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Analysis of Medium- and Long-term Coupling Effect of Energy- and Water-Saving Policies in Urban and Rural Areas in Beijing

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Abstract: An energy-water coupling model was established in this study based on long-range energy alternatives planning (LEAP) and water evaluation and planning (WEAP) scenarios, which were designed to explore both the energy- and water-saving effects of different policies in Beijing in the future and the combined effects of these policies. Sensitivity analysis of the results was also conducted. Results indicate that the total energy consumption in Beijing will grow gradually on a yearly basis, while water shortages are unlikely to occur. During the 13th Five-Year Plan, the total amount of energy saved as a result of the water-saving policies is 1.003 million tons of standard coal, and the total amount of water saved because of the energy-saving policies has reached 276 million cubic meters. The demand for energy and water by residents, the service industry, the construction industry, and the traditional manufacturing industry are correlated, as critical energy-water coupling sectors. In terms of the energy- and water-saving effects of different scenarios and periods, the policy for optimization of the industrial structure shows great energy-saving potentials in the short term, while innovations in irrigation technology and optimal planting in the agricultural sector both lead to good energy- and water-saving effects in the short term. A coordinated energy- and water-saving effect can be observed in the energy-saving scenarios of the service industry and the industrial sector. As for policies in the same sector, regulation concerning the intensity of energy use can achieve an obvious coordinated energy- and water-saving effect.

Keywords: urban and rural areas in Beijing; energy and water saving; policy coupling analysis

1 Introduction

Beijing is the political, economic, and cultural center of China; however, water shortages are considered to have limited the development of the city in the past. According to the structure of the water consumption, the total amount of water consumed in agriculture and its proportion to the total water consumption has decreased gradually on a yearly basis. This is because agricultural areas are decreasing in size and water-saving irrigation technologies are more widely applied [1]. The total amount of water consumed by industry has also significantly decreased while the total amount of water consumed by households has increased. In summary, Beijing is now facing a severe situation in terms of high rates of energy and water consumption. The growth in population and the expansion of industry has led to an increase in the demand for both energy and water in Beijing, and both energy

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and water supplies rely heavily on imports. Water resources are linked to energy through industrial activities such as coal washing, hydroelectric power generation, and the manufacture of solar panels. Energy is related to water resources through activities such as the extraction of groundwater, the long-distance transfer of water, and sewage purification. These factors are therefore complementary in terms of economics [2]. Meanwhile, the level of the groundwater has not yet recovered, and the overexploitation has not yet been completely alleviated.

Judging from past experience, conserving energy and water are effective means of alleviating problems surrounding both urban and rural energy requirements. The establishment of energy and water standards, the development of relevant laws and regulations, and the promotion of key energy-saving and water-saving technologies and other measures and methods can lead to the adequate conservation of both energy and water via a synergistic effect. During the “Eleventh Five-Year Plan”, the amount of energy saved by major industrial sectors reached 9.2% of the total energy consumption in China through the introduction of standards in various industrial sectors, improvements in the laws and regulations, and an increase in energy-saving policies [3]. In terms of specific sectors, the situation in each sector of industry is different. The energy-saving policies used by the building materials industry can achieve a 20.45% energy saving while also attaining a 15.91% saving in the amount of water used. Replacing parts of the industrial chain can therefore produce better energy- and water-saving synergies. For key light industries in Beijing, the energy-saving ratio can reach 23.65%, and the water-saving ratio is only 1.83%. [4].

In the agricultural sector, with higher water requirements, different water-saving policies also have a different energy-saving potential. According to the results of research investigating irrigation techniques by Liang and Wang, the energy-saving potential of drip irrigation is higher than that of sprinkler irrigation. However, the energy-saving potential of any form of irrigation is significant. The maximum energy-saving potential of using surface water irrigation is 7.1×10^8 kW·h, which accounts for 1.713% of the total electricity consumed in Beijing in the year studied [4]; while the maximum energy-saving potential of all irrigation is 6.16×10^8 kW·h, or 1.486% of the total electricity consumed that year in Beijing (the comprehensive value is less than the maximum energy-saving potential from surface water irrigation because groundwater irrigation has no energy-saving effect and increases the energy use compared to the baseline method).

Although constraints on energy and water consumption were set in the Twelfth and Thirteenth Five-Year Plans, these goals did not consider the close relationship between energy and water. Problems such as contradictory goals and failures commonly occur during the generation and implementation of water-saving policies. Energy plans often do not sufficiently consider constraints in the water resources and may contradict the “three red lines” of industrial water consumption [5] (total water consumption, water consumption efficiency, and pollution in areas of water-conservation). The water-saving measures in Beijing are currently mainly administrative, examples of which include planning of water consumption and the issuance of water withdrawal permits. The residents are not generally involved and their awareness of water conservation needs to be increased [6]. The South–North Water Transfer Project has influenced the water supply patterns in Beijing and impacted the original water resource system. However, the long-term effects are still unknown and further research detailing the subsequent resource allocation and management is necessary [7]. This study will assess the short-, medium-, and long-term nexus effects of the energy and water related policies in the urban and rural planning of Beijing, and seek a path for a coordinated and sustainable development of both urban and rural energy and water resources

2 Literature review of urban and rural energy-water dynamic prediction models based on the nexus concept

For decision managers to design energy and water consumption systems that can remain efficient in the long term, it is necessary that simulations are conducted that emulate different situations [8]. This can be achieved using dynamic models. There are currently several dynamic modeling methods that can be applied in urban energy-water nexus research, including system dynamics models [9], computable general equilibrium models [10,11], modified energy models (such as MARKAL/TIMES, MESSAGE and PRIMA) [12], and modified water models (such as AQUATOOL) [13].

Long-range energy alternatives planning (LEAP) and water evaluation and planning (WEAP) models have been adopted in several studies to examine energy-water nexus systems on both large and small scales, including engineering projects, sectors, cities, and regional scales. Research at the level of engineering projects and sectors dominates, with fewer studies using models generated at the city level. As the developer of the WEAP and LEAP models, the Stockholm Environment Institute has employed these models in real engineering projects, including seawater desalination and the construction of regional water pipelines. The influence of projects on energy consumption, water resources, and regional greenhouse gas emissions has been examined [14]. Based on the LEAP–WEAP model, Agrawal et al. [15] constructed a model emulating the water consumption and greenhouse gas emissions for the power sector in Alberta, Western Canada, and produced nine scenarios detailing the potential for reducing greenhouse gas emissions, water consumption, and the costs of reducing greenhouse gas emissions. Lin et al. [16] created a LEAP–WEAP model for energy-water nexus utilization at the city level. Using Xiamen city as an example, 11 scenarios were designed and the influences of various demand and supply factors on the urban energy-water nexus relationships were discussed. Li [17] employed the LEAP–WEAP model to examine the energy-water relationship in a case study on the region Ningxia. He estimated the water consumption used by energy systems and the energy consumption that occurred during the utilization of water resources. Ningxia was divided into five prefectural-level regions and WEAP and LEAP models were constructed separately for each region. The quantitative calculations that were made using these models indicated that the energy systems in Ningxia will face critical water resource shortages in the near future, while the relationship between energy and water systems can be improved through promoting the use of energy- and water-saving technologies and policy guidance in the long term. Based on the LEAP–WEAP model, Pan [2] discussed the energy-water nexus relationships of the power sectors in the Beijing–Tianjin–Hebei region under two climate scenarios and three development scenarios. He also analyzed the potential of adjusting the energy structure and the production of technological advancements in alleviating the pressure on regional water resources while also promoting sustainable development.

Compared to other models, the LEAP–WEAP model provides certain advantages for studying energy-water nexus relationships at the city level. The LEAP and WEAP models were developed by the Stockholm Environment Institute for energy and water resource planning and are based on the mass balance principle. The models can simultaneously consider energy and water resource situations from the perspective of both supply and demand and are also equipped with scenario analysis tools. Compared to system dynamics models, the WEAP model has powerful built-in hydrological analysis tools for simulating water supplies, and is therefore capable of simulating fine details such as river runoff, water intake points, and the distances over which water is transferred. Compared to the computable general equilibrium models, the WEAP models are user-friendly and have simple operational procedures. Unlike modified energy and water models, the LEAP–WEAP models have built-in data transmission functions, meaning that core parameters and energy and water simulation results can be shared, facilitating nexus analyses.

However, the construction of the LEAP–WEAP model is slightly more difficult than the aforementioned models. First, for the sector settings in each model, detailed data such as the activity levels, water or energy consumption, generator capacities, transformation efficiencies, hydrological runoffs, and the infiltration rates of sectors are required. After these factors are input, the LEAP–WEAP model conducts data transmission to relate the energy resources with the water resources in each model. The two models will not affect each other while they are running. Instead, the calculation results obtained separately by the two models are exchanged and input into the overall model. Thus, the models need to run several times in order to obtain the final results. Lastly, when setting up scenarios, it is more difficult for the LEAP–WEAP model to consider economic energy-saving or emission reduction measures such as carbon tax or emissions trading compared to the computable general equilibrium models.

In the aforementioned studies that employed the LEAP–WEAP model, the setting of each scenario is often based on literature reviews carried out by the authors and their own assumptions. The types of scenarios can be summarized as: (1) Economic development: Different economic growth rates and industrial structures are set; (2) Technological advancement: This is mainly reflected as reductions in the consumption, for example, a decrease in the water or energy consumption alone or the simultaneous reduction of both; (3) Climate change models: Various models are used, including RCP4.5 and RCP8.5, which mainly affect the entire system by influencing the water supply in the WEAP model; (4) Energy structure changes: These include developments such as nuclear energy, biomass energy, hydropower, and natural gas; and (5) Changes in the water supply priority: The authors can give priority to the use of local water resources over that of imported water resources and vice versa. Similarly, the total surface water or groundwater resources can be used before exploiting the other. As Beijing (where the case study in this paper is conducted) is different from the cities investigated in other studies, local planning and government documents have high reference value alongside the literature.

3 Methods

In this paper, we assume that the energy (or water) demand of Beijing is satisfied by the supply from within the city boundaries and cross-border resources. Only direct energy (or water) consumption is included, while water (or energy) consumption from long-distance electric power transmission (or water transfer across river basins) is not considered. The energy demands of water withdrawal (local groundwater and surface water), water purification, water supply, and sewage treatment are included as energy systems. Meanwhile, the water consumed in the generation of thermal power, hydropower, wind power, photovoltaic power, and biomass power is considered, whereas water consumed during the generation of external power at the origin is not.

As the data and technical parameters obtained from the electric power generation industry are required to begin in the same year for using these models, 2015 was selected as the reference year to predict the medium- and long-term energy and water utilization and their nexus relationships in Beijing from 2015–2050. Temporal increments of one year were employed and adopted in this manuscript.

3.1 WEAP and LEAP nexus module

As sister tools, WEAP and LEAP share many common design features and approaches because they were created by software teams that were working closely with each other. The two models share an identical software platform (Delphi), highly coordinated terminologies, closely integrated Application Programming Interfaces (APIs) based on the Windows Common Object Model, coordinated user interfaces for data input and output, similar and coordinated data definition languages for data entry and model construction, and similar and coordinated approaches for managing the scenarios.

The WEAP and LEAP areas are connected by using the Advanced: LEAP Link screen in WEAP (or the WEAP Link screen in LEAP). After a WEAP area is linked to a LEAP area, the LEAP value function can be used to read the data and the results produced by LEAP and vice versa.

In this study, an overview of the sector settings for LEAP and WEAP can be found in the analysis framework of the energy-water nexus model. Specifically, when WEAP is connected to LEAP, the withdrawal of water, purification and supply, and sewage treatment all play important roles. The total water supply is predicted by the WEAP model. According to the results of this prediction, the energy consumed during water withdrawal, transport, and treatment can be estimated. Reference values concerning the energy consumption are available for different components of the water supply [18].

Similarly, when LEAP is linked to WEAP, the water consumption of the energy transformation module is significant. The demands for power generation via different methods are calculated using the results for the energy structure prediction from LEAP. In the coupled model, the demands are input into the WEAP model, where the water consumption by various primary energy transformations can be established. Research by Jiang [18] provided reference values for these parameters. Thus, the corresponding descriptions of water and energy resources made by WEAP and LEAP can be linked successfully and the interactions between the energy and water systems can be simulated. These are summarized in Fig. 1.

3.2 Policy nexus module

The proposed model considers the actual current situation and the unique characteristics of Beijing, and provides a detailed division of the sectors while realistically reflecting the energy and water consumption, carbon emissions, and the energy-water-carbon nexus relationships for the city in the future. Beijing is, however, a big city with extremely insufficient water resources and its water supply heavily relies on imports. The energy consumed by transporting water over long distances is significant and groundwater is therefore exploited. In the model, the water production and supply sector is divided into four components: water withdrawal, water purification, sewage treatment, and the treatment of reclaimed water. In particular, water withdrawal is further divided into three processes: withdrawal of surface water, withdrawal of groundwater, and water transfer by the South–North Water Transfer Project. More than 20 million permanent residents currently live in the city; therefore, the energy-water nexus relationship of the household sector is worth studying. The proposed model also calculates the water consumed by households in activities such as boiling drinking water, bathing, and doing laundry. Fig. 2 shows the policy transmission path.

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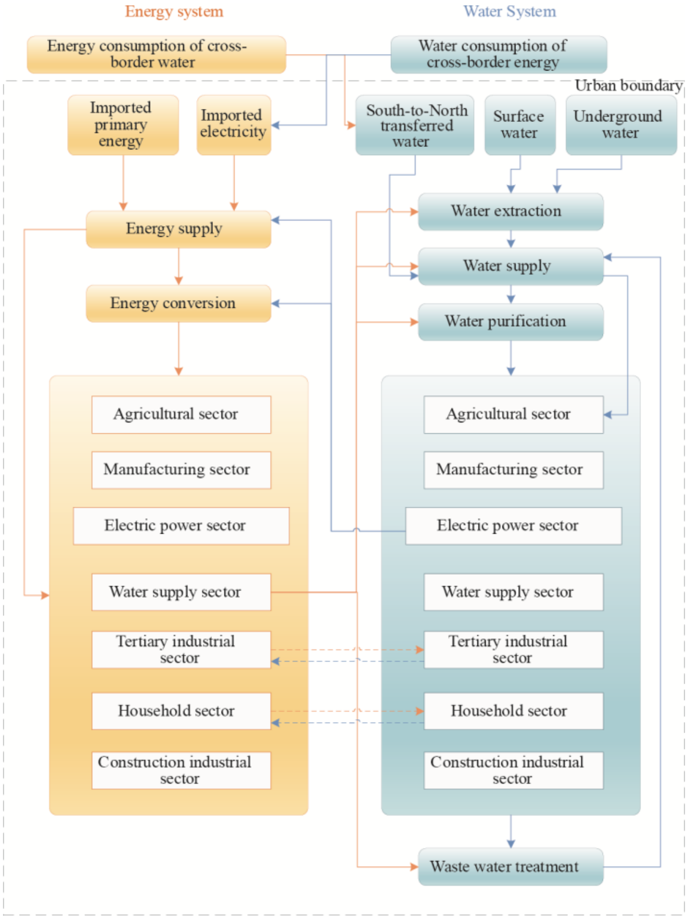


Fig. 1. Energy-water nexus model framework.

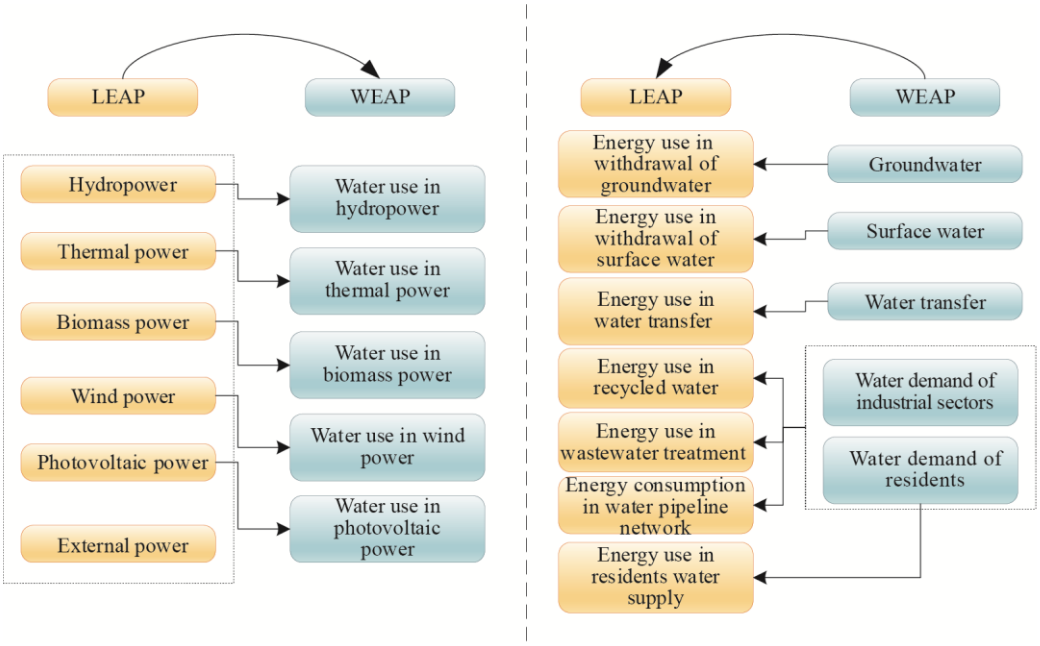


Fig. 2. Policy transmission path.

3.3 Scenario analysis

To design the different scenarios for the analysis, baseline scenarios were first created separately in LEAP and WEAP and were set according to the activity levels determined by the core parameters and extrapolation based on the current consumption levels without any interventions. Based on the baseline scenario, 23 sub-scenarios were constructed, each representing the energy- and water-saving performance and the joint effects of one single policy. The sub-scenarios from the six sectors were integrated to generate a reference scenario in LEAP and WEAP separately, in order to simulate the most realistic situation. Meanwhile, based on the current groundwater overexploitation in Beijing, two water supply scenarios were created based on the reference scenario; (1) restricted groundwater exploitation, and (2) the increased utilization of urban reclaimed water. A new airport is currently under construction in Beijing, and preparations for large-scale events such as the Winter Olympics are in progress. The proposed method considers all these factors and predicts the energy and water demands under these scenarios.

4 Results

4.1 Energy-water nexus analysis

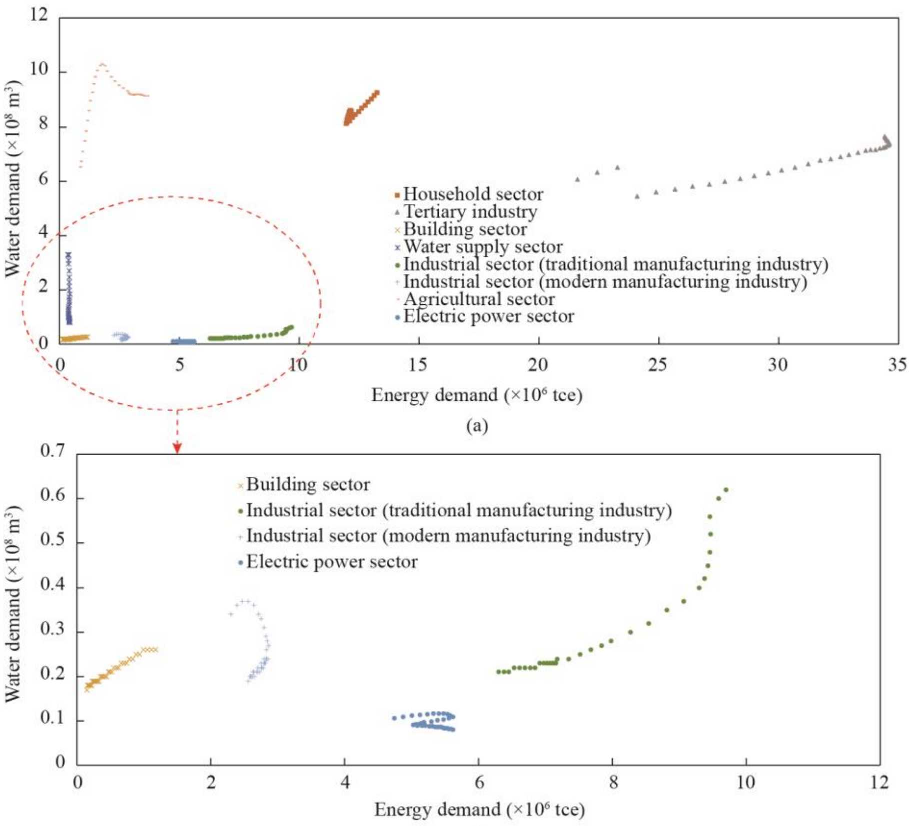
Fig. 3 shows a scatter plot demonstrating the water and energy demands of different sectors. As shown in Fig. 3(a), the household and service sectors have relatively high simultaneous demands for water and energy. The demand for energy by the residential sector was between 1 × 10^7 and 1.5 × 10^7 tons of standard coal equivalent (tce) during the study period, while the demand for water reached between 8 × 10^8 and 1 × 10^9 m^3. These factors are positively correlated. The water and energy demands are also positively correlated for the service sector. Regression analyses demonstrate that the regression slope for the service sector (0.140 ($R^2 = 0.78$)) was smaller than that of the household sector (0.693 ($R^2 = 0.8216$)), meaning that there is less water consumption per unit of energy consumption in the service sector. The agricultural sector had a relatively high water demand but its energy demand was low compared to that of the other sectors. There was no distinctive positive correlation between the water and energy demands in this sector. In 2029, when the energy demand of the sector increases to 1.668 × 10^6 tce, the water demand will reach a maximum of 1.023 × 10^9 m^3, followed by a reduction in demand. The figure indicates that the energy demand does not change significantly in the water production and supply sector, even if the water demand increases. This is probably because the energy consumption by the South–North Water Transfer Project was not included in the energy consumption for this sector. If not, a more distinguishable correlation may exist.

In Fig. 3 (b), a more detailed energy-water nexus relationship is illustrated, showing details for construction, traditional and modern manufacturing, and the power generation and supply sectors. The amount of energy and water consumed by the construction sector exhibits a linear positive correlation ($R^2 = 0.9801$). The demand for both energy and water increased in the traditional manufacturing sector, although the growth in water demand slowed over time, dropping considerably in some years. The demand for water by the modern manufacturing sector varied significantly, whereas the demand for energy did not. The energy-water relationship in the power generation and supply sector fluctuated; sometimes the demand for both energy and water increased while sometimes the energy demand increased while the demand for water was reduced, and at other times both decreased simultaneously. This is because of external electricity sources. The water consumption activity level of the power generation and supply sector in the WEAP model was based on the power generation value from the transformation module in LEAP. Under the influence of external electricity, the power generation value reduced while the total energy consumption increased. Meanwhile, in LEAP, the power generation and supply sector was associated with the total energy demand; therefore, the energy-water relationship of this sector fluctuates.

In summary, the correlation between the energy and water demands of households, the service industries, construction, and the traditional manufacturing sectors are relatively good, with the demand for energy and water varying synchronously. Hence, these sectors are of some importance in terms of the energy-water nexus.

4.2 Water-saving effect under the energy-saving scenarios

Of the scenarios used to achieve energy-saving goals (Fig. 4), the scenario with terminal technology innovation in the service sector had the optimal effect in saving water, reaching a water-saving ratio of 6.85% by 2050. The scenario in which external green electricity was imported also gave a relatively satisfactory water-saving effect and yielded a water-saving ratio of 5.67% by 2050. The variations in the water-saving effect over time suggest that the amount of water saved by importing external green electricity increases rapidly from 2015–2020 and slows down over the period 2020–2050. A turning point appears in 2020 because the proportion of thermal power to total power generation was reduced from approximately 30% to 10% from 2015–2020, after which it is reduced by 0.3% each year until thermal power is completely replaced.



(a)

(b)

Fig. 3. The energy and water demand of each sector in the reference scenario.

Note: The trajectory in the figure is the forecast results of Beijing urban and rural areas from 2015 to 2050.

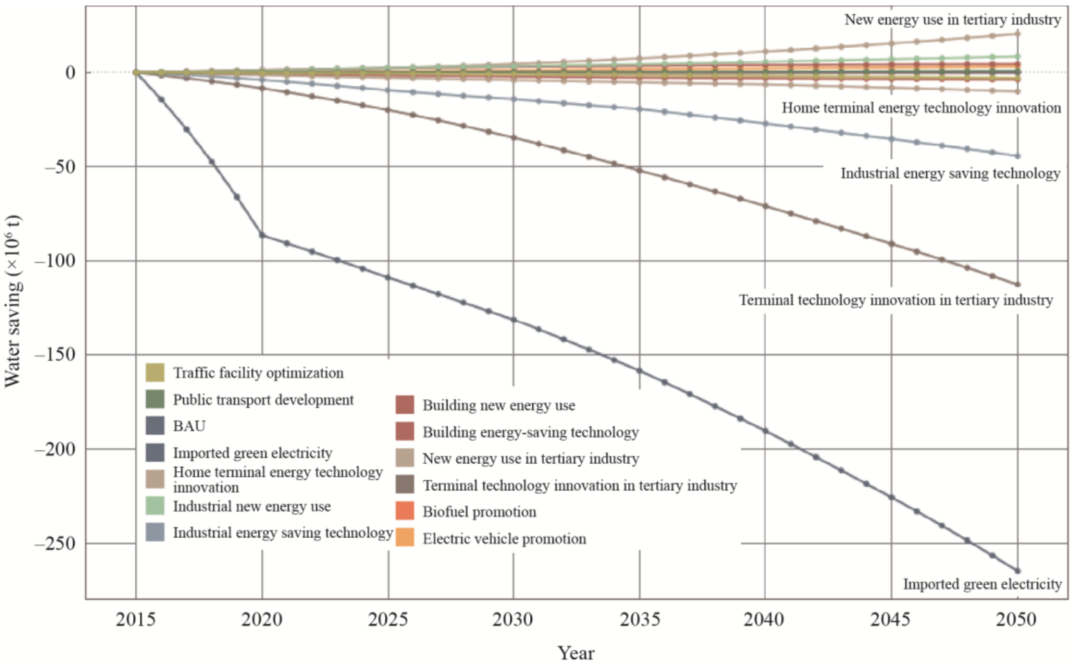


Fig. 4. Water-saving effects in energy-saving scenarios.

In addition, in scenarios in which electric cars were promoted and new energy sources were employed in the construction, service and industrial sectors, there were new water demands compared to the baseline scenario. In particular, in the electric cars scenario, there was an additional demand of 2×10^7 m^3 of water in 2050, accounting for 0.44% of the total water demand. The new water demands by construction, the service industries, and the industrial sectors accounted for 0.18%, 0.10%, and 0.07% of the total demand, respectively. As previously mentioned, while the promotion of electric cars reduced the total energy demand, it also led to an increase in the proportion of electricity required compared to the total power consumption. As a result, there was a net increase in the total electricity demand, and any increase in the amount of power generated leads to greater water demands.

4.3 Energy-saving effect under the water-saving scenarios

In the scenarios used to achieve water-conservation goals (Fig. 5), the overall amount of energy saved accounted for a maximum of 0.66% of the total energy demand. In the different scenarios, the variations in the short-, medium-, and long-term energy-saving effects differed. In terms of short-term effects, industrial water-saving measures (W3) lead to the best energy-saving effects by 2020. This was followed by optimizing the structure of agricultural planting method (W2), enhancing the awareness of residents in terms of water conservation (W6), innovation in irrigation technologies (W1), and the promotion of water-saving appliances (W4). The energy-saving effect of the W6 scenario surpassed that of the W2 scenario by 2025, while similar amounts of energy were saved in the W4 and W1 scenarios. From 2025, the amount of energy saved by the two water-saving measures in the agricultural sector starts to decrease, continuing until 2050. There was a turning point in this sector because the optimization of its structure is basically completed in 2025. The water consumed by the sector decreased from 6.89 × 10^8 m^3 to 4.05 × 10^8 m^3 and the groundwater withdrawal dropped from 1.7 × 10^9 m^3 to 1.683 × 10^9 m^3. The maximum amount of energy was saved at this time. As water consumption from the industrial and service sectors continues to grow, the amount of groundwater exploited increases again, reaching the maximum of 1.7 × 10^9 m^3 and becoming stable in 2041. As a result, the amount of energy saved becomes stable. Similarly, in the baseline scenario, the water supply cannot satisfy the water demand in 2040. In the W1 scenario, water shortages appear only after 2046. From 2040–2046, because the water supply increases, the amount of energy saved is reduced, and becomes stable by 2046.

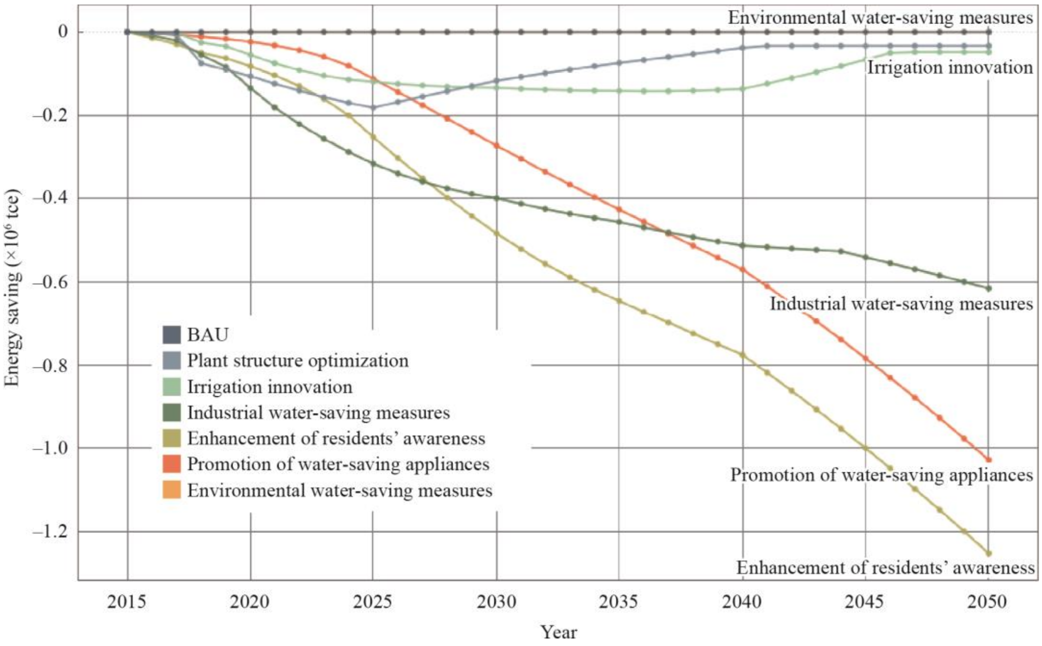


Fig. 5. Energy-saving effects in water-saving scenarios.

Relatively good long-term energy-saving effects are noted for scenarios W4 and W6. By 2050, each saves more than 1 × 10^6 tce. The energy is mainly saved by reducing the amount of energy consumed in the transportation and treatment of water. The variations in the amounts of energy saved are consistent with those in the amounts of water saved by the corresponding measures. The water-saving measures used by the industrial sector save energy mainly by reducing the amount of industrially reclaimed water that requires treatment and thus the energy consumption involved. The energy-saving curve for this scenario indicates that the amount of energy saved is gradually reduced. The reduction becomes more obvious after 2044. This turning point exists because the amounts of water withdrawn and produced in the model are estimated using inflowing water as the activity level, while the amount of water treated was estimated by adopting the demands for water at points of demand as the activity levels. Around 2044, in the scenario where water-saving measures were employed by the industrial sector, water shortages occur while the water supply becomes constant. From 2025–2044, the amount of energy saved in water withdrawal and production decreases gradually, leading to an associated decrease in the total amount of energy saved. After 2044, the variations in the total amount of energy saved are attributed completely to processes such as the discharge and treatment of sewage and treating reclaimed water, meaning that they become more distinct. In the model settings, environmental water consumption does not include the withdrawal, production, and transportation of water, or sewage treatment and the end-use of energy and water consumption by households. Therefore, no energy can be saved in this component.

To summarize the results, in the agricultural sector, scenarios W1 and W2 had relatively good short-term energy-saving effects. However, as water shortages appeared and expanded, their medium- and long-term effects were insignificant. The water-saving measures made by the industrial sector can effectively save energy in the short term. From 2018–2027, optimal energy-saving effects were observed for all scenarios in which water-saving measures were employed. The energy-saving effects of the water-saving measures made by the industrial sector only varied slightly. The short-term energy-saving effects were not obvious in scenarios W4 and W6. From 2025, the amounts of energy saved in these two scenarios increased considerably and surpassed those of the industrial sector in 2028 and 2038, respectively. Hence, scenarios W4 and W6 exhibited significant long-term energy-saving potentials.

4.4 Synergistic water-saving effect under different policy scenarios

Some measures were designed to save energy or water, but side effects may result from their implementation. Energy-saving measures may reduce the demand for water and achieve joint energy- and water-saving effects. Nevertheless, they can also increase the demand for water.

On the whole, the water-saving ratios brought about by energy-saving measures were greater than the energy-saving ratios resulting from water-saving measures. This is because the proportion of water needed during energy consumption as compared to total demand is higher than the amount of energy required for water consumption.

Energy- or water-saving measures made by different sectors have different joint effects. These depend on the energy and water consumption of a sector. Both energy and water consumption is high in the service sector, meaning that technological innovation in this sector can save energy and water effectively (by 29.43% and 2.41%, respectively). Being one of the dominant energy-consuming sectors, the industrial sector can save large amounts of water when energy-saving measures are considered. For example, industrial technology innovation can save 11.69% of the total energy and 0.95% of the water. Energy- or water-saving measures designed for the agricultural sector lead to insignificant joint effects. While this sector consumes massive amounts of water, water-saving measures made by this sector only have slight effects in terms of saving energy. On one hand, industrial water and energy consumption are initially high, while the agricultural sector consumes relatively less energy even without these measures. On the other hand, the proportion of water used during energy consumption compared to the total water consumption is greater than that of the amount of energy used via water consumption as compared to the total energy consumption.

Even if measures are carried out in the same sector, the joint effects vary according to the variables controlled. In scenarios with industrial technological innovation, terminal technology innovation in the service sector, and transportation facility optimization, energy consumptions are controlled and certain joint energy- and water-saving effects are noted. Meanwhile, optimizing the energy structure (including the introduction of new energy sources in the industrial, construction, and service sectors) and industrial structure can effectively reduce energy consumption and carbon emissions, but may increase water demands.

Furthermore, it was found that adjusting different parameters of the same measure resulted in two different distributions of the scatter points. One type represents independent energy- or water-saving variations. Examples are water-saving measures made by the industrial sector and via innovation in irrigation technology. The other type of distribution represents joint energy- and water-saving effects. Examples are a slowdown in economic growth, innovation in industrial technology, and terminal technology innovation in the service sector, for which the water-saving effects change with the energy-saving effects.

According to the results of the model, the total amount of water saved as a result of the energy-saving policies during the 13th Five-Year Plan in Beijing reached 2.76×10^8 m^3, in which the demand for water increased under the scenario of developing public transportation, promoting new energy vehicles, and using new energies in industry, construction, and service reached 1×10^7 m^3. The water saved as a result of the other policies was 2.86×10^8 m^3, and the comprehensive water-saving effect was 2.76×10^8 m^3 (which is close to half the average annual runoff from the North Canal, and is equal to the water storage capacity of 140 Kunming Lake at the Summer Palaces). The total energy saved by the water-saving policy reached 1.003×10^6 tons of standard coal, which is approximately equal to 8.165×10^9 kW·h. (close to 7.65% of the total electricity consumed by Beijing in 2017).

4.5 Energy-saving and water-saving effects of major events and infrastructure construction

The new airport is expected to open in 2019, with the World Horticultural Exposition held in Tongzhou in the same year. In 2022, the Winter Olympic Games will be jointly held in Beijing and Zhangjiakou. Hence, in the future, the organization of various major events and the construction of associated infrastructure will impose new pressures on the energy and water resources. Results from the modeling revealed that projects such as the construction of the new airport and Universal Studios, and the organization of the Winter Olympic Games and the World Horticultural Exposition will increase the total energy demand by 5%–6% each year. In the scenario that included the development of winter sports facilities, the development of the ice industry boosted by the Winter Olympic Games will cause water consumption to increase by less than 1% annually. The average annual increase will be approximately 2.6×10^7 m^3. Because of these projects, the efficiency of the water supply should be enhanced as much as possible.

5 Conclusion

Based on LEAP and WEAP tools, this paper establishes an energy-water nexus model using the characteristics of the urban and rural areas of Beijing. Scenario analysis is also used to explore the energy-saving/water-saving effects of different related measures in the future. This model can be used to understand the processes and mechanisms of the urban energy-water nexus.

In the BAU scenario, the energy demand related to water use, including the energy demand in the process of water extraction, supply, transfer, and household water demand, is 7.12×10^6 tce in total (in 2050), which is approximately 7.74% of the total energy demand in the forecast period (2015–2050). This includes 14.48% for energy consumption in the process of household water consumption, 45.48% for water intake, 4.15% for water production, 12.43% for water transfer, 2.41% for sewage disposal and treatment, and 21.05% for the recycling of sewage. The water demand that is related to energy consumption, including water used in the process of generating power, is 6.8×10^7 m^3 in 2050, which is approximately 2.45% of the total energy demand in the forecast period. This includes 81.7% for thermal power generation, 17.13% for hydropower generation, and 1.17% for other sources of power generation.

From the perspective of the energy-water nexus of the sectors investigated, strong correlations were observed in the energy and water demands of residents, the service industries, the construction industry, and traditional manufacturing. Energy and water use are synchronized in these sectors, which are therefore important in terms of the energy-water nexus.

The core parameter change scenario and the water-saving target scenario show different energy-saving/water-saving effects in the short, medium, and long term. Taking the industrial structure optimization policy as an example, it shows good energy-saving potential in the short term while increasing the water scarcity in a short period. The medium- and long-term energy-saving effect is not obvious, but it is still accompanied by an increase in the consumption of water. Therefore, if Beijing wants to save resources through optimizing the industrial structure, it should rationally adjust the direction of the industrial structure. Innovation in the irrigation technologies and the planting structure optimization scenarios in the agricultural sector have good short-term energy and water-saving effects, and the medium- and long-term water-saving effects are stable. However, with the appearance and further expansion of the total water gap, the medium- and long-term energy-saving effects are not significant. The results of further sensitivity analysis show that parameters that include regulation, such as economic slowdown, industrial structure optimization, public transportation development, and planting structure optimization, have a greater impact on the final energy/water savings, and the parameter sensitivity is relatively high.

With regards to the synergy of energy/water saving, there are obvious differences in the synergy of energy/water policies in different sectors, depending on the amount of energy and water consumed by the sector. If only the

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energy- and water-saving effects of a measure are considered, the technological innovation of the service sector has the optimal energy-saving effect while industrial and household water-saving measures have relatively good water-saving effects. In terms of joint energy- and water-saving effects, the energy- and water-saving measures taken by the service and industrial sectors are more effective. Although elimination of outdated industry at the provincial level and the promotion of new energy sources can effectively reduce emissions, they may increase water demands.

When both the comprehensive effects and implementation difficulties of measures are considered, industrial energy-saving measures lead to greater contributions to the net effect. However, industrial energy- and water-saving measures are hard to implement. Relatively speaking, public transportation development is the easiest of the various energy-saving measures to implement, while enhancing the awareness of residents about water conservation is the simplest water-saving measure. In the future, more attention should be placed on measures in these two areas. The importation of external electricity is relatively prominent in terms of policy evaluation and is advantageous in terms of its comprehensive effects and implementation. More external electricity can be imported in the future after the safety and stability of the power supply is guaranteed. The energy and water demands during the organization of major events such as the Winter Olympic Games, and the construction of new infrastructure such as the new airport, should also be monitored.

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