2 are as shown in table VII.

MEWDS can not only reduce large-scale waste, but also provide regulation for power grid. The influence of MEWDS and waste stockpile to power grid regulation demand has been obtained from simulation are as shown in figure 7.

From the analysis of figure 7, with the increase of schedulable waste stockpile, the power grid regulation also increased when MEWDS are reducing waste. However, the waste stockpile constraints also has superior limit on the improvement of power grid regulation capacity. More concretely, for the power grid peak regulation demand, the waste incineration power plants can provide up to 432MW for the peak value of the power grid when reduce large-scale solid combustible waste under the solid combustible waste stockpile constraints. For the power grid valley regulation demand, the faeces treatment facilities can provide up to 134MW for the valley value of the power grid when reduce large-scale faeces waste under the faeces waste stockpile constraints.

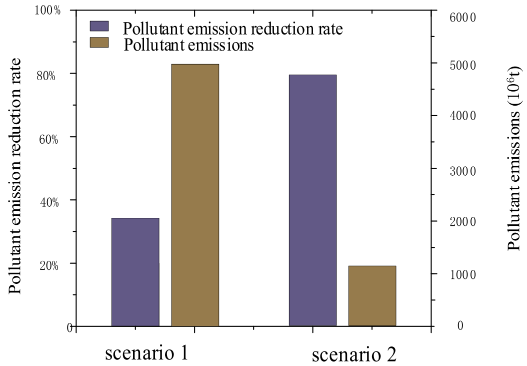


FIGURE 8. The comparison of environment.

High proportion of renewable energy and fuel cell used can reduce the utilization of primary energy, which can reduce pollutant emissions effectively, Meanwhile, MEWDS achieve large-scale waste reduction and recycling waste for energy system, which improve the emission reduction rate of pollutants. The comparison of environment between scenario 1 and scenario 2 is as shown in figure 8.

In summary, The MEWDS proposed in this paper has more flexible regulation ability compared with the traditional waste disposal facilities operation. high proportion of renewable energy can be used efficiently due to the coordinated operation between the energy conversion and storage devices and waste treatment facilities. MEWDS can be equipped with large capacity waste disposal facilities to achieve large-scale waste reduction and obtain waste disposal subsidies. In addition, MEWDS can participate in power grid regulation and gain energy storage and supply benefits. Meanwhile, With high proportion of renewable energy utilization and large-scale waste reduction, the emission of urban pollutants is reduced effectively, which have more contribution for the development of Zero Waste City.

V. CONCLUSION

In this paper, optimal operation model of MEWDS and optimal operation strategy is deeply studied for large-scale waste reduction and the optimization of the interconnection among various energy sources. Considering the energy supply and demand characteristics of waste disposal facilities and its waste disposal capacity, MEWDS achieve the coordinated and optimal operation of waste disposal facilities and multi-energy system. Through case studies, Compared to the traditional operation mode of waste disposal facilities, the proposed MEWDS optimal model can reduce the large-scale waste effectively and provide a certain regulation capacity for power grid concurrently, which is superior in recycling of waste. Moreover, the proposed MEWDS optimal model can get more economic benefits to reduce operating costs from energy supply and storage and waste reduction, and it will also improve eco-environmental quality effectively. Last but not least, the results of the paper can guide development of Zero Waste City from the energy perspective for the world.

Future work aims at exploring in more detail other types of MEWDS, for instance considering the relationship between waste disposal efficiency and cost brought by waste classification process, and analyze the impact of different proportion of renewable energy to the operation of the multi-energy system.

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