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Development of a Methodology for Forecasting the Sustainable Development of Industry in Russia Based on the Tools of Factor and Discriminant Analysis

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Abstract: The problem of sustainable development is one of the central issues on the agenda of the global community. However, it is difficult to assess the pace and quality of sustainable development of individual economic systems—in particular, industry—due to the lack of a unified methodological approach. In this regard, the following research goal was formulated—to develop and test a methodology for forecasting sustainable development by using statistical tools. The achievement of the goal was facilitated by the application of formalization methods, factor analysis, discriminant analysis, the method of weighted sum of the criteria, and the method of comparison. The results of the study are new scientific and practical solutions that develop the ability to diagnose economic systems for the transition to environmentally friendly production. Firstly, methodological solutions are proposed to assess the nature of the transition of industry to sustainable development (low, medium, or high rate). The methodology is based on the proposed aggregated indicator of sustainable industrial development based on the results of factor analysis (by the method of principal components). As a result, the patterns of sustainable development of the extractive and manufacturing sectors of the Russian economy are revealed. Secondly, integral indicators of economic, environmental and social factors of sustainable development are calculated, and classification functions for each type of industrial transition to sustainable development (low, medium, or high) are formed through discriminant analysis. Scenarios of industrial development are developed, taking into account the multidirectional trajectories of the socioeconomic development of the country. Thirdly, the DFD model of the process of scenario forecasting of sustainable industrial development is formalized, reflecting the movement of data flows necessary for forecasting sustainable industrial development. It is revealed that the manufacturing industry is expected to maintain a low rate of transition to sustainable development. On the contrary, for the extractive industry, if efforts and resources are concentrated on environmental innovations, average transition rates are predicted. The uniqueness of the proposed approach lies in combining two types of multivariate statistical analysis and taking into account the indicators that characterize the contribution of industrial enterprises to sustainable development.

Keywords: sustainable development; industry; factor analysis; discriminant analysis; forecasting; modeling; DFD (Data Flow Diagram)

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1. Introduction

Sustainable development issues occupy a central place at all levels of management. The concept is continuously supplemented by new directions that determine the modernization of strategic management of economic systems at the macro-, meso-, and microlevels the principles of ESG (Environmental, Social, and Corporate Governance), "green" economy, the economy of the closed cycle, and nature-inspired algorithms. Of course, the above concepts are related to and focused on achieving synergies, namely on the protection of the environment [1], the construction of "green" supply chains [2–5], and the provision of environmentally friendly industries against the background of intensive industrial development [6–8].

Thus, this article explores an important issue—the methodology of sustainable industrial development, the study of which is devoted to the works of scientists from different countries [9]. First of all, it is important to understand the essence of sustainable development. In our opinion, society has not yet come to a unified understanding of this concept and awareness of its significance in the conditions of approaching ecological catastrophe. The scientific literature presents an extensive array of conceptual studies in the field of sustainable development [10–22], the role of the closed-cycle economy in this process [23–27], and green production [28–30]. Summarizing these approaches, we note that sustainable development is the result of integrated management of information flows, resource provision, business processes and business model, business strategy, and awareness of competitive advantages. The implementation of the concepts presented above is a rather complex process that requires a rational combination of economic and administrative resources. In this regard, the quintessence of competitive and sustainable development of the enterprise is a strategy based on correct and high-quality methodological techniques.

The development of such methodological solutions is devoted to the research of many scientists. We are impressed by the approach of a team of scientists led by Laurett. The authors identified factors (five drivers and two inhibitors) that determine the sustainable development of agriculture [31]. Szabó et al. explored the issues of sustainable development at the regional level [32]. The authors developed an assessment system for the analysis of regional sustainability, taking into account institutional aspects and natural and human resources. At the same time, the authors have only systematized these categories. The study of private performance measures is highlighted in the works of Kashani and Hajian [33]. The authors define a system of sustainable development as a multidimensional concept that includes economic growth, income distribution, and human well-being. Rotmans believes that a comprehensive evaluation of sustainability involves a long-term comprehensive evaluation of international and national policy programs in accordance with specific goals and criteria [34]. He proposed to find new ways to make the most of current sustainability assessment tools and to develop new approaches to integrated assessment. At the same time, the author does not specify the methodology of the integrated assessment.

Moldavska and Welo [35] proposed a new method for assessing corporate sustainability that views sustainability as a process of directed change. Corporate sustainability assessment is related to the Sustainable Development Goals. However, the authors focused mainly on the architecture of corporate sustainability assessment. The relationship between the company's development indicators and global sustainable development goals was presented. The block approach to managing the sustainable development of the company is impressive, but the need to aggregate blocks into a single integral indicator is ignored.

Therefore, the key problem raised in our study covers two fundamentally important issues—the methodology of sustainable industrial development and the implementation of statistical tools in the development of this methodology. The study of this problem is based on reading foreign publications and the critical theoretical analysis of the approaches of other scientists to its solution.

Sustainable development issues and the way in which they are assessed at different levels of government are given high priority, both globally and nationally. In Russian practice, the methodology covers the monitoring of a number of indicators linked to the UN Sustainable Development Goals. These are the real monetary incomes of the population, as a percentage of the previous period, the index of the physical volume of gross domestic product per capita, the index of the volume of environmental expenditures for the conservation of biodiversity, and the protection of natural territories in % of the previous year and other indicators [36]. This technique covers all spheres of society. However, this approach is accompanied by difficulties of comparing an integrated assessment of the level of sustainable development of different economic systems.

We continue to explore methodological issues. Our research background covers the study of statistical tools and the possibility of their application to assess the sustainable development of socioeconomic systems [37–39]. This study proposes a new approach to assessing the sustainable development of industry based on the combined sequential application of factor and discriminant analysis.

Quality strategic planning is based on the application of mathematical methods of data processing, modeling, and identification of latent dependencies between individual subsystems. These methods include factor analysis, decision trees, discriminant analysis, etc. These methods are implemented through big-data and data-mining technologies. Sustainable development involves the collection and processing of a large amount of data characterizing the economic, environmental, and social development of economic systems. This makes it possible to comprehensively assess the patterns of development of a country, region, and industry. A qualitative methodology for assessing and predicting processes and phenomena should be based on statistical methods and techniques, in particular, regression, factor, and discriminant analysis. Their illumination is reflected in the works of Oda et al. [40], Martínez-Regalado et al. [41], Yadav et al. [42], Tavassoli and Farzipoor Saen [43], and other works.

The competitiveness of the Russian economy is determined by the level of industrial development. In this regard, it is important to forecast the development of Russian industry. The application of discriminant analysis in the context of improving production processes was reflected in the work of Zhang and Luo, where the authors developed an approach to the diagnostics of malfunctions of industrial applications [44]; in a study by Sueyoshi et al. they aimed at developing a unified method for assessing the efficiency of the electric power industry [45]; in the scientific article by Rodrigues Luciano and Rodrigues Lucas, who applied discriminant analysis as part of the classification of energy industry enterprises based on an assessment of financial and economic performance [46]; and in the works of Horváthová et al. [47] and Kočišová and Mišanková [48] where the main subject of the study was the financial condition of enterprises. In the context of sustainable development, discriminant analysis was applied in the work of Vazquez-Brust and Plaza-Úbeda, where the authors identify the characteristics of organizations that pollute the environment excessively [49].

As a result of a critical study of scientific papers (Table 1) published in Scopus journals, we have revealed that a generally recognized rational methodology for assessing sustainable development has not yet been developed. Of course, the international scientific groundwork is not limited to the illuminated works. However, it can be stated that there are few studies based on the use of statistical methods. In our opinion, there are very few publications addressing the use of discriminant analysis in order to improve the methodology of sustainable industrial development and forecasting trends in greening.

In this regard, it is of interest to apply a combined mathematical approach to scenario forecasting of sustainable industrial development. As a consequence, the following goals and objectives of the study are formulated. The purpose of the study is to develop and test a methodology for predicting sustainable development using factor and discriminant analysis. Research objectives:

- Using the method of the main components to develop a methodology for assessing the nature of the transition of industry to sustainable development;
- To identify patterns of sustainable development of the extractive and manufacturing sectors of the Russian economy;
- On the basis of discriminant analysis to develop classification functions of the transition of industry to sustainable development;
- To identify scenarios for the development of Russian industry;
- To form a DFD model of the process of scenario forecasting of sustainable industrial development.

Table 1. Methodological approaches to the diagnosis of sustainable development (compiled by the authors).

Authors	The Specifics of the Approach	Limitations of the Approach
Oda et al. (2020) [40]	A mathematical approach to assessing the consistency of variables based on a generalized information criterion in canonical discriminant analysis	Emphasis on mathematical modeling
Martínez-Regalado et al. (2021) [41]	Application of biplot methods as effective machine learning methods in the framework of sustainable development diagnostics	Only the social factor of sustainable development is affected
Yadav et al. (2021) [42]	The use of logistic regression and discriminant analysis in the search for significant variables in the identification of risk factors that determine hypertension	The study is limited to the medical direction, therefore, the authors cover only the social factor
Tavassoli and Farzipoor Saen (2019) [43]	The methodology of assessing the sustainability of suppliers (in the context of economic, environmental, and social components); the classification of suppliers based on stochastic discriminant analysis is presented	Takes into account the specific criteria of suppliers (advertising costs, number of days of delay, cost of delivery, etc.)
Zhang and Luo (2021) [44]	A new dynamic discriminant analysis of the main subspace for monitoring and troubleshooting of industrial applications was developed	Technical nature of the research results
Sueyoshi et al. (2020) [45]	A methodology for evaluating the efficiency of the electric power industry based on combining the capabilities of discriminant analysis and Data Envelope Analysis is presented	Attention is focused on the environmental component
Rodrigues Luciano and Rodrigues Lucas (2018) [46]	Energy companies are classified into 4 groups based on cluster and discriminant analysis	The methodology is based on the analysis of financial indicators
Horváthová et al. (2021) [47]	The comparative analysis of neural networks and discriminant analysis for bankruptcy forecasting is carried out	The study covers the financial component of the activities of the companies under study
Kočišová et al. (2014) [48]	The discriminant analysis for forecasting the financial condition of companies was refined	
Vazquez-Brust and Plaza-Úbeda (2021) [49]	Discriminant analysis was applied to diagnose companies that excessively pollute the environment	Attention is focused on the environmental aspects of development

2. Materials and Methods

As a key modeling method, we used linear discriminant analysis. Its essence is to identify variables that differ significantly on average in the selected groups; see Formulas (A1)–(A4) (Appendix A) [50]:

The canonical discriminant function will have the form (Formula (1)):

$$d_{kn} = a_0 + a_1 x_{1kn} + a_2 x_{2kn}, \quad (1)$$

where d_{kn} is the value of the discriminant function for object k in group n, and a_i stands for the coefficients of the discriminant function.

The study was based on statistical information on the development of the mining (i = 1) and manufacturing (i = 2) sectors of the economy for the period 2010–2019, published in the public domain on the website of the Federal Statistical Service [36]. The following 10 variables served as partial indicators.

Economic (Figure 1):

$I_{ecn,1i}$—the volume of shipped products by enterprises of the i-th sector of the economy, trillion rubles;

$I_{ecn,2i}$—gross value added by enterprises of the i-th sector of the economy, trillion rubles.

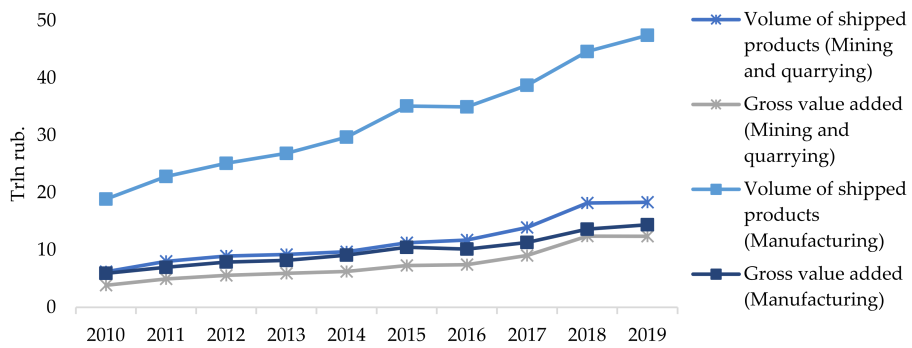

Figure 1. Dynamics of economic indicators of industrial development in Russia.

Ecological:

$I_{ecl,1i}$—the share of enterprises that have introduced innovations to reduce energy costs for production, %;

$I_{ecl,2i}$—the share of enterprises that have introduced innovations to reduce carbon dioxide emissions into the atmosphere, %;

$I_{ecl,3i}$—the share of enterprises that have introduced innovations to reduce environmental pollution, %;

$I_{ecl,4i}$—the share of enterprises that have introduced innovations in the secondary processing of waste, %;

$I_{ecl,5i}$—the volume of recycled and neutralized waste by enterprises of the *i*-th sector of the economy, billion tons;

$I_{ecl,6i}$—the volume of trapped and neutralized air pollutants emitted by enterprises of the *i*-th sector of the economy, million tons.

Social:

$I_{s,1i}$—the size of the average monthly salary of employees of enterprises of the *i*-th sector of the economy, thousand rubles.;

$I_{s,2i}$—average annual number of employees at enterprises of the *i*-th sector of the economy, million people.

The choice in favor of the listed 10 indicators is due to the following:

- In accordance with the forecast of the long-term socioeconomic development of the Russian Federation for the period up to 2036, the index of industrial production is expected to increase by 67.5% by 2036 (relative to 2018), which determines the importance of the volume of production and sale of industrial products;
- The same document indicates a guideline for increasing the share of products with high added value;
- Greening of production is central to the sustainable development of the national economy; the success of greening is possible as a result of the introduction of innovations, which determines the importance of studying the dynamics of environmental innovation in industry;
- In the conditions of industrial development and dangerous working conditions, the motivation factor is important, which is manifested, in particular, in the number of wages and the level of employment at industry enterprises.

(1) Based on the results of factor analysis, it is proposed to form an aggregated indicator of sustainable development of industry (Formula (2)):

$$I = \sum_{j=1}^{n} \left(d_j \times F_j \right), \tag{2}$$

where *j* represents the principal components aggregated over the original data, d_j is the proportion of variance of *j*-th component, and F_j is the value of the main component (factor), calculated by Formula (3):

$$F_j = \sum_{k=1}^{10} (a_k \times I_k), \quad (3)$$

where a_k represents the factor loadings for the variable k (10 variables indicated above are included in the analysis); and I_k is the value of the indicator (variable k), a private indicator.

(2) At the next stage, the growth rate is determined and the nature of the industry's transition to sustainable development is identified. The growth rate below 8% is proposed to be assessed as low; within 8–13%—as an average; and above 13%—as a high. The scale was determined by an expert method and can be used as a universal one. The scaling results allow us to take the nature of the dynamics (low, average, and high) as a categorical variable when conducting a discriminant analysis.

(3) Next, the weighted sum of criteria method is applied. To do this, private indicators are aggregated into a single generalizing factor, summing up the particular indicators, taking into account the assigned weight (w). The weight is assigned by the authors based on expert opinions and subjective assessment. As a result, it is proposed to calculate 3 indicators, namely $I_{ecn,i}$, $I_{ecl,i}$, and $I_{s,i}$, by Formulas (4)–(6):

$$I_{ecn,\ i} = I_{ecn,1i} \times w_{ecn,1i} + I_{ecn,2i} \times w_{ecn,2i}, \quad (4)$$

$$I_{ecl,\ i} = I_{ecl,1i} \times w_{ecl,1i} + I_{ecl,2i} \times w_{ecl,2i} + I_{ecl,3i} \times w_{ecl,3i} + I_{ecl,4i} \times w_{ecl,4i} + I_{ecl,5i} \times w_{ecl,5i} + I_{ecl,6i} \times w_{ecl,6i}, \quad (5)$$

$$I_{s,\ i} = I_{s,1i} \times w_{s,1i} + I_{s,2i} \times w_{s,2i}. \quad (6)$$

The sum of the weights for each of the three sustainable development factors is 1, as calculated by Formulas (7)–(9):

$$w_{ecn,1i} + w_{ecn,2i} = 1, \quad (7)$$

$$w_{ecl,1i} + w_{ecl,2i} + w_{ecl,3i} + w_{ecl,4i} + w_{ecl,5i} + w_{ecl,6i} = 1, \quad (8)$$

$$w_{s,1i} + w_{s,2i} = 1. \quad (9)$$

(4) Based on the calculated values of sustainable development factors (economic, ecological, and social), a discriminant analysis is carried out, and classification functions (10) are formed for each class of sustainable development (low, average, and high; dependence of I_{categ} from incoming predictors $I_{ecn,i}$, $I_{ecl,i}$, and $I_{s,i}$):

$$I_{categ} = a_0 + a_1 \times I_{ecn,i} + a_2 \times I_{ecl,i} + a_3 \times I_{s,i}. \quad (10)$$

The tool for statistical analysis was the Statistica program and its Discriminant Analysis module.

The criteria for evaluating the model are as follows:

- Wilks' Lambda, which, at a value close to 0, reflects the high quality of the model and good discrimination (the rate varies between 0 and 1);
- Criterion F, which must exceed the table value of the F-distribution; the criterion indicates that the null hypothesis (that the observations belong to the same class) is rejected and the discriminant analysis is qualitative;
- The significance level of the F-test p should be less than 0.05.

(5) Based on the results of formalized dependencies, scenarios for the sustainable development of industry are developed and the nature of the intensity of the transition to a new format of production systems is predicted.

3. Results

3.1. Patterns of Sustainable Development of the Mining and Manufacturing Industry in Russia

At the first stage of the author's methodological approach, a factor analysis was carried out. As a result, 10 input variables were aggregated into two or three factors, depending on the industry (Table 2).

Table 2. Principal components and factor loadings for two sectors of the economy (Varimax raw).

Mining and Quarrying			Manufacturing			
Variables	F_1	F_2	**Variables**	F_1	F_2	F_3
$I_{ecn,1}$	0.95	0.28	$I_{ecn,1}$	0.94	0.28	0.10
$I_{ecn,2}$	0.94	0.29	$I_{ecn,2}$	0.93	0.29	0.06
$I_{ecl,1}$	−0.44	−0.79	$I_{ecl,1}$	−0.68	−0.14	−0.54
$I_{ecl,2}$	−0.44	−0.87	$I_{ecl,2}$	0.30	0.90	0.08
$I_{ecl,3}$	0.51	−0.58	$I_{ecl,3}$	0.23	0.84	0.40
$I_{ecl,4}$	0.80	0.04	$I_{ecl,4}$	0.26	0.92	0.08
$I_{ecl,5}$	0.93	0.25	$I_{ecl,5}$	0.47	−0.14	0.31
$I_{ecl,6}$	−0.91	−0.26	$I_{ecl,6}$	−0.16	−0.10	−0.89
$I_{s,1}$	0.97	0.17	$I_{s,1}$	0.94	0.28	0.15
$I_{s,2}$	0.90	0.32	$I_{s,2}$	−0.23	−0.82	0.26
Explained variation	6.52	2.14	Explained variation	3.62	3.33	1.46
Proportion of total variance	0.65	0.21	Proportion of total variance	0.36	0.33	0.15

The factors of sustainable development of the mining industry were mainly included in the first component. Excluded from further analysis is an indicator that characterizes environmental innovations that reduce ecological pollution ($I_{ecl,3}$).

The evaluation of the sustainable development of the manufacturing industry is based on three main components. In this case, two variables (also ecological) are excluded from the matrix—$I_{ecl,1}$ and $I_{ecl,6}$, which is determined by a low factor load (below 0.7).

The formation of an aggregated indicator of industrial sustainable development is based on the dispersion of each selected component (Table 3).

Table 3. Eigenvalues.

Principal Components	**Eigenvalue**	**% Total—Variance**	**Cumulative—Eigenvalue**	**Cumulative—%**
		Mining and quarrying		
F_1	7.25	72.48	7.25	72.48
F_2	1.40	14.04	8.65	86.52
		Manufacturing		
F_1	5.51	55.13	5.51	55.13
F_2	1.89	18.85	7.40	73.98
F_3	1.01	10.13	8.41	84.11

The resulting factor loadings formed the basis for calculating the indicator of sustainable industrial development (Formula (2)) for the mining and manufacturing industries (Figure 2). There is a significant increase in the indicator in both cases (by 2.5 times). However, the mining industry demonstrates a higher efficiency of measures that contribute to environmental protection in the conditions of active economic development and an increase in production and production volumes. Thus, at the end of 2019, the level of the indicator for the mining industry was 86.44, and for the manufacturing industry, it was only 50.79.

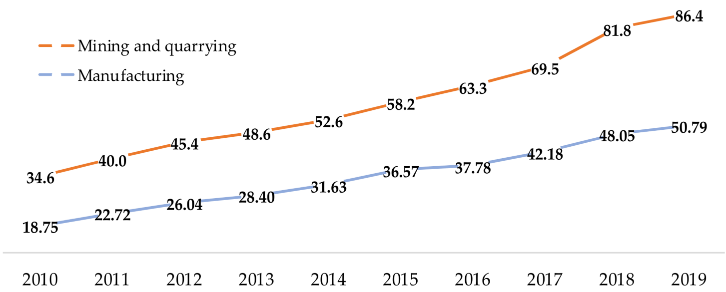

Figure 2. Change of aggregate indicator of sustainable development of industry in Russia.

The identification of patterns in the development of Russian industry is realized by estimating the growth rate of the aggregate indicator (Table 4).

Table 4. Dynamics of the aggregate indicator of sustainable industrial development.

Mining and Quarrying				**Manufacturing**			
Year	***I***	**Rate of Increase**		**Year**	***I***	**Rate of Increase**	
2010	34.60	-	-	2010	18.75	-	-
2011	40.01	15.66%	high	2011	22.72	21.16%	high
2012	45.41	13.48%	high	2012	26.04	14.61%	high
2013	48.58	6.98%	low	2013	28.40	9.08%	moderate
2014	52.59	8.25%	moderate	2014	31.63	11.36%	moderate
2015	58.17	10.62%	moderate	2015	36.57	15.61%	high
2016	63.28	8.79%	moderate	2016	37.78	3.32%	low
2017	69.47	9.77%	moderate	2017	42.18	11.65%	moderate
2018	81.80	17.75%	high	2018	48.05	13.90%	high
2019	86.44	5.67%	low	2019	50.79	5.70%	low
Average		10.77%				11.82%	

Despite the relatively low values of the aggregate indicator of sustainable development, the manufacturing industry demonstrates higher dynamics: the average growth rate (over 10 years) for the extractive industry was 10.8%, and for the manufacturing, it is 11.8%. The advantage of the manufacturing sector is due to the high volume of production of industrial products, and, accordingly, a relatively high growth rate of this indicator.

Furthermore, the authors assigned weight coefficients to each of the ten variables. The sum of weight coefficients, within the framework of each factor of sustainable industrial development, is 1 and meets Conditions (7)–(9) (Table 5). We applied a differentiated approach to assigning weights to the factors of sustainable development of the extractive and manufacturing sectors, which was dictated by the need to consider the contribution of each of the sectors to the development of the national economy and environmental pollution. Thus, earlier we noted that, within the framework of the economic factor of manufacturing industry, there is a predominance of production and sales volumes over the extractive sector of the economy, but insignificant differences in the value of gross value added (Figure 1).

Table 5. Weighting coefficients (mining and quarrying/manufacturing).

Symbol	Economic Factor	Ecological Factor	Social Factor
$w_{ecn,1}$	0.5/0.9		
$w_{ecn,2}$	0.5/0.1		
$w_{ecl,1}$		0.1/0.3	
$w_{ecl,2}$		0.2/0.1	
$w_{ecl,3}$		0.2/0.2	
$w_{ecl,4}$		0.1/0.1	
$w_{ecl,5}$		0.2/0.1	
$w_{ecl,6}$		0.2/0.2	
$w_{s,1}$			0.6/0.9
$w_{s,2}$			0.4/0.1
Sum total	1	1	1

Using the weighted sum of the criteria method, the importance of sustainability factors can be calculated in an alternative way. In addition, four alternative trajectories were proposed for consideration in order to develop sustainable industrial scenarios (Table 6):

- Development Pathway 1 (DP 1)—negative trends in sustainable development due to a reduction in production and sales, innovative activity in the field of environmental safety, and number of employees;
- Development Pathway 2 (DP 2)—moderate growth rates of indicators relative to the level of 2019;
- Development Pathway 3 (DP 3)—significant improvements, characterized in particular by a substantial increase in innovation activity and improved environmental safety in production;
- Development Pathway 4 (DP 4)—an innovative development trajectory (active efforts of industrial enterprises in the field of economic activity and in the field of environmental protection and social protection of employees of these enterprises).

Based on the weighting factors presented in Table 4 and the expected changes in Russian industrial performance according to Formulas (4) to (6), key factors for sustainable development are also calculated.

Based on the data in Tables 4 and 6, a discriminant analysis was carried out. Its purpose was to predict the pace of sustainable development of the mining and manufacturing sectors of the economy and determine the type of intensity of greening of industrial production. The main elements of the discriminant analysis procedure in the Statistica program are presented below:

- Grouping variable—rate of increase (low, moderate, and high);
- Independent variables—factors of sustainable development (I_{ecn}, I_{ecl}, and I_s);
- Observations—10 (2010–2019 years);
- Method for selecting significant variables—standard.

The calculations were made privately for each sector of the economy. As a result of calculations based on the estimated data of the mining industry, the following results were obtained:

- Wilks' Lambda = 0.0594848—lies near 0, which indicates a qualitative discrimination;
- Approximately F (6,10) = 5.166873 > F_{table} (table value F_{table} (0.05; 6; 10) = 3.21);
- Significance level $p < 0.0115$.

Thus, this classification is correct.

Table 6. Indicators of alternative directions of industrial development in Russia.

DP	$I_{ecn,1}$	$I_{ecn,2}$	$I_{ecl,1}$	$I_{ecl,2}$	$I_{ecl,3}$	$I_{ecl,4}$	$I_{ecl,5}$	$I_{ecl,6}$	$I_{s,1}$	$I_{s,2}$
Mining and quarrying										
2019	18.32	12.39	0.21	0.25	0.92	0.79	3.56	1.72	89.34	1.15
DP 1	17.00	12.00	0.20	0.20	0.90	0.75	3.40	1.70	85.00	1.10
DP 2	18.40	12.40	0.25	0.30	0.95	0.85	3.50	1.80	92.00	1.15
DP 3	18.50	12.50	0.30	0.40	0.99	0.90	3.60	2.00	95.00	1.16
DP 4	20.00	13.00	0.70	0.70	0.70	0.70	4.00	4.00	100.00	1.17
	Economic, I_{ecn}				Ecological, I_{ecl}				Social, I_s	
2019	15.36				1.39				54.07	
DP 1	14.50				1.34				51.44	
DP 2	15.40				1.42				55.66	
DP 3	15.50				1.52				57.46	
DP 4	16.50				2.02				60.47	
Manufacturing										
2019	47.44	14.41	0.58	0.46	0.78	0.55	0.18	31.99	43.86	9.96
DP 1	47.00	14.00	0.50	0.40	0.70	0.50	0.15	32.00	45.00	10.00
DP 2	48.00	15.00	0.60	0.50	0.80	0.60	0.20	34.00	46.00	10.20
DP 3	49.00	15.50	0.62	0.52	0.82	0.62	0.22	36.00	46.00	10.20
DP 4	50.00	16.00	0.80	0.80	0.95	0.80	0.30	50.00	55.00	10.30
	Economic, I_{ecn}				Ecological, I_{ecl}				Social, I_s	
2019	44.13				6.85				40.47	
DP 1	30.5				6.75				31	
DP 2	31.5				7.22				31.68	
DP 3	32.25				7.636				31.68	
DP 4	33				10.57				37.12	

Similarly, discrimination was assessed and recognized as qualitative for indicators of the manufacturing industry:

- Wilks' Lambda = 0.0989876—lies near 0, which indicates a qualitative discrimination;
- Approximately F (6,10) = 3.630678;
- Significance level $p < 0.0354$.

Moreover, in both cases, the correctness factor of the training samples was 100%. The classification functions for each type of industrial transition to sustainable development are further formalized. For the mining sector of the economy, we have Formulas (11)–(13), and for the manufacturing sector, we have Formulas (14)–(15):

$$\text{high (mining)} = -1555 + 94.69 \times I_{ecn} + 2264.8 \times I_{ecl} - 33.12 \times I_s, \quad (11)$$

$$\text{moderate (mining)} = -1391.41 + 87.96 \times I_{ecn} + 2136.12 \times I_{ecl} - 30.72 \times I_s, \quad (12)$$

$$\text{low (mining)} = -1194.41 + 82.21 \times I_{ecn} + 1981.48 \times I_{ecl} - 28.72 \times I_s, \quad (13)$$

$$\text{high (manuf.)} = -345.06 - 30.06 \times I_{ecn} + 267.97 \times I_{ecl} + 39.89 \times I_s, \quad (14)$$

$$\text{moderate (manuf.)} = -449 - 36.79 \times I_{ecn} + 299.22 \times I_{ecl} + 48.49 \times I_s, \quad (15)$$

$$\text{low (manuf.)} = -467.03 - 36.42 \times I_{ecn} + 306.22 \times I_{ecl} + 48.25 \times I_s. \quad (16)$$

Based on the formalization of classification functions and considering the calculated values of factors of sustainable development (Table 6), the nature of the transition of Russian industry to sustainable development is determined (Table 7).

Table 7. Alternative trajectories of industrial development in Russia (the best values (the largest) are highlighted in bold).

Mining and Quarrying				Manufacturing			
Qualities	**High**	**Low**	**Moderate**	**Qualities**	**High**	**Low**	**Moderate**
A Posterior Probability	$p = 0.5$	$p = 0.3$	$p = 0.2$	**A Posterior Probability**	$p = 0.5$	$p = 0.2$	$p = 0.3$
Economic, I_{ecn}	94.69	82.21	87.96	Economic, I_{ecn}	−30.060	−36.418	−36.788
Ecological, I_{ecl}	2264.80	1981.48	2136.12	Ecological, I_{ecl}	267.971	306.225	299.224
Social, I_s	−33.12	−28.72	−30.72	Social, I_s	39.894	48.246	48.487
Constant	−1555.00	−1194.41	−1391.41	Constant	−345.061	−467.031	−448.995
DP 1	1137.85	**1165.64**	1155.52	DP 1	1783.62	**2125.19**	1951.82
DP 2	1275.81	**1286.86**	1286.62	DP 2	1906.64	**2225.26**	2088.63
DP 3	1447.48	1437.46	**1449.34**	DP 3	1995.57	**3358.87**	2185.52
DP 4	**2579.61**	2428.10	2517.35	DP 4	2976.27	−467.03	**3299.62**

The most likely development alternatives are highlighted in bold in the table, indicating the following:

- For mining industry, high growth rate of the aggregate sustainable development indicator is most likely in the fourth alternative scenario (Development Pathway 4), low growth rate is in the first and second cases (Development Pathways 1 and 2), and moderate rate of transition is in the third case (Development Pathway 3);
- For the manufacturing industry, a low probability of achieving a high growth rate of the aggregate indicator of sustainable development was revealed; achieving breakthrough development requires intensive mobilization of resources to modernize production systems.

3.2. Modeling of a Scenario Prediction Process for Sustainable Industrial Development

The systematization of the proposed methodological solutions is formalized in the form of a decomposition model of the process of scenario forecasting of the sustainable development of industry. The DFD notation was used as a modeling tool, which makes it possible to visually reflect the data flows that are sequentially generated and circulated in an economic system focused on the transition to sustainable development (Figure 3). The description of the model is implemented on a process basis in the All-Fusion Process Modeler (Bpwin) program. Files and databases are presented as a data store—an integral element of the DFD diagram.

The initiative comes from the top managers of an industrial enterprise (at the microeconomic level), from representatives of government, in particular, the Ministry of Industrial Development (at the regional or federal level) in the form of an order to monitor sustainable development and stimulate the greening of production.

The process covers eight sub-processes which are interconnected by data streams. The fundamental models are big data and data mining, which allow us to aggregate a large array of data on the development of the industry.

The proposed model reflects the combined (covering factorial and discriminant analysis) methodical approach of the authors to forecasting industrial development trends. The model differs from previously proposed approaches in the following:

- By combining two types of multivariate statistical analysis,

- By an expanded set of variables taken into account in the aggregate indicator of sustainable development of industrial greening.

The proposed methodological solution makes it possible to implement a flexible approach to planning the activities of industrial enterprises and develop alternative development strategies according to the proposed scenarios.

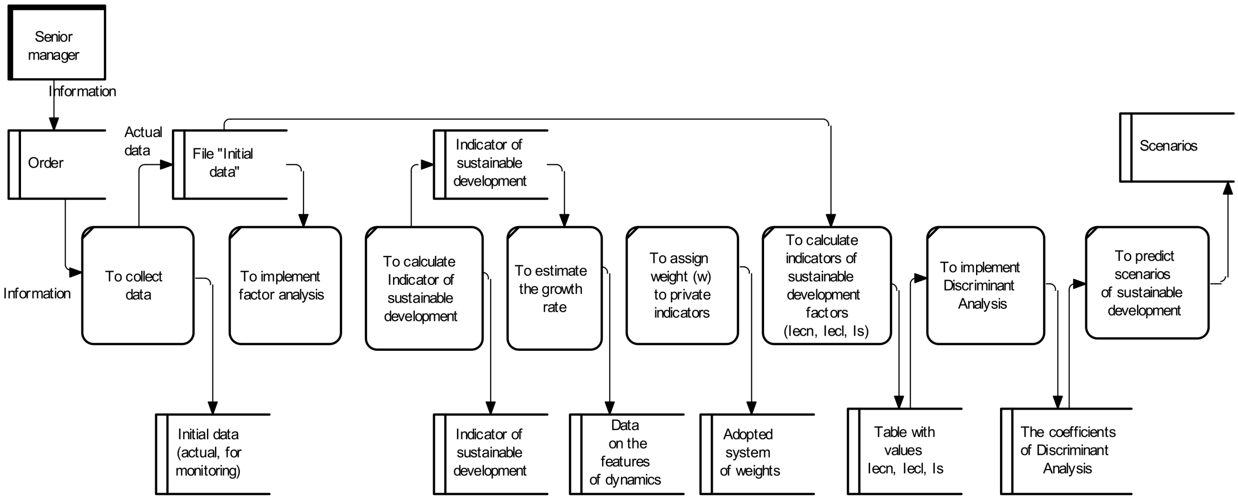

Figure 3. Model of the scenario prediction process of sustainable industrial development in DFD notation.

4. Discussion

In comparing the results of the assessment of the projected rate of transition to sustainable development, a high correlation of r was found (Table 8). In the case of the mining industry, the close link between the projected rate of transition to sustainable development is 87%, and in the case of manufacturing, it is 10%. Thus, it is advisable to recognize the author's methodology as successfully verified.

Table 8. Comparison of the results of factor and discriminant analysis.

DP	Mining and Quarrying		Manufacturing	
	Projected Pace of Transition to Sustainable Development			
	Factor Analysis	Discriminant Analysis	Factor Analysis	Discriminant Analysis
DP 1	low	low	low	low
DP 2	low	low	low	low
DP 3	low	average	low	low
DP 4	average	high	average	average
r	87%		100%	

Comparing the author's approach with previously published studies, it should be emphasized that the methodology proposed in this article is more capacious. We do not limit ourselves to assessing the impact of the functioning of industry on the environment, but take into account measures to reduce negative externalities (in the format of environmental innovations and the activity of enterprises in this area). In contrast to a number of approaches highlighted above [45–49] (analysis of financial and economic activity or environmental aspects), we include four aspects of industrial development (economic, innovative, social, and environmental) in the methodology at once. At the global level, the methodology for calculating the Sustainable Society Index is generally recognized. These are indicators Sufficient Food, Sufficient to Drink, Safe Sanitation, Education, Healthy Life, Gender Equality, Income Distribution, Population Growth, Good Governance, Biodiversity, Renewable Water Resources, Consumption, Energy Use, Energy Savings, Greenhouse Gases, Renewable Energy, Organic Farming, Genuine Savings, GDP, Employment, and Public Debt [51]. However, these indicators are aggregated only to the level of three factors of sustainable development (Human Well-Being, Environmental Well-Being, and Economic Well-Being) and cover society as a whole.

The methodology of sustainable development is also widely presented in the scientific works of Russian scientists. However, territories [52–54], environmental aspects [55], rationalization of water resources use [56,57], etc., prevail as the subject of research.

Of course, the detailed targeted elaboration of methodological solutions reflected in the designated publications is also of particular importance in the development of the methodology of sustainable development. However, the methodological approach we propose allows us to assess the following: firstly, not the statics of sustainable development, but the dynamics; secondly, sustainable development of the industry, which is strategically important in the development of Russia.

The factor and discriminant analysis we used confirmed the viability of the author's approach. The advantage of the first one is that it takes into account the latent patterns of industrial development in the economic, ecological and social planes and the possibility of formalizing the identified dependencies in the form of a function. In contrast to the cluster analysis, which focuses on the classification of observations, the factor analysis classifies variables and enlarges, thereby supplementing the explicit relationship between indicators, taking into account the hidden dependence. An alternative can also be multiple regression, which also formalizes the dependence of the response on predictors, but does not allow aggregating indicators.

Discriminant analysis complements factor analysis, includes elements of regression analysis, contributes to the formalization of the mathematical relationship between variables. In contrast to regression analysis, it includes a categorical variable described by a mathematical function. Thus, the discrimination problem provides the possibility of constructing discriminant functions and their separating power.

Summarizing the results of the study, the following conclusions can be drawn.

Firstly, a methodological solution was proposed for assessing the dynamics of sustainable development of the mining and manufacturing industries in Russia, based on the integrated use of factor and discriminant analysis. The difference of the methodology lies in taking into account the indicators characterizing the activity of enterprises in the context of three subsystems of sustainable development. The solution allows us to identify patterns occurring against the backdrop of greening industry change. The implementation of the methodology is aimed at assessing the contribution of enterprises to achieving harmony between the economic, ecological, and social interests of modern society.

Secondly, on the basis of the proposed methodology, four alternative scenarios of industrial development have been developed, taking into account crisis conditions related to the COVID-19 pandemic. If before 2019 there were periods with active phases of the transition of the Russian industry to a sustainable development model, then, in the short-term, high rates are unlikely. It is confirmed by the results of verification of the author's combined methodology.

Thirdly, the model of the process of scenario forecasting of sustainable industrial development in DFD notation is formalized. It reflects the logic of developing scenarios for future changes in the real sector of the national economy and allows for the implementation of a flexible approach to planning the activities of industrial enterprises.

A set of developments can be reflected in the context of developing a strategy for the socioeconomic development of the country and meso- and macroeconomic systems, encouraging them to participate in achieving sustainable development goals.

Our study has some limitations related to industry specifics, the choice of time series, and taking into account the crisis of 2020. It is planned to develop the methodological basis for managing the sustainable development of economic systems in the format of computer programs, as well as to expand the range of static analysis tools in the search for the most accurate methods and models.

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Appendix A. Formulas for Calculations

$$\overline{x_1} = \frac{1}{n_1}\sum_i^{n_1} x_{1i}, \tag{A1}$$

$$\overline{x_2} = \frac{1}{n_2}\sum_i^{n_2} x_{2i}, \tag{A2}$$

$$\overline{x} = \frac{1}{n_1 + n_2}(n_1 x_1 + n_2 x_2), \tag{A3}$$

$$S = \frac{1}{n_1 + n_2 - 2}\left[\sum_i (x_{1i} - \overline{x_1})(x_{1i} - \overline{x_1})^{\hat{A}} + \sum_i (x_{2i} - \overline{x_2})(x_{2i} - \overline{x_2})^{\hat{A}}\right], \tag{A4}$$

where n_1 and n_2 are conditional groups of observations, $\overline{x_1}$ and $\overline{x_2}$ are average values of conditional variables 1 and 2 for all groups, and S is the variation in groups (should be maximum).

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