



Review

# Regional Integration and Sustainable Development in the Yangtze River Delta, China: Towards a Conceptual Framework and Research Agenda

Jiawei Wu  and Wei Sun \* 

Key Laboratory of Watershed Geographic Sciences, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China

\* Correspondence: wsun@niglas.ac.cn

**Abstract:** Understanding the interactions between the human sphere and the natural sphere in key places and regions of the world is crucial for promoting sustainability science and achieving sustainable development. As one of the emerging global city-regions in China and the Global South, the Yangtze River Delta (YRD) plays an increasingly nonnegligible role in the globalized economy and telecoupling social-ecological systems (SESs). Considering the well-known importance and representativeness, the YRD has been regarded as an appropriate experimental site of integrated research on geographical and sustainability science at the subnational scale. This paper tries to establish theoretical and practical linkages between regional integration and sustainable development at the subnational scale based on the sustainable development goals (SDGs), the Chinese contexts, and a literature review of relevant researches. We argue that future research should pay more attention to the interdisciplinary, transregional, and multi-scale attributes of issues related to regional integrated and sustainable development in the YRD. The following research agendas, such as linking SDGs to regional integrative development, analyzing the sustainability of regional SESs, assessing the integrated region at the subnational scale, investigating the YRD at different geographical scales, exploring applicable governance structures and institutions, as well as applying multi-source data and interdisciplinary methodologies, call for more scholarly attention. We hope that this paper could be an initial motion to expand and enrich relevant research.

**Keywords:** regional sustainable development; social and ecological systems; regional integration; research agendas; SDGs; China



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## 1. Introduction

The world as a whole has been facing increased crises on multiple fronts, including climate change, economic recession, food and energy security, territorial conflicts, and public health emergencies [1,2]. Achieving sustainable development has increasingly become a global consensus; however, how to promote sustainable development has always been a thorny issue for policymakers around the world [2–4]. In 2015, the United Nations (UN) proposed the Sustainable Development Goals (SDGs), which were designed to find an effective path out for promoting sustainable development by dealing with the limited problems related to socioeconomic development, eco-environmental protection, and human well-being until 2030 [5,6]. SDGs and evaluation indicators from 17 aspects provide an action plan for sustainable development practices at different geographical scales, and the achieving trajectories and processes have attracted extensive attention from scholars of multiple disciplines [7–10]. Relevant research has profoundly facilitated the advances in theories, methodologies, and policy implications of sustainability science [11,12].

The concept of sustainable development, which is well-known but somewhat ambiguous, has gradually entered the literature on economic growth, eco-environmental

evolution, and public policy since the release of the Brundtland report (titled “Our Common Future”) and global Agenda 21 in the 1980s/1990s [13–15]. Particularly, sustainability science emerged as a new research field focusing on the interactive dynamics between natural and social systems across the full range of scales from local to global, and on how to form effective sustainable trajectories and adaptive governance frameworks to deal with the wide spectrum of challenges [16,17]. The regional character of research topics in sustainability science calls for more scholarly efforts in the long-term interdisciplinary investigation on nature–society (or social–ecological) interactions in specific regions with different territorial functions [16]. A large body of literature also indicated that examining the features, processes, and outcomes of social–ecological interactions in key places and regions of the world is still important for sustainable practices and achieving SDGs at the global scale [18–20].

As one of the largest developing and emerging economies around the world, China has been a strong advocate and practitioner of sustainable development since the implementation of “China’s Agenda 21” in 1994 [21,22]. However, the high-growth, resource-intensive, and export-oriented developmental trajectory that China pursued before the 2010s, as well as the relatively small resource amount per capita and the spatiotemporally uneven eco-environmental status, have sharpened the contradiction between human activities and ecosystems across the country [23,24]. This makes the developmental transition under the guidance of SDGs even more pressing in China [25–27], just as any other developing country is facing. Furthermore, considering the decisive role played by intensive human activities related to rapid industrialization and urbanization in eco-environmental changes in the Anthropocene Epoch [28], it is essential to further examine the interactions between nature and society in highly urbanized and ecologically sensitive regions around the world.

Therefore, the basis of our discussions is the importance of research on nature–society (or social–ecological) interactions and sustainable development practices at the subnational scale (e.g., highly urbanized regions located in the Global South and developing countries) for sustainability science and achieving SDGs. Following similar research veins, variegated issues related to economic, social, and eco-environmental sustainability in China’s major urban agglomerations, such as the Beijing–Tianjin–Hebei region (JJJ), the Yangtze River Delta (YRD), the Pearl River Delta (PRD), and the Chengdu–Chongqing economic circle (CY) region, have received much scholarly attention in multiple (inter)disciplines [29–34]. These urban agglomerations are key regions for regional integration and sustainable development in China. However, existing studies on the integrated or collaborative path to regional sustainable development, as well as the achievement of SDGs and the sustainability of social–ecological systems (SEs) at the regional scale, are quite limited. Focusing on the YRD, which is one of the national urban agglomerations in China and one of the emerging global city-regions in the Global South, this paper considers two interrelated objectives. On the one hand, this paper tries to develop a conceptual framework for building linkages between regional integrated collaboration and the promotion of regional sustainable development, with particular attention given to the nexus between SDGs and regional integrated development tasks. On the other hand, this paper tries to propose future research agendas related to regional integration and sustainable development of the YRD, especially issues related to the achievement of SDGs, regional SEs, and integrated regions at the subnational scale.

The remainder of this paper is arranged as follows. Section 2 introduces the development situation and representativeness of the YRD. Section 3 reviews and summarizes the literature on regional integrative and sustainable development in the YRD from geographical and human–environment interactive perspectives. Section 4 presents our conceptual framework and future research agendas. Then, we conclude and discuss in the end.

## 2. Developmental Situation and Representativeness of the YRD

According to “the outline of the regional integrated development plan of the YRD” issued by the CPC Central Committee and China’s State Council, the YRD includes four

province-level regions (i.e., Shanghai, Jiangsu, Zhejiang, and Anhui). Located in eastern coastal China (see Figure 1), the YRD has been regarded as the pioneer and frontier of China’s reform and opening-up, as well as the epitome of China’s industrialization and urbanization, since the late 1970s [35–37]. Moreover, the YRD has become one of the most developed regions, with the highest socioeconomic levels through rapid growth over the past half-century, contributing to the Chinese path to modernization and national rejuvenation [38]. The YRD carries 16.74% of China’s population, 24.14% of China’s GDP, and 14.59% of China’s fiscal revenue, with only 3.7% of China’s territory in 2021. The USD 4.28 trillion GDP of the YRD in 2021 also exceeded that of most developed economies such as Germany, the United Kingdom, and France. The proportion of the urban population of Shanghai, Jiangsu, Zhejiang, and Anhui, respectively, reached 89.30%, 73.94%, 72.70%, and 59.39%. The positions and roles of Shanghai, one of the recognized global cities, and other regional hubs (e.g., Nanjing, Hangzhou, Suzhou, Wuxi, Ningbo, and Hefei) of the YRD in the world city network and the globalized economy have been increasingly prominent [39,40]. The YRD has become an emerging global city-region led by Shanghai.

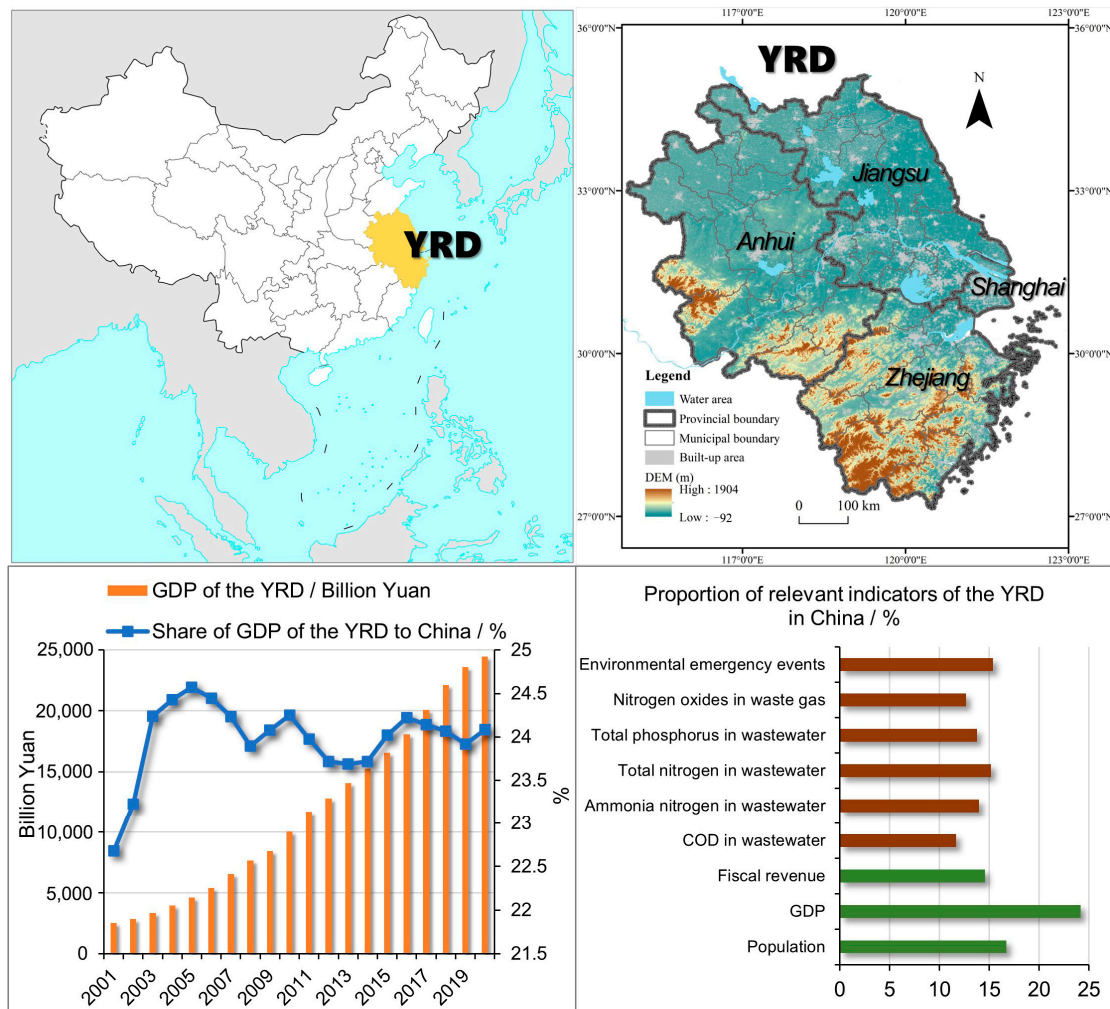


Figure 1. Geographical location and socioeconomic overview of the YRD.

With regard to the natural sphere or eco-environmental status, the YRD is composed of an estuary delta plain and surrounding hilly areas, resulting in relatively lower regional average elevation and slope. Located in the lower reaches of the Yangtze River, Huaihe River, Qiantang River, and ancient Yellow River, the YRD features variegated river–lake systems and abundant water resources. Moreover, the main climate type in the YRD is subtropical monsoon, characterized by warmth and humidity. The aforementioned

conditions related to climate, topography, and natural resource endowment are conducive to highly intensive urban development and industrial agglomeration in the YRD. However, the intensive exploitation and extensive utilization of natural resources (e.g., land, non-renewable energy, and mineral resources) have brought great pressure to the limited capacity of the regional ecological environment in the YRD [41–43]. The YRD, accounting for 15.1% of total nitrogen emissions, 13.8% of total phosphorus emissions, 12.7% of nitrogen oxides emissions, and 15.4% of environmental emergency events in China in 2020, has been viewed as one of the regions with the most serious industrial pollution across the country. This led to an investment of RMB 13.7 billion in the treatment of industrial pollution in the YRD, accounting for 30.2% of China. The contradiction between socioeconomic development and eco-environmental protection has been becoming increasingly acute in the YRD, especially in ecologically sensitive subregions.

Since the early 2010s, China has been promoting the trajectorial transition from the high-growth, resource- and pollution-intensive development mode to the high-quality, innovation- and green-oriented one [23,44,45]. A more prominent contradiction presented by the human–environment or social–ecological systems has forced local governments in the YRD to pursue the transition of developmental trajectories earlier. The YRD tends to be regarded as the pioneer in taking a trajectory for regional transition and sustainable development [36,46,47], namely, a harmonious development mode between human activities and the eco-environment in China. However, considering unbalanced regional socioeconomic development and eco-environmental status, as well as the division of administrative regions and local protectionism [35,37], it needs unified visions, place-tailored strategies, and integrative actions to promote sustainable development of the YRD. Interregional cooperation in industrial transition, technological innovation, infrastructure construction, and public services and policies should be key to achieving sustainable development of the YRD. Moreover, how to deal with regional inequalities at the economic level, eco-environmental quality, and social welfare are also important issues faced by the YRD in facilitating regional integration and sustainable development.

To sum up, as an emerging global city-region, the YRD will play an increasingly vital role in stimulating economic growth and addressing climate change in China and even the world. Located in the lower reaches of the Yangtze River, the YRD is a typical estuary delta with low mountains (hills) and variegated river systems. The complex or diverse ecosystems and territorial functions in the YRD have been largely affected by rapid urbanization and industrialization, as well as other intensive human activities. This brings about a series of problems, including eco-environmental degeneration, regional inequality, and homogeneous competition, that need to be solved for regional sustainable development in the YRD. “Regional high-quality-oriented and integrative development in the YRD” has become one of the national regional strategies in China since 2018. We argue that the development mode and predicaments of the YRD are representative of emerging economies, and the evidence of social–ecological interactions and the practices of sustainable development in the YRD can serve as a strong reference for China and other developing economies in the Global South.

### 3. Literature Review under Geographical and Sustainable Perspectives

Considering the aforementioned importance and representativeness of the YRD, critical issues related to economic restructuring, urbanization, eco-environmental changes, and collaborative governance in the YRD have been profoundly examined by scholars from various disciplines. In order to develop a conceptual framework for research on regional integration and sustainable development in the YRD, our literature review focuses on the seminal works and impressive findings based on geographical, sustainable development, or human–environment interactive perspectives. We mainly conclude the relevant research hotspots and main signs of progress from the following aspects.

### 3.1. Industrial Restructuring, Technical Innovation, and Economic Growth

Industrial restructuring and technical progress in the YRD, as well as its impact on China's economic transition and the globalized economy, have received much scholarly attention [34,48,49]. Since China's reform and opening-up in 1978, the industrial development of the YRD has long been featured as township- and village-owned industries, export-oriented industrialization, and footloose foreign direct investment (FDI), which are respectively known as the Sunan model, the Wenzhou model, and the development-zone fevers in the literature [50–54]. With the increased pressure on economic efficiency and environmental protection, local governments in the YRD have been increasingly promoting industrial transformation oriented to producer services, advanced manufacturing, and high-tech and knowledge-intensive industries during the past two decades [34,36]. Scholars and policymakers put more emphasis on the role played by entrepreneurship and technical innovation in industrial transformation and spatial relocation in the YRD [55,56]. Existing studies have indicated that knowledge-intensive industries and relevant innovative activities are largely concentrated in major cities and the core YRD (e.g., Shanghai, southern Jiangsu, and northern Zhejiang), while traditional and low-end manufacturing industries are gradually transferred to the peripheral YRD [57–60]. Research also signified that industrial distribution and its changing trends might vary across different sectors in the YRD [36,57].

In addition, the continuous upgrading and relocation of various industries have profoundly shaped the regional division of labor in the YRD [38,59,61–63]. Major cities such as Shanghai, Nanjing, Hangzhou, Suzhou, and Hefei largely act as gathering centers of high-end industries and innovative activities. Cities and counties along the Yangtze River and coastline, as well as various development zones, are the gathering places of advanced manufacturing. The peripheral regions (e.g., northern Jiangsu, southwestern Zhejiang, and northern and southern Anhui), as well as counties around major cities, tend to have advantages in undertaking industrial transfer and promoting the agglomeration of green- and ecologically oriented industries (e.g., ecotourism and eco-agriculture).

### 3.2. Urbanization, Urban System, and Urban–Rural Relations

The proportion of the urban population in the YRD has increased from 43.01% in 2000 to 60.33% in 2011 and 70.85% in 2020. Such a rapid urbanization process accompanied by large-scale construction of urban infrastructure and public utilities has aroused widespread concern among scholars [64–66]. Existing studies have comprehensively investigated spatiotemporal variations and driving forces of the urbanization process in the YRD [67,68]. With the spatial agglomeration of industries and population, as well as the excessive reliance on land revenue, the urbanized or built-up areas in the YRD have experienced rapid expansion since the 1990s [69–71]. The urban built environment, infrastructure, and living convenience have been greatly improved in the YRD; however, urban sprawl or the traditional mode of urbanization also brought a series of problems such as inefficient land use, job–housing imbalance, unaffordable housing, unequal welfare, and eco-environmental degeneration [71–74]. Under the guidance of the national strategy of new-type or people-centered urbanization, the speed of urban expansion in the YRD has slowed down since the early 2010s. More attention has been paid to the quality of urbanization, especially equal access to high-quality public services for all urban and rural residents [64]. Research has also implied that the level and quality of urbanization significantly differ across regions, for instance, urbanization in Shanghai, southern Jiangsu, and northeastern Zhejiang presented better performance [65].

The restructuring of urban hierarchies and networked connections in the YRD has also been the subject of empirical research [75–77]. The literature illustrated that, with the improvement of transportation and information infrastructure networks, socioeconomic exchanges and element flows among cities in the YRD have been increasingly closer [78,79]. Meanwhile, there exist significant differences between cities in the attractiveness and carrying capacity of high-end productive factors, industries, and services in the YRD

due to urban disparities in administrative levels, geographical locations, resource endowments, and agglomeration economies [58,75]. Major cities, such as Shanghai, Nanjing, and Hangzhou, tend to occupy leading positions in urban networks related to various inter-city relations (e.g., population mobility, traffic flow, and corporate linkages) [63,80,81]. Existing studies, therefore, have mapped a significant “core–periphery” network structure, in which Shanghai and regional hubs dominate inter-city relations and urban hierarchies in the YRD, marginalizing the middle-sized and small cities or counties located in the peripheral regions [77,82].

The urban system features of being networked, polycentric, and asymmetric in the YRD facilitated inter-city linkages and collaboration on the one hand, and strengthened the spatial polarization effects of major cities on the other hand. For instance, scholars found that job opportunities, better-built environment, and high-quality public services and amenities tend to concentrate in a few metropolises and urban districts [35]. Issues related to urban social spaces, including housing, rural–urban migration, and public welfare in the YRD have been widely discussed in the literature [73,81,83,84]. In addition, the rapid industrialization and urbanization processes have also triggered researchers’ thinking on research topics associated with urban–rural relations and the territorial functions of rural areas. The potential trajectories to restructure the urban–rural dual structure, and then achieve rural revitalization and sustainable development, have become new hotspots in empirical research on the YRD [85,86].

### 3.3. Natural Resource Utilization and Eco-Environmental Changes

The basal characteristics and human utilization of various natural resources in the YRD have been widely investigated in the existing studies [69,87,88]. Spatiotemporal heterogeneities of natural resource use forms, use efficiency, and management systems in the YRD have become topics of common concern [70,89]. With the socioeconomic transition, the natural resource utilization mode has transformed from irrational and extensive to economical and intensive in the YRD, largely resulting in continuous changes in the scale, structure, and spatial pattern of natural resources. Existing studies also documented that natural resource use efficiency, which could be measured by economic output or eco-environmental consequences, in the YRD has been increasingly improving, although efficiency differences between sub-regions, provinces, cities, or counties are still obvious [90,91]. Take land resource as an instance; the transformation from the natural surface or cultivated land to construction land is the main manifestation of land use transition or land cover change in the YRD due to rapid industrialization and urbanization [92]. Urban or construction land use efficiency, which could be affected by multiple factors including technical progress, industrial structure, policy setting, and ecosystem constraint, might present a better performance in the core YRD and relevant central cities [71]. The renovation of the land management system oriented by rational, intensive, and efficient utilization in the YRD has also attracted much scholarly attention [93].

The extensive and ineffective utilization of natural resources, which are associated with traditional trajectories of industrialization and urbanization, has led to serious ecological damage and environmental pollution in the YRD over a long period. Existing studies have adequately examined spatiotemporal variations of air pollution (quality), water pollution (quality), soil pollution, solid waste pollution, and emission patterns of various contaminants (e.g., PM<sub>2.5</sub>, COD, NH<sub>3</sub>-N, and industrial sulfur dioxide and wastewater) in the YRD [94–97]. With economic transition and the strengthening of environmental regulations, the eco-environmental quality in the YRD has gradually improved; however, pollution problems in some areas or territorial types, including lake basins, coastal zones, riverside areas, and hilly areas, are still precarious and intractable. Furthermore, environmental problems related to greenhouse gas emissions (e.g., CO<sub>2</sub> emissions), urban heat islands, and extreme weather in the YRD against the background of global climate change have received increasing scholarly attention [72,98–100].

The over-exploitation of natural resources and severe environmental pollution caused by human activities have profoundly threatened ecosystems and relevant service functions in the YRD. The contradiction between the rapid socioeconomic development and the limited resources and environmental carrying capacity can be widely observed in the YRD [41,101]. The existing literature suggests that ecosystem services such as resource abundance, climate comfort, soil conservation, and environmental self-purification have been degraded, and present significant regional disparities in the YRD [102–104]. This forces the central and local governments in China to pay more attention to ecosystem restoration and the improvement of ecological functions in the YRD. According to “the plan for the joint-protection of the eco-environment of the YRD”, regions with higher ecological importance and service function, such as Yangtze River, Huaihe River, Taihu Lake, and Hongze Lake, as well as hilly areas in western Anhui, southern Anhui, southern Zhejiang, and western Zhejiang, have been highlighted in the planned pattern of ecological security in the YRD.

#### *3.4. Interregional Cooperation and Collaborative Governance*

The YRD, which is different from integrated regions across national borders (e.g., EU and NAFTA) or city-regions located within a single subnational administrative area (e.g., the PRD), is a trans-provincial mega-city-region with a long history of region-building and integrative experiments in China [105]. Based on the theoretical perspective of China’s city-regionalism, existing studies focused on the region-building process and the changing governance structure in the YRD since the early 1990s [106,107]. Scholars elaborated that the integrated development of the YRD might be driven by the synergy of governmental intervention and market forces [35,108]. On the one hand, a series of regional plans and supporting policies issued by the Chinese central government, which could be viewed as a top-down process dominated by the state, largely promoted regional identity and integration of the YRD [105]. On the other hand, various interregional collaborations have been initiated by local governments, which are the main feature of the bottom-up mechanism of regional integration of the YRD, to implement national strategies and handle trans-administrative affairs [109–111]. Moreover, with increased marketization, the weakening of local protectionism has greatly facilitated enterprise investment and population migration across administrative boundaries within the YRD. These forces, derived from the market and individuals, matter more for regional integration, making the YRD different from other trans-provincial mega-city-regions (e.g., the JJJ) in China.

Considering the challenges and tasks of regional integrative development, existing studies have widely discussed the processes, modes, and consequences of interregional cooperation related to various trans-administrative affairs in the YRD [61,108,110]. Especially, interregional cooperation within fields such as industrial relocation, collaborative innovation, infrastructure construction, and eco-environmental protection, has attracted much scholarly attention. For instance, in addition to interregional enterprise investment and relocation, cooperative construction and operation of industrial districts or high-tech parks have been the main measurement of regional city-to-city cooperation in the YRD [112–114]. Scholars tend to investigate collaborative innovation in the YRD from the perspective of the spatial transfer and off-site commercialization of valuable patents [115,116]. Some studies have been designed to examine driving mechanisms, and the role played by multilevel governments and market entities, in the construction of cross-regional transport infrastructure [117]. Furthermore, aiming at addressing interregional or watershed eco-environmental problems, regulatory systems, and policy settings (e.g., the interregional river or lake chief system) involving different local governments in the YRD have gradually become research hotspots [111,118].

In sum, existing studies and relevant findings have largely advanced our understanding of the spatiotemporal heterogeneities and changing dynamics of various aspects related to socioeconomic, eco-environmental, and institutional systems in the YRD. The literature has also indicated increasing interest in complex relationships or interactive dynamics

between the human sphere and the natural sphere from the perspective of social–ecological systems [41,43,92]. Particularly, extensive empirical investigations of eco-environmental changes in the YRD have underlined the adaptation and feedback of ecosystems under the influences of human activities [43,47]; Meanwhile, urban expansion, industrial (re)distribution, and regional development strategies in the YRD would be profoundly affected by place-specific ecosystems and institutional contexts of eco-environmental protection [71]. To better understand and promote regional high-quality-oriented, integrative, and sustainable development in the YRD; however, the existing studies may have the following limitations or less concerning issues: First, while interregional linkages and cooperations have attracted considerable attention from scholars, few theoretical and empirical researches have discussed the measurement (or assessment) and driving mechanisms of regional integrated development in the YRD. Second, the timely and comprehensive investigation of sustainable development practices, especially the achievement of different SDGs at the regional or urban level, in the YRD has been largely neglected in the literature. Third, existing studies on a single socioeconomic, eco-environmental, or governing phenomenon, as well as a single productive element or natural resource, are extensive, while interdisciplinary researches on the complex human–environmental systems or SESs in the YRD are quite limited. Fourth, little scholarly attention has been paid to transitional or sustainable trajectories of the YRD under the new global context and challenges, especially climate change, COVID-19, anti-globalization, and territorial conflicts.

#### 4. Conceptual Framework and Research Agenda

To fill the aforementioned research gaps and then promote regional development more effectively in the YRD, one key question we need to answer is how to make a causal association between integration and sustainable development at the subnational scale (or in a trans-administrative mega-city-region). Regional integration at the subnational scale can be regarded as the process of interregional division of labor and collaboration based on common benefits, attitudes, actions, and expectations [38,111]. The cruxes of this process might be the consensus, joint action, and systematic consideration among different places (e.g., developed and developing regions), fields (e.g., social, economic, and eco-environmental issues), and agents (e.g., governments, market entities, NGOs, and the public), which are also the main challenges to be overcome to accelerate the simultaneous implementation or achievement of the full set of SDGs [3,4,119]. We argue that the implementation, assessment, and realization of 17 SDGs, as well as sustainable development practices, at the subnational scale should be placed in the process of regional integration. By highlighting the shared visions, multi-dimensional synergies, interregional cooperation, stakeholders' joint-action, institutional reformation, and mission-oriented and place-based policies, the process of regional integrative development could be an effective strategy or approach to achieve sustainable development at the subnational scale (see Figure 2). Following this vein, we try to match 17 SDGs with major tasks of regional integration documented in “the outline of the regional integrated development plan of the YRD” (see Table 1).

**Table 1.** The association between 17 SDGs and major tasks of regional integrative development in the YRD.

Major Tasks of Regional Integrative Development in the YRD		Relevant SDGs
Task Categories	Task Definitions (or Contents)	
Promoting a new pattern of regional coordinated development	Strengthening regional division of labor and cooperation	SDG10: Reducing inequality SDG11: Sustainable cities
	Accelerating integrative development in metropolitan areas	
	Promoting urban-rural integrated development	
	Promoting joint development of transboundary regions	



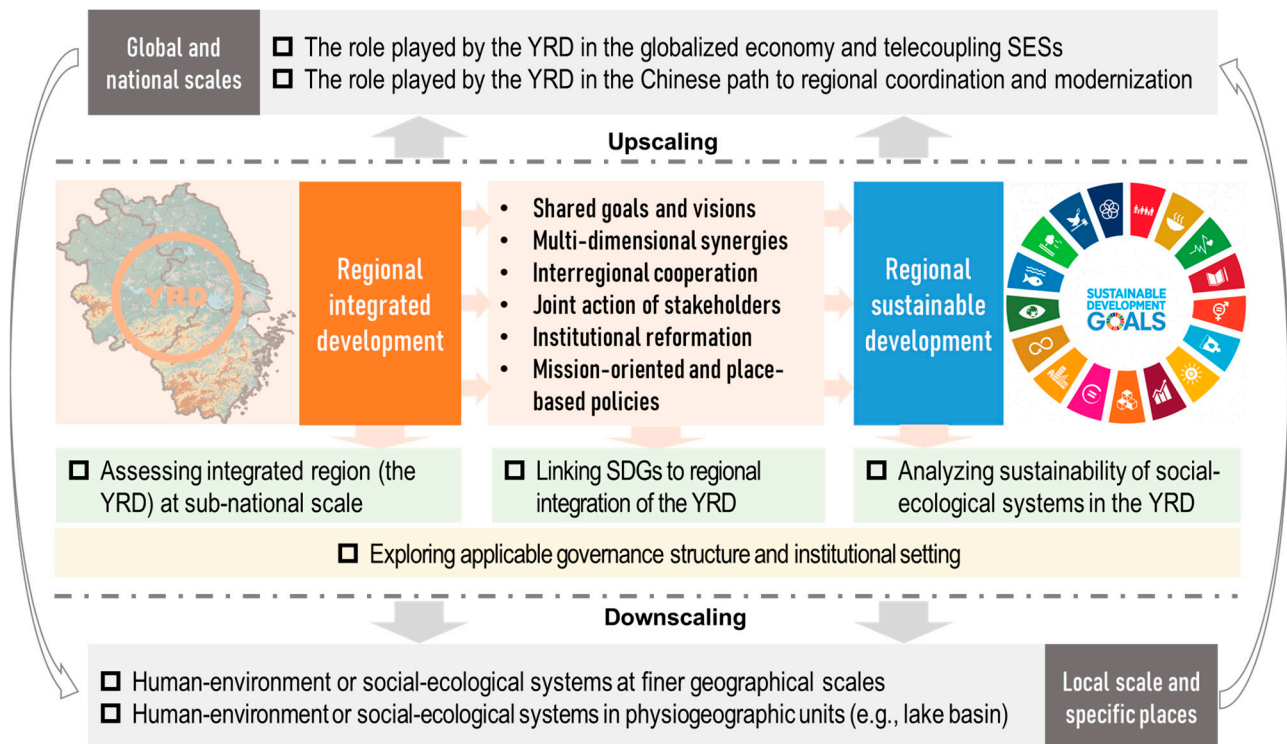
Table 1. Cont.

Major Tasks of Regional Integrative Development in the YRD		Relevant SDGs
Task Categories	Task Definitions (or Contents)	
Establishing a regional system of industrial cooperation and collaborative innovation	Building regional innovation communities Promoting interregional industrial division and cooperation Facilitating the integration of industry and technical innovation	SDG1: No poverty SDG8: Decent job SDG12: Responsible consumption and production
Improving infrastructure connectivity	Building regional transportation systems Building the digital YRD Advancing trans-regional energy infrastructure Improving inter-provincial water conservancy projects	SDG6: Clean water SDG7: Clean energy SDG9: Infrastructure SDG11: Sustainable cities
Strengthening joint protection of eco-environmental system	Jointly strengthening ecological protection Promoting coordinated environmental prevention and pollution control Promoting coordinated eco-environmental regulation	SDG6: Clean water SDG13: Climate action SDG14: Life below water SDG15: Life on land
Facilitating public services sharing	Promoting standardization and facilitation of public services Sharing high-quality education and medical services Promoting regional cooperation in cultural tourism Jointly building a fair and inclusive social environment	SDG1: No poverty SDG2: Zero hungry SDG3: Health and well-being SDG4: Quality education SDG12: Responsible consumption and production SDG5: Gender equality SDG16: Inclusive society
Promoting high-level and coordinated opening-up	Jointly building advanced opening-up platforms Deepening opening-up in key fields and regions Jointly building a world-class business environment	SDG12: Responsible consumption and production SDG17: Global partnerships
Reforming institutional setting for regional integration	Establishing an institutional system with unified rules Promoting regional integration of factor markets Improving regional collaborative mechanisms at multi-levels and in various fields	SDG10: Reducing inequality SDG17: Global partnerships
Building a demonstration zone of green and integrated ecological development	Creating a regional model for eco-friendly integrated development Innovating the institution for integrated development in key fields Strengthening the integration and innovation of reform approaches	SDG6: Clean water SDG10: Reducing inequality SDG13: Climate action SDG14: Life below water SDG15: Life on land
Building the new functional area of China (Shanghai) Pilot Free Trade Zone	Building pilot free trade zones at a higher level Promoting investment/trade liberalization and facilitation Improving supporting institutions and supervision systems Driving a new round of reform and opening up in the YRD	SDG12: Responsible consumption and production SDG17: Global partnerships

Note: Major tasks of regional integration in the YRD were documented in “the outline of the regional integrated development plan of the YRD”.

In addition, to better understand and unravel complex nexuses between regional integration and regional sustainable development, it is essential to conduct an in-depth and interdisciplinary analysis of the human sphere (socioeconomic development and institu-

tional context), the natural sphere (eco-environmental system), and interactive mechanisms between the two in and out of the YRD. Considering interdisciplinary, transregional, and multi-scale attributes of issues related to regional integrative development and SDGs achievement, as well as the challenges and tasks faced by regional integration of the YRD after it rose to one of the national regional strategies in China, future trends and research agendas could be derived from the following aspects: the synergistic achievement of regional integration and SDGs; the analysis of the sustainability of regional SESs; noteworthy issues considering multiple geographical scales; the innovation in governance structure and institutional setting; and the support or application of big data and new methodologies.



**Figure 2.** Conceptual framework and research agendas of regional integrated and sustainable development in the YRD.

#### 4.1. Linking SDGs to Regional Integration of the YRD

The assessment of SDGs achievement and the measurement of individual SDG indicators have been widely examined in extensive literature since the UN released the SDGs (including 17 goals and 169 targets) in 2015 [6,120]. In addition to the global scale, the key to implementing and achieving SDGs, as well as sustainable development practices guided by SDGs, at the national, regional, or local scale, has attracted much scholarly attention [8,25]. Based on the Chinese context, seminal works have discussed comprehensively and in-depth the classification, measurement, and achievement of strategies and approaches of SDGs at the national and provincial scales, especially the complex interactions, synergies, and trade-offs among the 17 SDGs [3,4,25]. However, empirical researches on achieving SDGs in trans-administrative regions (e.g., mega-city-regions, urban agglomerations, and metropolitan areas) in China are thin on the ground.

“The outline of the regional integrated development plan of the YRD” issued by the CPC Central Committee and China’s State Council has specified the objectives and tasks of regional coordination, industrial transformation, cross-border infrastructure, eco-environmental protection, social welfare, opening up, and institutional reform for the YRD in the coming 15 years (see Table 1). How to promote and then achieve these visions has attracted extensive attention from policymakers and scholars. Existing studies indicated that promoting economic agglomeration, social equity, and ecological security, which are

consistent with the main dimensions of SDGs, might be the keys to achieving integrated development in the YRD [38]. Moreover, there is a consensus that promoting and achieving socioeconomic and eco-environmental sustainability are the ultimate goals of integrative development in the YRD. We argue that the implementation of planning tasks and the achievement of the 17 SDGs should and could be synchronized in the YRD. Linking the full set of SDGs and the approaches to their achievement to the process of regional integration in the YRD deserves more scholarly attention.

The following issues should be of concern in future research: First, considering limitations on regional and local data availability, comprehensive and applicative assessment frameworks of regional sustainable development in the YRD should be developed on the basis of the broad content and detailed indicators of the SDGs. Second, the degree of achievement of the 17 SDGs (or specific indicators) and their regional differences, as well as the driving mechanism behind relevant results, should be measured and discussed by future research. Third, to achieve sustainable development in an integrated pathway in the YRD, the interactions among different SDGs and interregional achievement synergy need more scholarly attention. Furthermore, future research needs to further uncover the relations between the SDGs contents and integrated development tasks in the YRD, and then find the key to promoting joint action by local governments and various departments through top-down and collaborative governance.

#### *4.2. Analyzing Sustainability of Social–Ecological Systems in the YRD*

The harmony (or balance) between the human sphere and the natural sphere, namely the stability of our integrated nature–society system, is both an important foundation and the ultimate goal of regional integration and sustainable development in the YRD. A large body of literature has suggested that the framework of SESs could be an effective perspective and analytical tool for sustainable development issues [121–123]. According to the framework developed by Ostrom (2009), SESs are composed of various subsystems, including resource systems, resource units, users, social, economic, and political settings, related ecosystems, mutual interactions, and outcomes [121]. Similar to the regional character of research topics in sustainability science, some scholars have illustrated that a better understanding of the SESs framework and relevant concepts or theories, such as resilience, adaptability, and transformability [124], need to be based on complex contexts of specific scales and places [20,125,126]. The literature implied increasing interest in the multi-scale and cross-scale assessment of SESs, as well as SESs of regions with special territorial functions (e.g., plateau, watershed, and urban agglomerations) [18,19,126–128].

Focusing on simplified subsystems of SESs, as well as the interactive dynamics between specific subsystems or individual variables (e.g., urbanization and land use change), existing studies on human–environment systems or SESs in the YRD are slightly fragmented. Researches on evolutionary dynamics and feedback mechanisms of complex coupled SESs in the YRD are quite limited. This situation is inconsistent with the intensified contradiction between human activities and eco-environmental systems, as well as regional disparities in territorial functions and social–ecological importance, within the YRD. We argue that deepening the examination of the evolutionary processes and feedback mechanisms of the coupled SESs and then generating policies tuned to place-specific conditions are the main requirements of the human–environmental equilibrium and sustainable development in the YRD.

The following issues call for more scholarly attention: First, the research application of theoretical conceptions such as resilience, adaptability, and transformability, as well as the evolutionary dynamics, feedback mechanisms, and regime shifts of SESs and relevant subsystems in the YRD should be in the center of future research. Second, the dynamics and sustainability of SESs in the YRD's subregions with special territorial functions (e.g., Yangtze River Basin, Taihu Basin, Jianghuai Plain, hilly and mountain areas, and estuarine and coastal regions) deserve more empirical investigations. Third, critical issues related to the feedback mechanism of SESs, including land cover change, ecosystem services,

the water–energy–food nexus, environmental economic geography, as well as the coupling mechanism between urbanization and eco-environmental systems, deserve more scholarly investigations.

#### *4.3. Assessing Integrated Region at Subnational Scale*

The essence of regional integration both at the supranational scale and the subnational scale is to achieve interregional economic convergence and welfare equilibrium by breaking administrative barriers, weakening local protectionism, and promoting cross-border factor mobility. The single market and customs union without national borders, as well as the Eurozone or monetary integration, are the prominent features or achievements of the EU, which is a well-known integrated region at the supranational scale [129]. The social, cultural, and institutional contexts of the YRD, a trans-provincial integrative region at the subnational scale, are significantly distinct from the EU. Although different provinces, cities, and counties in the YRD have the same official currency, language, and taxation system, the fiscal decentralization and the performance appraisal of officials in China have largely led to regional competition and local protectionism across the country. Without state intervention and the top-down directives from the Chinese central government, local governments and officials tend to value local socioeconomic development more, rather than trans-administrative public affairs within the YRD. Existing studies have examined interregional corporate linkages, technical cooperation, and population mobility, suggesting that national plans and policies related to integrative development play an increasingly positive role in eliminating administrative division and promoting regional equality in the YRD [38,105,107]. However, it is difficult to have an insight into the overall picture of the integrative development process in the YRD from research based on specific issues.

The driving mechanisms, achievement approaches, and evaluative criteria of regional integration in the YRD and other integrative regions at the subnational scale call for more scholarly investigations. First, a more general theoretical framework, which can comprehensively uncover the motivations, actions, and roles of different stakeholders (e.g., individual enterprises, multi-level governments, the public, and NGOs) and their gaming relations associated with cross-border affairs and regional integration, should be developed for the YRD. Second, more empirical research should be designed to better understand the synergies among different realms, such as industrial collaboration, eco-environmental protection, infrastructure connectivity, and public services sharing, which are crucial for roundly promoting regional integrated development in an orderly fashion. Third, developmental orientations, industrial or innovative directions, and transitional trajectories of regions with different development bases and stages in the YRD should be further discussed in future research, especially based on theoretical perspectives such as smart specialization and spatial division of labor. Fourth, a results-oriented assessment system and relevant appraisable indicators should be developed to identify the propulsion phases and achievements of regional integration in the YRD. Evaluating indicators of regional integration in the YRD could include but are not limited to dimensions such as density, distance, efficiency, and specialization and division. In addition, some new ways of interregional collaboration, such as innovation enclaves, industrial chain alliances, and the joint development of transboundary regions, deserve more scholarly attention.

#### *4.4. Investigating the YRD at Different Geographical Scales*

On the one hand, theoretical and empirical studies on the YRD, which is an emerging global city-region deeply embedded in the global nature–society system, and the strategic layout of China’s reform and opening-up, should be placed under the context of increased globalization and transitional China. On the other hand, the YRD is composed of different administrative areas (e.g., province-, city-, or county-level) and territorial types (e.g., plain, hills, and lake basin), so future research should pay more attention to special features of various administrative levels and physical geographic units in the YRD. Differences between geographical scales within the YRD have been widely discussed in existing studies

on topics related to socioeconomic linkages and eco-environmental changes. More detailed research on the interactions of geographical scales, particularly the role and position of the YRD within the nature–society system at the global or national scale, is also needed in the future.

First, the development practices, crisis countermeasures, and notable contributions of the YRD in the processes of economic globalization and global climate change call for more scholarly investigations. For instance, future research needs to focus on how the cities or enterprises located in the YRD engage in and affect the international trade system, the world city network, and the global production network. Based on the integrated framework of telecoupling [130], the examination of the interactions between distant coupled human and eco-environmental systems including the YRD may be an important and interesting issue in future research. Second, the role played by the YRD, one of the urban agglomerations with the highest level of socioeconomic development, in the economic transition, regional collaboration, and sustainable practice of China deserves empirical research. In particular, comparative studies of the YRD and other urban agglomerations (e.g., the JJJ and PRD) in China, as well as the radiation and spillover effects of the YRD on the Yangtze River Economic Belt and inland regions of China, call for more scholarly attention. Third, more effort should be made to examine socioeconomic statuses, eco-environmental changes, urban–rural relations, and human–environment systems at a finer geographical scale (e.g., township, village, and gridded units), as well as in physical geographic units (e.g., lake basins and hilly regions).

#### *4.5. Exploring Applicable Governance Structure and Institutional Setting*

Existing studies have signified that promoting regional integration or dealing with trans-administrative affairs requires a good balance between multi-level governments, different local authorities, as well as the government, the market, and the public [111]. Moreover, regional disparities in economic level, factor endowment, and eco-environmental conditions determine that one-size-fits-all regional development policies are not feasible in the YRD. To optimize the institutional setting and support policies of integrative development of the YRD, applicable governance structures and policy instruments related to interregional cooperation and synergetic growth need more scholarly attention.

Future research could focus on the following aspects: First, orientations of institutional reforms, especially the specific approach to establishing an intergovernmental consultation platform and a trans-administrative integrated market, need to be deeply discussed to weaken the negative impacts of administrative division in the YRD. The governance structure and maintaining mechanism of intergovernmental cooperation based on cost-, risk-, and benefit-sharing principles should be at the center of relevant research. Second, regional policy instruments and implementation standards should be determined according to the actual situation of specific places and issues; mission-oriented and place-based policies matter more to regional integration. More empirical studies should be conducted to support the assessment of existing regional development policies related to industrial cultivation, technical innovation, and eco-environmental regulation, as well as their impacts on socioeconomic development and ecosystems, within the YRD. Third, the potential trajectories and policy implications of adaptive, transformative, and collaborative governance for the sustainability of SESs and the realization of sustainable development (or SDGs) in the YRD call for more studies. In addition, the experience generalization and demonstration effect of integrated development practices in a few fields (e.g., free trade, systematic innovation, and ecological compensation) and regions (e.g., demonstration zone of green and integrated ecological development of the YRD) deserve tracking and further examination.

#### *4.6. Applying Multi-Source Data and New Methodologies*

The aforementioned research agendas need more empirical investigations based on the interactions between multiple domains, regions, and spatial scales, and this generates new requirements for research materials, data, and methods. The data widely used in

existing studies, such as attribute data of specific regions, as well as statistical data and published materials based on administrative divisions, are difficult to support research on the sustainability of SESs, the achievement of SDGs, and interregional synergies. With regard to data collection and processing, future research should pay more attention to the application of socioeconomic big data based on individual and corporate attributes, as well as multi-source geospatial data based on the virtual constellation and cloud computing. According to the features of human–environment systems, coupled SESs, and interregional linkages, attribute datasets should be transformed into various relational datasets. In addition to the administrative division, the physical geographical unit (e.g., watershed and lake basin) should be emphatically considered in data fusion and database building. With regard to the innovation of analytical methodologies, future research should explore the transdisciplinary application of methods derived from economics (e.g., composite indexes and econometric models), sociology (e.g., social network and structured interview), geography (e.g., spatial analysis and geographical statistics), ecology (e.g., field observations and laboratory experiments), management, etc.

## 5. Conclusions and Discussion

Integrating the effects of key processes across the full range of scales from local to global is crucial for understanding the interactions between the human sphere (or social systems) and the natural sphere (or ecological systems) [16,23,121]. Such an understanding calls for long-term integrated research on the sustainability of SESs and relevant issues in key places and regions of the world. Previous literature has also indicated that, in addition to global-scale analyses, SDG achievement and interactions at the subnational (or regional) scale deserve more attention from policymakers and scholars [2,8,25]. Therefore, it is essential and urgent to conduct systematic and in-depth research into the sustainable development of regions with different territorial functions, especially those highly urbanized regions with complex human–environment relations, around the world.

Located in the eastern coast of China, the YRD is known as one of the emerging global city-regions, as well as one of the urban agglomerations or integrated regions with the highest level of urbanization, economic growth, and social welfare in China and the Global South. The YRD and its major cities, industrial clusters, and lead firms play an increasingly vital role in the globalized economy and Chinese path to modernization. Meanwhile, the eco-environmental systems of the YRD are vulnerable to and have been largely influenced by the rapid and continuous changes in socioeconomic systems, such as the irrational and extensive utilization of natural resources. The development mode and predicaments, especially the increasingly striking contradiction within the human–environment system of the YRD, are representative of mega-city-regions located in emerging economies. The YRD could be taken as an experimental site for the integrated research on geographical science, sustainability science, and human–environment systems [131,132]. To better understand and promote high-quality-oriented, integrative, and sustainable development of the YRD, this paper aims to propose a conceptual framework to link regional integration with sustainable development at the subnational scale, and then generate future research agendas related to the YRD based on research gaps and the Chinese contexts.

We mainly reviewed the literature on the YRD from perspectives such as geography, human–environment interaction, and integrated and sustainable development. With particular attention given to issues including urbanization, economic restructuring, natural resource utilization, eco-environmental changes, and collaborative governance, the existing studies and relevant findings have largely advanced our understanding of the temporal and spatial variations of socioeconomic and eco-environmental systems in the YRD. The literature also indicates an increasing interest in the interactions between social and ecological systems. However, previous studies on the human–environment system or SESs of the YRD seem to be slightly fragmented. Theoretical research on regional integration and empirical research on SDG achievements and interactions in the YRD are also thin on the

ground, which is inconsistent with the intellectual support needed for regional integrated and sustainable development.

This paper tries to develop a conceptual framework to make the causal association between integration and sustainable development at the subnational scale (or in a trans-administrative mega-city-region). We argue that regional sustainable development practices and SDG implementation and realization could be placed in the process of regional integration. By highlighting the shared visions, multi-dimensional synergies, interregional cooperation, stakeholders' joint-action, institutional reformation, and mission-oriented and place-based policies, the process of regional integrative development could be an effective strategy or approach to achieve sustainable development at the subnational scale. To better understand and unravel complex nexuses between regional integration and regional sustainable development, future research should pay more attention to the interdisciplinary, transregional, and multi-scale attributes of issues related to the interactions between the human sphere and the natural sphere in the YRD. We propose the following six research agendas: First, linking the SDGs to regional integrated development in the YRD, the assessment of SDG achievement, and the interactions between the 17 SDGs call for more scholarly investigation. Second, based on the analyses of single socioeconomic and environmental phenomena (or factors), the evolutionary dynamics, feedback mechanisms, and regime shifts of SESs in the YRD need long-term systematic research. Third, more research attention should be paid to the driving mechanisms, achievement approaches, and evaluative criteria of regional integration in the YRD and other integrative regions at the subnational scale. Fourth, more detailed research on the interactions of geographical scales, particularly the role and position of the YRD within the global or Chinese context, is also needed in the future. Fifth, studies based on perspectives such as smart specialization should be conducted to discuss governance structures, institutional settings, and policy instruments related to interregional cooperation and synergetic growth in the YRD. Sixth, the application of multi-source datasets and the integration of interdisciplinary methodologies should be strengthened in future research.

The special issue "Regional Sustainable Development of Yangtze River Delta, China" and this paper aim to call for more scholarly attention on noteworthy topics related to regional integrated and sustainable development in the YRD on the one hand, and provide alternative perspectives and applicatory approaches for the analysis of the sustainability of SESs and the achievement of SDGs at the subnational scale (or within regions with unique territorial function) on the other hand. Research articles included in this special issue examine a wide range of agendas, such as industrial restructuring, technical progress, population migration, urban systems, urban–rural relations, land use change, ecological systems, environmental protection, and collaborative governance, related to the YRD. Some scholars further investigated the interactive dynamics between urbanization (or land use change) and ecosystems (e.g., ecological services) [133–136]. These studies and relevant findings will advance our understanding of regional integration and sustainable development practices in the YRD. However, theoretical discussion and empirical research on the dynamics of regional integration and the sustainability of regional SESs, as well as SDG achievements and interactions in the YRD are quite limited in this special issue. It is difficult for this paper or special issue to cover all seminal works, enlightening findings, and prospective research agendas. We hope this paper or special issue becomes an initial motion to expand and enrich relevant research.

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