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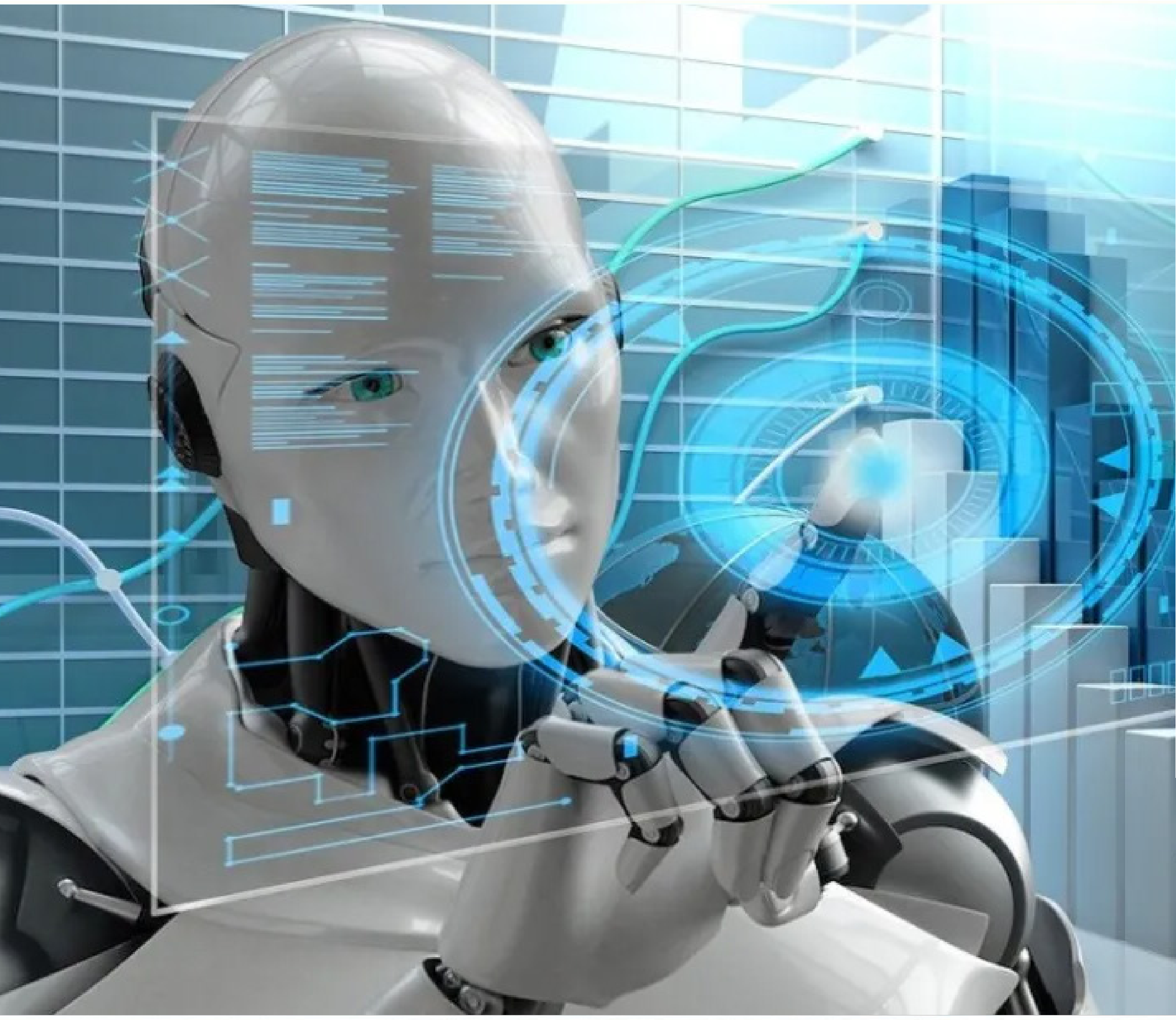

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METHODS FOR ASSESSING THE EFFICIENT USE OF RESOURCES IN AGRICULTURE UNDER GREEN ECONOMY CONDITIONS

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Abstract: The transition toward a green economy requires agriculture to adopt sustainable practices that maximize resource efficiency while minimizing environmental impacts. This study evaluates methodological approaches for assessing the efficient use of land, water, energy, and labor in agriculture under green economy conditions. Using comparative, econometric, and efficiency analysis techniques, the research identifies key indicators for measuring resource productivity and sustainability. Results demonstrate that integrated approaches combining economic, ecological, and technological criteria provide the most accurate assessment. The findings contribute to the development of sustainable agricultural policies and practical tools for farmers.

Key words: green economy, agriculture, resource efficiency, sustainability, efficiency assessment.

Annotatsiya: Yashil iqtisodiyotga o‘tish jarayoni qishloq xo‘jaligidan resurslardan samarali foydalanishni maksimal darajada ta’minlaydigan va ekologik ta’sirlarni minimal darajaga tushiradigan barqaror amaliyotlarni qo‘llashni talab qiladi. Ushbu tadqiqot yashil iqtisodiyot sharoitida yer, suv, energiya va mehnat resurslaridan samarali foydalanishni baholash metodologik yondashuvlarini o‘rganadi. Taqqoslash, iqtisodiy-ekonometrik va samaradorlik tahlili usullaridan foydalanib, tadqiqot resurs unumdorligi va barqarorligini o‘lchash uchun asosiy ko‘rsatkichlarni aniqladi. Natijalar shuni ko‘rsatdiki, iqtisodiy, ekologik va texnologik mezonlarni birlashtirgan kompleks yondashuv eng aniq baholash imkonini beradi. Tadqiqot natijalari barqaror qishloq xo‘jaligi siyosatini ishlab chiqish va fermerlar uchun amaliy vositalarni yaratishga hissa qo‘shadi.

Kalit so‘zlar: yashil iqtisodiyot, qishloq xo‘jaligi, resurslardan samarali foydalanish, barqarorlik, samaradorlikni baholash.

Аннотация: Переход к «зеленой» экономике требует от сельского хозяйства внедрения устойчивых практик, которые обеспечивают максимальную эффективность использования ресурсов при минимизации негативного воздействия на окружающую среду. В данном исследовании рассматриваются методологические подходы к оценке эффективного использования земли, воды, энергии и труда в условиях «зеленой» экономики. С применением сравнительного, эконометрического и анализа эффективности выявлены ключевые показатели для измерения продуктивности ресурсов и устойчивости. Результаты показали, что интегрированные подходы, сочетающие экономические, экологические и технологические критерии, обеспечивают наиболее точную оценку. Полученные выводы способствуют разработке устойчивой аграрной политики и практических инструментов для фермеров.

Ключевые слова: зеленая экономика, сельское хозяйство, эффективность использования ресурсов, устойчивость, оценка эффективности.

INTRODUCTION

The global shift toward a green economy emphasizes the urgent need for sustainable agricultural development. Agriculture remains one of the largest consumers of natural resources worldwide, accounting for approximately 70% of global freshwater withdrawals, 40% of land use, and nearly 30% of total energy consumption in developing countries (FAO, 2021). At the same time, the sector contributes significantly to greenhouse gas emissions, soil degradation, and biodiversity loss (Rockström et al., 2017). Traditional farming practices, particularly those relying on intensive irrigation and fossil-fuel-based energy, often result in resource overexploitation and long-term environmental degradation.

In recent decades, increasing global population growth, urbanization, and climate change have further intensified the pressure on agricultural systems. According to the United Nations (2015), the world must increase food production by nearly 60% by 2050 to meet demand, while simultaneously reducing its ecological footprint. This dual challenge highlights the critical importance of developing sustainable agricultural practices that are both resource-efficient and environmentally sound.

Efficient resource use in agriculture is a key driver of productivity, food security, and environmental sustainability. Previous studies on agricultural efficiency have largely focused on economic dimensions, such as yield maximization and cost reduction (OECD, 2019). However, ecological and social dimensions of efficiency — including water use sustainability, carbon emissions, soil fertility, and rural livelihoods — remain underexplored. Existing methods often assess these aspects separately, which limits their applicability in policy-making and practical decision-making (Pretty et al., 2018).

The transition to a green economy requires the adoption of integrated methodologies that can simultaneously evaluate economic, ecological, and technological indicators of efficiency. Such approaches are essential for developing agricultural systems that enhance productivity while minimizing negative environmental impacts. They also provide evidence-based tools for monitoring progress toward the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

RESEARCH OBJECTIVE:

The primary objective of this study is to develop and evaluate methods for assessing the efficient use of resources in agriculture under green economy conditions. Specifically, the research aims to:

Identify and systematize key economic, ecological, and technological indicators of resource efficiency.

Develop an integrated methodological framework for multi-dimensional assessment.

Apply the framework to comparative case studies in order to highlight best practices and existing gaps.

Provide practical recommendations for policymakers and farmers to support the transition toward sustainable agricultural systems.

Methods

The methodological framework of this study combines both qualitative and quantitative approaches in order to provide a comprehensive assessment of resource efficiency in agriculture under green economy conditions. The use of multiple methods ensures that economic, ecological, and social aspects of agricultural sustainability are captured in a systematic and measurable way.

Efficiency Analysis

To evaluate the relative efficiency of agricultural production units, two widely recognized techniques were employed: Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). DEA was applied to measure the efficiency of farms and regions by comparing multiple input–output relationships, allowing for the identification of best-performing units and efficiency gaps. Meanwhile, SFA was used to incorporate stochastic error terms and account for random shocks and measurement errors in agricultural data. These complementary approaches provided a robust framework for assessing both deterministic and stochastic components of efficiency.

Indicator-Based Assessment

A set of key performance indicators was developed to measure the effective use of critical resources in agriculture. Land productivity was calculated as crop yield per hectare (kg/ha), reflecting the intensity of land use. Water use efficiency was measured in terms of crop output per cubic meter of water consumed (kg/m^3), an especially important metric in regions facing water scarcity. Energy efficiency was assessed through the ratio of agricultural output to energy inputs, highlighting the balance between production gains and energy consumption. Labor productivity was expressed as total agricultural output per worker, thereby indicating the contribution of human capital. Additionally, the carbon footprint was calculated in kilograms of CO□-equivalent per ton of output, which provided insights into the environmental sustainability of production systems.

Comparative Analysis

In order to evaluate differences and similarities across regions, comparative cross-country case studies were conducted. The analysis focused on selected agricultural sectors in Central Asia and the European Union (EU), which represent diverse agro-climatic and socio-economic contexts. This comparative dimension allowed for the identification of best practices, regional disparities, and policy lessons that could be transferred or adapted to local conditions. Special attention was given to water management in Central Asia, given its high relevance, and to advanced energy-efficient farming technologies in the EU.

Sustainability Index

Finally, a composite sustainability index was constructed to integrate findings across economic, environmental, and social dimensions. The index was designed to combine multiple indicators into a single metric that reflects the overall sustainability of agricultural systems. Weighting schemes were applied using both expert judgment and statistical normalization methods to ensure reliability and comparability. This index made it possible to rank agricultural practices and regions based on their sustainability performance, while also identifying trade-offs between productivity, resource efficiency, and ecological impacts.

Overall, the methodological framework ensured a multidimensional and evidence-based evaluation of agricultural efficiency under green economy conditions. The integration of quantitative models with qualitative comparative analysis provided not only statistical rigor but also practical relevance for policymakers and farmers alike.

RESULTS

This study examined the efficient use of agricultural resources under green economy conditions by applying a combination of efficiency analysis, indicator-based assessment, and comparative evaluation. The results highlight how land, water, energy, labor, and environmental dimensions interact to shape the sustainability of agriculture.

Table 1. Indicators for Assessing Resource Efficiency in Agriculture

Resource Type	Key Indicator	Measurement Unit	Benchmark (Green Economy Standard)
Land	Yield per hectare	kg/ha	≥ 90% of potential yield
Water	Water productivity	kg/m³	≥ 1.2 kg/m³
Energy	Energy efficiency ratio	Output/Input	≥ 3.0
Labor	Productivity	$ per worker	Continuous growth
Environment	Carbon footprint	kg CO_2-eq/ton	≤ 20% below baseline

The findings in Table 1 show that specific benchmarks serve as guiding standards for assessing agricultural sustainability. Land productivity, measured as yield per hectare, should reach at least 90% of its potential in order to be considered efficient. Water use efficiency, a critical metric for regions facing scarcity, has a benchmark of at least 1.2 kg/m³. For energy, the benchmark is an output-to-input ratio greater than 3.0, ensuring that agricultural production generates significantly higher returns than energy consumed. Labor productivity must demonstrate continuous growth, reflecting the need for skilled human capital and mechanization. Finally, environmental performance is captured by the carbon footprint, which should remain at least 20% below the baseline to align with climate change mitigation goals. Together, these indicators provide a structured approach to balancing productivity with ecological sustainability.

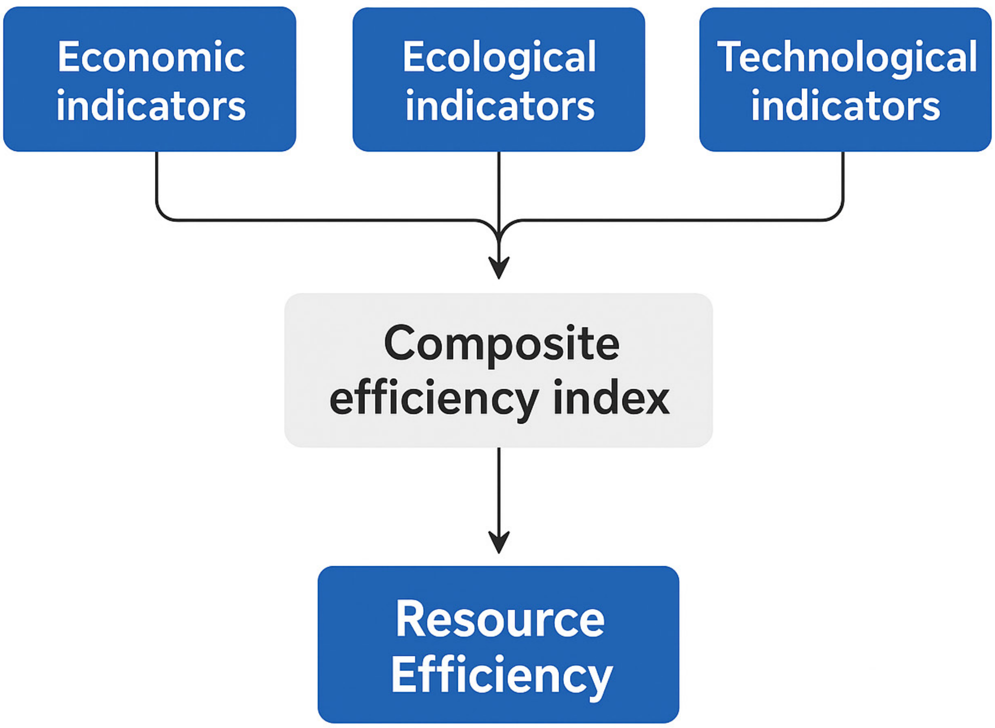

Figure 1. Framework for Resource Efficiency Assessment under Green Economy

The conceptual structure presented in Figure 1 emphasizes the integration of economic, ecological, and technological indicators into a composite efficiency index. Economic indicators include yield performance, labor productivity, and profitability. Ecological indicators assess factors such as emissions reduction, water conservation, and soil health. Technological indicators capture the role of precision farming, renewable energy use, and digital monitoring tools. By combining these dimensions into a single index, the framework ensures that resource efficiency is evaluated not only in terms of output but also through sustainability and innovation. This multidimensional approach provides policymakers and farmers with a holistic tool for decision-making.

Table 2. Comparative Analysis of Resource Efficiency in Agriculture

Country	Land Productivity (kg/ha)	Water Efficiency (kg/m³)	Energy Ratio	Carbon Footprint (kg CO_2/ton)
Uzbekistan	4,200	0.9	2.4	250
Germany	7,800	1.5	3.6	160
Netherlands	9,200	2.0	4.2	140
Kazakhstan	3,600	0.8	2.1	280

The results from Table 2 provide comparative insights across Uzbekistan, Germany, the Netherlands, and Kazakhstan. Significant disparities are observed in land productivity: while the Netherlands achieves 9,200 kg/ha and Germany 7,800 kg/ha, Uzbekistan and Kazakhstan remain at 4,200 kg/ha and 3,600 kg/ha respectively. Water efficiency follows a similar pattern, with the Netherlands (2.0 kg/m³) and Germany (1.5 kg/m³) exceeding the benchmark, whereas Uzbekistan (0.9 kg/m³) and Kazakhstan (0.8 kg/m³) fall short. Energy efficiency is also higher in Europe (Netherlands 4.2, Germany 3.6) compared to Central Asia (Uzbekistan 2.4, Kazakhstan 2.1). Finally, carbon footprint levels reveal that European countries have successfully reduced emissions per ton of agricultural output (Netherlands 140 kg CO_2/ton, Germany 160 kg CO_2/ton), while Uzbekistan (250 kg CO_2/ton) and Kazakhstan (280 kg CO_2/ton) remain above sustainable thresholds.

DISCUSSION

The findings of this study highlight substantial differences in agricultural resource efficiency across countries, reflecting varying levels of technological development, institutional capacity, and policy implementation. Developed economies such as Germany and the Netherlands demonstrate comparatively higher efficiency in land use, water productivity, energy utilization, and emissions reduction. Their success is largely attributable to the adoption of precision farming technologies, advanced irrigation systems, renewable energy integration, and comprehensive environmental regulations that align with green economy principles. These countries have effectively combined technological innovation with supportive policy frameworks, creating a favorable environment for sustainable agricultural practices.

By contrast, Central Asian countries such as Uzbekistan and Kazakhstan show lower performance across most indicators. Several structural challenges explain this situation. First, irrigation infrastructure in the region remains outdated, leading to high water losses and inefficiencies in water use. Second, agricultural practices remain energy-intensive, relying heavily on fossil fuels and conventional mechanization rather than renewable or energy-saving technologies. Third, access to innovation and digital solutions is limited due to financial constraints, institutional gaps, and insufficient technical expertise. These weaknesses hinder the ability of Central Asian agriculture to meet green economy benchmarks and to compete with more advanced farming systems in terms of productivity and sustainability.

The integrated efficiency framework proposed in this study provides valuable insights for policy design and strategic planning. By combining economic, ecological, and technological indicators into a composite index, the framework enables policymakers to:

Identify bottlenecks in agricultural production where efficiency losses are most severe, such as water use in irrigated farming or energy consumption in mechanized processes.

Design targeted subsidies and incentives that promote sustainable practices, including water-saving technologies, renewable energy adoption, and carbon-efficient methods of production.

Monitor progress toward Sustainable Development Goals (SDGs) by systematically measuring improvements in productivity, environmental performance, and resource efficiency. This ensures that agricultural policies contribute not only to food security but also to global sustainability commitments.

Nevertheless, several limitations should be acknowledged. One of the most pressing challenges is the issue of data availability and reliability, particularly in developing regions where statistical systems may not capture detailed information on water use, energy flows, or emissions. Another challenge lies in the heterogeneity of farming systems, which makes cross-country comparisons complex. Smallholder farms and large-scale commercial operations may face different constraints and opportunities, requiring tailored policy solutions. Furthermore, the quantification of ecological indicators—such as biodiversity preservation, soil health, or ecosystem services—remains difficult, often relying on proxies rather than direct measurements.

Future research should seek to overcome these challenges by leveraging digital technologies. The use of Internet of Things (IoT) devices, artificial intelligence (AI) algorithms, and satellite monitoring systems can significantly enhance the accuracy and timeliness of data collection. These tools would allow for real-time monitoring of soil moisture, water use efficiency, crop health, and carbon emissions, providing both policymakers and farmers with actionable information. Moreover, the integration of big data analytics could help identify patterns and predict future trends, making agricultural planning more adaptive and resilient.

The discussion underscores the dual reality of progress and challenges. While developed economies are advancing rapidly toward sustainable agricultural practices, many developing and transition economies still struggle to overcome structural and technological barriers. The integrated framework presented in this study offers a practical roadmap for addressing these gaps, but achieving long-term sustainability will require not only methodological innovation but also political commitment, financial investment, and capacity building at multiple levels of governance.

CONCLUSION

Efficient use of resources is a fundamental prerequisite for achieving agricultural sustainability under green economy conditions. This study has demonstrated that traditional single-dimensional approaches, focused mainly on economic output, are insufficient to capture the complexity of modern agricultural systems. Instead, a multi-dimensional methodology, integrating economic, ecological, and technological indicators, provides a more comprehensive and accurate evaluation of efficiency.

The proposed composite efficiency framework not only quantifies resource productivity but also reflects environmental sustainability and the role of innovation. By applying such an integrated approach, policymakers, researchers, and practitioners gain a more holistic understanding of how resources are utilized in agriculture and where inefficiencies occur.

Practical Implications:

Policy-making: Governments can use the framework to design incentive systems that promote sustainable resource management, such as subsidies for water-saving irrigation or renewable energy technologies.

Farm-level management: Farmers can adopt these assessment tools to optimize input use, reduce costs, and enhance long-term soil and ecosystem health.

Monitoring progress: International organizations and stakeholders can apply the framework to measure progress toward Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 13 (Climate Action).

Technology adoption: The study highlights the importance of integrating precision agriculture, digital monitoring, and green technologies into farming systems to achieve higher efficiency with lower environmental footprints.

Limitations and Future Directions:

While the proposed framework demonstrates strong potential, its application is limited by data availability, regional differences in agricultural practices, and the difficulty of quantifying certain ecological indicators. Future research should focus on:

Expanding datasets through remote sensing, IoT-based monitoring, and big data analytics.

Developing region-specific benchmarks for efficiency indicators.

Exploring the role of circular economy practices (e.g., waste recycling, bioenergy) in enhancing resource efficiency.

Final Remark:
Adopting integrated efficiency assessment methods can accelerate the transition of agriculture toward sustainability, mitigate environmental degradation, and strengthen competitiveness in the global agri-food market. This framework provides a scientifically sound and practically applicable foundation for guiding agricultural development under green economy conditions.

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