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Sustainable Regional Development: A Challenge Between Socio-Economic Development and Sustainable Environmental Management

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Abstract

In the context of sustainability, the concept of balanced development is crucial at both global and regional levels. This principle is equally significant for specific regions, natural-economic complexes, and local communities. Sustainable regional development necessitates a holistic approach to addressing economic, social, and environmental challenges, which are particularly pertinent at the regional scale. The sustainable development of nations is intrinsically linked to their integration into global processes; however, its resilience and stability are contingent upon balanced regional progress. The West Kazakhstan region exemplifies an economic powerhouse within the country and plays a pivotal role in national regional policy. This study introduces a conceptual model designed to evaluate sustainable development through the balanced interaction of various indicators. The results reveal a disparity between the financial and economic potential of different regions and their environmental challenges. These findings form the foundation for developing a new paradigm of sustainable development that emphasizes the integration of economic growth, social stability, and environmental security. The proposed model has the potential to be adapted in various regions of the world facing similar climatic, water, and social challenges. However, it is necessary to consider local characteristics, data availability, and institutional contexts.

Keywords: balanced development; sustainable growth model; sustainable natural resources use; regional progress; West Kazakhstan



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1. Introduction

Global trends in human development have led to income inequality, resources scarcity, and environmental and climate transformations. These drivers contributed to the development of the Global Plan for Sustainable Development, adopted under the auspices of the United Nations (UN) [1]. This plan is the result of decades of international initiatives, concepts, and agreements aimed at balancing economic growth, social justice, and environmental protection [2–9]. Sustainable development is a fundamental principle for advancing human and economic progress while preserving the functional integrity of ecological and social systems that support regional economies. Achieving sustainable development

requires clearly defined parameters to set goals and assess both development potential and progress made [10,11]. Meadows et al. [12] associate sustainable development with resource constraints and the environmental sustainability of the Earth's natural systems. They argue that the Earth's development operates as a closed system. Therefore, development cannot be based solely on quantitative growth, but must follow a qualitatively transformative path. No simple thresholds guarantee sustainable development. Indicators are typically dynamic, reflecting sustainable socio-economic development on the one hand, and sustainable environmental management on the other.

Achieving full sustainable development depends on access to sustainable livelihoods and socio-economic development at the individual level. This ensures progress toward other development goals. Improving quality of life and securing sustainable livelihoods are key objectives of socio-economic policy, as real and lasting development is only possible through inclusive growth [13].

This study aims to identify the relationships between individual well-being, socio-economic development, and sustainable forms of environmental management. Conversely, satisfying human needs and maintaining economic development requires sufficient natural resources—land, water, minerals, and biodiversity—which together constitute the natural resource potential. This highlights another side of sustainable socio-economic development: sustainable environmental management. This aspect considers the ecological impacts of natural resource use in each area and seeks to minimize negative environmental consequences.

The current literature on sustainable regional development reveals significant gaps. Most studies concentrate on global and national levels [14]. This is particularly evident in Central Asian countries despite their urgent need for location-specific solutions. Research on Central Asian regions typically fails to integrate socio-economic and environmental factors [15,16], analyzing these components separately and hindering comprehensive sustainability assessment. Shaker, Song et al. [17,18] show that a comprehensive approach to regional sustainable development assessment remains understudied in Central Asian countries. However, the absence of development priority areas and limited spatial coordination between countries indicates that this research field is still emerging in the region. This study addresses these gaps by applying a comprehensive approach that considers spatial and regional characteristics while integrating socio-economic and environmental factors in assessing the sustainability of Kazakhstan's Western region.

Therefore, the global environmental agenda and the need for national sustainable development strategies underscore the importance of socio-economic development alongside rational natural resource use.

It is hypothesized that sustainable environmental management is a prerequisite for achieving balanced socio-economic growth under conditions of climatic and anthropogenic changes. The main research questions are as follows: What regional characteristics determine the sustainability of environmental management? What mechanisms can integrate sustainable environmental management principles into regional socio-economic policy? Understanding and addressing these questions requires deep immersion in the historical and theoretical foundations of human–environment interactions. Analyzing past development trajectories can reveal how socio-economic priorities have evolved alongside or in opposition to environmental considerations.

Since the 18th century, the Industrial Revolution has brought irreversible transformations to human societies. Human development became closely associated with economic growth and material progress. Worster [19] described industrialization as “the greatest revolution in worldview that has ever taken place”, as it led people to believe they had the right to dominate nature and convert it into consumer goods.

There was a widespread belief that scientific and technological progress would lead to humanity's moral advancement [20]. However, industrial capitalism did not benefit all equally. The advantages of the global economic system accrued mainly to industrialized nations, widening the gap between rich and poor societies. In the long term, this inequality in wealth distribution will likely become a key point of contention in discussions about development and sustainability.

Many consequences of industrial development were initially unrecognized but eventually led to significant environmental degradation due to large-scale exploitation of raw materials [21,22]. This gave rise to widespread concerns about sustainability.

Van Zon noted that the demand for raw materials and its environmental consequences have been constant throughout human history [23]. Thinkers like Plato in the 5th century BCE, Strabo and Columella in the 1st century BCE, and Pliny the Elder in the 1st century CE discussed environmental degradation resulting from human activity [24]. These scholars not only analyzed degradation processes but also proposed practices that we would now call "sustainable" to preserve the Earth's vitality. For instance, in the 1st century CE, Varro wrote that "we can, by exercising caution, reduce the deleterious effects" [25]—highlighting the importance of careful resource use.

G. P. Marsh's foundational text (1864) on environmental conservation argued that "man has long since forgotten that the earth was given to him for use only, not for consumption and still less for waste" [26]. His work emphasized protecting nature for humanity's benefit—a perspective shared by modern sustainable development proponents.

In the 19th century, population growth and its impact on resource consumption emerged as a critical research focus [27]. T. R. Malthus's influential work (1803) warned that unchecked population growth could exceed food production capacity [28].

Attention later shifted to coal as the primary energy source, raising concerns about depletion. During the early 20th century, scientists highlighted limitations of raw materials and energy sources while cautioning against wasteful consumption [29,30]. T. Veblen et al. [31–36] examined the consequences of natural resources overexploitation and advocated responsible resources use to ensure civilization's continued existence.

K. W. Kapp (1950) published an analysis of environmental issues that now form core elements of sustainable development discourse [37]. According to Van Zon, many 19th-century publications anticipated the concept of "sustainable development" before the term itself emerged [23].

Soviet scholars also established foundations for modern sustainability approaches. Armand (1964) [38] emphasized responsibility toward future generations regarding environmental matters. This concept continues evolving in contemporary Russian research by E. V. Girusov and S. N. Bobylev [39,40].

Internationally, Johan Rockström leads sustainability science with his "planetary boundaries" concept. This idea defines critical environmental thresholds that, if exceeded, could have catastrophic consequences for humanity [41].

Herman Daly, a founder of ecological economics, proposed reconsidering economic growth within environmental constraints and advocated structural reforms to align economic system with ecological limits [42–44]. Daly's ideas have influenced environmental standards in the UN, World Bank, and EU [45,46]. Nevertheless, many countries still lack a unified sustainability assessment index, complicating investment attraction.

Financial development also plays a crucial role in implementing sustainable policies. It connects directly to economic growth and system efficiency [47,48] and serves as a public policy tool for addressing environmental problems [49,50].

Contemporary research employs various indices to evaluate sustainability across economic, social, and environmental dimensions [51–55]. These indices measure environmental policy effectiveness using different resource management and ecosystem health indicators.

F. Hinterberger made a key contribution by developing a framework for assessing progress toward sustainable development. His model aims to ensure a decent life for all people within planetary and social boundaries [56]. The idea of the study is to create an indicator system that accurately demonstrates how different actors and policies contribute to global sustainable development goals.

In Kazakhstan researchers focus on sustainable agricultural development, including efficient environmental management, agroecosystem preservation, and enhanced agricultural productivity [57–60]. These studies show how combined factors strengthen rural sustainability and highlight investment and innovation’s importance in improving economic efficiency.

Central Asian countries face serious socio-economic challenges exacerbated by climate change. The region’s geographical location significantly impacts sustainability, particularly regarding transboundary water resources management. These factors shaped our research methodology.

For visual representation of the evolution of the sustainable development approach and its application within the context of our study area, the Aktobe region, a conceptual framework was developed (Figure 1). This framework illustrates the transformation from the general sustainable development concept to a comprehensive assessment methodology that incorporates regional specificity and integrates socio-economic and environmental factors.

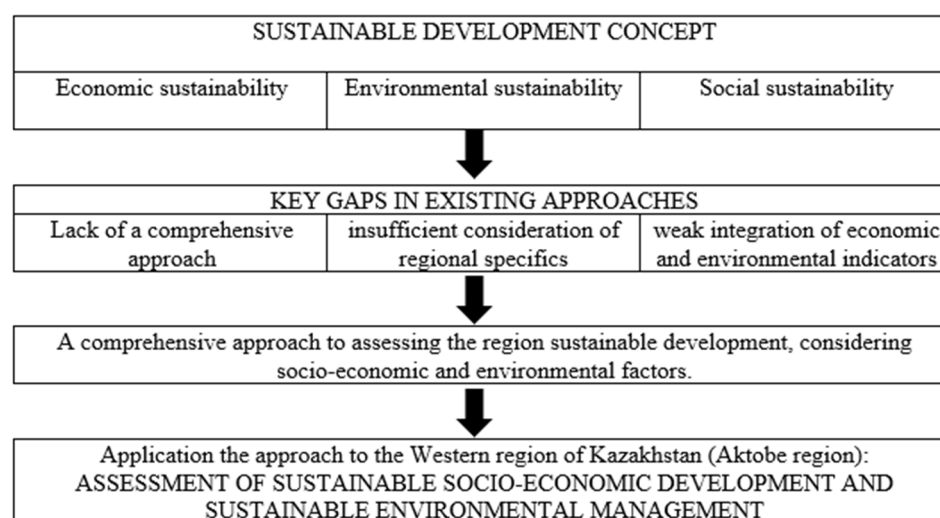


Figure 1. Conceptual framework depicting the evolution of the sustainable development approach: from general concept to comprehensive assessment using the Aktobe region as a case study.

The framework identifies three critical gaps in existing sustainable development assessment approach: the lack of a comprehensive approach; insufficient consideration of regional specifics; weak integration of economic and environmental indicators. Our proposed comprehensive approach to regional sustainable development assessment integrates socio-economic and environmental factors, thereby enabling a more precise evaluation of the sustainability trajectory of the Aktobe region.

The proposed approach applies not only to Central Asian regions but also to other areas where climate aridization and sustainable resource use are pressing concerns. This research methodology can assess sustainability in any regionally isolated area, according to the limitations (theorems) established in our framework.

In conclusion, sustainable development concepts trace back to antiquity, but today’s urgency stems from rising populations, post-industrial consumption growth, and resource

depletion risks. Concerns that future generations may be unable to maintain their quality of life have driven the development and global adoption of sustainable development principles.

2. Materials and Methods

2.1. Case Study Area

Kazakhstan is one of the most dynamically developing countries in Central Asia and offers a compelling example of achieving ambitious goals while considering national priorities and characteristics. It is part of the “One Belt, One Road” initiative, acting as a bridge between Europe and Asia [60]. Kazakhstan also collaborates actively with international organizations such as UNEP (United Nations Environment Programme) and GEF (Global Environment Facility), and it initiated the establishment of the International Green Technologies and Investment Projects Center under the UN framework [61]. Since the adoption of the Sustainable Development Goals (SDGs), the United Nations Development Programme (UNDP) has provided active support to Kazakhstan, helping the country identify priority SDG areas and offering technical and material assistance for their implementation [62–66]. However, ongoing global crises and transformations necessitate the development of long-term, science-based national strategies for sustainable development that can respond to 21st-century challenges.

Kazakhstan has made significant socio-economic progress since adopting the SDGs, elevating its national human development level. According to the Human Development Report of 2015 [67], Kazakhstan’s Human Development Index was 0.788; by 2022, the country had entered the group of nations with a very high level of development, achieving a score of 0.811 [68,69].

This study focuses on the western region of Kazakhstan, especially the Aktobe region, where unique characteristics and barriers to sustainable development practices can be identified (Figure 2). A comprehensive approach is used to analyze not only economic aspects but also social and environmental factors. Despite its high development potential, the region faces serious environmental challenges and social tensions that adversely affect both public health and the biodiversity of the ecologically sensitive arid landscape.

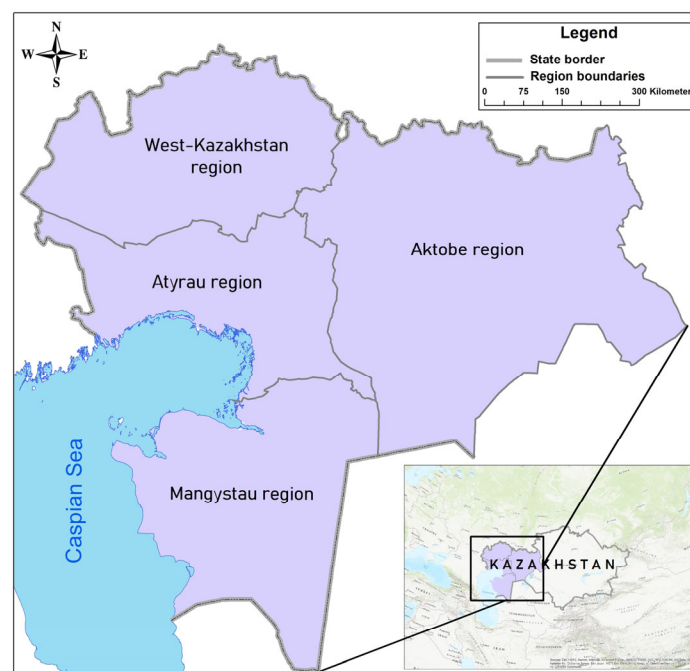


Figure 2. West Kazakhstan region map.

The Aktobe Region in Western Kazakhstan (Figure 2) is one of Kazakhstan's key industrial regions, attracting large-scale investments across multiple sectors, including mining, traditional and renewable energy, agro-industrial development, and transport infrastructure. The region benefits from well-developed transport infrastructure and is rich in mineral resources. Industry accounts for about 40% of the region's gross product [70].

2.2. Estimation Strategy of Sustainability

An effective assessment of sustainable environmental management requires a system of indicators reflecting the economic, environmental, and social sphere [71]. In our view, sustainable development represents a form of equilibrium—a balance of heterogeneous indicators or opposing forces. Therefore, the selection of assessment factors depends on the study's purpose. In the context of Kazakhstan, two key factors are used to assess sustainable development in isolated areas, consistent with the goals of this study:

1. The capacity (potential) of the natural environment and resources to support sustainable growth for a defined population engaged in economic activity;
2. The amount of investment required to support such growth.

When assessing sustainable socio-economic development using these two parameters, we can assume that a single person living in a remote area requires substantial investments to ensure access to social services: communications, security, clean drinking water, and other basic amenities. As the population size increases, the cost per person decreases due to economies of scale. However, once a certain population threshold is reached, the effect of scale diminishes, and further increases do not significantly reduce per capita costs. Moreover, in regional sustainable development, additional factors such as the size of the area and the ecological sensitivity of habitats must also be considered.

The size of a territory is directly proportional to the number of people who can live on it. Hence, it is logical to analyze population density (people per km²), which ultimately determines environmental pressure and infrastructure investment requirements.

Another crucial factor is the ecological sensitivity of natural habitats. Deserts and semi-deserts are particularly sensitive to anthropogenic impacts and often cannot absorb waste products on their own. The fragile structure of such ecosystems makes them highly vulnerable to disruption, leading to biodiversity loss.

Before proposing our sustainable population livelihoods analysis function, we establish two foundational theorems:

Theorem 1. *A population density of 1 person per km² has minimal environmental impact that natural self-regulating processes can mitigate. This principle applies to most territories except extreme environments such as Arctic ice deserts or high-altitude glacial areas.*

Theorem 2. *The maximum level of investment required to support sustainable human livelihoods can be quantified per unit of population density.*

From these, we derive Equation (1) as follows:

$$f(x) = (I_{max} - I_{min}) / \sqrt{x} + I_{min} \quad (1)$$

where

$f(x)$ = investment per capita for sustainable development;

I_{max} = investment per capita at a population density of 1 person/km²;

I_{min} = investment per capita when the effect of scale no longer applies;

x = population density of the area under study.

This study employs probabilistic forecasting and macroeconomic analysis to determine key equations. We set threshold values for selected coefficients from 0 to 1, basing our evaluation criteria on macroeconomic analysis principles that measure how specific economic processes affect the final outcome.

In our framework, a region's ecological sensitivity is represented by the relative difference between maximum and minimum investment levels. Greater differences indicate more environmentally sensitive territories requiring higher investment. This relationship can be quantified as a coefficient between 0 and 1 as shown in Equation (2):

$$Kes = Imin / Imax, \quad (2)$$

where

Kes = coefficient of ecological sensitivity;

$Imin$ = investment per capita when effect of scale no longer applies;

$Imax$ = investment per capita at 1 person/km².

Hence, the basic equation can be transformed in Equation (3) as follows:

$$f(x) = Imax((1 - Kex) / \sqrt{x}) + Kex, \quad (3)$$

where

$f(x)$ = investment per capita for sustainable development;

$Imax$ = investment per capita at 1 person/km²;

Kes = coefficient of ecological sensitivity;

x = population density of the area under study.

To determine ecological sensitivity, we identify four coefficients:

1. Water stress coefficient.
2. Atmospheric air pollution coefficient.
3. Landscape stress factor.
4. Biodiversity distribution coefficient.

The Water Stress Index (WSI) measures pressure on water basins with significant irrigation demands. This index reflects the relationship between water withdrawals and availability. Forecasts of future water withdrawals are based on projected population growth and anticipated changes in water use intensity across domestic, industrial, and agricultural sectors.

However, this indicator does not account for water quality. According to the United Nations (UN) framework on Water Resources Management under SDG 6, water stress is calculated at the national level using Equation (4) for the Water Stress Index (WSI) [72]:

$$(WSI) = Total\ freshwater\ withdrawal / Available\ water\ resources \cdot 100\%, \quad (4)$$

Values range from 0 (no stress) to 1 (severe stress).

The "atmospheric air pollution coefficient" lacks a standardized formulation. For this study, we derive it from environmental risk assessment principles, incorporating air quality and population vulnerability components in Equation (5):

$$Atmospheric\ air\ pollution\ coefficient = Actual\ pollutant\ emissions / Maximum\ permissible\ emission\ standard \quad (5)$$

Landscape stress refers to pressure or disturbance experienced by natural landscapes due to human activities or natural processes. This factor incorporates elements such as land-

use change, habitat fragmentation, pollution, and other anthropogenic impacts affecting terrestrial ecosystems. We propose the following generalized Equation (6):

$$\text{Landscape stress factor} = \text{Used area of the region} / \text{Total area of the region} \quad (6)$$

This coefficient integrates indicators assessing landscape disturbance or degradation, expressed as a value from 0 to 1, where 0 indicates minimal stress (healthy landscape), and 1 indicates severe stress (highly degraded landscape).

The biodiversity distribution coefficient quantifies species spatial distribution within a specific region or ecosystem. It is calculated from species occurrence data, comparing observed distribution to theoretical uniform distribution [73]. We propose the following generalized Equation (7):

$$\text{Biodiversity distribution coefficient} = (\text{Endangered species} / \text{Total number of species}) / (\text{Specially protected area} / \text{Total area}) \quad (7)$$

A coefficient close to 0 indicates freely dispersing biodiversity with high rates of species migration or colonization. Conversely, a coefficient approaching 1 suggests limited species movement, implying ecological isolation or fragmentation, with species confined to specific habitats and little exchange between populations.

The primary assessment inputs include the following: per capita investment required for sustainable development at a population density of 1 person per km² and environmental sensitivity of natural habitats (determined by land resources, water availability, and biodiversity).

Sustainable environmental management represents the other side of sustainable development. Human activity produces both useful outputs (goods and services) and waste requiring processing or disposal. Environmental management addresses impact such as air, water, and soil pollution, including recycling or disposal of goods after use. Higher population density increases pressure on natural ecosystems from human-generated waste.

Consequently, investments in environmental management increase with population growth and socio-economic activity, both absolutely and per capita. More economic activity necessitates higher investments to maintain environmental quality. Capital investments in sustainable environmental management include treatment facilities, waste incinerators, land reclamation projects, green energy initiatives, and endangered species conservation.

Several parameters affect final investment levels.

First, the structure of regional economic activity. Economies based primarily on natural resource extraction impact natural systems more significantly than those focused on producing final consumer goods. Manufacturing complex goods and providing highly skilled services typically exert less ecosystem pressure while producing stronger multiplier effects—indicating an inverse relationship between environmental impact and economic return on investment. Second, social well-being levels influence sustainable environmental management. More socially prosperous populations consume more goods and services, creating greater environmental impact. Third, the sustainable development investment indicator should be adjusted for import–export rations, as exported goods do not generate waste or environmental pressure within the producing region.

Considering these factors and constraints, the function can be represented as noted in Equation (8):

$$f(x) = ((I_{\text{gross}} - I_{\text{green}}) / \text{average annual population}) \cdot (1 / \sqrt{\mu_{\text{GRP}}}) \cdot I_{\text{Nsw}} \cdot I_{\text{m}} / E_{\text{x}} \cdot \sqrt{x} \quad (8)$$

where

$f(x)$ = investment per capita in sustainable environmental management;
 I_{gross}, I_{green} = gross capital and green/environmental investment per capita;
 μ_{GRP} = gross regional product (GRP) multiplier;
 IN_{sw} = Human Development Index (normalized for the region);
 Im, Ex = regional import and export volumes;
 x = population density of the area under study.

Sustainable development is thus viewed as a target state of dynamic equilibrium. The key parameter for assessing regional sustainability is investment per capita, which varies with population density (Figure 3). The optimal investment level occurs where sustainable socio-economic development and sustainable environmental management indicators intersect.

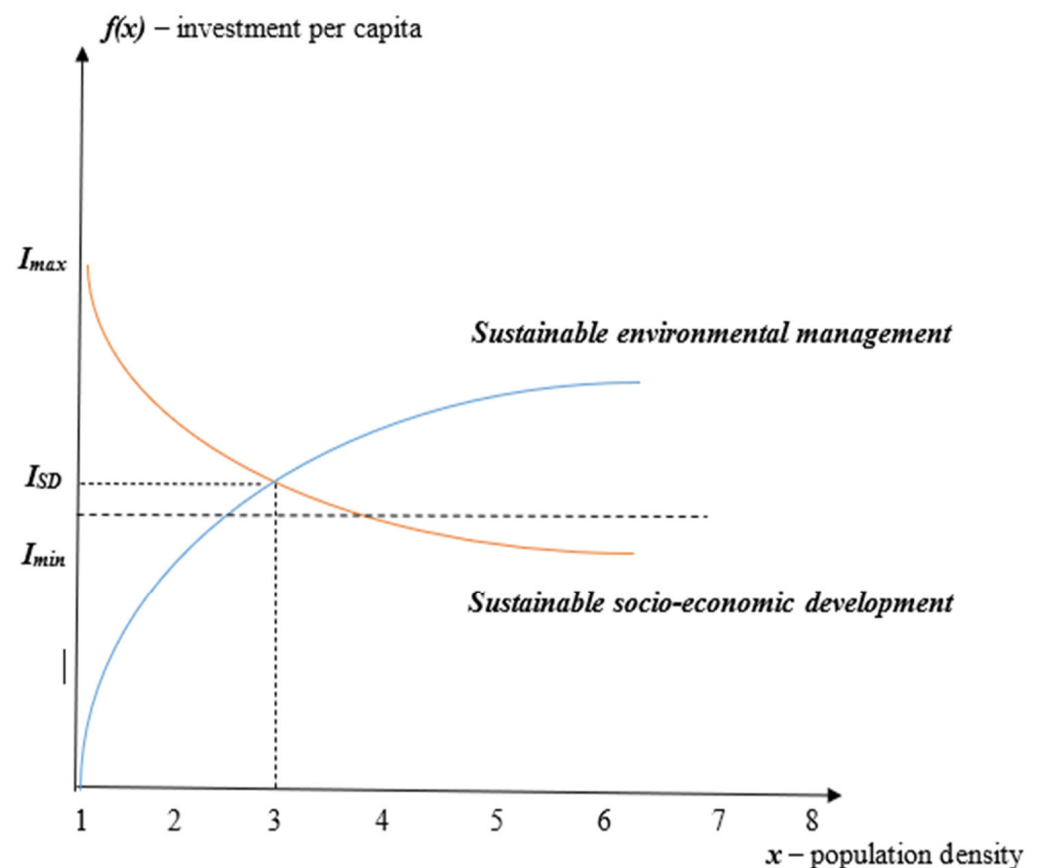


Figure 3. Sustainable development factors in the investment/population system.

The conceptual methods developed in this study for assessing sustainable development are grounded in the balanced evaluation of indicators defining both sustainable socio-economic development and sustainable environmental management parameters. The optimal per capita investment volume required for regional transition to sustainable development is considered the most informative and significant indicator.

The equations presented were developed by the authors using probabilistic forecasting, spatial, and macroeconomic analysis approaches. Some indicators were adapted from international practices [72,73], while others were selected by the authors based on regional specifics and the study's interdisciplinary nature.

3. Results

3.1. Sustainable Socio-Economic Development: Data-Based Insights

Australia was selected as a benchmark for state-driven financial investment in sustainable development based on several key criteria. The methodology uses Australian development indicators as a reference base while acknowledging hypothetical elements in the results. Australia serves as an ideal model due to its balanced approach to sustainable environmental management and socio-economic development, making it relevant for both Kazakhstan and other countries. The natural conditions of Australia and Western Kazakhstan share significant similarities, with both regions dominated by desert, semi-desert, and steppe landscapes. Additionally, both regions exhibit comparable socio-economic characteristics: low population density and economies oriented toward natural resource extraction. Both areas also face similar extreme climatic events including droughts, heat waves, and floods, though these occur with seasonal shifts due to their opposite hemispheric locations. Despite the COVID-19 pandemic challenges, Australia maintained growth in public investment throughout 2019 [74], with state and local governments focusing on essential infrastructure such as hospitals, schools, roads, and railways.

Between 2016 and 2022, Australia's average annual public investment reached USD 2089 per capita [74]. Using this figure and adjusting for a population density of 1 person/km², we established a maximum investment value (Imax) of USD 3315 per capita (Table 1). This benchmark figure represents the investment required to ensure a high quality of life and provides a comparative standard for assessing other regions, including Kazakhstan's Aktobe Region.

Table 1. Estimated indicators for sustainable socio-economic development (2022) compiled by the authors according to [70,74].

Indicators	Australia	Aktobe Region (KZ)
Water stress coefficient	0.05	0.482
Atmospheric air pollution coefficient	1.5	0.506
Landscape stress factor	0.51	0.44
Biodiversity distribution coefficient	0.04	4.4
Ecological sensitivity index	0.19	0.541
Population density	3.4	3.07

Our calculations indicate that sustainable socio-economic development in Aktobe Region requires an investment of USD 2657.951 per capita (equivalent to 1,249,237.4 KZT at the 2022 exchange rate of 470 KZT/USD). However, actual public investment from national and local budgets in 2022 amounted to only 76.8 billion KZT, or 82,626.9 KZT per capita—14 times below the required level. Notably, labor productivity in Aktobe is only three times lower than in Australia, suggesting that increasing per capita investment to 417,000 KZT annually (a threefold increase) would be both economically justified and achievable given current income levels.

3.2. Sustainable Environmental Management: Data-Based Insights

To estimate investment requirements for sustainable environmental management in Aktobe Region, we analyzed comprehensive data from 2022 (Table 2) [70]. These calculations incorporate multiple economic and environmental factors to determine optimal funding levels.

Table 2. Indicators for calculating investments in sustainable environmental management (2022) [75–77].

Indicators	Aktobe Region (KZ)
Investments in fixed assets	960,039 million KZT 817,136 million KZT (2021)
Environmental protection investments (green)	4335.3 million KZT
Average annual population	922,456 persons
Import	USD 1379.7 million
Export	USD 3568.4 million
GRP (Gross Regional Product)	4,416,899.4 million KZT 3,586,222.6 million KZT (2021)
Human development index	0.843
Population density	3.09
Per capita investment in environmental management	246,206.88 KZT

Our analysis reveals that strategic investment in environmental sectors generates broader economic benefits through the multiplier effect, where initial spending stimulates additional economic activity across related sectors. Based on our calculations, sustainable environmental management in Aktobe Region requires 246,206.88 KZT per capita, totaling 227.1 billion KZT for the entire region’s population of 922,456 residents.

Currently, green investments constitute merely 0.452% of the local budget. Our model indicates this should increase to 23,655% to effectively improve environment conditions and minimize human impact. This specific target percentage is derived from our assessment of regional ecological sensitivity and required remediation measures

Western Kazakhstan’s relatively low population density partially mitigates the high ecological sensitivity of its landscapes. However, continued insufficient environmental funding will likely result in accumulated ecological problems that could eventually reach crisis levels. The Aktobe region’s favorable export-to-import ratio (exports significantly exceeding imports) reduces pressure on local waste management infrastructure, as exported goods generate waste elsewhere. This factor, combined with our analysis confirming relatively low current anthropogenic pressure, positions the region favorably for sustainable population growth without compromising environmental integrity.

4. Discussion

The assessment of sustainable development within the context of climate and socio-economic challenges in Central Asian countries has been examined across multiple studies. Kuanova et al. [78] evaluated Kazakhstan’s regional sustainable development using socio-economic and environmental indicators. However, their analysis remains generalized and fails to account for the spatial and natural variations within the country. Similarly, studies by Saparov, Baytelieva et al. on climate change in Central Asia [79,80] address sustainability with narrow sectoral focuses—examining only agriculture, tourism, or other individual sectors. These studies collectively emphasize the necessity for developing a comprehensive analytical framework that integrates natural, economic, and managerial factors to ensure regional sustainable development.

Our methodology employs a balanced set of indicators that capture the region’s dynamic state. We recognize that sustainable development lacks definitive, static indicators precisely because sustainability itself is an evolving process. The combination of balanced socio-economic development metrics with sustainable natural resource use parameters provides a real-time assessment of regional conditions, aligning with the principle that sustainability perspectives continuously evolve over time.

Our findings reveal a critical imbalance in the Aktobe region. Despite relatively high incomes and positive economic indicators, inadequate investment in environmental infrastructure significantly constrains sustainable development. This underscores the intrinsic connection between socio-economic development and population welfare with sustainable natural resource management practices.

The investment deficit, particularly in environmental management, directly restricts the region's capacity to preserve its natural resource potential and meet long-term population needs. This evidence supports our conclusion sustainable environmental management constitutes a fundamental prerequisite for balanced development, especially under intensifying anthropogenic and climatic pressures.

Our research successfully addresses the key research questions initially posed, identifying environmental fragility, underdeveloped infrastructure, and investment imbalance as the defining characteristics of the Aktobe region's sustainability challenges.

While investments in quality of life and environmental protection are key to regional sustainable development, the required investment volume has remained undefined. Our methodology now enables calculation of necessary annual investments based on specific area characteristics, ensuring balanced regional sustainable development.

5. Conclusions and Outlook

Our study introduces a novel conceptual model for sustainable development assessment based on two interrelated pillars: sustainable socio-economic development and sustainable environmental management. This approach evaluates human activity in interaction with the natural environment, ensuring holistic regional sustainability assessment.

The provision of sustainable livelihoods serves as the principal criterion of sustainability, reflecting the potential for socio-economic progress. While improving quality of life remains the primary objective of socio-economic policy, natural resources are essential for meeting human needs—necessitating responsible, long-term environmental management practices.

Our model estimates required per capita investment at varying population densities at both regional and national levels. The findings demonstrate that sustainable development depends on achieving a dynamic equilibrium between human and environmental systems.

The Aktobe region exhibits a significant imbalance in sustainable development due to the gap between financial capacity and environmental challenges. Currently, environmental problems are predominantly addressed through increased spending on short-term solutions. However, our analysis indicates that strategically planned investments—particularly in water management, renewable energy, and ecosystem protection—would enable a shift toward forward-looking regional development.

Based on our study, we recommend the following policy changes for the Aktobe region: (1) rank regional policy objectives into short-term (requiring expenditure) and long-term (requiring investment) objectives; (2) prioritize long-term goals by increasing public investment's share in the regional budget; (3) attract external funding for infrastructure; (4) promote green technologies through targeted investments; (5) strengthen civil institutions for better local oversight by invest.

The growing climatic challenges require targeted investments in adaptation measures, particularly modernizing hydraulic structures and preventing land degradation. Renewable energy development warrants special attention given the region's natural potential, especially solar and wind energy.

Future research should focus on refining investment calculation methodologies and integrating climate change variables. The challenges identified in Aktobe region parallel those in neighboring regions of Kazakhstan and Central Asia, highlighting the broader

applicability of our approach in areas characterized by climate aridization and limited water resources.

Our findings provide a foundation for a new development paradigm that balances economic growth, social stability, and environmental security—achievable through strategic planning and adequate investment in education, healthcare, infrastructure, and environmental protection.

Author Contributions: Conceptualization, A.M. and M.A.; methodology, A.M.; software, A.Z.; validation, M.A. and A.Z.; formal analysis, A.M. and U.B.; investigation, A.Z. and U.B.; resources, A.Z. and U.B.; data curation, A.M. and H.K.; writing—A.M.; writing—review and editing, M.A., A.Z. and H.K.; visualization, A.Z.; supervision, A.M.; project administration M.A.; funding acquisition, A.M. and M.A. All authors have read and agreed to the published version of the manuscript.

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