

Assessing the Impacts of Climate Change on the Water-Energy

Nexus: Case study for Shanxi's energy bases, China

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Abstract: The water and energy security issue is a big challenge for sustainable development in China. In this study, the impacts of future climatic changes and human activity on water resources in Shanxi's energy base (main energy producing region) has been investigated base on the Coupled Land surface and Hydrology Model System using three different IPCC AR5 emission scenarios. Comparing with the current national policy, the supporting capacity of water resources in mid-21st Century on the energy bases development was discussed. It's showed that Shanxi's energy bases water demand will continue to grow, the region's water resources pressure will be further intensified.

Key words: Water resources, Energy security, Climate change, Coupled land surface-hydrology model, Shanxi energy bases

1 Introduction

Water and energy are crucial for human well-being, economic development and social progress (WWAP, 2014). Water and energy systems are interdependent. Water resources is the used in all phases of energy production, and energy is need in water supply and treatment. Since the middle of last century, the interconnection between water and energy consumption have gradually appeared (Harte & El-Gasseir, 1978). However, in recent decades, the unprecedented magnitude and rates of water cycle change, along with other environmental changes, lead to serious imbalance between human and natural (Piao et al., 2010). As the world's demand for energy is still growing, the healthy development of water and energy is directly related to economic security and ecological security. Compared with other countries in the World, China's water and energy security situation is particularly serous (Kahrl & Roland-Holst, 2008). The increasing water scarcity problem has already restricted the development of economy, especially the energy industry in the western region of China (Shang et al., 2016).

China is rich in coal, poor in oil, and deficient in gas. Coal accounts for about 70% of the total primary energy consumption of China. In order to sufficiently satisfy the energy demands for economic development, the NEA proposed five national integrated Energy Bases during the period of the 12th FYP (2010-2015), including Shanxi, Eastern Inner Mongolia, Ordos, Xinjiang and Yungui base. These Bases have been reemphasized in the 13th Five-Year (2016-2020) National Electric Power Development Plan (2016). Among them, Shanxi province is the largest coal energy base in China. The coal energy supply chain is very water intense, form coal mining to cooling power plants and coal chemical industry.

To address these challenges, this paper analyzes the present and future situation of development and water demand of Shanxi's energy base. The water resources variation in the coming year is predict with the IPCC AR5 emission scenarios. The CMIP Representative Concentration Pathways (RCPs) are used as the atmospheric driver of the Coupled Land surface and Hydrology Model System (CLHMS) to simulate the response of water cycle under different scenarios. The supporting capacity of water resources in mid-21st Century on the energy bases development was also discussed in this paper.

2 Model and Study area

2.1 Model description

This study is intended to estimate the changing trends of water resources in the basins where Shanxi Energy base is located in the future climatic conditions based on the Coupled Land-surface and Hydrological Model System (CLHMS) (Yu, Pollard & Cheng, 2006). It is a beneficial tool to explore the changes of land-surface water cycle in

China's basin scale in the climate change as well as the temporal-spatial distribution of water cycle in the extreme climatic conditions. CLHMS includes a large scale land surface model, LSX (Pollard and Thompson, 1995) and a fine grid distributed hydrological model, HMS (Yu et al., 1999). The coupling between the LSX and HMS is based on predicted soil moisture and surface water depth. The land-surface models include two-layer vegetation model, three-layer snow model and six-layer soil model; the hydrological models include terrestrial hydrologic model (THM), groundwater hydrologic model (GHM) and channel ground-water interaction (CGI).

The parameters in the CLHMS model include soil texture, vegetation type, hydrological parameters and hydrogeological parameters. Soil texture is interpolated with the global dataset of Global Environmental and Ecological Simulation of Interactive System, vegetation type uses China Land-use Data for Hundred (CLDH) years. Hydrologic parameters in the basin are developed from the USGS HYDRO1k DEM with ZB algorithm. The hydrogeological parameters such as hydraulic conductivity and porosity are interpolated with the Harmonized World Soil Database. The CLHMS reproduces well the natural hydrological processes, the simulation of the water balance and the seasonal and inter-annual variation of streamflow. It has been verified against historical data for the Yellow River Basin, hydrogeological parameters such as hydraulic conductivity and porosity are interpolated with the Harmonized World Soil Database. The CLHMS reproduces well the natural hydrological processes, the simulation of the water balance and the seasonal and inter-annual variation of streamflow. It has been verified against historical data for the Yellow River Basin, Huaihe River Basin, Song-Liao River Basin and Pearl River Basin in China (Yang et al., 2010; Zhu, Lin & Hao, 2015).

2.2 Study area

Shanxi province is located in mid-latitude inland on the eastern continent. Blocked by the eastern mountains, its temperate continental monsoon climate is less affected by the sea. Its winter is long dry and cold, while summer is affected by maritime warm current prevailing southeast monsoon with concentrated precipitation, which increases from northwest to southeast with annual average precipitation ranging 400 - 600 mm, and above 700 mm in parts of mountainous area. The Yellow River forms the western border of Shanxi province. Two major tributaries of the Yellow River, the Fen and Qin rivers run north-to-south through the province, drain 97 138km² in Shanxi, accounting 62% of the province's area. The north of the province is drained by tributaries of the Hai River.

The total water resources is 12.38 billion m³ in Shanxi, with a total current water supply of 7.34 billion m³, including 3.18 billion m³ of surface water, 3.64 billion m³ of groundwater, and 514 million m³ of other water sources. Its total water consumption is 7.34 billion m³. There are 3.99 billion m³ of water used for agricultural irrigation, 1.55 billion m³ for industrial purposes and 923 million m³ for domestic use.

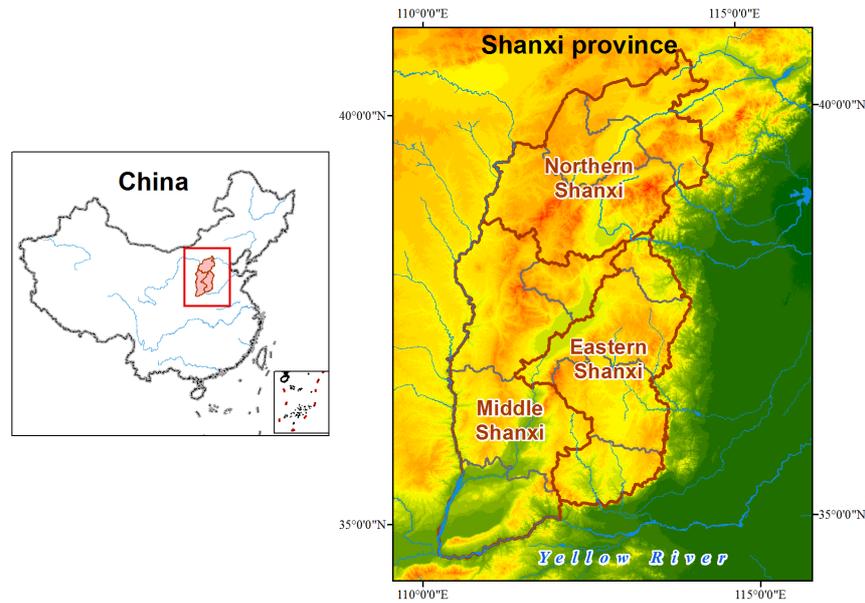


Figure 1 River system and topography of the Shanxi province

As the largest coal energy producing region in China, Shanxi's identified coal reserve is 2688 tons, accounting for about 25% of national coal resources. It has more coal companies than any other province. Industry in Shanxi is centred on heavy industries such as coal production and power generation. Shanxi is one of the major integrated Energy Base proposed by the National Energy Administration (NEA) during the period of the 12th FYP (2010-2015), and it have been reemphasized in the 13th Five-Year National Electric Power Development Plan (2016-2020).

Table 1 Current situation of water withdrawal in coal powers bases of Shanxi

Coal bases	Industrial water withdrawal	Coal industry water withdrawal			
		Coal power	Coal production & washing	Coal chemistry	Total
Northern Shanxi	4.81	0.78	1.39	0	2.17
Middle Shanxi	5.73	0.58	0.57	0	1.15
Eastern Shanxi	4.95	0.90	0.92	0.08	1.90
Total	15.49	2.26	2.88	0.08	5.22

Unit=100 million m³

According to the different coal mine and industrial types, Shanxi province can be subdivided into 3 bases, namely Northern, Middle and Eastern Shanxi bases (Figure 1). Water withdrawal data for three coal bases are showed in table1. The coal industry

water withdrawal in Northern, Middle and Eastern Shanxi coal bases are accounting respectively for 45.1%, 20.1% and 38.4% of the total industrial water withdrawal.

3 Analysis of water supply of Shanxi

3.1 Methodology

To analyze the water resource variation in the coming years in the study areas, first an extrapolation for recent trends is done to establish the Base representation for China future water supply. The CMIP Representative concentration Pathways (RCPs) are then used as the atmospheric driver of CLHMS simulation of the response of water cycle under different possible scenarios. Based on the evaluation results of 14 climate models of CMIP5 (the Coupled Model Intercomparison Project Phase 5) (Zhu et al., 2016), the CNRM-CM5 model was selected for this study.

CNRM-CM5 (Voltaire, 2013) model was developed by CNRM-GAME (France National Centre for Meteorological Research – Meteorological and Atmospheric studies Group) and CERFACS (European Centre for Research and Advanced Training). It contains an atmospheric model ARPEGE-Climate v5.2, a land surface model SURFEX/TRIP, an ocean model NEMO v3.2, a sea ice model GELATO v5 and OASIS v3 coupler with 1.4° atmospheric model resolution, 31 layers in vertical direction and 1° ocean model resolution.

Firstly, changing spatial characteristics of climatic factors in benchmark phase was done to correct the models' climatic estimate results. Then the corrected estimated results of precipitation are further applied to analyze the trend of climate change in the study area under three different emission concentration path scenarios in the future.

Climate change may increase frequency and intensity of extreme disasters as flood and drought, exert a direct impact on rainfall, evaporation, runoff and soil moisture. By applying IPCC AR5's high resolution model of CNRM-CM5, climatic estimates of the 21st century are made in low, moderate and high emission concentration path scenarios. With CLHMS model, water cycle changes in the study area under future climate change scenarios are estimated as discussed below.

3.2 Regional precipitation change in climate change scenario

The Shanxi province is mainly located in the Yellow River basin and a small part of Shanxi is in Hai River basin. Therefore, the future changes of water resources in these two basins are simulated, so as to obtain the changes of precipitation and water resources in the region. According to China's medium-term and long-term development plans and developing level, the low, mid and high typical standard greenhouse gas emission scenarios are selected, that is RCP 2.6, RCP 4.5 and RCP 8.5.

The RCP2.6 scenario is assumed that there the future energy structure will be changed thoroughly with development of energy saving and carbon fixed techniques. The world energy will be in a negative emission in the latter half of the 21st century, and the radiation forcing will be up to peak, and go down to 2.6 W/m^2 before 2100 (Vuuren et al., 2011). Under the mid concentration emission pathway (RCP 4.5) scenario, the wide application of electricity and low emission energy technology makes greenhouse gas emission effectively controlled with changing world energy system in the future. With carbon capture and geological storage techniques, the radiation forcing will be steady at 2.5 W/m^2 in 2100 (Thomson et al., 2011). The high concentration emission pathway (RCP 8.5) is assumed that there are most population in a long-term energy demand and high greenhouse gas emission but in a slow technical innovation. The radiation forcing goes up continuously to 8.5 W/m^2 and the temperature is estimated to be up by 4 – 10 degrees Celsius (Riahi et al., 2011).

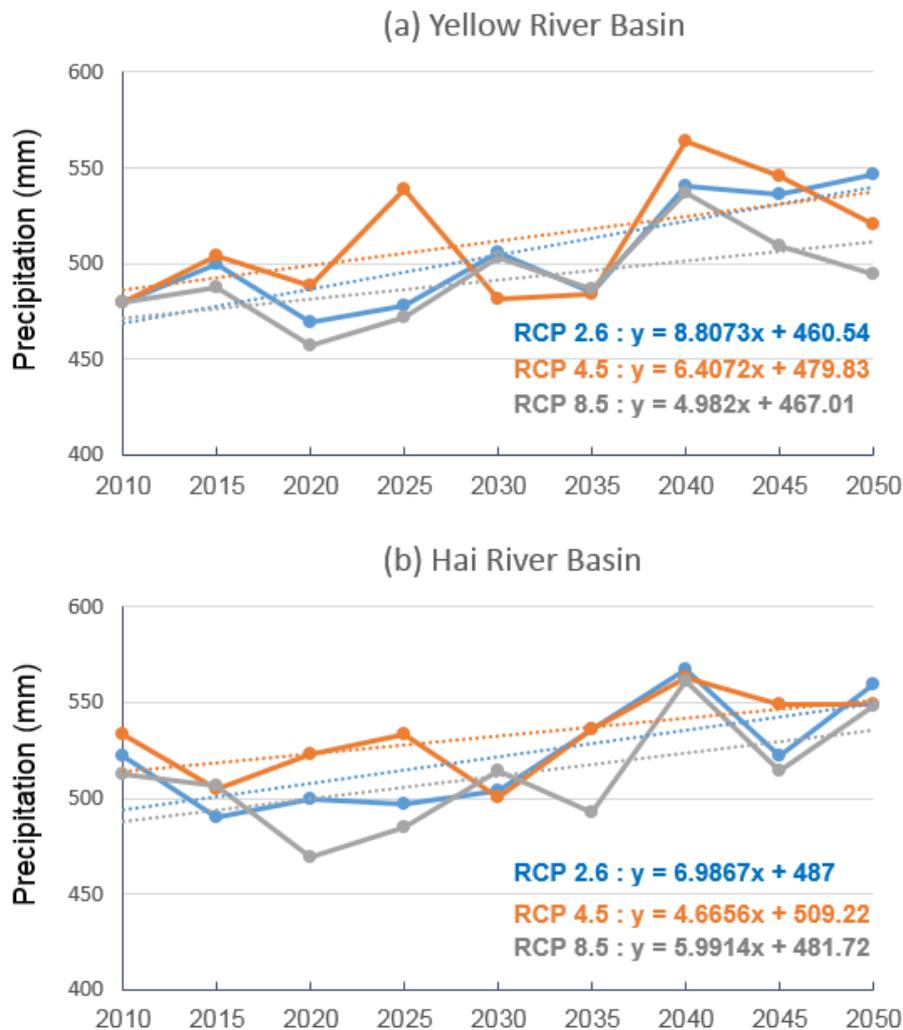


Figure 2 Future trend of precipitation in Yellow River Basin and Hai River Basin

Figure 2 shows precipitation variation for Yellow River basin and Hai River basin, with 2010 as the benchmark year. It shows that precipitation in the future has an increasing

trend to varying degrees in Yellow River and Hai River Basin, and with big inter-annual variation. The majority area of Yellow river basin and Hai river basin are both located in the East Asia temperate monsoon climate zone, therefore, the simulation results show that the precipitation change characteristics are basically the same. In the first half of 21th Century, the average precipitation will be slightly more than the current mean annual precipitation. All the 3 RCP scenarios show a slight decreasing trend before 2035, then the regional precipitation increase around 2040s. In Hai River basin, under the RCP 4.5 scenario, the precipitation will increase around 2025; on the contrary, RCP 2.6 and 8.5 scenarios simulation results show a decreasing trend. Future research is still needed to discuss the uncertainty of precipitation under the climate change.

3.3 Future water resources of Shanxi

The CLHMS, combining climate with hydrological model, is a basic idea to study the impact of climatic changes on water cycle and hydrological water resources. However, the CLHMS is mainly used to study the water resources changes at a basin level due to the setting of research object and mode. Shanxi province located both in the Yellow River and Hai River Basin. Therefore, the future changes of water resources in these two basins are simulated, so as to obtain the changes of water resources in Shanxi. The spatial distribution of regions is available by statistic downscaling.

Driven by the impacts of global warming, land water form changes impact the entire water cycle process and the temporal-spatial distribution of water resources. By applying IPCC-AR5's high resolution model of CNRM-CM5, climatic estimates of the 21st century are made in low, moderate and high emission concentration path scenarios (RCP2.5, RCP4.5 and RCP8.5). With the CLHMS model, water cycle changes in the study area under future climate change scenarios are estimated as shown in Figure 3.

The simulation results shows that the average total water resources in the first half of 21st century in RCP 2.6, RCP4.5 and RCP 8.5 scenarios are respectively 8.1, 8.0 and 7.3 billion m³, which respectively holds -34%, -35% and -41% deviations to the total water resources based on the evaluation results of the second water resources investigation (1956-2000). Around 2020s and 2030s, Shanxi will continue to decline, the region will face severe water problems.

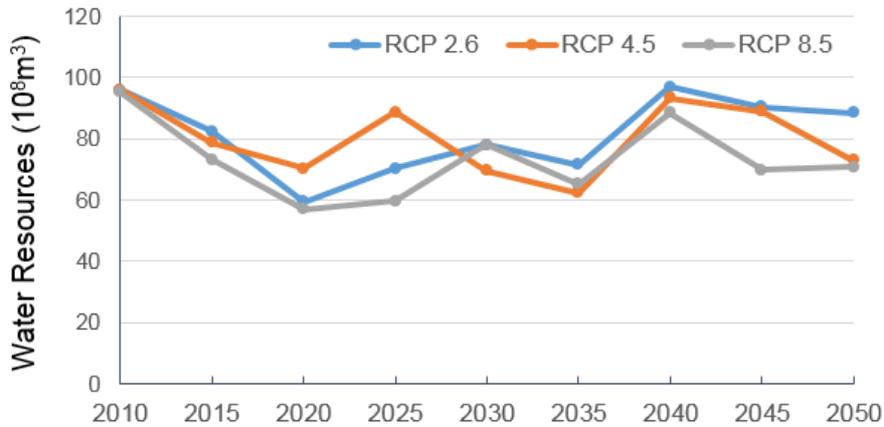


Figure 3 Trend of water resources in Shanxi

4 Analysis of water demand of Shanxi

China's rapid social-economic development has been accompanied by a similar increase in industry, especially in coal and energy industry with high water consumption. To promote a rational industrial scale compatible with the water resources and the environment, the "most stringent water resources management system" was implemented in 2012 (Zuo et al., 2014). In 2020 and 2030, the national water use will be kept within 670 billion m³ and 700 billion m³. The water use for Shanxi will be strictly controlled below 9.3 billion m³ in 2020 and 9.9 billion m³ in 2030 at the provincial level.

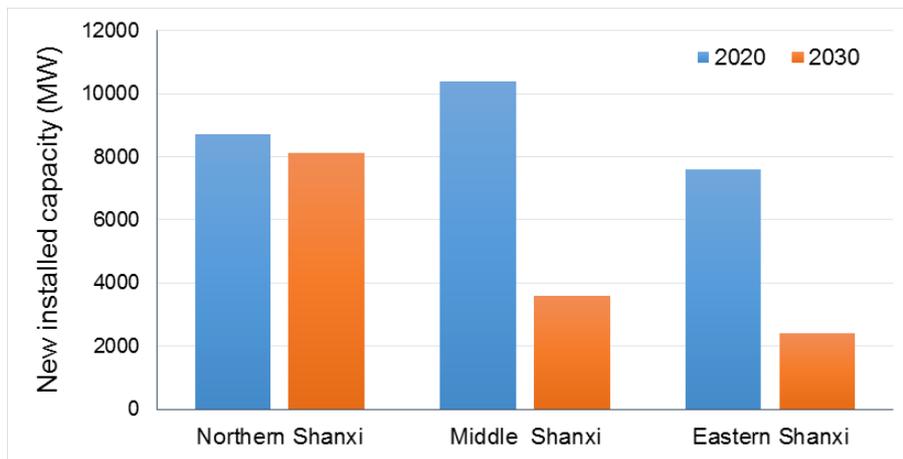


Figure 4 New installed energy capacity in 2020 and 2030

Current water withdrawal in Shanxi Energy producing regions amount to 0.78 billion m³, which is 53.4% of the industrial water withdrawal. Clearly, water use in energy base comprises a high ratio of total industrial water use. According to medium and long term development plan of energy bases, the planning newly installed thermal power capacity of Shanxi is shown in Figure 4. In 2030, Shanxi is expected to expand

or newly built 50 thermal power projects. The installed capacity will reach 40 million KWh, the new thermal power installed capacity of northern, middle and eastern Shanxi is 16.8, 13.9 and 10.0 million KWh.

In order to estimate the future water demand in Shanxi, BAU (Business-as-usual) and WSC(Water saving) scenarios are designed as according to the guide to water efficiency in key industrial sector published by the Ministry of industry and Information Technology.

As shown in Figure 5, the water use of the coal industry in Shanxi province will both increase significantly in BAU and WSC scenarios. In BAU scenario, the water use in 2030 will increase 49% over the current level, that is 337 million m³ for coal industry. Between the two scenarios, there is a difference of 160 and 230 million m³ for 2020 and 2030 respectively.

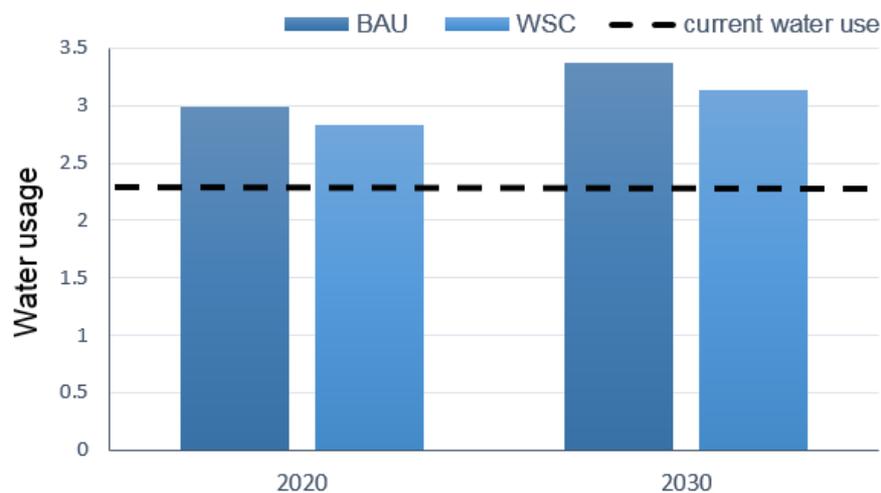


Figure 5 Future water demand in Shanxi (unit: 100 million m³)

5 Discussion and conclusions

5.1 Marching analysis of water resources supply and demand

With the rapid development of economy, energy demand and consumption continues to grow. As a water-intensive energy industries, according to the forecast, in China the newly increased water demand of energy industry will reach 3.8 billion m³ by 2020. Shanxi as the country's largest coal energy base, which is already water stressed area, the contradiction between water resources and energy development is becoming more and more serious.

This study is focus on the issue of water resources and energy suitability in Shanxi. According to the national and local development plan, the analysis results indicate that the water demand of Shanxi Energy base will reach to 0.6 billion m³ by 2030. Compared with the current water demand, at least 13% more water is needed under

the water saving scenario; under the current technical conditions, the water demand of energy base will increase by 17%. However, affected by climate change, water resources of Shanxi will change significantly. Compared with the amount of water resources in 2010s, the water resources will be reduced by 18% around 2030s under RCP2.6 and RCP 8.5 scenarios. In RCP 4.5 scenario, a -25% deviation to the water resources is expected in 2030s. In the current water supply situation, severe water resource limitations are foreseen as a challenge to Shanxi's energy development strategies that continue to see a central role for coal.

5.2 Energy development and water resources security policy

Energy security has become one of the biggest obstacles to the economic and social development of China. It relates to the security of energy supply and the ecological environment management. Most of energy bases of China are located in arid or semiarid regions that are deficient in water. Severe water resources challenge China's energy development strategy is foreseeable. In order to meet the requirements of energy development with local water resources limitations and hydrologic variability linked to climate change, it is urgent to develop the non-conventional water resources, including mine water and reclaimed water. Furthermore, it is necessary to explore the inter-industry and inter regional water right replacement, with the development of water market, the water right could transfer to energy industry from other sector.

5.3 Conclusions

In this study, the impacts of future climatic changes and human activity on water resources in Shanxi's energy base has been investigated base on the Coupled Land surface and Hydrology Model System (CLHMS) using three different IPCC AR5 emission scenarios (RCP2.6, RCP4.5 and RCP8.5). The simulation result indicate that the average water resources of Shanxi Energy Base will decrease in the first half of 21th Century. However, comparing with the current national policy, Shanxi is expected to expand or newly built 50 thermal power projects in 2030. With the continuous development of energy industry, water demand will increase by 17%. For the rational utilization of the limited water resources in Shanxi Province, water resources management policies are bring forward to realize the sustainable use of the water resources in Shanxi Province.

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