Assessment of Geothermal Resources and Distributed Photovoltaic Heating Models in Xiaowangzhuang Town

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Abstract. This study focuses on Xiaowangzhuang Town in Binhai New Area, Tianjin, employing the thermal reservoir method and solar thermal collection technology to assess regional geothermal resource reserves and distributed photovoltaic heating potential. It analyzes urban heating demand response patterns, providing scientific support for achieving carbon neutrality. Results show that: The heat demand of Xinyuan Li is 107 trillion J. The heat demand of Xiangyang Li is 605 trillion J. Supply-demand matching analysis shows: Combined geothermal (B59) and Xinyuan Li’s rooftop PV system can supply 0.0807 quadrillion J heating. Combined geothermal (B60) and Xiangyang Li's rooftop PV system can supply 0.0825 quadrillion J heating. Combined geothermal (B59) and Xinyuan Li’s rooftop PV system can meet most demands of Xinyuan Li residential area. Combined geothermal (B60) and Xiangyang Li's rooftop PV system can fully cover the demands of Xiangyang Li residential area. The study validates the feasibility of geothermal-solar hybrid systems for regional clean heating, offering practical insights for energy transition under the carbon peak and carbon neutrality goals in the Beijing-Tianjin-Hebei region.

Keywords: geothermal resources; thermal reservoir method; distributed photovoltaic (PV); multi-energy complementarity; carbon neutrality

1 Introduction

Northern China faces significant winter heating demands, currently dominated by coal-dependent systems(coal-fired electricity and boilers), whose high carbon footprint is driving renewable energy adoption in the building heating sector[1]. The single-source heat pump system demonstrates relatively low comprehensive heating efficiency, primarily due to inadequate heating performance and the temperature decline of geothermal water[2]. The coexistence of stable Guantao Formation geothermal reservoirs and abundant solar resources in Xiaowangzhuang Town enables a synergistic heating solution. Due to the stability of geothermal heating, the synergistic heating system dominated by geothermal heating can compensate the instability of solar heating caused by weather fluctuations and diurnal variations[3]. The synergistic model of geothermal-

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photovoltaic hybrid heating systems establishes a replicable paradigm for optimizing local energy structures. It’s essential for meeting China's carbon peak and carbon neutrality goals. The comprehensive utilization of solar and geothermal energy has been extensively studied by scholars worldwide. Geng Zhi et al. (2023) proposed an integrated heating system that effectively couples solar, geothermal, and wind energy, leveraging multi-energy complementarity to ensure stable thermal energy supply. Boniface Wainaina Kariuki et al. (2025) found that integrating low-temperature geothermal with high-temperature solar thermal sources creates synergistic effects: the hybrid system can improve power generation efficiency by up to 20% compared to standalone geothermal plants[4]. Younes Noorollahi et al. (2023) conducted a groundbreaking study in Iran's Khorasan region, revealing that the hybrid geothermal-solar system achieved a 585.12% higher annual average heat flux productivity compared to conventional geothermal hot springs alone[5].

2 Methods and Datas

2.1 Geothermal

The Xinyuan Li and Xiangyang Li areas feature two distinct types of geothermal reservoirs: one is Porous Sandstone Reservoirs which is predominantly from the Neogene Minghuazhen and Guantao Formations thermal reservoirs and mainly composed of sandstone, it is distributed throughout the entire area. The other is karst-fractured carbonate reservoirs mainly composed of carbonate rocks which is mainly from the Jixian System Wumishan Formation. This assessment focuses exclusively on the Neogene Guantao Formation reservoir. The locations are shown in Fig.1. Although the intensified recharge efforts have curbed the rapid decline of water levels, long-term mining in some areas has formed groundwater depression cones, posing a risk of resource depletion—though its development is not directly linked to land subsidence. To address these issues, it is necessary to implement the "mining based on recharge" principle, carry out technical demonstrations such as "heat extraction without water consumption", establish an intelligent monitoring network, and optimize development plans by zoning and stratification to balance resource development and ecological protection[6].

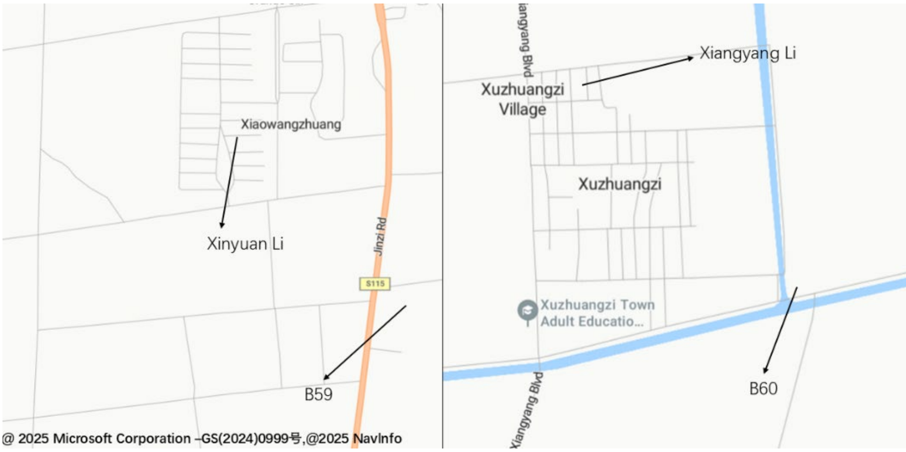

Fig. 1. Location diagram (*Map data © Microsoft Bing Maps (2023).)*

Total Geothermal Energy in Reservoir.

According to the specification for estimation and evaluation of geothermal resource[7], the thermal reservoir method is shown in equation (1):

$$Q_k = R_E * [Ad\rho_r c_r(1-\emptyset)(t_r - t_0) + (A\varphi d + ASH)c_w\rho_w(t_r - t_0)] \quad (1)$$

In Eq. (1): Q_r is heat stored in the rock matrix (J); A is area (m^2); d is thickness of the reservoir (m); ρ_r、ρ_w are the density of rock and water (kg/m^3); c_r、c_w are the specific heat capacity of rock and water (J/(kg·°C)); φ is the porosity of the reservoir rock; t_r is the temperature of the geothermal reservoir (°C); t_0 is the local annual average air temperature (°C); S is the elastic water release coefficient ; H is the depth (m); Q_k is recoverable geothermal resources (KJ); R_E is the recovery factor (%) .

Utilizable Thermal Energy.

The equations to estimate the cumulative utilizable thermal energy from annual geothermal fluid extraction are shown in equation (2)[7]:

$$\sum W_t = \frac{86.4D}{K} 4.1868 Q_3\{[(Z-h)*G] \div 100 + T_0 - t_0\} \quad (2)$$

In Eq. (2): Q_3 is exploitable geothermal fluid flow rate (L/s); t is geothermal fluid temperature (°C); t_0 is local annual average air temperature (°C); $\sum W_t$ is utilizable thermal energy from one year of extraction (J); D is annual extraction days (d); 86.4 is unit conversion factor; K is thermal efficiency ratio (0.6 for coal-fired boilers); G is geothermal gradient (°C/100m); T_0 is constant-temperature zone temperature (°C); h is depth of constant-temperature zone (m).

2.2 Solar Heat Supply

The core of is to use the building roofs of Xinyuan Li and Xiangyang Li area, for estimating photovoltaic system heating. The method is shown in equation (3):

$$\mathrm{E} = A_{pv} \times G_n \times \eta \times \lambda \tag{3}$$

In Eq. (3): E is the solar heating capacity (J); A_{pv} is the area of photovoltaic modules on the roof, calculating the total roof area of Xiangyang Li is 20,975 m^2, and that of Xinyuan Li is 10,599 m^2on the map;G_n is the radiation received by the photovoltaic modules per month (280562KJ/m^2)[8];η is the conversion efficiency in theoretical tests, taken as 0.2 as usual[9]; λ is the operating efficiency, taken as 0.75 as usual.[9]

2.3 Heat Demand

The heat demand in heating period Wangxiaozhuang Town is estimated using the heat load method. The formula is shown in equation (4), the parameters are shown in Table 1:

$$Q_2 = 29270000 * A_2 q \tag{4}$$

In Eq (4): Q_2 is the heat required during the heating season(J);2927000 is the calorific value of 1 kg of standard coal(J/kgce); A_2 is the total heating area (m^2);q is the average comprehensive energy consumption for heating (kgce/m^2).

Table 1. Main Parameters

Parameters		value	data sources
A(km^2)	B59	2.69	Tianjin Municipal Planning and Natural Resources Bureau
	B60	2.69	
φ(dimensionless)		0.3	Tang Yongxiang[10]
ρ_r(kg/m^3)		2103	
c_r(J/kg·°C)		910	
ρ_w(kg/m^3)		980.76	
φ_r(J/(kg·°C))		4180	
G(°C/100m)		3.0	
S(dimensionless)		3.4×10^{-5}	
d(m)		390	
A_2(m^2)	Xinyuan Li	166500	National Compendium of Typical Renewable Energy Heating (Cooling) Cases (2024)
	Xiangyang Li	94000	
R_e(%)		25	Geological and Mineral Industry Standard of the People's Republic of China — Methods and Regulations for Geothermal Resource Assessment and Estimation[7]
Q_3(L/s)		25	Zhao Yanting[11]
q (kgce/ m^2)		22	Clean Heating Plan for Winter in Northern Regions (2017 - 2021)

3 Conclusion

Based on the above parameters and models, the calculated data are shown in Fig.2. and conclusion are shown as follows.

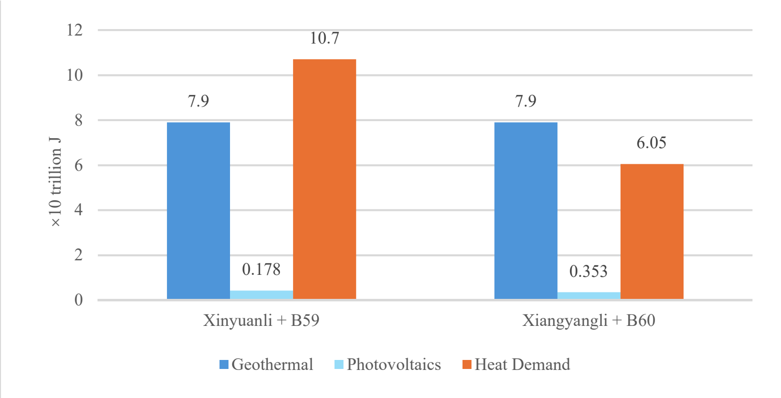

Fig. 2. heat demand-supply matching and location

1. The evaluation of geothermal resources in B59 and B60 shows that both have an extractable geothermal resource amount of 12.75 quadrillion J and an annual utilizable heating of 79 trillion J, indicating huge heating potential. The sustainable development and utilization of this heat energy are of great significance for energy conservation and emission reduction.
2. The annual total combined heat supply from geothermal and solar energy in B59 and Xinyuan Li area is 80.78 trillion J, which can meet the most heat demand of Xinyuan Li. In contrast, the annual total combined heat supply in B60 and Xiangyang Li area is 82.53 trillion J, which can not only meet all the heat demand of Xiangyang Li but also has surplus heat equivalent to the heating demand of approximately 35,000 m^2 of building aeras.
3. For scalability, the system can be adapted to different cities by adjusting the PV/geothermal ratio, making it suitable for areas with abundant geothermal and solar resources like Beijing, Tianjin, while colder regions require optimized thermal storage design. For transferability, core components (PV panels, fine sand thermal storage, heat pumps) can be replicated through standardization, but the feasibility must be assessed based on local resource conditions. We will conduct in-depth research on scalability and scalability in the following studies.

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