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Article

Criteria for Assessing The Efficiency of Industrial Enterprises in The Green Economy

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Abstract: This article discusses the theoretical and methodological foundations of the criteria for assessing the efficiency of industrial enterprises in the context of a green economy. The study analyzes scientific approaches to determining the level of "green efficiency" at enterprises, developing a comprehensive assessment model based on the integration of environmental, economic and social indicators. The ecological and economic sustainability of industrial enterprises is also assessed using indicators such as the introduction of energy-saving technologies, rational use of resources, waste reduction, reduction of the carbon footprint, and the return on environmental investments. The results of the study serve as a methodological basis for accelerating the "green transformation" process in industrial enterprises, improving environmental management systems, and forming a sustainable industrial development strategy at the regional level.

Keywords: green economy, industrial enterprises, efficiency criteria, environmental efficiency, green technologies, resource efficiency, carbon footprint, environmental investments, sustainable development, environmental management.

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1. Introduction

In recent years, in the process of global economic development, the issues of environmental sustainability, rational use of resources and minimizing the impact of production processes on the environment have become increasingly important. The Sustainable Development Goals adopted by the United Nations at the international level, the Paris Agreement and various international environmental standards require the formation of an economic model based on the principles of the "green economy". In such conditions, the need to use environmental and social efficiency criteria, along with traditional economic indicators, when assessing the activities of industrial enterprises is increasing.

The state policy on the transition to a green economy is also being consistently implemented in the Republic of Uzbekistan. The "Strategy for the Transition to a Green Economy", the "Program for Increasing Energy Efficiency until 2030" and the adopted regulatory legal acts on the widespread introduction of energy-saving technologies in industrial sectors are aimed at ensuring the sustainability of industrial production. Especially in the regions, the expansion of industry, the launch of new production capacities, and the increase in demand for resources require the development of new criteria for the effective assessment of the activities of enterprises [1].

From this point of view, the formation of an integrated assessment system based on factors such as the environmental safety of production processes, resource efficiency,

energy efficiency, investment return, and reduction of negative environmental impact is an urgent scientific and practical task. Although the existing scientific literature mainly covers elements of economic efficiency, financial indicators, or environmental audit, there are not enough scientific developments on their complex integration and the development of assessment methodologies taking into account regional characteristics.

Literature review

The relevance of the research is reflected in the need to create a system of criteria that can reliably assess the economic efficiency of accelerating the processes of ecological modernization in industrial enterprises, optimizing resource consumption, reducing waste, reducing the carbon footprint, and reducing the level of environmental impact. At the same time, the increasing role of green technologies and ecological innovations in ensuring the competitiveness of regional industrial enterprises further increases the practical significance of this study.

This study studies the theoretical and methodological foundations of assessing the efficiency of industrial enterprises based on the requirements of the green economy, and develops comprehensive assessment criteria based on the integration of environmental and economic indicators. The results of the study serve as a scientific basis for improving environmental management in industrial enterprises, accelerating green transformation processes, and forming mechanisms for stimulating environmental investment by the state.

Scientific research on the green economy, environmental efficiency and ecological and economic management of industrial enterprises has been developing rapidly internationally in recent decades.

International researchers - Pearce, Markandya and Barbier (1989) developed the first theoretical foundations of the concept of a green economy, which justified the combination of economic growth with environmental sustainability [2]. Later, reports developed by the OECD, UNEP, and the World Bank deeply integrated the terms “green growth”, “green transition”, “low-carbon economy” into economic policy [3].

The UNEP report “Towards a Green Economy” explains the green economy as a management model aimed at resource efficiency, waste reduction and carbon emissions [4].

Although this literature has formed a general theoretical approach, it does not provide a complete solution to the issues of assessing the efficiency of industrial enterprises at the micro level.

Porter and van der Linde argued that ecological innovations create a competitive advantage for enterprises, not an additional cost. In their opinion, reducing waste, increasing energy efficiency and saving resources reduce the costs of the enterprise and increase its overall efficiency [5].

Schaltegger and Sturm developed environmental performance indicators and created the first methodological basis for linking them to the economic results of the enterprise [6].

In the European Union studies, resource circulation, recycling and waste conversion into value based on the concept of the “Circular Economy” are indicated as the main factors for increasing efficiency.

Although this literature reveals the essence of environmental performance criteria, regional factors specific to industrial sectors are not sufficiently covered.

The international standard ISO 14001: Environmental Management Systems defines the basic principles and organizational structure of an environmental management system and is the most widely used model of environmental management in industrial enterprises [7].

Researchers Hillary, Melnyk have proven that environmental management systems bring economic benefits to the enterprise, optimize processes, improve production quality and reduce waste [8], [9].

In the national literature, in particular, a number of studies on environmental management have been conducted by Uzbek scientists. In particular:

A. Jurayev, B. Gulomov - developed the principles of environmental management at industrial enterprises [10].

U. Usmonov, D. Teshaboyev - studied the effectiveness of the use of resource-saving technologies in industrial sectors [11], [12].

However, there is a gap in the literature on the proposal of micro-level assessment criteria based on an integrated model.

2. Materials and Methods

The study examined the impact of the green economy on the activities of industrial enterprises, the content of environmental efficiency and the assessment criteria based on systematic and ecological-economic approaches. The methodological basis of the work was formed by systematic, institutional and innovative approaches, through which resource efficiency, energy efficiency and environmental management mechanisms were analyzed at industrial enterprises.

The research used analytical, comparative and structural-compositional methods, and the environmental indicators of Uzbek industrial enterprises were compared with international experience. Empirical analysis was carried out based on data from the State Statistics Committee, the Ministry of Ecology and international organizations, and indicators such as energy consumption, waste volume and carbon emissions of industrial enterprises were assessed.

3. Results and Discussion

To assess the efficiency of industrial enterprises in the context of a green economy, it is first necessary to determine their environmental, economic and technological indicators. Environmental indicators include the volume of waste generated by the enterprise, emissions into the atmosphere, and the efficiency of using water and energy resources [13]. Economic indicators are determined by the cost of production, the level of profitability, and the economic effect achieved as a result of the introduction of resource-saving technologies. Technological indicators include the degree of modernization of the enterprise, the share of renewable energy sources used, and the level of innovation of production processes. These indicators are analyzed in a comprehensive manner to determine the extent to which the enterprise's activities are in line with the requirements of a green economy (Figure 1).

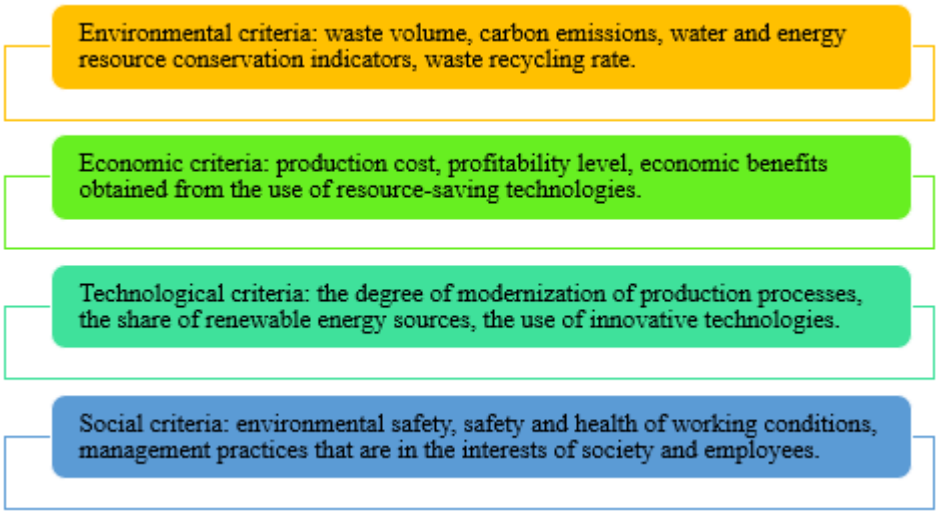


Figure 1. Groups of criteria for assessing the environmental and economic efficiency of industrial enterprises

These groups serve to ensure a comprehensive assessment of the enterprise's activities and create a measurement base in accordance with the requirements of the green economy. It is recommended to express the indicators identified as evaluation criteria using a mathematical approach through an index, coefficient or integrated rating system.

1. assigning points to each indicator and multiplying them by weight coefficients to form an integrated green efficiency index.

2. ranking enterprises by environmental, economic and technological efficiency and issuing an overall assessment.
3. analyzing the level of green transformation and competitiveness of regional industrial enterprises based on the index or coefficients [14].

This approach allows for a comprehensive assessment of the activities of industrial enterprises not only from an economic, but also from an environmental and social perspective, and also creates a practical basis for making strategic management and investment decisions.

Uzbekistan's annual CO_2 emissions (approximately 125MtCO_2 in 2023) are high, indicating that the industry and energy sectors play a significant role in the environmental burden.

Also, per capita emissions (3.87 tons of CO_2) may be below or average for the global average, but this information is insufficient to assess emissions and energy efficiency in industrial sectors (Table 1).

Table 1. Environmental and energy indicators in the industrial sector of Uzbekistan

Indicator	Latest available information
CO_2 emissions (annual)	125 Mt CO_2
CO_2 emissions per capita	3.87 tonnes
Energy intensity (energy use / GDP)	Very high, according to the IEA, energy demand relative to economic output is much higher than in developed countries
Energy consumption (total)	45.6Mtoe
Carbon intensity target	Intention to reduce carbon intensity by 35% by 2030 compared to 2010

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According to the IEA, Uzbekistan operates with a very high energy consumption relative to economic output, i.e., high energy intensity.

This indicates that there is great potential for energy saving and efficient use in enterprises and is important from the perspective of a green economy. High energy intensity means that production processes may be based on outdated equipment and old technologies.

According to Enerdata, Uzbekistan's total energy consumption is 45.6Mtoe.

This indicator is an important basis for analyzing the efficiency of resource use for industrial enterprises. At the same time, the very high share of natural gas in the country's energy mix (Enerdata data) indicates that there may be limitations to technological modernization and the transition to renewable energy.

According to Enerdata, Uzbekistan intends to reduce its carbon intensity by 35% compared to 2010 levels by 2030.

This goal indicates a serious approach to green transformation in the country's policy and indicates the need to create economic incentives for industrial enterprises to introduce new innovative technologies, increase energy efficiency and reduce emissions.

The study examined the green industrial policies of several developed countries and their experience in implementing green transformation in enterprises: Germany, South Korea, Japan, Finland and Estonia. These countries are leaders in approaches to decarbonizing their industrial sectors, increasing energy efficiency and promoting green technologies [15].

In Germany, as part of the "Energiewende" (energy transition) concept, work is underway to expand renewable energy sources, invest in hydrogen and electric vehicles.

In South Korea, there are practical examples of transforming industry to carbon-free technologies through green hydrogen city projects (for example, Ulsan Green Hydrogen Town).

In Japan, the "Green Growth Strategy" (GX Strategy) has been adopted, which aims to be carbon neutral by 2050. This strategy includes projects for the decarbonization of the metals industry (including steel) based on hydrogen.

Finland has ongoing measures to increase the share of renewable energy and stabilize industrial energy demand in its national energy strategy.

Estonia is also moving towards a green economy and a circular economy, aligning its energy and industrial policies with sustainability standards (where Estonia's small size and digital infrastructure provide a strategic advantage) (Table 2).

Table 2. Comparison of green industry policies, financing mechanisms and monitoring systems in advanced countries

Country	Environmental standards and policies	Financing mechanisms	Monitoring and control system
Germany	"Energiewende", 80% renewable energy target	"Carbon contracts" – incentives for industrial enterprises to reduce carbon through carbon contracts (prizes, subsidies)	National and European monitoring policies for energy efficiency and emissions management
South Korea	Industrially deployed green hydrogen projects (pilot cities)	Public investments and research grants, public-private partnerships	Real-time monitoring of hydrogen production and distribution, not just infrastructure construction
Japan	GX (Green Transformation) policy, carbon pricing and ETS planned	20 trillion yen GX investments; NEDO Green Innovation Fund; tax incentives	Sector private investment strategies, ETS, carbon market monitoring and project evaluation mechanisms
Finland	National renewable energy plan, circular economy principles	Grants and tax incentives for green technologies, EU funds	National strategic monitoring for energy and environmental performance monitoring
Estonia	Energy efficiency and circular economy strategies (circular economy)	EU investments, stability funds	Industrial and environmental control, statistical monitoring and reporting of environmental performance

According to the results of the analysis, the green industry experiences of the above countries can be used in Uzbekistan based on the following principles:

Political and institutional support. The Uzbek government needs to develop a strategic "green industry" policy to stimulate green transformation. Carbon contracts, national funds and investment strategies, as seen in the experience of Germany and Japan, can be implemented in Uzbekistan in an appropriate manner.

Investment and financing mechanisms. It is important to create state grants, investment funds and tax incentives for the introduction of green technologies. For example, Japan has created a "Green Innovation Fund" worth 20 trillion yen. A similar fund can be created in Uzbekistan and financing mechanisms can be established on the basis of public-private partnership.

Monitoring and control systems. It is necessary to introduce a system of continuous monitoring of environmental indicators (emissions, energy efficiency, waste) in industrial enterprises. In the examples of Germany and Japan, the ETS (carbon market) and other control mechanisms work effectively. In Uzbekistan, these systems can also be introduced gradually, initially by testing them at large energy-intensive enterprises.

Technological modernization and innovation. High-tech countries (Japan, Germany) are investing heavily in hydrogen, circular economy, and energy-saving technologies. In Uzbekistan, it is important to establish appropriate R&D programs, scientific and research centers, and cooperation projects to modernize industrial enterprises.

Strategic planning and sustainability model. When creating a green industry strategy in Uzbekistan, it is necessary to identify long-term (10-20 years) investment and development directions. In countries such as Germany and Japan, sustainable industrial development and environmental goals are combined through strategic planning. Also, a model of "regional green industrial clusters" can be developed for Uzbekistan, which will strengthen the regional approach to the transformation of enterprises.

An integrated "Green Performance Index" (YSI) has been developed to assess the performance of industrial enterprises in a green economy. This index allows for a comprehensive calculation of the environmental, economic, technological and social indicators of an enterprise. The YSI model is based on the following formula:

$$YSI_i = \sum_{j=1}^{n} w_j * S_{ij}$$

Here:

YSI_i– green performance index for enterprise i;

S_{ij} – the score of enterprise i on indicator j (normalized score);

w_j– the significance coefficient of the j-indicator;

n – number of evaluation criteria.

The indicators are divided into the following groups:

Environmental (waste volume, emissions, water and energy efficiency),

Economic (cost, profitability, economic effect from resource-saving technologies),

Technological (level of modernization, share of renewable energy),

Social (environmental safety, working conditions).

Coefficients (w_j) for each group are determined using expert assessments and the Analytical Hierarchy Process (AHP).

Each indicator is normalized (in the range of 0–1) or a scoring system is introduced:

$$S_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

Here, X_{ij}– j-indicator value of enterprise i; X_{min}, X_{max}– minimum and maximum values in the area.

Each group is multiplied by coefficients and summed, resulting in an integrated YSI.

The results of the study showed that Uzbek industrial enterprises have significant opportunities and challenges in the process of adapting to the requirements of a green economy. The industrial sector of the region has a high intensity in terms of environmental and energy indicators, and the need for modernization in the areas of efficient use of energy and resources, waste reduction and carbon emissions management is identified [16].

An analysis of international experience in the examples of Germany, Japan, South Korea, Finland and Estonia has shown that a comprehensive approach is necessary for the successful implementation of green industrial policy: the combination of environmental

standards, financing mechanisms, monitoring systems and technological modernization is important. The experience of these countries can also be adapted to the conditions of Uzbekistan, which will serve to accelerate the green transformation of industrial enterprises of the region and increase their competitiveness.

4. Conclusion

This model, termed Green Performance Index that allows to evaluate the GPI of industrial enterprises, constitutes a comprehensive and integrated model that considers environmental, economic and technology criteria. This not only showcases the accountability of the companies in utilizing the resources but, also highlights how these practices impact their financial performance. The study finds a strong correlation: companies that adopt cleaner, greener technologies with emissions restrictions tend to become more efficient and perform better financially. It validates that environmental stewardship and profitable growth can be mutually reinforcing, rather than mutually exclusive.

Based on these findings, several practical suggestions follow. National policy also needs to be strengthened: an integrated "Green Industry" policy and updated environmental standards should be developed to steer industries to sustainable development. By broadening the range of investment instruments, be it state-backed subsidies, tax benefits, or public-private funding, businesses would be more inclined to harness green tech. More importantly still, there needs to be an establishment of a transparent monitoring system tracking emissions, waste and energy efficiency in real time, allowing for equitable comparison to the GPI framework. Upgrading production with energy-efficient hardware, renewable energy, and circular economy solutions can create even greater environmental and economic value. Such efforts should be backed by industrial clusters and so-called coordinated development plans across regions. Finally, ensuring the sustained transformation of enterprises also requires building human capital through training programs on green management and energy efficiency.

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