



**SUSTAINABLE DEVELOPMENT IN WATER-ENERGY-FOOD NEXUS
PERSPECTIVE FOR THE YELLOW RIVER BASIN, CHINA**

By

YAN XIAOHAN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
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Philosophy**

December 2023

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DEDICATION

To my loving parents, husband and sons.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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By

YAN XIAOHAN

December 2023

Chair : Lee Chin, PhD
School : Business and Economics

The Yellow River is the fifth longest river in the world, flowing through nine provinces in China. The **Yellow River Basin (YRB)** accounts for about 8% of China's land area and 32% of population with significant status in energy and food sectors in China. Besides, the climate there is dry with shortage of water resource, the imbalance relationship between water, energy and food is an significant problem there restricting local environmental quality. Further, 'The high-quality development of the Yellow River Basin' has been put forward as a fundamental national policy for China. Aiming to investigate local **Sustainable Development Goals (SDGs)** achieving, from the perspective of **water-energy-food nexus (WEF)** analysis, this study investigates how WEF relates to the economy, public health, and the catalytic role of green finance with mechanism behind it.

First, this study constructs a more comprehensive measure of WEF compared to literature providing a holistic assessment of the environmental potential capacity in the region. This study systematically explored sustainable related indicators that are relevant to the WEF to form an indicator system, and innovate utilize the combining weighting method AHP-CRITIC by which the **coupling and coordination degree (CCD)** be calculated. Moreover, Moran's I index was utilized to check the spatial correlation of it. And the results shown that the degree of WEF CCD exhibited a pattern of initial decrease followed by subsequent increase and it is in the range between 0.7 to 0.8. In order to enhance the coordination of water, energy, and food sectors, considering the specific characteristics of each sector, the public should focus on infrastructure development, industrial upgrading, and technological innovation, respectively. And the decision-maker could hasten the planning and building of the western portion of the South-to-North Water Diversion Project, which will aid in reducing YRB's resource competitiveness and uneven distribution of water.

Second, for investigating the promotion of environmental quality, this study measured the local development of **green finance** more comprehensively via entropy weight approach, and then examined the influence mechanism of green finance on WEF CCD via industry upgrading, environmental regulation and green innovation simultaneously. Since the data is long panel, the full Feasible Generalized Least Squares (FLGS) tested to be appropriate and the results indicate a U-shaped relationship between WEF CCD and economic progress, while green finance can significantly promote WEF CCD growth. Besides, this study verified green finance mainly promotes local WFE CCD via mechanism of promoting industrial upgrading and green innovation, though the effect of green regulation was not found clear evidence to simulate WEF CCD. Therefore, further environmental regulation strengthening via green finance is more necessary to be placed in a prominent position. And it is crucial that provincial governments modify their green finance development strategies in accordance with the resources and features unique to their respective regions.

Finally, motivated by figuring out the inter-relationships between **environmental quality, economic development** and **public health**, the multivariate analysis was carried out by using **Panel Structure Vector Auto Regression (PSVAR)** and the results revealed that the expanding YRB economic development mode was detrimental to the environment. The rise of healthcare expenditures would also negatively impact the economy and environment. Nonetheless, environmental quality was not a contributing factor to economic development and public health at the current stage. Policies promoting resource efficiency and coordination, clean technologies, and preventative healthcare practices could assist in reducing the negative environmental impacts while promoting long-term sustainability.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN MAMPAN DARI PERSPEKTIF HUBUNGAN ANTARA
AIR-TENAGA-MAKANAN (WEF) UNTUK
YELLOW RIVER BASIN, CHINA**

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Yellow River merupakan sungai kelima terpanjang di dunia, mengalir melalui sembilan wilayah di China. **Yellow River Basin (YRB)** merangkumi kira-kira 8% daripada jumlah keluasan tanah negara China dan 32% penduduk negara China, dan memainkan peranan yang penting dalam sektor tenaga dan makanan di negara China. Selain itu, iklim yang kering dengan kekurangan sumber air, hubungan ketidakseimbangan antara air, tenaga dan makanan adalah masalah utama yang menyekat peningkatan kualiti alam sekitar tempatan. Tambahan pula, 'Pembangunan Yellow River Basin yang berkualiti tinggi' telah dikemukakan sebagai dasar kebangsaan asas negara China. Bertujuan untuk mengkaji pencapaian **SDG** tempatan dari perspektif hubungan **air-tenaga-makanan (WEF)**, kajian ini mengkaji bagaimana WEF berkaitan dengan ekonomi, kesihatan awam, dan peranan kewangan hijau dalam mekanisme ini.

Pertama, kajian ini membina satu ukuran WEF yang lebih komprehensif berbanding dengan kajian lepas, di mana ia memberikan penilaian keseluruhan terhadap keupayaan potensi alam sekitar di kawasan ini. Kajian ini meneroka secara sistematik petunjuk-petunjuk yang berkaitan dengan WEF untuk membentuk satu sistem penunjuk, dan menggunakan kaedah pemberat gabungan AHP-CRITIC di mana **koordinat dan penyelarasan (CCD)** boleh dikira. Selain itu, indeks I Moran digunakan untuk menguji korelasi spatial di antara mereka. Dan keputusan menunjukkan bahawa WEF CCD mempamerkan corak penurunan pada peringkat awal, diikuti dengan kenaikan, dan nilainya berada dalam julat antara 0.7 hingga 0.8. Untuk meningkatkan penyelarasan sektor air, tenaga, dan makanan, dengan mengambil kira ciri-ciri khusus setiap sektor, orang ramai harus memberi tumpuan kepada pembangunan infrastruktur, peningkatan perindustrian, dan inovasi teknologi.

Dan pengubal dasar boleh mempercepatkan perancangan dan pembinaan di sebelah barat Projek Lencongan Air Selatan-ke-Utara, yang akan membantu mengurangkan persaingan sumber dan pengagihan air yang tidak sekata di YRB.

Kedua, untuk mengkaji peningkatan kualiti alam sekitar, kajian ini mengukur pembangunan **kewangan hijau** tempatan yang lebih komprehensif melalui pendekatan pemberat entropi, dan kemudian mengkaji peranan kewangan hijau pada WEF CCD melalui peningkatan industri, peraturan alam sekitar dan inovasi hijau secara serentak. Oleh kerana data adalah panel yang panjang, Feasible Generalized Least Squares (FLGS) penuh sesuai digunakan dan keputusan kajian menunjukkan satu hubungan berbentuk U antara WEF CCD dan pembangunan ekonomi, sementara kewangan hijau dapat meningkatkan pertumbuhan WEF CCD. Selain itu, kajian ini mengesahkan bahawa kewangan hijau meningkatkan WEF CCD tempatan melalui mekanisme menggalakkan peningkatan industri dan inovasi hijau, manakala peraturan hijau tidak mempengaruhi WEF CCD. Oleh itu, pengukuhan peraturan alam sekitar melalui kewangan hijau perlu diutamakan. Dan adalah penting bagi kerajaan tempatan mengubah suai strategi pembangunan kewangan hijau mereka mengikut sumber dan ciri-ciri yang unik di wilayah masing-masing.

Akhir sekali, untuk mengkaji hubungan antara **kualiti alam** sekitar, **pembangunan ekonomi** dan **kesihatan awam**, analysis pelbagai pembolehubah dijalankan dengan menggunakan **Panel Structure Vector Auto Regression (PSVAR)** dan keputusan kajian menunjukkan bahawa mod pembangunan ekonomi YRB telah memudaratkan alam sekitar. Peningkatan perbelanjaan kesihatan juga memberi kesan negatif kepada ekonomi dan alam sekitar. Namun begitu, kualiti alam sekitar bukanlah faktor penyumbang kepada pembangunan ekonomi dan kesihatan awam pada peringkat semasa. Dasar yang menggalakkan kecekapan dan penyelarasan sumber, teknologi bersih, dan amalan penjagaan kesihatan dapat mengurangkan kesan negatif alam sekitar sambil mempromosikan pembangunan mampan jangka panjang.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LISTS OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
CAPM	Capital Asset Pricing Model
CCD	Coordination and Coupling degree
CO ₂	Carbon Dioxide
CRITIC	Criteria Importance Through Intercriteria Correlation
EKC	Environmental Kuznets Curve
EMH	Efficient Markets Hypothesis
FGLS	Feasible Generalized Least Squares
GDP	Per capita real GDP
HCE	Healthcare expenditure
LSDV	Least Squares Dummy Variable
OECD	Organisation for Economic Cooperation and Development
PCSE	Panel Corrected Standard Error
PSVAR	Panel Structural Vector Auto-regression
SDGs	Sustainable Development Goals
SDM	Spatial Durbin Model
SYS-GMM	System Generalized Method of Moments
VIF	Variance Inflation Factor
WEF	Water-Energy-Food Nexus
YRB	Yellow River Basin

CHAPTER 1

INTRODUCTION

1.1 Overview

The Yellow River Basin (YRB) is one of the most important environmental and economic regions in China. The current study aims to perform a comprehensive analysis to explore the key issues and factors pertinent to sustainable development, depending on the local situation.

Given the pronounced ecological and environmental challenges in the YRB, coupled with its significant role as a crucial grain-producing region, the Chinese government elevated the 'YRB conservation and development' to a fundamental national policy in 2019. This decision placed environmental protection and sustainable development in the YRB at a paramount national strategic level.

And in the study of the sustainability of YRB, several crucial questions can be raised. What is the current state of environmental quality in the Yellow River Basin? What is the developmental trend and main trajectory of the YRB's environment? Specifically, taking into consideration the actual regional conditions, this study derived a comprehensive measure of environmental quality from the perspective of water-energy-food Nexus coordination and coupling degree (WEF-CCD) for nine YRB provinces. The measure encompassed the interdependencies between water, energy, and the food sector and provided a holistic assessment of the environmental potential capacity in the region, which could demonstrate environmental quality.

Moreover, as the environmental quality of YRB is of paramount importance, the effective promotion of it has become a crucial issue. With increasing awareness of sustainable development, more and more resources are allocated to improve environmental quality. The traditional finance that previously provided low-cost loans to polluting companies for promoting industrialization but accelerated the deterioration of environmental quality, is no longer viable. In contrast to conventional financial activities, green finance places a greater emphasis on the ecological environment's benefits and the industry that protects the environment (Wang et al., 2016). Existing studies generally convince that green finance helps to improve the environment and sustainability via offering support and direction to stakeholders to create a win-win situation between the economy and the environment (eg. Asif et al., 2022; Afzal & Malik, 2022; Zhang et al., 2021). Therefore, studying the mechanisms of green finance for environmental quality is meaningful for sustainability.

Further, environment, wealth, and health are significant pillars of sustainability, and how to manage and coordinate the relationships among them is a hotly discussed issue worldwide. With a growing population and expanding industries, YRB is encountering significant challenges related to economic development, environmental quality, and public health. High energy consumption entails substantial demand for energy resources, potentially leading to excessive depletion and exhaustion of these resources, posing a threat to future energy supply. Besides, extensive production processes often generate substantial emissions and waste, that may contaminate the air, water resources, and soil, causing ecological damage. Environmental pollution and greenhouse gas emissions might have adverse effects on human health, such as respiratory and cardiovascular diseases. And the harm to the labor force's health can, in turn, impact further economic development. Extensive economic development faces challenges in achieving sustainability, presenting greater obstacles to future economic development. Therefore, studying the interaction and balance among the environment, public health and economy is of great significance to local sustainability. Subsequently, panel structural vector auto-regression (PSVAR) was conducted to determine the interrelationships between environmental quality, economic development, and public health in the YRB.

Overall, the interplay mechanisms among water, energy, and food, as well as the measurement of the coordinated degree among them, are investigated. Furthermore, the mechanism of green finance in the water-energy-food nexus is discussed. Lastly, a broader perspective is taken to study the relationship between the water-energy-food nexus, health, and economic development. These factors and research topics are closely related to the sustainable development goals (SDGs), providing theoretical and empirical evidence for policy formulation in local sustainable development.

1.2 Definition of Key Terms

Next, this section introduces the key concepts, including sustainable development, the water-energy-food nexus (WEF), environmental quality, green finance, and citizen's health.

1.2.1 Sustainable Development

In the articles of Costanza and Daly (1992) and Hediger (1999), two concepts of sustainable development are defined: weak sustainability and strong sustainability. Weak sustainability is an economic principle that requires production capacity to decline over time. Comparatively, in the perspective of ecological economics, the strong sustainable requirements of the natural value not falling over time (Caviglia-Harris, 2009). This view proposes that natural capital is precious, plays an irreplaceable role for humans, and is therefore unique (Barbier, 2005). Since resources are finite, infinite growth cannot be continuous if it is achieved through the use of natural resources. If development

is achieved through increased efficiency, it can guide the sustainable use of resources now and into the future (Costanza and Daly, 1992).

1.2.2 Water Energy Food Nexus

The WEF nexus is a concept that highlights the interconnection and interdependence of water, energy, and food systems. It was first proposed in 2011 at the Bonn Conference in Germany¹. Since then, it has become an attractive topic in the fields of environmental science, system engineering and economics (Liu et al., 2017). Against the background of soaring food prices, technological revolution, and the continuous development of sustainability in interdisciplinary research, the WEF nexus has been widely adopted as an indicator system to measure sustainable development. Relevant indicators have been systematically identified to construct index system to evaluate the WEF Nexus development at different spatial and temporal scales (Li, 2016).

The interdependent relationships among the WEF sectors are shown in Figure 1.1. In the water value chain, food and energy are essential input factors. Energy is needed for pumping water, purification, especially desalination and wastewater treatment, and transportation (Siddiqi& Anadon, 2011). And food can store and transport virtual water, which induces grain virtual water international trade (Xia et al., 2022). In the energy system, substantial water resources are needed and utilized. The production of oil and natural gas requires 1 to 10 liters per gigajoule (GJ) of water, while the mining of oil sands and gas requires 100 to 1000 liters per GJ of water². And on its own, water itself can be used as energy. Hydropower has shown the fastest growth rate in global power development over the past decade, with an annual average growth of 3% (CIC Consultant, 2021). Likewise, crops can also be turned into energy, which is called bioenergy, like maize transferring into ethanol (Lawford et al., 2013). Moreover, in the food sector, agriculture irrigation, harvesting, and distribution can only take place with water and energy. And the utilization of agricultural equipment is closely intertwined with the availability and utilization of energy resources.

1 "The Water, Energy and Food Security Nexus: Solutions for the Green Economy". <https://www.water-energy-food.org/about/bonn2011-conference/>

2 Figure Source: China Energy Statistical Yearbook (2022)

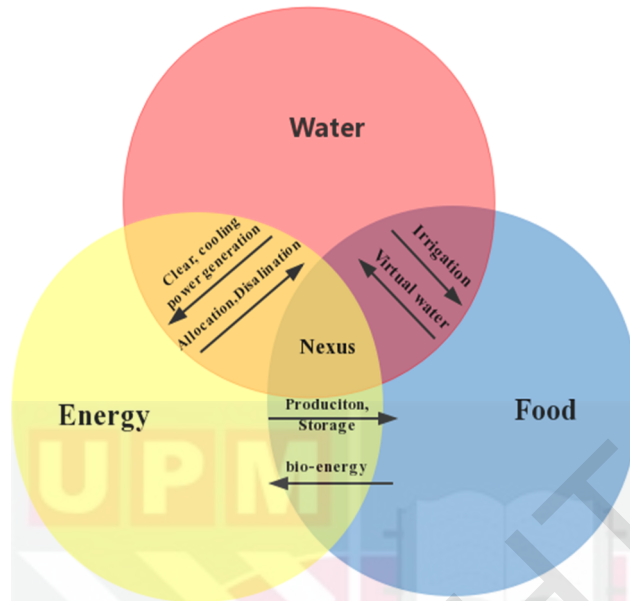


Figure 1.1: The Relationships among the WEF Subsystems
(Source: Constructed by author)

1.2.3 Environmental Quality

The term ‘environmental quality’ refers to the sustainability of the components essential for human life and social development (Van Kamp et al., 2003). In particular, numerous scholars have supported the WEF nexus as a critical marker of environmental quality and sustainable development (e.g., Li et al., 2022; Zarei et al., 2021; Urbinatti et al., 2020). The WEF nexus quantifies future patterns of environmental quality by investigating the impact and feedback mechanisms among water, food, and energy resources, as these three sectors have a close relationship in the processes of production and transportation. Hence, this study utilized the WEF nexus coordination degree to reflect environmental quality. A more coordinated relationship between WEF resources leads to higher benefits for the environment and promotes sustainable development.

1.2.4 Green Finance

The definition of green finance varies across scholars and institutions, but it generally refers to financial activities and instruments that support environmentally sustainable projects and businesses. According to Lindenberg (2014), financial investments made in projects and initiatives for sustainable development, environmental production, and regulations that support the growth of a more sustainable economy are called green finance. The goal of green

finance is to redirect capital flows away from activities that harm the environment and towards those that support sustainability and climate resilience. It helps bridge the gap between the financial sector and environmental goals, making it a critical tool in the fight against climate change and the pursuit of a more sustainable future (Ozili, 2022).

Green finance encompasses a variety of financial instruments, from green financial bonds, green banks, carbon market tools, and other new financial instruments to new policies, fiscal policy, a green central bank, fintech, community-based green funds, and expanding the investments financing that provide environmental benefits (Duchêne, 2020).

1.2.5 Citizen's Health

The words health are frequently used without a clearly defined meaning. A structural, functional, and emotional state that is consistent with leading a successful life as an individual or as a member of society mean being in good health (McCartney et al., 2019). In this study, the concept of health adherence is employed without specific differentiation between physical and mental health.

The close relationship between healthcare expenditure and residents' health has been widely substantiated (e.g. Onofrei et al., 2021; Novignon et al., 2012). Therefore, many scholars consider healthcare expenditure as a representative proxy variable for public health (e.g. Kaur, 2023; Kuan et al., 2020; Ray & Linden, 2020; Alimi et al., 2020). Healthcare expenditure includes all expenditures for the provision of health services, family planning activities, nutrition activities, and emergency aid allocated for health, and health financing being a vital part of health systems (WHO, 2023)³. And Poullier has divided total health expenditures into two categories of public and private health expenditures. Public health expenditures include social security costs, taxes on the public and private sectors, and foreign aid in the form of loans and subsidies. However, private health expenses contain out-of-pocket medical expenses, private health insurance, etc (Rad et al., 2013). However, in the YRB context, directly using healthcare expenditure as a representation of health status might be biased to some extent. China experienced rapid economic development with a average growth rate 9%⁴, leading to significant development in infrastructure and public services, including healthcare facilities and public health services. As a result, the substantial growth in government health services expenditure in China can primarily be attributed to the economic boost, demonstrating a strong endogenous relationship between public health expenditure and the economy. Based on the actual situation of the study area, this study utilizes proportion of average private healthcare expenditure to consumption per capita to present public health status.

³ Source: <https://www.who.int/data/nutrition/nlis/info/health-expenditure>

⁴ Figure Source: Statistics of China, 2004-2019

1.3 Introduction to the Study Area: The Yellow River Basin

The Yellow River is the fifth longest river in the world, being the cradle of the Chinese nation and one of the birthplaces of the whole world's civilization. In 2019, President of China emphasized that protecting the Yellow River is a great cause vital to the rejuvenation of the Chinese nation for generations. He issued a call to turn the Yellow River into a river of happiness benefiting the people, elevating the 'YRB conservation and development' to a major national strategic priority. As shown in the Figure 1.2, the 5,464-kilometer-long Yellow River covers a basin area of 79.5×10^4 square kilometers⁵, flows through nine provinces, including Qinghai, Sichuan, Gansu, Ningxia, Mongolia, Shaanxi, Shanxi, Henan, and Shandong, from upstream to downstream with the total administrative area is 349.02×10^4 square kilometers⁶. By the end of 2020, with 47.47% of the land area and 2% of the country's total water resources, the basin supported 32% of the country's population and irrigated 34% of its cultivated land, contributing 26.5% of the national GDP (Sun et al., 2020; Mao, 2020).

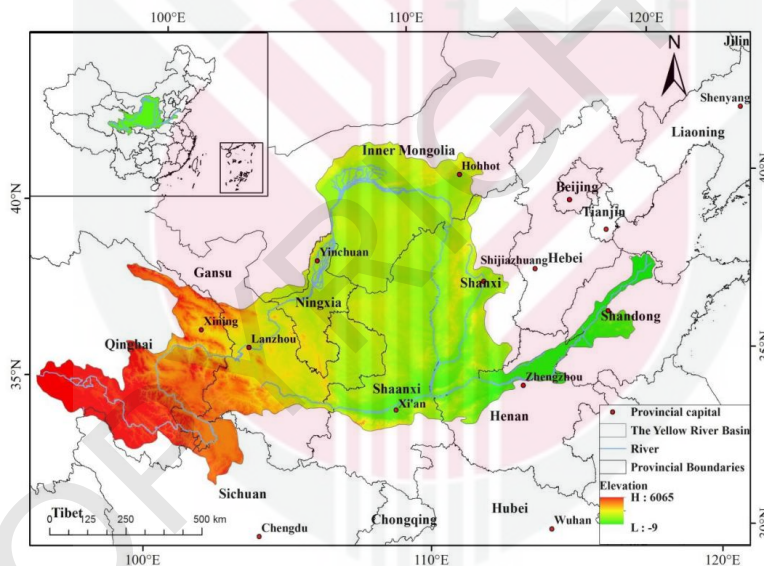


Figure 1.2: The Map of the Yellow River Basin
(Map Layer Source: IMDN.cn, 2023)

To justify YRB as the focal study area for this thesis, a comprehensive examination of its unique ecological and socio-economic characteristics is presented. The following sections mainly introduce the environmental quality

⁵ Chinese National Bureau of Statistics, 2022

⁶ Chinese National Bureau of Statistics, 2022

from perspective of water, energy and food sectors, economic status, green finance development, and citizen's health condition of YRB aiming to facilitate a clear understanding of the issues and objectives under investigation in this study.

1.3.1 Environment Quality of Yellow River Basin

The environmental quality of the YRB faces several significant challenges, largely stemming from human activities and natural conditions. From a WEF Nexus perspective, this study exhibits the relevant situation and problems of the YRB in the three sectors of water, energy, and food, as well as the main problem of the local WEF Nexus.

As early as 1987, the Chinese State Council approved the *Yellow River Water Supply Distribution Plan*, utilizing 58 billion cubic meters of natural runoff from the Yellow River as a water distribution base. However, the latest water resources survey shows that the Yellow River's natural runoff is less than 50 billion cubic (CNBN, 2017). Since the YRB is mostly made up of arid and semi-arid land with an average yearly rainfall of only 200-350 mm and evaporation as high as 2000mm (Sun et al., 2020). As shown in figure 1.3, the annual runoff and available water consumption of the Yellow River were not stable, indicating a limited and inconsistent water source supply.

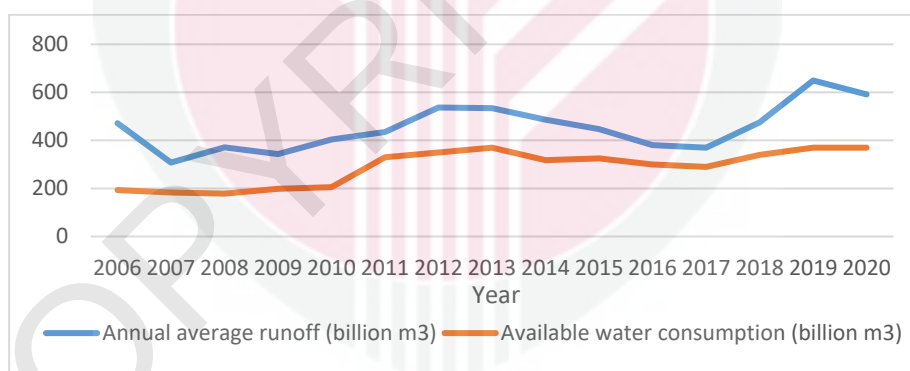


Figure 1.3: The Annual Average Runoff and Available Water Consumption in YRB

(Data source: Yellow River Water Resources Bulletin and Chinese National Bureau of Statistics, 2006-2020)

From 2000 to 2020, the average water consumption of the nine provinces in the YRB is 1003.36×10^8 cubic meters⁷, accounting for about 17.61% of the national total. As can be seen from Table 1.1, in terms of water usage composition,

⁷ National Bureau of Statistics, 2000-2020

agricultural water accounts for the highest proportion (66.6%), followed by domestic water (14.5%), industrial water is less (10.7%), and ecological water is the lowest (8.1%). It can be found that agriculture consumes more water than the total of industrial, domestic, and ecological water, with ecological water accounting for a very low proportion. In the YRB in 2020, as the orange line in figure 1.4 shows, food production remains the largest usage of water, however, since the water supply are limited, that is lower than the global level of 70% (FAO, 2020).

Table 1.1: The Water Resources Demand in Specific Sectors in YRB in 2020 (10⁸m³)

Provinces	Water supply amount	Water Demand for Industry	Proportion of Water Use in Industry	Domestic Water	Proportion of Water for Life	Water for Agriculture	Proportion of Water Use in Agriculture	Water Demand for Ecology	Proportion of Water Use in Ecology
Qinghai	24.3	2.4	9.88%	3	12.35%	17.7	72.84%	1.1	4.94%
Sichuan	236.9	23.5	9.92%	53.6	22.63%	153.9	64.96%	5.9	2.49%
Gansu	109.9	6.2	5.64%	9.3	8.46%	83.7	76.16%	10.7	9.74%
Ningxia	70.2	4.2	5.98%	3.7	5.27%	58.6	83.48%	3.7	5.27%
Inner Mongolia	194.4	13.4	6.89%	11.6	5.97%	140	72.02%	29.4	15.12%
Shannxi	90.6	10.9	12.03%	18.9	20.86%	55.6	61.37%	5.6	5.74%
Shanxi	72.8	12.4	17.03%	14.6	20.05%	41	56.32%	4.8	6.59%
Shandong	222.5	31.9	14.34%	37.5	16.85%	134	60.22%	19.1	8.59%
Henan	237.1	35.6	15.01%	43.1	18.18%	123.5	52.09%	35	14.72%

(Data source: China Water Resources Bulletin, 2021)

Meanwhile, as the industrial and ecology sectors have increased demand for water, agriculture is under pressure in water-stressed provinces, especially the four provinces (Shannxi, Shanxi, Shandong and Henan) which are located in the middle and lower reaches and have incentive to reallocate water to economically and ecologically productive sectors, which in turn would hurt the food sector. Besides, the over-exploitation and extensive utilization of water resources in YRB and the low efficiency of agricultural water consumption, especially the traditional farming based on low technology irrigation, have caused the contradiction between supply and demand of water resources for a long time. Besides, the water uses structure of different provinces show varies pattern resulting in conflicts and water resource competition to some extent. From Figure 1.4, we can see that the variation in water distribution among provinces is huge. The excessive use of water resources in the upstream and middle streams further aggravates the problem of insufficient water usage downstream. Shanxi, Qinghai and Ningxia use less water; Henan, Shandong and Inner Mongolia consume more water, especially in agriculture.

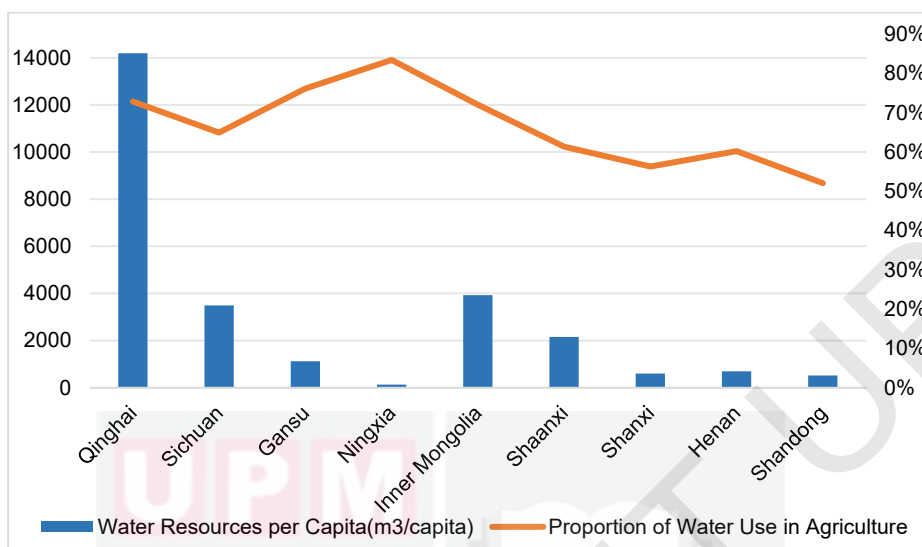


Figure 1.4: The Water Resources per Capita and Agriculture Water Use Proportion of Nine Provinces in the YRB

Note: The provinces on the horizontal axis from left to right are arranged in order from upstream to downstream.

(Data source: Chinese National Bureau of Statistics, 2020)

Besides, as an 'energy basin', YRB is the core of the national energy supply area. The economically amount of coal resources ranks first in China at present, and 9 out of the 14 large-scale coal production bases are located along the river with the largest proportion of coal exploitation (Peoples net, 2020). In 2022, the coal and natural gas production in YRB accounted for over 70% of the national total production, while the crude oil production took up over 30% of the nation's total production⁸.

⁸ Figure source: Chinese National Bureau of Statistics, 2022

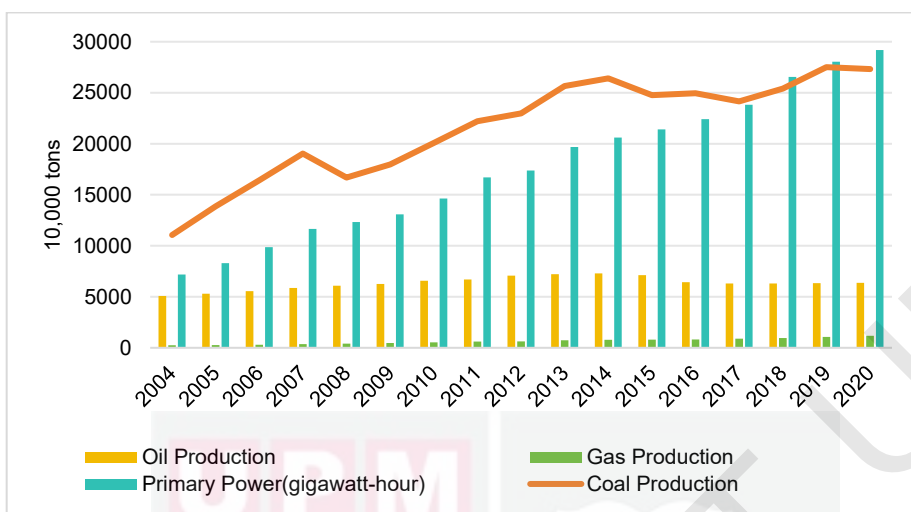


Figure 1.5: Primary Energy Production in the YRB During 2004-2020
(Data source: Chinese National Bureau of Statistics, 2004-2020)

As can be seen in Figure 1.5, from the perspective of energy production structure, coal production accounts for the largest proportion, followed by crude oil and electricity, and natural gas producing is the lowest, which is consistent with the resource endowment of *rich coal, poor oil and less gas* in China. Consequently, the basin occupies an extremely important strategic position in China, the amount of primary energy production in the YRB accounts for about 39% of that in the whole of China. Coal chemical enterprises in the YRB account for 80% of the country's total⁹.

Table 1.2: Area of Cultivated Land in 9 Provinces of The YRB and its proportion in the Whole Country (2013-2017)

Province	2013	2014	2015	2016	2017
Qinghai	58.82	58.57	58.84	58.94	59.01
Sichuan	673.48	673.42	673.14	673.29	672.52
Gansu	537.88	537.79	537.49	537.24	537.7
Ningxia	128.11	128.59	129.01	128.88	128.99
Inner Mongolia	919.9	923.07	923.8	925.79	927.08
Shannxi	399.2	399.48	399.52	398.95	398.29
Shanxi	406.2	405.68	405.88	405.68	405.63
Henan	814.07	811.79	810.59	811.1	811.23
Shandong	763.35	762.06	761.1	760.69	758.98
YRB	4701.01	4700.45	4699.37	4700.56	4699.43
Nation	13516.34	13505.73	13499.87	13492.09	13488.12
proportion of the national cultivated land area/%	34.78	34.8	34.81	34.84	34.84

Note: Area measured in million hm²

(Data Source: China statistical yearbook, 2014-2018)

⁹ Figure source: Chinese National Bureau of Statistics, 2022

Besides, the basin is also an important food base, as Table 1.2 shown, cultivated land in the YRB made up approximately 34% of the country's cultivated land in the period 2013-2017 implying the YRB strategic status in China. At present, it has 13 million hectares of arable land, 10.2 million hectares of land, 27.9 million hectares of pasture and grassland, and two million hectares of wasteland suitable for forestry and reclamation (Yang, 2000). As can be seen from Figure 1.6, in YRB's cultivated land use, the proportion of food crops is the highest, accounting for about 72% of the total cultivated land and showing an overall increasing trend, and formed a pattern dominated by grains and mixed with beans and tubers, in which grains and beans mainly showed an increasing trend, while tubers showed a decreasing fluctuation. Among which, grain is the most important food crop, accounting for about 60% of the entire cultivated land area, and the growth trend is similar to that of food crops, showing an increasing characteristic. More specifically, the main grain here are wheat, maize and rice. Among which, the area sown for wheat is about 42,000 hectares, while the area sown for corn is about 31,000 hectares, and the area sown for rice is about 13,000 hectares¹⁰. On the other hand, the economic crops, mainly oil crops in YRB, show a slightly volatile but generally stable development trend characteristic.

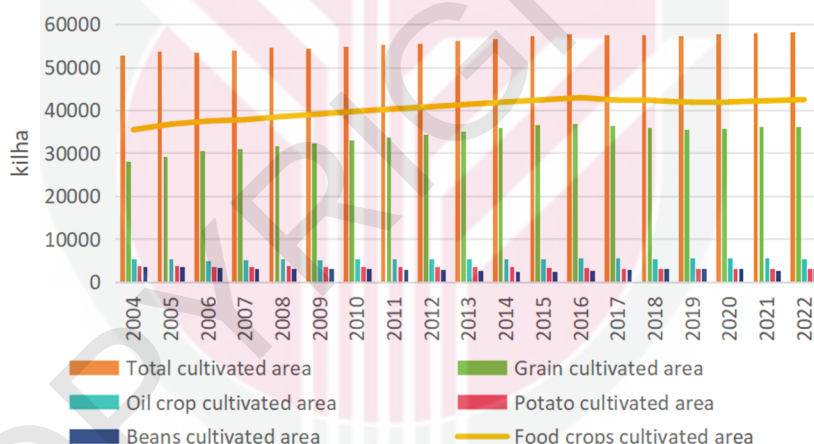


Figure 1.6: Cultivated areas in the YRB during 2004-2022
(Data source: Chinese National Bureau of Statistics, 2004-2022)

From the perspective of water, energy, and food relationships, agricultural source water emissions in the middle reaches of the Yellow River account for about 40% of the total amount of pollutants in the Yellow River basin. Only 48.6% of the water quality in the mainstream and the main tributaries reached the national standard (Zhang et al., 2021). In other words, agricultural source pollution has a serious impact on the main agricultural production areas, which is an important reason for the water quality of major tributaries not reaching the standard.

¹⁰ Figure source: China Agricultural Statistical Yearbook, 2022

Moreover, the discharge of waste water is increasing with the rapid economic development and exploitation of energy in YRB. According to statistics, the annual discharge of waste water was 1.85 billion tons in the early 1970s, 2.17 billion tons in the late 1980s, and more than 4 billion tons in 2000s¹¹. And the annual discharge of chemical oxygen demand, the main pollutant, accounts for about 7% of the total national discharge. Most of energy and chemical enterprises are distributed in important tributaries along the river, resulting in the water quality of tributaries in Ningxia, Inner Mongolia, Shanxi, Shaanxi and other provinces in poor situation for a long time. In fact, 37% of the Yellow River's water carrying capacity bears more than 91% of the river's pollution load, causing serious overloading in the main water functional areas and putting great pressure on water pollution control and environmental risk prevention in the YRB (Tengxun news, 2021).

1.3.2 The Economic Status of Yellow River Basin

During the period of 2004 to 2019, China's economy experienced rapid development, with an average growth rate of 9.1%¹² that far exceeded the global growth rate of 2.9%¹³ during the same period. This rapid growth was accompanied by industrialization and urbanization, leading to sustained and significant energy exploitation and a heightened demand for intensive labor inputs. The country's development exhibited characteristics of *high consumption*, *high pollution*, and *high resource utilization* (Shao et al., 2019). As can be seen in Figure 1.7, similar to the national provincial average gross domestic product (GDP), the provincial average GDP of the YRB has been consistently growing fast during 2004-2022, with the average GDP growth reaching 9%. However, the average provincial growth rate in YRB has been slower than that in the nation, indicating that the economic development in the basin lagged behind the national average level.

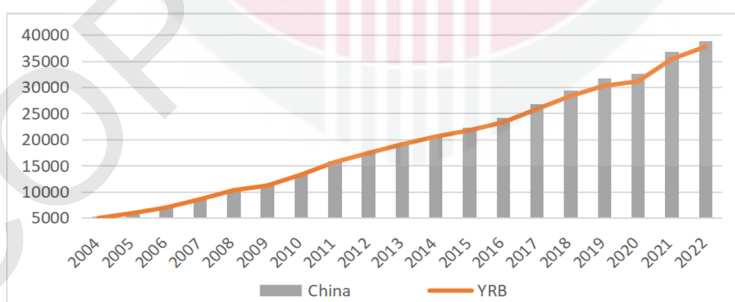


Figure 1.7: Gross Domestic Product (100 million RMB) in YRB and China in 2004-2022

(Data source: Chinese National Bureau of Statistics, 2004-2022)

¹¹ Figure source: Yellow River water resources Bulletin, 2021

¹² Figure source: Chinese National Bureau of Statistics, 2004-2019

¹³ Figure source: World Bank, 2005-2020

As can be seen in Figure 1.8, the main contributed industries in the YRB are secondary and service industries, among which the pillar industry is energy and chemical industry. Before 2015, the secondary industry made the largest contribution to GDP. Since then, the contribution of industry gradually declined while that of tertiary industry gradually increased. The proportion of agricultural value added has been declining year by year.

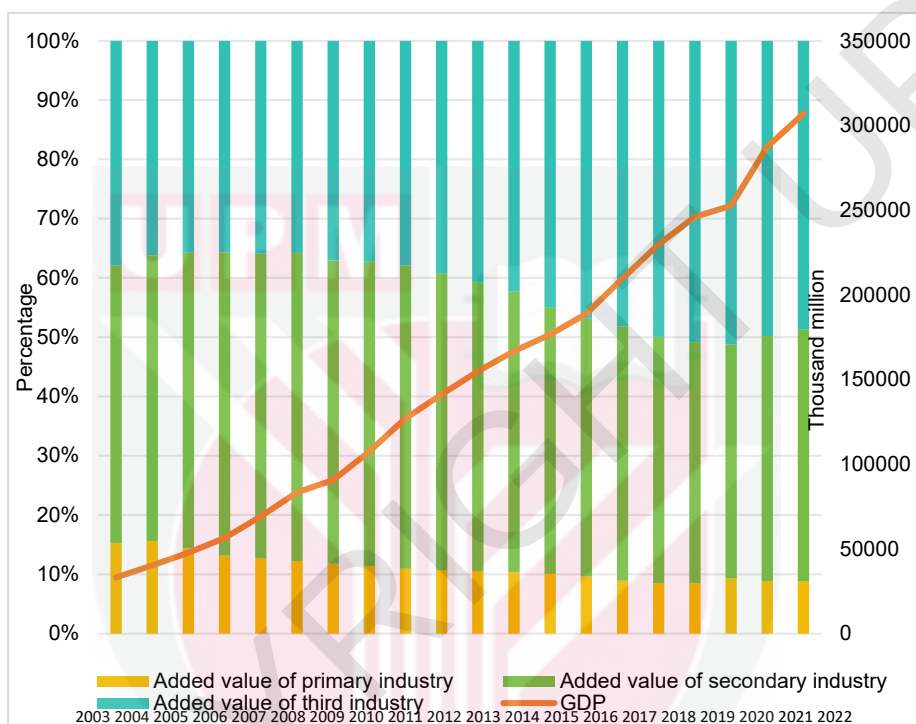


Figure 1.8: Proportion of industry's value added and GDP in the Yellow River Basin in 2003-2022
(Data source: Chinese National Bureau of Statistics, 2003-2022)

Besides, China's economic spatial differentiation is mainly reflected in the disparity between the East, the Middle, and the West region. As can be seen in Figure 1.9, the YRB also presents similar characteristics, that is, the obvious development imbalance, the overall pattern is *strong in the east and weak in the west*, in other word, *strong in the lower reaches and weak in the upper reaches*, and this gap has increased over time. Specifically, the total downstream GDP is about 3 times that of the upstream, and the per capita GDP is about 1.28 times that of the upstream. The difference between upper, middle, and lower reaches can be regarded as the epitome of East, Middle, and West of China. Factors that cause this imbalance include resource endowment, ecological condition, population, industrial structure and so on.

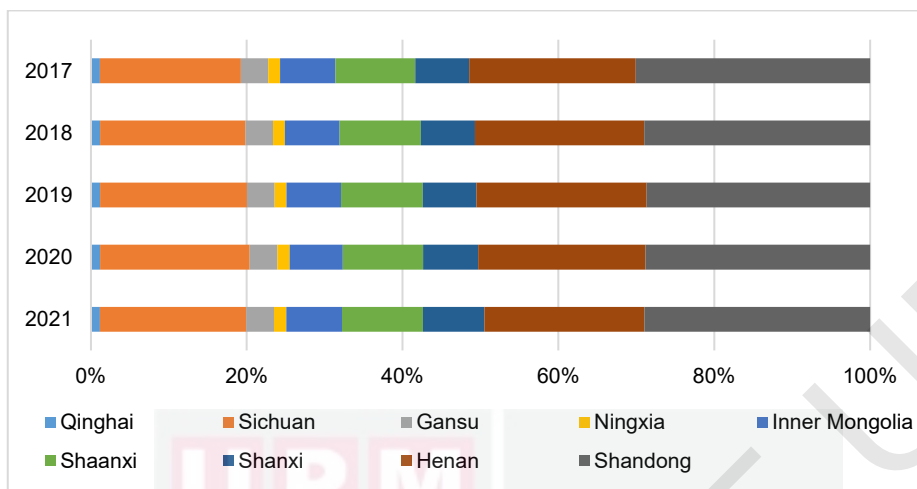


Figure 1.9: Proportion of GDP of Provinces in the Yellow River Basin in 2017-2021

Note: The horizontal bar chart from left to right was presented in order of upstream to downstream of Yellow River

(Data source: Chinese National Bureau of Statistics, 2017-2021)

1.3.3 The Green Finance Status of YRB

Green development is a comprehensive development system including environment, energy and economy. Its connotation is to realize the goal of environmental improvement naturally while economic development by transforming the energy structure. Therefore, green finance will play a role in the green development of environment, energy, economy and many subsystems, and then promote sustainability. As mentioned in the previous section, green finance, focused on directing investments towards environmentally responsible and sustainable projects, reducing pollution and discharge, simulating new renewable energy sources and improve green production efficiency, holds the potential to revolutionize how we manage the vital resources of water, energy, and food.

In China, despite the belated inception of green finance, it has been rapidly advancing. In 2007, the China Banking Regulatory Commission (CBRC) released 'Opinions on Implementing Environmental Protection Policies and Rules of Preventing Credit Risks' and 'Guiding Opinions on the Credit Work for Energy Conservation and Emission Reduction'. In 2012, it also published 'Green Credit Guidelines'. The documents created the fundamental structure of the green credit system and guaranteed that funding should be distributed to low-carbon, recycling, and ecological fields. Since then, further green financing initiatives have been introduced (Yu et al., 2021).

As can be seen from Figure 1.10, the average amount of green loans disbursed in the YRB was steadily increasing year by year, indicating significant and rapid growth in green finance within the basin. This growth rate was roughly in line with the overall trend of green finance in China.

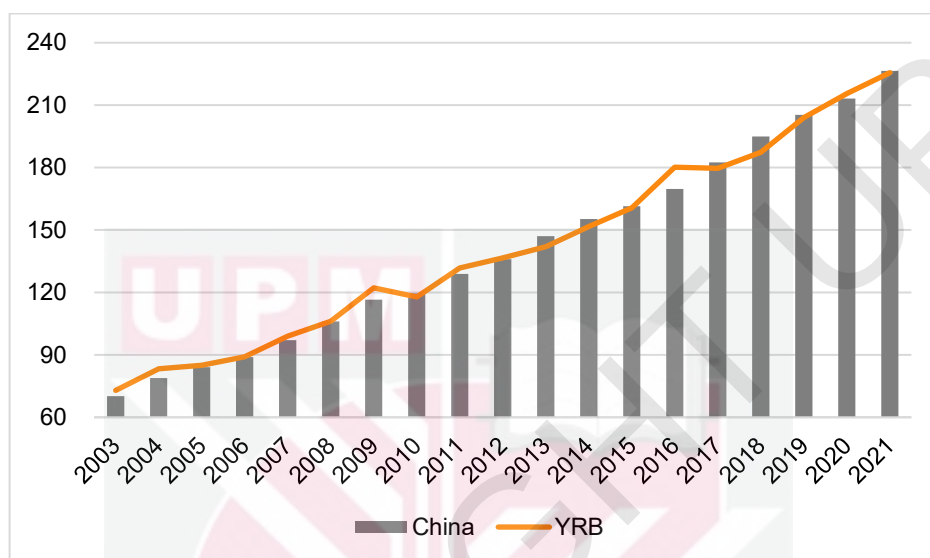


Figure 1.10: Average Amount of Green Loans (100 Million RMB) in YRB and China during 2003-2021
(Data source: Chinese Wind Database, 2003-2021)

1.3.4 The Citizen Health Status of Yellow River Basin

In terms of other valuable sustainable-related indicators, life expectancy and mortality rate are commonly used to represent overall health status (Turnock, 2012). As can be seen from Figure 1.11, the average life expectancy of YRB increased by approximately 8% between the years 2004 and 2022. The steadily increasing numbers indicate that the health status of residents keeps improving. However, compared with the whole nation, the average life expectancy in YRB kept lagging behind the country's average. It implied that even though the citizen's health status has increased over the years, as shown by the average life expectancy, it also has improving rooms to reach the national average.

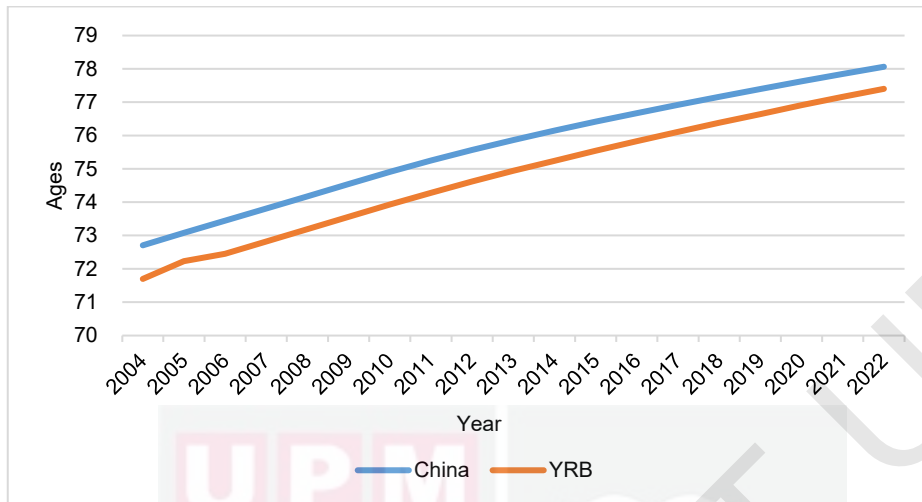


Figure 1.11: Average Life Expectancy in China and YRB during 2004-2022

Note: The average values presented herein are derived from data collected from nine provinces. The missing values of the original data were completed by interpolation and the ARIMA14 method.

(Data source: National Bureau of Statistics, 2004-2022)

Meanwhile, as Figure 1.12 shown, the mortality rates of provinces in YRB remained basically stable until the sudden outbreak of the COVID-19 epidemic in 2019, which caused a rise in mortality forming public health emergencies. This is not within the scope of this study. In general, the life expectancy of residents in YRB has increased while the mortality rate remains basically stable, but the public health of YRB still lags behind the average level in China.

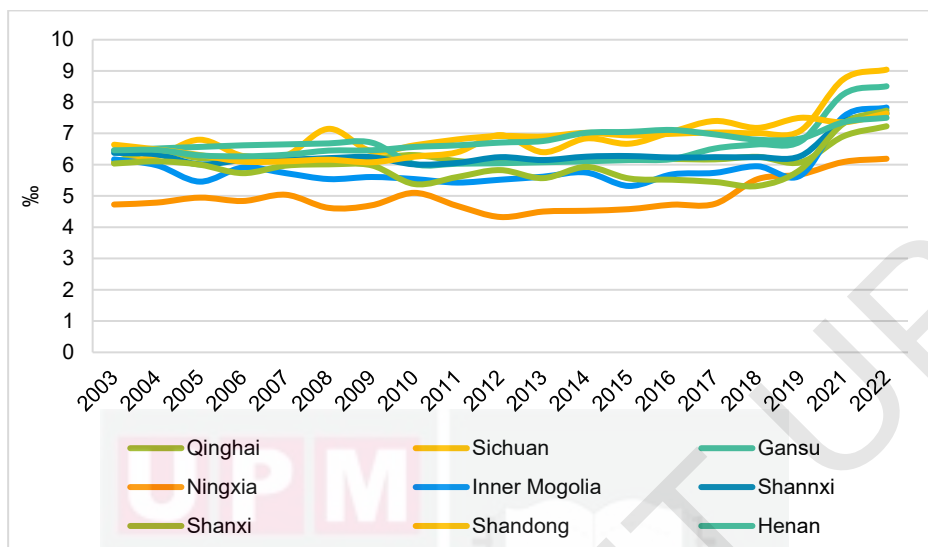


Figure 1.12: Mortality Rate in YRB during 2003-2022
(Data source: National Bureau of Statistics, 2003-2022)

In sum, the YRB holds a highly significant position in China's economic, social, and ecological security. Since it serves as a crucial economic hub for energy and food production, where there is a contradiction between the huge water demands of key industries and the inadequate availability of water resources. Simultaneously, apart from green finance, the region experiences rapid economic development and public health improvement but lags behind the national average. This region has many issues affecting China's sustainable development. Therefore, in order to enhance China's overall sustainability, special attention needs to be given to the YRB.

1.4 Problem Statement

As mentioned earlier, the YRB has dry climate, fragile ecology and serious pollution, to some extent, is an area with many issues. Meanwhile the public health in this region lags behind the national average level in which the environmental quality might be highly related, therefore the study of environmental quality of the local region becomes necessary. In terms of the measurement of environmental quality, many existing studies have used single environmental degradation indicators, such as carbon emissions and deforestation, as a reverse measure of environmental quality (e.g., Adebayo et al., 2022; Destek, 2021; Kwakwa et al., 2021). However, these indicators only cover a narrow scope; a more comprehensive index system to assess environmental quality in a broader context, such as ecological footprint and environmental quality index (e.g., Solarin et al., 2021; Khan & Hou, 2020; Hao et al., 2018; Lobdell et al., 2011) become essential. Based on local actual situations in YRB, this study utilized WEF coupling and coordination degree to represent

environmental quality since it is the more harmonious and coordinated the relationship among water, energy and food sectors. The more effective use of resources, the more conducive to saving and protecting resources that would be more beneficial to the improvement of environmental quality. Besides, some studies, such as Gu et al. (2022), Ren et al. (2022), Xiang et al. (2016), Lawford et al. (2013), investigated the WEF Nexus in YRB. They utilized the methods of pressure-state-response, potential factor analysis, theory analysis and optimal models which measure water, energy and food from different aspects. However, the index system evaluating WEF Nexus used in these studies might not be comprehensively enough, in which, three or four indicators were usually chosen to gauge development of each sector. Comparatively, this study measure water, energy, food, and the degree of coordination between them from different perspectives especially add a sustainability attribute, constructing a index system with 21 indicators totally. This study made a more comprehensive indicator system from four different aspects for each sector, namely, aggregate demand and supply allocation, effectiveness, structure, and sustainability, hoping to help supplementing the theoretical research in the corresponding field. Additionally, in the construction of this index system, the determination of the weights for each indicator was innovatory achieved through a combination of objective and subjective determining methods, the analytic hierarchy process-criteria importance through intercriteria correlation (AHP-CRITIC) approach, aiming for a more comprehensive and accurate assessment of indicator weights.

Besides, in research of environmental quality promoting, green finance is an important simulating approach that has been widely discussed in recent years. In terms of the relationship of environmental quality and green finance, some research attempted to empirically validate the impact of green finance on environmental quality. Existing studies show that green finance not only helps to alleviate environmental problems but also has a positive impact on the economy (e.g., Zhang et al. 2021; Muhammad Asif et al. 2022; Afzal & Malik 2022). By channeling financial flows to environmentally friendly projects, green finance helps to create jobs, improve resource efficiency, and promote the growth of low-carbon and renewable energy sectors. And does this phenomenon also apply in the YRB? This study will examine the local relationship between green finance and environmental quality locally under scheme of the environmental Kuznets curve (EKC). According to EKC (Grossman and Krueger 1995), there is an inverted U-relationship between economic development and environmental degradation. Some scholars questioned its existence since the model did not take into account important macroeconomic factors. Therefore, a few scholars have incorporated the green finance variable into the analysis (e.g., Saleem et al. 2022b; Gu et al. 2023; Ma et al. 2023). However, these studies only utilized single pollution indicators like CO₂ emissions or waste discharge to represent the environment, which could not comprehensively measure the research variable. And the similar situation applies to variable green finance as well. Existing research had used single indicator such as green bonds to measure green finance (Shang et al, 2023; Meo & Abd Karim, 2022). While a few researchers had combined multiple proxies to provide a comprehensive index of green finance, such as climate mitigation finance (Jiakui et al., 2023a; Khan et al., 2022). This study constructed a comprehensive index of green finance determined by the entropy weight technique, which can more thoroughly and

properly reflect the green finance development level. The index system incorporated green credit, green investment, green insurance, green bonds, green support, green funds, green equity, and green securities to comprehensively reflect green finance. Meanwhile, apart from the primary variables, there is relatively less consideration given to other factors influencing environmental quality when investigating the relationship. Besides, most studies concentrated their research on one transmission mechanism. Lack of research that examines and compares three mechanisms simultaneously. This study will be supplemented to some extent in these aspects.

Although there are some studies investigated relationships among the environment, health expenditure, and the economy, limited studies have focused on the interaction among all these variables simultaneously (Vyas et al., 2023; Li et al., 2022; Nasreen, 2021; Anwar et al. 2021; Usman et al. 2019; Khoshnevis Yazdi and Khanalizadeh, 2017). Notably, these studies all utilized a single indicator (e.g., CO₂, toxic gas, or forestation) to evaluate environmental degradation or improvement as a proxy for environmental quality. And the studies utilized the method of auto regressive distributed lag, Lagrange Multiplier bootstrap and heterogeneous panel causality test. Different from the existing literature, in view of the strong endogeneity between variables and the data set characteristic of long panel, the Panel SVAR method with good robustness to panel data of endogenous variables is selected. Moreover, different from existing research that has primarily focused on the relationship between healthcare expenditure and the economy, this study examined citizens' health rather than health expenditures. This is because, in the YRB context, directly using healthcare expenditure as a representation of health status might be biased to some extent.

1.5 Research Questions

As analyzed above, this thesis proposes to answer three questions:

1. What is the environmental quality in the YRB from a WEF perspective?
2. Does green finance play its role in promoting environmental quality in YRB? And what is the mechanism?
3. What is the interactive relationship among the environment quality, public health, and wealth in the YRB?

1.6 Research Objectives

In order to study sustainable development, offer some development suggestions for policy makers, the general objective of this thesis is to explore environmental quality in YRB through a comprehensive measure, namely the water-energy-

food nexus, and find out the interrelationship between selected sustainable important variables, green finance, public health and economic development.

The general objective could be divided into three sub-objectives.

Objective 1: To construct an assessment indicators system for the WEF Nexus in the YRB.

Objective 2: To analyze the impact of green finance on the WEF nexus in the YRB.

Objective 3: To examine the relationship among the WEF Nexus, public health, and economic development in the YRB.

1.7 Significance of Study

As introduced, the YRB is the area with many challenging issues. The arid climate, fragile ecological environment, pollution and the need to promote economic development, provide a compelling backdrop for exploring the complex interplay between protecting and restoring water resources for the environment while meeting the escalating water needs of the region's growing energy and food sectors. Due to the fact that these three sectors are vital for a country or region, it fully illustrates the importance of studying that water, energy and food nexus and their interrelationships for the sustainable development. Based on the actual situation of the YRB, investigate the coordinated development of the three sectors of water, energy, and food is of great significance to the improvement of local environmental quality. Besides, comprehensive index systems were established for the measurement of key variables instead of considering a single indicator which can more broadly evaluate the targeted variable. Studying local environmental quality from the perspective of water, energy and food is innovative to some extent and in line with local situation, and could provide policy makers with a more specific and executable direction. In summary, this study is of practical significance to investigate environmental quality from the WEF Nexus perspective in the area. This study adopted a targeted research design, demonstrating originality.

Secondly, there is a consensus view that increasing investment in green industry will help to optimize and upgrade the local industrial structure, production, and lifestyle, thereby improving energy efficiency and reducing carbon emissions from primary energy sources, which will promote environmental quality and sustainability. Yet a lot of initiatives related to green projects have been implemented by both corporations and governments at a fast rate in YRB, and some of the environmental problems still have not been effectively solved. Hence, there is a question about whether green finance has a substantial role in promoting environmental quality in the YRB and what the impact mechanisms are? Therefore, studying the causal relationship and mechanisms of green

finance's impact on environmental quality is of great significance in better understanding the role of green finance in promoting environmental sustainability and exploring more effective policies and methods. Apart from the contemporary literature with relatively less consideration given to other factors influencing environmental quality beyond the realm of green finance, this study provided a more comprehensive consideration of the impact of economic, climatic, urbanization, population density, forest coverage, and educational factors on environmental quality and examined and compared the mechanisms simultaneously, a more comprehensive measurement of the factors affecting local environmental quality is of practical significance for the formulation of local sustainable development policies.

As mentioned earlier, the average expected life expectancy in the YRB is lower than the national average for the same period indicating the local public health issues need to be paid more attention. Since the conflict between resource and environmental constraints, sustained economic growth, and public health has become increasingly acute, studying the interaction and balance among the environment, public health, and the economy is of great significance to local sustainability policy making. Accordingly, the effective management and coordination of these factors has garnered significant policy attention. However, there is limited relevant studies, particularly lacking articles that concurrently examine the relationship among the variables. Therefore, this study serves as a valuable supplement in addressing this gap.

1.8 Organization of Chapters

Chapter 1 is organized to provide an introduction, including an overview, key concepts, study area, problem statement, research question and objectives, and significance of the study. Chapter 2 reviews the relevant theoretical and empirical literature and summarizes the literature gaps. Moreover, Chapter 3, 4, and 5 sequentially present each of the research objectives separately one by one. Finally, Chapter 6 is the summary, conclusion, and recommendations for future research.

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