

Innovation Impact Index: Harmonizing Environmental Sustainability and Export Development

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Babak Feizullaev , Fuad Bayramov

^{1,2} Odlar Yurdu University, Baku, Azerbaijan
babek.feyzullayev@oyu.edu.az
bayramovfuadcbc@gmail.com

Abstract. In the context of the global transition to sustainable development, reducing the carbon footprint of export-oriented industry has become a key challenge for developing countries, including Azerbaijan. Traditionally, innovation plays a crucial role in achieving this goal; however, existing methods for assessing its impact on environmental productivity and foreign trade potential are often limited and insufficiently adapted to local conditions. This paper introduces the I_{III} (Innovation Impact Index), formula, developed for analyzing and forecasting the consequences of implementing advanced technologies in export-oriented industries. The formula integrates macroeconomic, sectoral, and environmental indicators, including a key component — carbon efficiency ($C_{carbon,i}$). Using the formula, an analysis was conducted on how innovative solutions influence the CO₂ footprint and export potential of Azerbaijan's oil and gas sector. The results demonstrate that introducing modern scientific and technological developments, such as energy-efficient technologies, can, in the short term, reduce emissions by 25% and increase the overall I_{III} index by 15%. This improvement enhances the industry's competitiveness in international markets. The formula also proved its versatility, allowing the consideration of specific characteristics in various sectors and enabling comparative analysis with international standards. The proposed methodology opens new opportunities for monitoring and managing the environmental and economic efficiency of export-oriented industries, making it a valuable tool for researchers, government authorities, and businesses.

Keywords: Innovations, Carbon Efficiency, Export-Oriented Industry, Sustainable Development, Scenario Modeling, Innovation Impact Index, Export

1 Introduction

In the contemporary world, sustainable development has become one of the primary benchmarks for national economies. Reducing greenhouse gas emissions and enhancing environmental efficiency are of particular importance in export-oriented industries that directly influence countries' international competitiveness. Azerbaijan, whose economy largely depends on resource exports such as oil and natural gas, faces the necessity of adapting its industries to new environmental standards. This adaptation requires the active implementation of revolutionary ideas capable of reducing the carbon footprint, increasing productivity, and opening new opportunities for foreign trade.

The role of innovation in improving emissions management efficiency lies not only in reducing carbon output but also in strengthening the economic resilience of industries. In this context, international cooperation can significantly stimulate the dissemination of innovative technologies and the exchange of technological implementation experience, especially in industries such as energy and transportation. [1] However, at present, the scientific literature is notably lacking in comprehensive methods that would allow assessment of the impact of various types of innovation on both carbon and economic efficiency. This issue is particularly relevant for developing countries, where data availability is limited and economic conditions demand specific analytical approaches.

This paper proposes the I_{III} (Innovation Impact Index) formula as a tool for evaluating the influence of innovations on export-oriented industries. The formula integrates key macroeconomic and industry-level indicators, paying special attention to carbon efficiency. It not only facilitates the analysis of the

current situation but also enables forecasting the consequences of introducing innovations—such as energy-efficient technologies or process digitalization—under different economic scenarios. This makes the formula useful for both government bodies and businesses, providing the means for more precise planning and monitoring.

The aim of this work is to demonstrate the theoretical and practical value of the I_{III} formula using its application to Azerbaijan's oil and gas industry as an example. The study examines changes in the greenhouse gas footprint, external trade potential, and overall sustainable development metrics resulting from the introduction of creative scientific concepts. The research findings confirm that the proposed methodology opens new horizons for monitoring and managing economic development in the context of the global environmental agenda.

2 Methods

To assess the impact of cutting-edge technological solutions on the carbon and economic efficiency of Azerbaijan's export-oriented industry, the I_{III} formula was developed. This formula represents an integration of key macroeconomic, industry-specific, and environmental indicators, allowing for a comprehensive analysis of the effects of implementing innovations. It is also important to understand that optimizing supply chains and production stages through predictive analytics and automation can reduce emissions by 20%. [2] In this context, employing the formula enables scenario modeling that takes into account key indicators of carbon efficiency.

$$I_{III} = M_{short,i} * M_{long,i} * F_i * K_{potentials,i} * K_{funds,i} * M_{multiplier,i} * K_{innovation,i} * C_{carbon,i} \quad (1)$$

The formula's core structure includes the following components, with each indicator reflecting a specific aspect of the export-oriented industry. Data determination for calculation involves:

- Macroeconomic Indicators ($M_{short,i}, M_{long,i}$): These include inflation, interest rates, exchange rates, and long-term investments.
- Financial Efficiency (F_i): Revenues, costs, net profit, and the value of the industry's assets.
- Potentials ($K_{potentials,i}$): Resource and workforce potentials, employment levels, and access to ICT.
- Capital Intensity ($K_{funds,i}$): The degree to which the industry is equipped with fixed assets, including equipment, infrastructure, and other tangible resources.
- Multiplier Effect ($M_{multiplier,i}$): The influence of innovations on economic activity in related industries or the economy as a whole.
- Innovation Activity ($K_{innovation,i}$): The type and level of innovation implementation within the industry and its impact on productivity and efficiency.
- Carbon Efficiency ($C_{carbon,i}$): The volume of emissions per unit of output.

2.1 Methodological approach

The methodology of the I_{III} formula is based on integrating economic, environmental, and innovation factors into a single index, thereby enabling a quantitative assessment of the impact of innovations on export-oriented industry. At the core of the formula lies a multi-factor analysis approach that ensures a comprehensive evaluation by accounting for macroeconomic stability, production and carbon efficiency, as well as innovation activity. This approach aligns with international scientific standards, which employ similar models for assessing sustainable development and innovation impacts—for example, in OECD research or United Nations sustainable development programs.

A key mathematical principle of the formula is the normalization and aggregation of heterogeneous data. The variables in the I_{III} formula is expressed as coefficients or weights, normalized between 0 and 1 to ensure comparability across various sectors. This is achieved through the use of relative indicators such as carbon efficiency ($C_{carbon,i}$), short-term and long-term stability ($M_{short,i}, M_{long,i}$), and

innovation activity ($K_{innovation,i}$). Aggregation is performed using geometric means or weighted averages, allowing each factor's contribution to be considered according to its significance.

The formula also employs an approach to smoothing volatile macroeconomic indicators, such as inflation and exchange rates. Instead of relying on data from a single year, averaged or static equivalents are introduced to minimize the influence of short-term fluctuations. This makes the formula more resilient to external shocks and enhances its practical applicability for long-term forecasting.

An important methodological innovation of the I_{III} formula is the use of a component-based analysis of innovation, where each area of innovation activity (technological, organizational, environmental) has its own assigned weight. This enables the assessment of individual innovation types' contributions to the overall efficiency of the industry. Such a structure allows the formula to serve not only as an assessment tool but also as a strategic planning instrument, helping identify the most promising directions for introducing innovations into export-oriented industries.

Calculation base. For testing the formula, data on production and environmental indicators of Azerbaijan's oil and gas industry were used. Both real and simulated data were employed to model potential scenarios.

Carbon efficiency analysis. The $C_{carbon,i}$ variable was calculated as:

$$C_{carbon,i} = \frac{1}{E_{carbon,i}}, \quad (2)$$

where

$$E_{carbon,i} = \frac{\text{Total carbon emissions}}{\text{The volume of products produced}}, \quad (3)$$

2.2 Software tools

To automate calculations and scenario modeling, a specialized Python code integrated with machine learning algorithms was developed. This tool made it possible to implement the I_{III} formula within an artificial intelligence framework, significantly expanding its scope of application. Through machine learning technologies, thousands of scenarios were simulated, varying the values of variables such as carbon efficiency, innovation activity, and macroeconomic stability. During the test computations, not only the variable coefficients but also the weights were adjusted. This approach allowed a thorough examination and validation of the formula's practicality across various national economic models, differing widely in scale, structure, and level of development. Analyzing the obtained data revealed patterns inaccessible through conventional methods, substantially improving the understanding of how innovative developments affect the export-oriented industry. Artificial intelligence has opened new horizons for analysis and forecasting. Machine learning enabled:

- **Optimization of calculations.** Automated computations ensured high data processing speeds, which is especially crucial when analyzing large data volumes. Multivariate calculations allowed the formula to be tested for robustness and applicability under diverse economic, social, and environmental conditions.
- **Identification of patterns.** By examining thousands of scenarios, it was possible to identify critical variables exerting the greatest influence on the overall I_{III} index. Interrelationships between innovation activity, macroeconomic volatility, carbon efficiency, and the relative importance of each variable's weight were established—relationships that are extremely difficult to detect using traditional approaches.

- **Forecasting and scenario modeling of innovation outcomes.** The formula was utilized to model changes in indices under various scenarios of implementing innovations (technological, organizational, and environmental). Indicators before and after the adoption of advanced approaches, including projected productivity growth ($\Delta P_{\text{innovation},i}$), were compared. Furthermore, scenario modeling made it possible to forecast changes in environmental impact and export potential at different investment levels in research and development. Hypothetical scenarios—such as introducing environmentally friendly technologies into the oil and gas industry—were tested to evaluate potential economic and environmental benefits.

The methodology proved its practical applicability, providing not only an analysis of current conditions but also predictions of the consequences of innovation implementation. This approach accommodates both local characteristics and international standards, making the formula a universal tool. Integrating artificial intelligence into the research methodology, in turn, enhanced the analytical potential of the formula, rendering it more flexible, precise, and universally applicable.

3 Results

To verify the effectiveness of the I_{III} formula, a multi-level analysis was conducted involving real data from Azerbaijan's oil and gas industry, scenario modeling of various conditions, and the identification of underlying patterns. The primary focus was on how emissions management efficiency and innovation activity influence export potential and the overall I_{III} index.

3.1 Analysis of real data from Azerbaijan

Using 2023 data, the carbon efficiency value for the oil and gas industry was calculated. The total emissions were estimated at 15.1 million tons of CO₂, with a production volume of 30.2 million tons. This yielded a carbon intensity of $E_{\text{carbon},i} = 0,5$, resulting in a final carbon efficiency index of $C_{\text{carbon},i} = 2,51$. Based on the I_{III} formula, taking into account innovative factors and macroeconomic stability, it was projected that implementing energy-efficient technologies could raise $C_{\text{carbon},i}$ до 2,5, which in turn would increase the overall I_{III} index by 20%. These results confirm the importance of integrating innovative developments to enhance the industry's international competitiveness.

3.2 Results of testing various cross-industry scenarios

A scenario-based approach makes it possible to assess the impact of innovation on an industry's carbon efficiency. [3] Drawing on this premise, 5 thousand of test scenarios were run to model the influence of various I_{III} formula variables, such as short-term stability ($M_{\text{short},i}$), long-term stability ($M_{\text{long},i}$), innovation activity ($K_{\text{innovation},i}$) and carbon efficiency ($C_{\text{carbon},i}$). The results showed:

- The maximum index ($I_{III} = 21,96$) was achieved in a scenario with high values of potentials ($K_{\text{potentials},i} = 1,77$), innovation activity ($K_{\text{innovation},i} = 1,59$) and carbon efficiency ($C_{\text{carbon},i} = 2,88$). The minimum index ($I_{III} < 5,0$) was observed with low $C_{\text{carbon},i} < 1,8$ and weak financial efficiency ($F_i < 0,8$).
- Testing revealed that the greatest multiplicative effect is achieved by simultaneously improving emissions management efficiency and innovation activity. For example, in scenarios where $K_{\text{innovation},i} > 1,5$ and $C_{\text{carbon},i} > 2,5$, the overall I_{III} index increased by 25–30%.

3.3 Results of testing various cross-country scenarios

The I_{III} formula is highly adaptable, making it applicable under a wide range of economic conditions and accommodating the specific characteristics of individual countries and their industrial structures. Several theoretical scenarios were modeled for testing purposes, covering economies at different stages of development, with varying degrees of export orientation and innovation activity. Let us briefly consider the key aspects of applying the formula in different contexts.

- Developed countries such as Germany and Japan exhibit high I_{III} values due to a combination of

macroeconomic stability, innovation activity, and high carbon efficiency. These economies feature a minimal carbon footprint and active use of environmentally friendly technologies, underscoring the key role of innovation in sustainable development. In these countries, the index reached values of 0.85–0.95, reflecting their leading positions in the global market.

- Developing countries such as India and Vietnam show moderate I_{III} levels, associated with insufficient capital intensity and limited innovation implementation. However, their export-oriented industries possess high growth potential through increased technological investment and infrastructure optimization. The index values ranged from 0.55 to 0.65, highlighting the need for supportive policies and economic diversification.
- Resource-oriented economies such as Saudi Arabia and Kazakhstan benefit from substantial resource potential, but low carbon efficiency and limited innovation activity constrain their development. The index for these countries varied from 0.45 to 0.55, indicating the necessity of introducing environmental and technological solutions to enhance competitiveness.
- Highly digitalized economies such as South Korea and Singapore demonstrate elevated levels of sustainable development through the active use of information technologies and advanced innovative solutions. I_{III} values in these countries reached 0.75–0.85, confirming their leadership in the digitalization and greening of exports.
- In countries with vulnerable infrastructure and restricted access to innovation, for example in Sub-Saharan Africa, the index remains at 0.25–0.35. Limited technological investments, weak digitalization, and low carbon efficiency are the main barriers to sustainable growth. However, even under such conditions, the formula can be employed to identify development strategies and adapt to international requirements.

3.4 Identified Patterns

- **The key role of carbon efficiency.** Carbon efficiency ($C_{carbon,i}$) has a direct impact on the overall index. Increasing $C_{carbon,i}$ by one unit raised I_{III} by 10–15%, even when other variables were at moderate levels.
- **Innovation as a growth driver.** A high level of innovation activity ($K_{innovation,i} > 1,5$) increased the overall index by 15–20%. The combined effect of an advanced approach and carbon efficiency led to the highest index values.
- **The importance of macroeconomic stability.** High values of short-term ($M_{short,i} > 1,1$) and long-term stability ($M_{long,i} > 1,2$) ensured a steady increase in the index, even at moderate levels of innovation activity.
- **Synergistic effect.** The maximum I_{III} index was achieved through the synergy of all key factors, emphasizing the need for a systematic approach to developing the export-oriented industry. This finding aligns with the international empirical base and confirms the thesis: «Energy-efficient technologies have become a critical factor in competitiveness». [4]

The results of analyzing real data, scenario modeling, and the identified patterns demonstrate the practical value of the I_{III} formula. It not only allows for analyzing the current situation but also serves as a tool for forecasting and strategic planning, both for individual industries and entire economies. Applying the formula makes it possible to integrate innovations to improve carbon efficiency and export potential, which is particularly relevant for Azerbaijan against the backdrop of the global environmental agenda.

4 Discussion

The analysis results confirm that the I_{III} formula serves as an effective tool for assessing the impact of various types of innovations on Azerbaijan's export-oriented industry. Particular attention was devoted to the carbon efficiency variable ($C_{carbon,i}$), which demonstrated its key role in ensuring sustainable

growth. This aligns with global trends toward CO₂ emissions reduction efficiency, requiring export-oriented industries to adapt to environmental standards.

One important conclusion is the significance of innovation activity ($K_{innovation,i}$) as a growth driver for the I_{III} index. Scenario models showed that investments in energy efficiency and digitalization technologies lead to increases in both environmental productivity and external trade potential. This finding is especially relevant for Azerbaijan, where new developments can facilitate economic diversification, reduce dependence on hydrocarbon exports, and create new sources of growth.

The I_{III} formula proved its versatility, demonstrating the ability to incorporate both macroeconomic and industry-level indicators. Nonetheless, several important aspects require further analysis. Primarily, the formula's sensitivity to the quality of source data highlights the need to improve statistical accounting in Azerbaijan. Accurate data on CO₂ emissions, innovation activity, and economic efficiency will enhance forecast accuracy and make the formula more reliable.

Another area for further investigation involves examining the specific impacts of different types of innovations (technological, organizational, environmental) on the export-oriented industry. Scenario modeling revealed that the greatest effect is achieved through the comprehensive integration of innovations. However, a more detailed analysis is needed to accurately understand the contribution of each technology type.

Furthermore, the formula has shown its applicability not only for analyzing current conditions but also for strategic planning. It can assess the long-term consequences of introducing new developments, which may prove useful in forming state policies and business strategies. For example, using the formula to monitor carbon efficiency could become an important tool for meeting Azerbaijan's national environmental commitments. One example involves fiscal mechanisms such as carbon taxes, which, according to international experience, play a crucial role in stimulating innovation [5].

However, the issue of local adaptation of the formula for different industries remains open. Differences in economic structures and levels of technological development require customizing the formula to account for the specifics of each industry. This is especially important for the oil and gas, agriculture, and chemical sectors, which are key export-oriented spheres for Azerbaijan.

Artificial intelligence played a significant role in testing the formula, demonstrating the prospects for its further use. Machine learning enabled the simulation of thousands of scenarios and the identification of patterns that would not have been evident through traditional approaches. Implementing such technologies can accelerate the analytical process, making it more flexible and adaptive to changes in the economic and environmental landscape.

Thus, the I_{III} formula displays high practical value both for analyzing the current situation and for forecasting changes. Its use can be an important step toward building a sustainable and competitive Azerbaijani economy. This idea is also reflected in scientific research. In particular, the scholarly article «Contemporary State and Prospects of Carbon Integration in the Eurasian Space» affirms that modern carbon integration technologies provide a competitive advantage in the global market [6].

Therefore, realizing the formula's full potential requires taking local characteristics into account, improving data access, and continuing to explore the relationship between innovation, carbon efficiency, and export potential.

5 Conclusion

In the course of this study, the I_{III} formula was developed and tested to assess the impact of innovations on Azerbaijan's export-oriented industries. The formula integrates key macroeconomic, industry-level, and environmental indicators, including carbon efficiency, financial, and innovation activity, thus serving as a universal tool for analyzing current conditions and forecasting the consequences of implementing new developments.

An analysis of 2023 data, using Azerbaijan's oil and gas industry as an example, showed that introducing energy-efficient technologies can increase environmental productivity by 25–30% while simultaneously enhancing foreign trade potential. Modeling thousands of scenarios with artificial intelligence confirmed that the highest index values are achieved through the synergy of innovation activity, carbon efficiency, and macroeconomic stability. These identified patterns underscored the importance of a comprehensive approach to developing export-oriented industries.

The I_{III} formula proved its applicability for strategic planning and monitoring, demonstrating high sensitivity to changes in key variables. It can take into account Azerbaijan's local characteristics—such as its reliance on hydrocarbon exports—and serves as a tool to achieve national sustainable development goals. Employing artificial intelligence in testing the formula showcased its flexibility and capacity for adaptation under various scenarios.

However, additional research is needed for a detailed analysis of the effects of different types of innovations and to improve the formula's local adaptation. Nevertheless, the I_{III} formula already provides a scientific and practical foundation for formulating government policies and business strategies aimed at improving the carbon and economic efficiency of Azerbaijan's key export-oriented industries. According to international experience, public and private sectors that implement low-carbon technologies occupy more competitive positions in the market. Thus, adopting the formula can play a key role in building a sustainable, competitive, and innovative national economy.

In conclusion, the I_{III} formula demonstrates how science can guide economic transformation, helping Azerbaijan and other countries adapt to the challenges of the 21st century. Its practical value lies in its ability to shape strategic decisions that not only accelerate innovation but also ensure sustainable growth, preserving natural resources for future generations. This is not merely a mathematical tool, but a bridge between today's challenges and tomorrow's opportunities.

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