

Environmental efficiency: analysis of measurement and evaluation methods

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Abstract: Eco-efficiency is defined by the World Business Council for Sustainable Development as creating more value with less impact. A study of the issue of measuring and evaluating eco-efficiency has been conducted on Science Direct platform sources from 2021-2023. Current global trends and approaches to this issue are identified. The methods used for measuring and evaluating ecological efficiency are presented and analyzed. The author's provisions on an alternative variant of measuring the environmental performance of a company and (or) an investment project are presented for discussion. The proposed measurement model allows taking into account the undesirable result of environmental impact in natural measures. The assessment is carried out when selecting the optimal variant from a set of existing alternative projects for planning future activities. In this case, the decision maker (LPR) is required to set restrictions (min, max) to achieve target values in future activities by indicators: product and service value (PSV) and environmental impact (EI). Keywords: environmental efficiency, investment projects efficiency assessment, environmental assessment parameters, integral assessment indicator

1 Introduction

The World Business Council for Sustainable Development (WBSD) defines eco-efficiency as *creating more value with less impact*. The World Business Council for Sustainable Development (WBCSD) is a coalition of about 150 international companies united by a shared commitment to environmental protection, social justice and economic growth - in other words, sustainable development. Members are drawn from more than 30 countries and 20 major industrial sectors. The WBCSD also benefits from a thriving global network of national and regional business councils and partner organizations.

This means creating more goods and services with less and less resource use, waste and pollution. *Eco-efficiency* is achieved by providing goods and services at competitive prices that meet people's needs and ensure quality of life. It progressively reduces environmental impact and resource intensity throughout the life cycle to a level at least equal to the assumed carrying capacity of the land [1].

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The concept of eco-efficiency is defined in “Changing Course”, written by Stefan Schmidheiny with the Business Council for Sustainable Development (BCSD) as a concept that, by combining environmental and economic improvements, will make sustainability a business issue [2]. This work defined eco-efficient companies as those that add more value while continuously reducing resource consumption and pollution. This concept has been further developed by the WBCSD as well as many other organizations.

Eco-efficiency is a state in which business practices are utilized that contribute to environmental improvement and generate economic benefits in parallel. Businesses should be environmentally responsible and at the same time be profitable. All this contributes to innovation and competitiveness. Eco-efficiency is not limited to areas of the enterprise, such as production and plant management. It is also valid for activities before and after the manufacturing process and includes supply chains. Opportunities to improve eco-efficiency can arise at any stage of the entire product life cycle.

OECD called eco-efficiency an indicator that is defined as the ratio of the result of activity (the value of products and services produced by an enterprise, industry or the economy as a whole) to emissions, pollution (the sum of environmental loads carried by an enterprise, industry or the economy as a whole). The European Environment Agency (EEA) defines eco-efficiency as *greater well-being with less of nature*. Many entrepreneurs, both inside and outside the WBCSD, often refer to eco-efficiency as *creating more value with less impact or accomplishing more with less*.

Ways to measure environmental performance are detailed in a separate WBCSD report, “Measuring Environmental Performance: a Guide to Reporting Corporate Performance”, which was published in 2000 [3]. This paper proposes briefly a framework that can be used to measure progress towards economic and environmental sustainability. The eco-efficiency measurement framework is flexible enough to be widely used and easily interpreted for all areas of business. A common set of definitions, principles and indicators is provided.

The concept defines two types of indicators:

1. *Generally applicable indicators* (small number; applicable to virtually all enterprises). They are broadly applicable and subject to a common measurement approach. However, they may not have the same value or importance for companies in different industries (sectors). There are measurement methods and definitions established for them that are accepted worldwide.

2. *Business-specific indicators*. Each company should assess its own business to determine which business-specific indicators should apply to it. These indicators should be useful to management and external stakeholders, in addition to the generally applicable indicators.

Various steps are being taken to harmonize sectoral indicators. Swiss and German firms are working on defining indicators to measure the environmental performance of banking services. The European Chemicals Manufacturers Association (CEFIC) develops and harmonizes environmental performance indicators for its companies. The WBCSD has launched sectoral projects for the mining, cement and transportation sectors. It is recommended that these projects develop environmental performance indicators relevant to each sector [1].

A common indicator for assessing eco-efficiency is the ratio:

$$EE = \frac{PSV}{EI}, \quad (1)$$

where EE – eco-efficiency; PSV – Product or Service Value; EI – Environmental Influence.

This is a basic factor, an indicator that occurs for all areas of business activity. Both Product or Service Value and Environmental Influence can include many different indicators that need to be combined into a single number in both the numerator and denominator of the formula (1). Businesses will need to develop these ratios that best suit their communication and decision-making process. The specific calculations will depend on the needs of individual decision-makers.

The WBCSD proposes 12 action points. Adoption of these by different stakeholder groups will help to improve the environmental performance of ongoing projects around the world. Table 1 shows these relevant and necessary key actions for the identified groups [1].

Table 1. Key measures to improve environmental efficiency of investment projects and programs

Government leaders and public servants	
1.	Establish macroeconomic eco-efficiency targets and criteria for transition to sustainable development.
2.	Integrate policy measures to improve eco-efficiency (e.g. make changes in tax policy).
3.	Work to change international policy rules and systems for trade, financial transactions. Support higher resource productivity and emissions reductions and improvements for the poor.
Civil society leaders and consumers	
4.	Encourage consumers to favor environmentally efficient, more sustainable products and services.
5.	Support policy measures to create framework conditions that encourage eco-efficiency.
Educators	
6.	Incorporate eco-efficiency and sustainability into high school and university curricula; incorporate into research and development programs.
Financial analysts and investors	
7.	Recognize and reward environmental performance and sustainability as investment criteria.
8.	Help eco-efficient companies and sustainability leaders communicate their successes and associated business benefits to financial markets.
9.	Promote and utilize sustainability assessment tools and ratings to support markets and increase understanding of the benefits of eco-efficiency.
Business leaders	
10.	Integrate environmental performance into their business strategy, including operational, production and marketing strategies.
11.	Openly communicate the company's environmental performance and sustainability indicators to stakeholders.
12.	Support policies that encourage eco-efficiency.

Let us consider in what aspects environmental efficiency (EE) is considered in the works of other researchers. We are interested in the possibility of measuring and accounting for this category, parameters and indicators of environmental efficiency and issues related to the motivation of investment activities on the basis of environmental efficiency. It should be noted that this problem is seriously paid attention to in foreign countries, where the issues of impact assessment of projects on the environment have been studied for a long time and are under close observation.

In recent years, financial market participants have become increasingly concerned about corporate social responsibility (CSR) practices, particularly with respect to environmental and social issues. More than 70% of investment professionals consider companies' environmental and social information when selecting their investment opportunities. Firms

face increasing pressure to increase transparency of environmental and social practices in investment choices. The results show that greater environmental and social transparency improves the information environment of financial analysts and contributes to investment performance. Analyzing a sample of firms that includes companies from the S&P 500 index for the years 2012-2018 showed [4] that environmental and social transparency are positively related to investment performance. Transparency is based on comprehensive ratings compiled by Bloomberg.

Based on the industry-level analysis, a spectrum of policy instruments that can incentivize energy efficiency investments is presented [5]. Energy efficiency is considered a very cost-effective way to reduce air emissions and improve the economic performance of the manufacturing industry, i.e. eco-efficiency improvements. Spanish industry was studied for the period 2010-2017. The impact of four incentive instruments in energy efficiency (and hence in "eco-efficiency") is identified: regulation, taxes, subsidies and tax credits.

The root causes of pollution lie in three structural problems facing the economy: a polluting energy structure, a polluting industrial structure, and a polluting transportation structure. A significant contributor to pollution (to negative eco-efficiency) is China's energy structure [6]. China is currently increasing its green investment. Enterprises have become the main driver of this form of investment. But very often investments are made under external pressure (to maintain social reputation, remove government regulation and respond to negative media coverage). "Green" investments have a rather definite interpretation. These are investments aimed either at environmental sustainability and a circular economy, or at climate change mitigation and adaptation, or at addressing and recovering from environmental degradation during the investment project and its associated life cycle [6].

A study on the relationship between the EU's fourth industrial revolution (Industry 4.0) and eco-efficiency identified multidirectional dependencies [7]. The fintech industry of the fourth industrial revolution has grown manifold, which means that energy costs have increased. The results show that the overall environmental performance of EU countries has improved over the years. The following indicators of eco-efficiency growth have been identified: a) fintech industry and e-commerce have a positive impact and increase eco-efficiency; b) high-tech industry reduces eco-efficiency; c) industrialization and R&D worsen eco-efficiency; d) economic growth and investment in "green" finance contribute to eco-efficiency.

Based on the analysis of production data in thirty provinces in China from 2005 to 2017, the authors of the paper [8] found the multidirectional impact of certain types of production transfer and spatial agglomeration effect on environmental performance. Namely: a) the transfer of labor-intensive production reduces eco-efficiency; b) the transfer of capital and high-tech production has no significant effect on eco-efficiency; c) eco-efficiency is significantly enhanced by the spatial agglomeration of high-tech production, but significantly reduced by capital-intensive production.

Many governments around the world are increasingly focusing on improving their eco-efficiency, that is, reducing undesirable products while increasing desirable products (economic efficiency). The main method for measuring environmental performance is data envelopment analysis (DEA) [9]. DEA evaluates the production performance of units making event-driven decisions. Has the ability to consider multiple inputs and outputs to assess performance [9]. Handles both desirable and undesirable outcomes in environmental impact assessment. Numerous environmental performance studies in recent years have followed the DEA approach. In 1972, a common environmental protection policy was first proposed at the Paris Summit. In 1992, the European Union (EU) adopted the environment and climate action program (LIFE). It finances many different environmental projects.

When assessing environmental performance in the EU, the problem is mostly considered at the macro level of countries, regions and economies. But the micro-economic perspective is also used, i.e. emissions and pollution are studied at the level of industries and enterprises.

One of these sectors is food production and consumption in the EU. About 88 million tons of food is thrown away in Europe every year, making it one of the most serious regions of the world in terms of food waste. The authors of the paper [10] conducted a study using a two-stage data envelopment analysis (DEA) model to investigate the environmental performance of food production and consumption in 25 European Union (EU) countries from 2010 to 2018. Two questions were asked: a) to estimate greenhouse gas emissions from production in agriculture and fisheries (from food production); b) food losses from food production and food waste from food consumption in European countries. The results of the study are as follows [10]:

- the efficiency of greenhouse gas emissions from agriculture and fisheries in most countries is improving every year (eco-efficiency is increasing);
- the problem of food waste caused by food consumption is more serious than the problem of food waste caused by food production; consumers are the main sources of waste;
- France, Hungary, Iceland, Hungary, Italy, Malta and the Netherlands have higher eco-efficiency and environmental sustainability in food production and consumption compared to, for example, Ireland, Portugal and Slovenia.

The research in the field of evaluating the environmental performance of electric vehicles taking into account different options for power generation is relevant [11]. The environmental performance of battery electric vehicles was analyzed in 27 European countries. The environmental impact of battery electric vehicles and the environmental impact of electricity producers were calculated for each country. Finland and the Netherlands are the most environmentally efficient countries using battery electric vehicles (BEVs) for all electricity generation scenarios.

During the authors' study of 42 professional and 55 semi-professional greenhouse farms growing tomatoes using soilless farming technology in Turkey [12], it was found that considering variables such as "farmers' education level", "size of glass greenhouses", "net income", "investment in recycling", "farmers' level of environmental knowledge" and the availability of "green" production methods had a positive impact on eco-efficiency. The monetary value of reducing greenhouse gas emissions and composting all organic waste in greenhouse tomato farms was \$1,037.14 and \$5,700, respectively. The average environmental performance score of greenhouse farms was 0.86, while that of professional farms and glass greenhouses was higher. The findings of the study actualize awareness, extension and training activities to reduce the negative impact of environmental inefficiency at farm level.

Energy economics and environmental protection are important issues in a modern society striving for sustainable development. Renewable energy sources, especially hydroelectricity, geothermal, solar and wind, are playing an increasingly important role in the energy sector. In the article by the author S. Jarboui [13] studies the impact of renewable energy sources on two types of efficiency of oil companies: operational (economic) and environmental. The results show that the overall average operational efficiency (desired outcome) of US oil and gas companies is 76% over the period of 19 years (2000-2018), while the overall average CO₂ efficiency (undesired outcome) of oil and gas companies is 79%. But in recent years, U.S. oil and gas companies have begun to cut CO₂ emissions.

The following paper [14] analyzes the environmental performance of 104 coal-fired power plants in China by simultaneously considering the multiple undesirable products

(CO₂, SO₂, NO_x and PM_{2.5} particulate matter emissions) generated during the generation process and the heterogeneity caused by the differences among the five major generating companies (Datang, Guodian, Huadian, Huaneng and Power Investment). The analysis showed that the main sources of overall environmental inefficiency are *PM_{2.5} and SO₂ emissions*. It is found that the bulk of the overall environmental inefficiency for each coal-fired power plant is due to management gaps rather than technology gaps among the five major generating companies.

The following paper [15] presents an improved method for evaluating energy and environmental efficiency (EEE) in China's transportation sector, which suffers from excessive energy consumption and excessive CO₂ emission. The improvement is to combine stochastic multicriteria acceptability analysis (SMAA-2) and data envelopment analysis (DEA) to evaluate the energy and environmental performance of China's transportation sectors in the presence of uncertain CO₂ emission data. This method (SMAA-DEA) handles the uncertainty of the CO₂ data (which occurs in the estimates) well, and also accounts for all possible input and output weights.

The subjective assessments of decision makers are not insignificant in assessing environmental performance. This approach in evaluation was used by the authors of the article [15] in the field of land use. A new structure of land use efficiency analysis was proposed. The framework uses environmental contamination results as a bridge to build a two-stage data envelopment analysis (DEA) model to evaluate economic efficiency, environmental efficiency, and overall land development efficiency. And weighting parameters were constructed to express decision makers' preferences. The overall conclusion of the study is that ignoring the pollution problem will lead to lower economic efficiency over time.

Authors L. Yi-Chia, L. Chompunut, P. Tonapa, and W. Anupong [16] investigate the factors affecting the environmental performance of offshore wind energy companies in Taiwan using super-efficiency data envelopment analysis (SE-DEA) and Tobit regression model, respectively. The SE-DEA model was theoretically used in the first stage of analysis, followed by the Tobit model in the second stage. The study was based on cross-sectional data for 2019 from seven locations in Taiwan. It was found that offshore wind energy companies in Taiwan have an average eco-efficiency score of 1.8953, which is very high.

The authors of the paper [17] J. Zhang, A. K. Patwary, H. Sun, M. Raza, F. Taghizadeh-Hesary, and R. Iram applied DEA model simultaneously to measure energy efficiency and eco-efficiency in some selected countries in Central and Western Europe. The DEA method was applied to measure cross-efficiency using two inputs (energy consumption, labor), a desired outcome (gross domestic product) and an undesired outcome (CO₂ emissions).

The essence of eco-efficiency, which is laid down in many sources of literature, is the efficiency of production, which is carried out with less consumption of natural resources and thus reduces the impact on the environment. However, there are points of view that complicate this concept. For example, the article [17] defines ecological efficiency from the position of both production and mortality due to pollution. The authors of this paper use Data Envelopment Analysis (DEA) and Malmquist Index (MI) to investigate environmental performance. 20 European countries between 2014 and 2018 were studied. The results show a good performance of almost all European countries, which is not due to their wealth or their economic growth. Eastern European countries show the most room for improvement.

In the article [18] by the authors G. Halkos and C. Bampatsou ecological efficiency is considered as the dependence of desirable results of activity (gross domestic product, GDP) and undesirable results (CO₂, CH₄ emissions) on the expenditures of labor, energy, fixed

assets together with land use. At the same time, the authors make a scientific comparison of static and dynamic characteristics of performance efficiency, which may differ in the period under consideration.

In a paper by authors M. del P. Rodríguez-García, A. F. Galindo-Manrique, K. A. Cortez-Alejandro, and A. B. Méndez-Sáenz [19] empirically present the economic effects of environmental performance of listed companies in Brazil, Chile, Colombia, and Mexico using an environmental intensity approach. A positive relationship between environmental performance and financial performance is identified, namely, a lower ratio of CO₂ emissions to sales has a stronger impact on companies with the highest financial performance (in Brazil and Chile), with a smaller impact on companies in Colombia. This correlation is not seen in Mexico.

Regardless of the intention, any production process has an impact on the environment. In the agricultural sector, this link is directly related to the interaction with natural resources. In the work of the authors F. S. Riera and B. Brümmer [20] analyze the ecological efficiency of grapevine producers in Mendoza (Argentina) taking into account the production of grapevines (desired result) and the danger of salinization of irrigation water (undesired result). The use of directional output distance functions (DODFs) in an efficiency model allows for the estimation of efficiency that accounts for desirable and undesirable outcomes given each producer's production technology.

In [21], four composting methods were analyzed by life cycle assessment method for environmental performance (authors: Z. Liu, X. Wang, S. Li, Z. Bai, and L. Ma). Demand for intensive livestock farms and increased public awareness of sustainability required improvements in composting technology. The following technologies (methods) were considered: static heaps (SH), windrow composting (WC), membrane-covered composting (MC) and reactor composting (RC). Advanced composting technologies did not significantly reduce direct economic costs. However, compared to SH, WC and MC, the closed composting process and reduced infrastructure reduced the final environmental impact of RC by 11.3%, 21.7% and 6.5% respectively. This led to an increase in RC environmental performance, which is 296.9%, 54.7% and 87.6%, respectively. In the article, eco-efficiency is defined as the ratio of economic profit to potential environmental impact as a percentage.

A study by a collaboration of authors [22] evaluated the effectiveness of switching from coal and firewood to electricity in the context of reducing areas with hazardous concentrations of benz[a]pyrene (BaP) and particulate matter (PM10) in six cities. In this case there was a qualitative assessment of environmental effectiveness. Studies have shown that it is possible to practically reduce to zero the areas of negative impact of pollutants in the surface layer (at a height of up to 10 m) when half of the households switch to electricity.

In another paper [23], by calculating and then analyzing various key environmental performance indicators (KEPI) based on Corporate Social Responsibility (CSR) reports, the environmental impacts of the world's leading semiconductor fabs and plants are analyzed and evaluated. The study aims to emphasize the relationship between company size, technological capability and environmental impact. It is found that higher value added per wafer produced (specific marginal revenue) means higher resource utilization. Higher R&D spending means higher greenhouse gas emissions and waste generation. This is the opposite of what happens in other industries. The environmental impact in the form of greenhouse gas emissions, waste generation, wastewater, and the amount of energy and resources consumed (eco-efficiency indicators) is increasing in this strategically important industrial sector while adding value.

2 Research Methods

The research was conducted by searching and analyzing relevant sources (articles, conference proceedings, reports, etc.) on the subject of "environmental efficiency", "eco-efficiency" on the Science Direct platform for the period from 2021 to February 2023. The 100 sources obtained for the above search phrases were reviewed, as well as some sources referenced repeatedly in the sources of the researched base. Particular attention was paid to the study of the regulations of the World Business Council for Sustainable Development (WBCSD), which is a coalition of about 150 international companies.

3 Research results and discussion

The analysis of materials and articles on the issue of assessment of environmental performance allowed us to draw certain conclusions and identify research trends:

1. Environmental efficiency is understood as a value measured in the form of a *coefficient*. The coefficient is defined as the ratio of the value of added value from the activity (desirable result) to the cost estimate of greenhouse gas emissions (in CO₂ equivalent), wastewater, waste during this activity (undesirable result or cost of environmental impact). *The higher the coefficient, the greater the environmental performance of the activity or project.*

2. In the process of measuring environmental performance, the amount of resources expended must be taken into account. The more resources spent, the greater the environmental influence. Therefore, the next approach to measuring environmental efficiency is to calculate an indicator that takes into account the dependence of desirable performance outcomes (gross domestic product, for example) and undesirable outcomes (CO₂, CH₄ emissions in value terms) on inputs of energy, fixed assets, land, labor, etc. other resources. This indicator can be calculated in the form of two separate indicators: *a) the ratio of a desirable result to the amount of resources spent and b) the ratio of an undesirable result to the amount of those same resources.* The comparison of these indicators with each other allows to estimate by how much *the resource efficiency* of the desirable result is more or less than *the resource efficiency* of the undesirable result, respectively. *The resource efficiency of an undesirable result is an absolute measure of environmental efficiency.* The lower this indicator is, the better. Since there is less environmental impact, but there is no connection with economic efficiency (resource efficiency of the desired result). Dividing the above indicator *a)* by indicator *b)* yields a relative measure of environmental efficiency - *the environmental efficiency* ratio discussed in paragraph 1. The result is an interrelated assessment of environmental efficiency.

3. A method for measuring the relative effectiveness of carbon (greenhouse gas CO₂ equivalent) emission reductions in a group of homogeneous decision-making units with multiple inputs and multiple outputs. This method is called Data envelopment analysis (DEA). It represents a linear programming methodology that empirically (on the basis of events) determines the relative efficiency of several similar objects or decision-making units (DMU). DEA is a benchmarking tool that evaluates a set of DMUs on their effectiveness in converting input data into output data [24],[25]. If we take a region of Russia, for example, as a decision-making unit (DMU). And the output result is minimization of the volume of undesirable results of activity (greenhouse gas emissions, for example), then the purpose of the analysis is to identify regions that most effectively convert their costs into an output result (reduction of greenhouse gas emissions). DEA sets benchmarks for the output, i.e. identifies regions that emit the least amount of greenhouse

gases (produce undesirable output). Such a region is assigned an efficiency equal to one ($\varphi = 1$). DEA measures the efficiency (ratio of the amount of undesirable performance) of the remaining DMUs compared to these benchmarks ($\varphi < 1$) and reports how best to achieve the benchmarks. I.e. DEA model allows to obtain as main results relative efficiency indicators and certain operational benchmarks for each DMU (in our case for Russian regions) [25].

DEA has been used extensively over the past 30 years in estimating production functions for manufacturing corporations, hospitals, commercial banks, and electric utilities [26]. The DEA's task is to identify a reference frontier and determine the position of each monitored object (DMU) relative to that frontier.

The features of the DEA method include the following [25]:

- A DEA can simultaneously utilize multiple outputs and multiple inputs, each scaled in its own units of measure;
- DEA calculations are value-free and do not require specification or knowledge of any a priori weights or prices for inputs or outputs;
- DEA can be adjusted for the presence of exogenous variables and may include categorical variables;
- DEA may take personal judgment into account when necessary.

4. Improved relative efficiency measurement models [27], [28]: super-efficiency data envelopment analysis (SE-DEA) or super efficiency of slacks-based measurement (SE-SBM). There are also other measurement methods that are locally modified to solve a strictly defined problem. The above measurement models are characterized by the following features:

- These models, unlike the classical model, can account for the fact that not all input and output parameters of the model can be controlled by management, i.e. some inputs and/or outputs may be uncontrollable. There is an element of randomness.
- Can evaluate various mixed outputs (real and integer) with real input data.
- Allow selection of subsets of efficiency factors from a set of alternatives that lead to acceptable outcomes. This eliminates the problem of classical DEA: "if the number of efficiency factors is large compared to the number of similarly evaluated units (DMUs), then most DMUs will be identified as efficient, which is unacceptable" [29].

5. Improving environmental efficiency is highly dependent on the awareness, education and degree of social responsibility of entrepreneurs with regard to environmental and social issues. Environmental and social transparency of investment methods also positively affect the economic efficiency of investments, especially in the long term.

6. Four main economic sectors can be identified as the main causes of environmental pollution: energy structure, production structure, transportation structure and food consumption structure. It is the consumer of food products who is the main source of food waste and losses, not the producer of food products. Therefore, it becomes urgent to *educate the consumer, to instill in him a sense of duty and responsibility from the moment of birth.*

7. When producing high-tech products with high added value, the environmental impact increases, i.e. environmental efficiency decreases.

Let us present the developed provisions for an alternative option of measuring the environmental efficiency of the company's activity and (or) investment project, which is proposed by the authors of this article. The author's assumptions are based on the vision that the indicator represented by formula (1) is simple, reliable and uses cost values of indicators both in the numerator (Product or Service Value) and in the denominator (Environmental Influence). The availability of cost values of the indicator is a necessary

condition for the application of the presented formula. This formula will be the basis of our proposal for evaluating environmental efficiency, but under some other conditions outlined below:

1. The assessment is carried out when selecting the optimal variant according to this indicator from a set of existing alternatives for planning the future operating activities of the company or for the implementation of an investment project.

2. There are target criteria (indicators) of Product or Service Value in *value terms* and Environmental Influence in *physical terms*, e.g. greenhouse gas emissions in carbon dioxide equivalent in weight units (tons or kilograms). There is no need to calculate the cost of environmental impacts (or no ability to calculate).

3. The decision maker (DM) sets the desirable level of constraints (non-strict) on achieving the value of the product and service, and on achieving greenhouse gas emissions in carbon dioxide equivalent weight units. I.e. sets the minimum desirable level of prospective product or service value (PSV). Sets the maximum desirable level of negative environmental influence (EI). And in accordance with these constraints plans its activities (operational or project).

Under such circumstances, the following general formula for determining eco-efficiency is proposed:

$$EE = \frac{\text{Desirability PSV}}{\text{Undesirability EI}} = \frac{D_{PSV}}{1-D_{EI}} \quad (2)$$

where D_{PSV} – value of the generalized Harrington desirability function (integral criterion) of the PSV indicator (or PSV desirability), which will be determined by formula (3).

D_{EI} – value of the generalized Harrington desirability function (integral criterion), EI indicator, which will be determined by formula (4).

$1 - D_{EI}$ – undesirable environmental influence (EI).

The values of Harrington's generalized desirability function (D) lie between 0 and 1 [30]. The desirability scale has its levels: very poor (0 - 0.20); poor (0.20 - 0.37); fair (0.37 - 0.63); good (0.63 - 0.80); excellent (0.80 - 1.00). The indicator D is defined as the geometric mean of the private indicators of desirability (d_i).

$$D_{PSV} = \sqrt[n]{d_1 \times d_2 \times \dots \times d_i \dots d_n} \quad (3)$$

where d_i – desirability of private indicators of product and service value (private desirability PSV). The formula (3) has a place to be applied if the value of a product and service is estimated by several private indicators of value in number n .

The value of Harrington's generalized desirability function (integral criterion), EI indicator, is calculated in the same way:

$$D_{EI} = \sqrt[n]{d_1 \times d_2 \times \dots \times d_i \dots d_n} \quad (4)$$

where d_i – desirability of private indicators of environmental influence (private desirability EI). Formula (4) can be applied if environmental influence is assessed not only by greenhouse gas emissions, but also possibly by other private indicators in quantity n (industrial waste, consumption waste, wastewater volumes, etc.).

The desirability of Harrington's private indicators is determined by the formula [30]:

$$d_i = e^{-e^{-y_i}} \quad (5)$$

where y'_i – normalized intermediate value of the i -th private indicator, which is determined by the formulas:

$$y'_i = \frac{y_i - y_{min}}{y_{min}} \quad (6)$$

$$y'_i = \frac{y_{max} - y_i}{y_{max}} \quad (7)$$

where y_{min}, y_{max} – lower and upper limits of unilateral restriction of the i -th private indicator y_i . Limitations may be lower or upper depending on the specifics of the evaluation indicators used.

Thus, the criterion of ecological efficiency will have the following form:

$$EE \rightarrow \max \quad (8)$$

But provided that $EE > 1$. Only in this case the *desirability of PSV* will exceed the *undesirability of EI*. That is, if $EE = 2$, then the desirability of PSV will be *twice* the undesirability of EI. If $EE = 1$, then the desirability of PSV will be *equal* to the undesirability of EI. If $EE < 1$, then the project will be *environmentally inefficient*. Such activity or such investment project should be abandoned in the conditions of "green economy" priority.

4 Conclusion

The analysis of methods of measuring and evaluating environmental efficiency in the modern world according to a number of relevant works presented in the last 2021-2023 years allowed us to identify trends in the evaluation of environmental efficiency of companies from different sectors of activity. The analysis allowed to identify, generalize and describe the main relevant methods of assessment and measurement of environmental efficiency in the world practice in the current operating conditions. It has been established that a systemically important factor in determining environmental efficiency and how to measure it is a coalition of companies united by a common commitment to environmental protection - the World Business Council for Sustainable Development (WBCSD).

But, nevertheless, the authors of the article, based on the research conducted on this issue, allowed themselves to present and justify their model of environmental efficiency assessment. This model is simple and is developed on the basis of the eco-efficiency coefficient represented by formula (1). The proposed model (2) is relevant in the process of planning future operational or project activities of the company (enterprise), it allows to avoid cost estimation of environmental influence and to take into account EI indicators in natural terms. It can only be used when the DM sets desirable constraints (min, max) on achieving targets in future activities: on product and service value (PSV) and environmental influence (EI). This allows optimizing the planning process and (or) selecting the best project option from the set of existing alternatives according to the criterion of maximum environmental efficiency (EE).

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