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ENVIRONMENTAL QUALITY CERTIFICATION AS A VECTOR OF SUSTAINABLE ENTREPRENEURSHIP DEVELOPMENT IN INDUSTRY 4.0

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A B S T R A C T

The purpose of the article is to propose and substantiate the preference of a new vector of entrepreneurship development in industry 4.0 – the vector of its sustainable development based on environmental certification of product quality. The methodological apparatus of the study is based on the use of the regression analysis method for modeling patterns based on international experience for 2022. The authors' main conclusion is that environmental quality certification accelerate the development of industry 4.0 and has almost as much impact on the environment as the development of industry 4.0. The article contributes to the literature through the development of the TQM concept, justifying the expediency of choosing environmental certification of product quality as a new vector of sustainable entrepreneurship development in industry 4.0. The originality of the article is due to the study of industry 4.0 and its products from an ecological perspective, but from a new angle, in which, instead of calculating environmental damage, the possibilities of improving the environmental characteristics of industry 4.0 and its products are revealed. The theoretical significance of the results of this article is due to the fact that it has proposed a new dimension of the quality of the products of business entities in industry 4.0: "Green 4.0", and also has developed a new approach to TQM of entrepreneurship in industry 4.0 to achieve the quality of "Green 4.0" and the implementation of the vector of sustainable development of industry 4.0. The practical significance of the authors' conclusions and recommendations is that they will allow the fullest disclosure of the potential of entrepreneurship development in industry 4.0 due to the systemic improvement of its product quality in unity and consistency of its technical and environmental properties.

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1. INTRODUCTION

By analogy with the previous industrial revolutions, the fourth of them, which took place at the beginning of the second millennium, ensured the availability of breakthrough technologies and initiated their development and active implementation. However, the uniqueness of the Fourth Industrial Revolution lies in the fact that it has provided not only a technological leap, but also what has been achieved for the first time and is no less important - its deep and comprehensive reflection by all interested parties.

Thanks to this, the fourth revolution stands out from the rest and for the first time occurs consciously. In this regard, it is fair to call industry 4.0 “smart”, not only in the sense that it is accompanied by the spread of artificial intelligence, but also in the sense that it does not develop spontaneously, but has an objective and independent assessment, as well as a rational justification. The marked difference is especially clearly manifested from the ecological perspective of industry 4.0.

Never before the environmental consequences of technological breakthroughs have so much worried not only the general public, but also entrepreneurs and managers of industrial production, as it is currently observed in industry 4.0 (Turginbayeva and Shaikh, 2022). In many ways, this evolutionary change in the nature of scientific and technological progress is due to a combination of aggravation of environmental problems and the growth of demands for a high quality of life (where the environmental friendliness of urban spaces plays a central role), which previously represented parallel processes, and now intersected at the critical point

This critical point, at which society has finally realized that the environment is no longer favorable enough for urban residents and continues to deteriorate, has been passed. The growing contradiction of economic growth associated with its high environmental costs has been recognized by society and has received a wide resonance. In response to this contradiction, environmentally responsible economic practices are gaining popularity: both in the business and in the social environment.

The focus of this article is an actual scientific and practical problem related to the lack of a well-formed view of the opportunities and prospects for sustainable entrepreneurship development in industry 4.0. The published literature is dominated by a negative interpretation of industry 4.0 and its products in terms of environmental consequences, however, these consequences have not been sufficiently specified and have not yet received an accurate quantitative assessment and therefore remain vague and largely subjective.

The need to solve this problem is explained by the fact that without a solid scientific and theoretical basis, the potential for environmental optimization of the product quality of industry 4.0 is not disclosed, and this quality continues to be quite low. This contrasts with a clear scientific understanding of environmental quality management in other sectors of the economy. There is a significant demand for recommendations in the field of environmental quality management from entrepreneurs doing business in industry 4.0, openly supporting the SDGs and striving to contribute to sustainable development. This request is formed from a variety of motives: from altruism and environmental responsibility to commercial benefits from environmental management.

The main idea of this article is that the environmentally unfriendly nature of industry 4.0 and its products is a prejudice. The message of the article is that industry 4.0 and its products can and should be eco-friendly. The article is aimed at forming a scientific and methodological base and applied recommendations for solving the problem, which is seen in the environmental certification of the product quality of enterprises in industry 4.0. The originality of the article is connected with the study of industry 4.0 and its products not only from an ecological perspective, but also from a new angle, in which, instead of calculating environmental damage, the possibilities of improving the environmental characteristics of industry 4.0 and its products are revealed.

The purpose of the article is to propose and justify the preference of a new vector of entrepreneurship development in industry 4.0 – the vector of its sustainable development based on environmental certification of product quality. After this introduction, a literary review is carried out in the article. It presents the authors’ criticism of the existing vector – the vector of industrial entrepreneurship development in industry 4.0 – in the context of the “Decade of Action”. It also reveals the specifics of environmental certification of product quality as a tool of total quality management (TQM) in entrepreneurship of industry 4.0.

The results of the study are methodically described in the main part of the article. Firstly, the environmental consequences of entrepreneurship development in industry 4.0 and their mitigation through environmental quality certification. Secondly, environmental scenarios of entrepreneurship development in industry 4.0, depending on the approach to TQM. Thirdly, “Green 4.0” as a new dimension of the product quality of the entrepreneurship of industry 4.0. Fourthly, a new approach to the TQM of entrepreneurship in industry 4.0 to achieve the quality of “Green 4.0”.

2. LITERATURE REVIEW

2.1. The vector of industrial development of entrepreneurship in industry 4.0: criticism in the context of the "Decade of Action"

To date, the vector of industrial development of entrepreneurship in industry 4.0 has taken shape and is currently being implemented. This vector assumes industrial growth of the economy due to the scaling of production in industry 4.0 (Grenčíková et al., 2021). The rationale for the chosen vector is the need to develop the real sector of the economy to reduce its cyclical fluctuations, meet domestic demand for industrial products, increase the positive trade balance and expand the presence in the fast-growing global markets of products in industry 4.0, characterized by stable demand and high profits of its enterprises (Popkova et al., 2018a; Popkova et al., 2018b; Sergi et al., 2019).

With the development of entrepreneurship in industry 4.0 according to a given vector, much attention is paid to measuring and managing the quality of its products (Alrabadi et al., 2023). The current measurement is Quality 4.0. In order to meet its standards, the products of enterprises in industry 4.0 must have complex technical properties, be manufactured using advanced automation tools, as well as comply with the modern technological order and be applicable based on the existing telecommunications infrastructure (Maganga and Taifa, 2023). That is, Quality 4.0 is measured in terms of the technical properties of industrial products (Ali and Johl, 2023).

Rethinking the current vector of industrial development of entrepreneurship in industry 4.0 in the new and unique context of the "Decade of Action" makes it possible to use its reasoned criticism from the standpoint of all factors of production, indicating that they are not optimal from an environmental point of view. From the standpoint of labor, most of today's highly qualified workers are "green" personnel. Weak environmental properties of enterprises of industry 4.0 cause low loyalty towards them on the part of their "green" personnel. This prevents the best workers from being attracted to industry 4.0 and hinders the disclosure of their human potential (Bazrkar et al., 2022; Popkova et al., 2017).

From the standpoint of the earth, industrial production of industry 4.0 mainly uses natural raw materials, as well as fossil-fuel energy, that is, exhaustible resources (Ammar et al., 2021). From the standpoint of capital, enterprises in industry 4.0 receive less "green" investments, which limits their ability to attract additional financial resources, as well as understates the market capitalization of their assets (Flora and Tankov, 2023).

From the standpoint of entrepreneurial ability, developing according to the industrial vector, industry 4.0 hinders the disclosure of entrepreneurial talent in the field of environmental protection (Chen et al., 2023 From the standpoint of technology, "green" technologies receive only limited application in industry 4.0, since only those that are not associated with the risks of slowing down industrial growth of the economy are implemented (Tian and Pang, 2023).

Thus, the above criticism puts into question the expediency of the entrepreneurship development in industry 4.0 in the "Decade of Action" on the industrial vector.

2.2 Environmental certification of product quality: specifics of application as the instrument of TQM in the entrepreneurship of industry 4.0

The fundamental basis of this research is the concept of TQM, the principles of which are laid down in international product quality standards (Shkromyda et al., 2021; Urbaniak and Zimon, 2021). The existing approach to TQM of entrepreneurship in industry 4.0 is associated with the standardization of Quality 4.0 according to the international standard ISO-9001 (Anvari and Anvari, 2023). At the same time, quality control is focused on the technical properties of industrial products (Alketbi et al., 2022).

This approach to TQM contrasts with the popularization of the attitude towards the sustainable entrepreneurship development, which is understood as the achievement and preservation of its equilibrium state in the ecosystem "business (economy)-society-nature" (Popkova and Shi, 2022; Popkova, 2022). The practical implementation of the intended purpose in business practice is carried out through environmental certification of product quality in accordance with the international standard ISO-14001 (Halkos et al., 2021; Opoku-Mensah et al., 2023).

Environmental quality certification harmoniously fits into non-digital economic practices (Nikolic et al., 2022; Ociepa-Kubicka et al., 2021). The specifics of using environmental certification of product quality as the TQM tool of entrepreneurship in industry 4.0 is that it may conflict with the standardization of Quality 4.0 due to the antagonism of the technical and environmental properties of products of industry 4.0 (Ong et al., 2023; Seroka-Stolka and Fijorek, 2022).

While the indication of the direct connection of environmental quality certification with the state of the environment (Abid et al., 2021; Zimon et al., 2022) and the inverse relationship of this certification with the development of enterprises in industry 4.0 (Abid et al., 2022; Alsulamy et al., 2022) is directly or indirectly observed in a variety of published literature sources, they do not achieve a sufficiently high level of detail required for the recognition of the noted connections as scientific facts. Due to the above-mentioned disadvantage of the existing literature, the cause-and-effect relationships of environmental certification of the product quality of enterprises in industry 4.0 are vague and need to be clarified.

The first research question of this article is as follows. **RQ_1:** What are the implications of environmental quality certification for industry 4.0? In the available publications, the following key indicators of the development of industry 4.0 are mentioned:

- Medium and high-tech manufacturing value added (Soniewicki, 2022);
- ICT goods exports (Blyde, 2022);
- Medium and high-tech exports (Shmarlouskaya et al., 2023).

Bashir et al. (2022), Castillo-Martinez et al. (2021) note in their works that environmental quality certification hinders the development of industry 4.0. Along with this, there are publications by Arocena et al. (2021), Mansour and Alsulamy (2021), in which scientists cite separate scientific evidence that due to environmental quality certification, products of Industry 4.0 gain competitive advantages and increased consumer loyalty.

Based on the above sources and guided by the above indicators, this article puts forward **the hypothesis H_1** that environmental quality certification accelerates the development of industry 4.0, providing an increase in: 1) medium and high-tech manufacturing value added; 2) ICT goods exports and 3) medium and high-tech exports.

The second research question of this article is as follows. **RQ_2:** To what extent can the advantages of environmental quality certification mitigate the environmental damage caused by industry 4.0? Taking into account the latest trends in environmental protection, this article, based on the available literature, highlights the following main environmental impacts that are important for sustainable development, directly related to the SDGs and the potential connection with environmental certification of product quality:

- Decarbonization (Sam and Song, 2022);
- Conservation of biodiversity and protection of terrestrial ecosystems (Carrasco et al., 2023; von Jeetze et al., 2023) and aquatic ecosystems (De Valck and Rolfe, 2022; Pearson and Thompson, 2023).

In their works, Erauskin-Tolosa et al. (2020), Jovanovic et al. (2020) note that industry 4.0 has a much greater impact on the environment than environmental quality certification. Their argument is based on the fact that the environmental costs of industrial economic growth are very high, while the positive effect of environmental certification of product quality can be moderate – only slightly reducing these costs (Bugdol et al., 2021).

In contrast, Bravi et al. (2020), Steblyakova et al. (2022), Yarahmadi and Soleimani-Alyar (2021) indicate in their publications that the introduction of “green” technologies in industry 4.0, due to “smart” automation tools, generates a synergistic effect from their combination. That is, it makes it possible to increase energy and resource efficiency so much, as well as reduce production waste in industry 4.0, which can potentially provide even better environmental characteristics in it than in other sectors of the economy where “green” technologies are introduced without “smart” automation tools.

Based on the above sources and guided by the above indicators, this article puts forward **the hypothesis H_2** that environmental quality certification has almost as much impact on the environment as the development of industry 4.0. To test hypotheses, this article provides a system analysis of the relationship between industry 4.0 and the state of the environment, and also checks the potential corrective effect on this relationship of environmental certification of product quality.

3. MATERIALS AND METHODOLOGY

This purpose determined the formulation of the following four tasks of this study, each of which is solved using the appropriate methodology. The study is based on a sample of 122 countries around the world, for which all the necessary statistical information is available (there are no data gaps). The study is based on data for 2022, which are given in the appendix to this article.

The first task is to determine the environmental consequences of the entrepreneurship development in industry 4.0 and their mitigation through environmental quality certification. It is solved using the regression analysis method. This method is used for mathematical modeling of the patterns of changes in the state of the environment as industry 4.0 develops. At the same time, the following indicators of the state of the environment are used (UN, 2023):

- Carbon Pricing Score at EUR60/tCO_2 c EnvSert (%, worst 0-100 best) as an indicator of the success of decarbonization ($Ecology_1$);
- Mean area that is protected in terrestrial sites important to biodiversity c EnvSert, % ($Ecology_2$);
- Mean area that is protected in freshwater sites important to biodiversity c EnvSert, % ($Ecology_3$).
- The following are indicators of the development of industry 4.0:
- Medium and high-tech manufacturing value added (% manufacturing value added) (World Bank, 2023c) ($I_{4.0(1)}$);
- ICT goods exports (% of total goods exports) (World Bank, 2023a) ($I_{4.0(2)}$);

- Medium and high-tech exports (% manufactured exports) (World Bank, 2023b) ($I_{4.0(3)}$).

Mathematical modeling of the patterns of changes in the state of the environment and the level of development of industry 4.0 is also carried out under the influence of environmental certification of product quality, the indicator of which is "ISO 14001 Environmental certificates/bn PPP$ GDP" (WIPO (2023) (EnvSert). The research model has the following form:

$$\begin{cases} Ecology=a_1+b_1I_{4.0(1)}+b_2I_{4.0(2)}+b_3I_{4.0(3);} \\ Ecology=a_2+b_2EnvSert; \\ I_{4.0}=a_3+b_3*EnvSert. \end{cases} \quad (1$$

The reliability of the regression equations in model (1) is verified by conducting Fisher's F-test, as well as using correlation analysis. The hypothesis H_1 will be considered proved if the regression coefficient b_3 in the model (1) takes a positive value. This will mean that environmental quality certification accelerates the development of industry 4.0, providing an increase in:

1) medium and high-tech manufacturing value added;
2) ICT goods exports and
3) medium and high-tech exports.

The hypothesis H_2 will be considered proved if the correlation coefficient in the equation $Ecology_1$=F($I_{4.0(1)}$, $I_{4.0(2)}$, $I_{4.0(3)}$) is similar to the correlation coefficient in the equation Ecology=F(EnvSert). This will mean that environmental quality certification has almost as much impact on the environment as the development of industry 4.0.

The second task is to create environmental scenarios for the entrepreneurship development in industry 4.0, depending on the approach to TQM. To create the scenario of industrial development, the values of factor variables are substituted at the maximum level among them (the maximum is observed at $I_{4.0(3)}$ and is 37.12) in the equation $Ecology_1$=F($I_{4.0(1)}$, $I_{4.0(2)}$, $I_{4.0(3)}$) in the model (1). To create the scenario of sustainable development, the maximum possible value of the factor variable (EnvSer=100) is substituted into the equations Ecology=F(EnvSert) и $I_{4.0}$=F(EnvSert) in the model (1). The consequences of alternative scenarios are compared with each other.

The third task is to substantiate "Green 4.0" as a new dimension of the quality of entrepreneurship products in industry 4.0. To solve this problem, different dimensions of the product quality of entrepreneurship in industry 4.0 are compared with each other through the prism of the stages of the life cycle of products in industry 4.0. The fourth task is to develop a new approach to TQM of entrepreneurship in industry 4.0 to achieve the quality of "Green 4.0". To solve this task, the alternative approaches to the quality management of products in industry 4.0 are compared with each other from the standpoint of differences in the implementation of the principles of TQM.

4. RESULTS

4.1. Environmental consequences of entrepreneurship development in industry 4.0 and their mitigation through environmental quality certification

To solve the first task of this study, the authors have carried out a regression analysis of the dependence of the state of the environment on the factors of the development of industry 4.0. The results are reflected in Tables 1-3.

The results from Table 1 show that the change in the carbon pricing score by 59.91% is explained by the influence of industry 4.0 factors. Fisher's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in the carbon pricing score as industry 4.0 develops:

Ecology1=-7.6754+0.4022I4.0(1)-0.5617I4.0(2)+0.3005I4.0(3) (2)

Equation (2) means that the manufacturing value added carbon pricing score rises by 0.4022 points with an increase in medium and high-tech manufacturing value added by 1%. Carbon pricing score is reduced by 0.5617 points with an increase in ICT goods exports by 1% of total goods exports. Carbon pricing score rises by 0.3005 points with an increase in medium and high-tech exports by 1% of manufactured exports.

Results from Table 2 show that the change in mean area that is protected in terrestrial sites important to biodiversity by 32.91% is explained by the influence of factors in industry 4.0. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in the mean area that is protected in terrestrial sites important to biodiversity as industry 4.0 develops:

Ecology2=35.9457-0.1470I4.0(1)-0.4611I4.0(2)+0.4796I4.0(3) (3)

Equation (3) means that the mean area that is protected decreases by 0.1470% with an increase in medium and high-tech manufacturing value added by 1% of manufacturing value added. Mean area that is protected in territorial sites important to biodiversity is reduced by 0.4611% with an increase in ICT goods exports by 1% of total goods exports. Mean area that is protected in terrestrial sites important to biodiversity grows by 0.4796% with an increase in medium and high-tech exports by 1% of manufactured exports.

Table 1. Regression in the function $Ecology_1=F(I_{4.0(1)}, I_{4.0(2)}, I_{4.0(3)})$

Regression Statistics	
Multiple R	0.5991
R-Square	0.3589
Adjusted R-Square	0.3426
Standard Error	16.2893
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	3	17526.2105	5842.0702	22.0172	$2.2*10^{-11}$
Residual		11831310.2589	265.3412		
Total	121	48836.4694			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	-7.6754	2.8740	-2.6707	0.0086	-13.3666	-1.9842
$I_{4.0(1)}$	0.4022	0.1563	2.5737	0.0113	0.0927	0.7116
$I_{4.0(2)}$	-0.5617	0.2112	-2.6596	0.0089	-0.9799	-0.1435
$I_{4.0(3)}$	0.3005	0.1206	2.4911	0.0141	0.0616	0.5394

Source: calculated and compiled by the authors.

Table 2. Regression in the function $Ecology_2=F(I_{4.0(1)}, I_{4.0(2)}, I_{4.0(3)})$

Regression Statistics	
Multiple R	0.3291
R-Square	0.1083
Adjusted R-Square	0.0857
Standard Error	23.4867
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	3	7908.4274	2636.1425	4.7789	0.0035
Residual	118	65091.5592	551.6234		
Total	121	72999.9866			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	35.9457	4.1438	8.6746	2.7E-14	27.7399	44.1516
$I_{4.0(1)}$	-0.1470	0.2253	-0.6524	0.5154	-0.5931	0.2992
$I_{4.0(2)}$	-0.4611	0.3045	-1.5143	0.1326	-1.0641	0.1419
$I_{4.0(3)}$	0.4796	0.1740	2.7568	0.0068	0.1351	0.8240

Source: calculated and compiled by the authors.

Table 3. Regression in the function $Ecology_3=F(I_{4.0(1)}, I_{4.0(2)}, I_{4.0(3)})$

Regression Statistics	
Multiple R	0.2851
R-Square	0.0813
Adjusted R-Square	0.0579
Standard Error	28.5550
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	3	8515.1019	2838.3673	3.4810	0.0182
Residual	118	96215.9154	815.3891		
Total	121	104731.0173			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	39.7686	5.0380	7.8937	1.7E-12	29.7919	49.7452
$I_{4.0(1)}$	-0.4645	0.2739	-1.6958	0.0926	-1.0069	0.0779
$I_{4.0(2)}$	-0.5212	0.3702	-1.4079	0.1618	-1.2543	0.2119
$I_{4.0(3)}$	0.6369	0.2115	3.0112	0.0032	0.2180	1.0557

Source: calculated and compiled by the authors.

The results from Table 3 show that the change in mean area that is protected in freshwater sites important to biodiversity by 28.51% is due to the influence of factors of industry 4.0. Fischer's F-test has been passed at a significance level of 0.05, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in mean area that is protected in freshwater sites important to biodiversity as industry 4.0 develops:

$$Ecology_3=39.7686-0.4645I_{4.0(1)}-0.5212I_{4.0(2)}+0.6369I_{4.0(3)} \quad (4)$$

Equation (4) means that mean area that is protected in freshwater sites important to biodiversity is reduced by 0.4645% with an increase in medium and high-tech manufacturing value added by 1% of manufacturing value added. Mean area that is protected in freshwater sites important to biodiversity is reduced by 0.5212% with an increase in ICT goods exports by 1% of total goods exports. Mean area that is protected in freshwater sites important to biodiversity grows by 0.6369% with an increase in medium and high-tech exports by 1% of manufactured exports.

The regression analysis of the dependence of the state of the environment and the level of development of industry 4.0 on the factor of environmental certification of product quality has also been carried out. The results obtained are shown in Tables 4-9.

Table 4. Regression in the function $Ecology_1$=F(EnvSert)

Regression Statistics	
Multiple R	0.2555
R-Square	0.0653
Adjusted R-Square	0.0575
Standard Error	19.5041
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	1	3187.0851	3187.0851	8.3780	0.0045
Residual	120	45649.3843	380.4115		
Total	121	48836.4694			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	8.3427	2.2231	3.7528	0.0003	3.9411	12.7442
EnvSert	0.2512	0.0868	2.8945	0.0045	0.0794	0.4230

Source: calculated and compiled by the authors.

The results from Table 4 show that the change in carbon pricing score by 25.55% is explained by the influence of the factor of environmental certification of product quality. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in the carbon pricing score with the environmental certification of product quality:

$$Ecology1=8.3427+0.2512EnvSert \quad (5)$$

Equation (5) means that carbon racing score rises by 0.2512 points with an increase of ISO 14001 environmental certificates/bn PPP$ GDP by 1 point.

The results from Table 5 show that the change in mean area that is protected in terrestrial sites important to biodiversity by 32.69% is explained by the influence of the factor of environmental certification of product quality. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in mean area that is protected in terrestrial sites important to biodiversity with the environmental certification of product quality:

$$Ecology2=41.6025+0.3929EnvSert \quad (6)$$

Equation (6) means that mean area that is protected in terrestrial sites important to biodiversity rises by 0.3929% with an increase of ISO 14001 environmental certificates/bn PPP$ GDP by 1 point.

Table 5. Regression in the function $Ecology_2$=F(EnvSert)

Regression Statistics						
Multiple R	0.3269					
R-Square	0.1068					
Adjusted R-Square	0.0994					
Standard Error	23.3095					
Observations	122					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	7799.9664	7799.9664	14.3558	0.0002	
Residual	120	65200.0202	543.3335			
Total	121	72999.9866				
	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	41.6025	2.6568	15.6588	$8.8*10^{-31}$	36.3422	46.8628
EnvSert	0.3929	0.1037	3.7889	0.0002	0.1876	0.5982

Source: calculated and compiled by the authors.

Table 6. Regression in the function $Ecology_3$=F(EnvSert)

Regression Statistics						
Multiple R	0.4253					
R-Square	0.1809					
Adjusted R-Square	0.1740					
Standard Error	26.7376					
Observations	122					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	18943.1734	18943.1734	26.4977	$1*10^{-6}$	
Residual	120	85787.8439	714.8987			
Total	121	104731.0173				
	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	38.7907	3.0475	12.7285	$5.2*10^{-24}$	32.7568	44.8247
EnvSert	0.6123	0.1190	5.1476	$1*10^{-6}$	0.3768	0.8479

Source: calculated and compiled by the authors.

The results from Table 6 show that the change in mean area that is protected in freshwater sites important to biodiversity by 42.53% is explained by the influence of the factor of environmental certification of product quality. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in mean area that is protected in freshwater sites important to biodiversity as the environmental certification of product quality:

Ecology3=38.7909+0.6123EnvSert (7)

Equation (7) means that the mean area that is protected in freshwater sites important to biodiversity rises by 0.6123% with an increase in ISO 14001 environmental certificates/bn PPP$ GDP by 1 point.

The results from Table 7 indicate that the change in medium and high-tech manufacturing value added by 30.04% is explained by the influence of the factor of environmental certification of product quality. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in medium and high-tech manufacturing value added with environmental certification of product quality:

I40(1)=23.6551+0.2617EnvSert (8)

Equation (8) means that medium and high-tech manufacturing value added rises by 0.2617% of manufacturing value added when ISO 14001 environmental certificates/bn PPP$ GDP increases by 1 point.

Table 7. Regression in the function $I_{40(1)}$=F(EnvSert)

Regression Statistics	
Multiple R	0.3004
R-Square	0.0902
Adjusted R-Square	0.0827
Standard Error	17.0502
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	1	3460.4780	3460.4780	11.9036	0.0008
Residual	120	34885.0309	290.7086		
Total	121	38345.509			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	23.6551	1.9434	12.1722	$1.1*10^{-22}$	19.8074	27.5029
EnvSert	0.2617	0.0759	3.4502	0.0008	0.1115	0.4119

Source: calculated and compiled by the authors.

Table 8. Regression in the function $I_{40(2)}$=F(EnvSert)

Regression Statistics	
Multiple R	0.1215
R-Square	0.0148
Adjusted R-Square	0.0066
Standard Error	8.2065
Observations	122

ANOVA

	df	*SS*	*MS*	*F*	*Signi-ficance F*
Regression	1	121.1642	121.1642	1.7991	0.1824
Residual	120	8081.6695	67.3472		
Total	121	8202.8337			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	3.4779	0.9354	3.7182	0.0003	1.6259	5.3299
EnvSert	0.0490	0.0365	1.3413	0.1824	-0.0233	0.1213

Source: calculated and compiled by the authors.

Fischer's F-test has been passed at a significance level of 0.20, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in ICT goods exports with the environmental certification of product quality:

$$I40(2)=3.4779+0.0490EnvSert \quad (9)$$

Equation (9) means that ICT goods exports grow by 0.0490% of total goods exports with an increase of ISO 14001 environmental certificates/bn PPP$ GDP by 1 point.

The results from Table 9 indicate that the change in medium and high-tech exports by 39.68% is due to the influence of the factor of environmental certification of product quality. Fischer's F-test has been passed at a significance level of 0.01, which indicates the reliability of the results of regression analysis and makes it possible to mathematically write down the pattern of changes in medium and high-tech exports as the environmental certification of product quality:

$$I40(3)=29.9261+0.4625EnvSert \quad (10)$$

Equation (10) means that medium and high-tech exports grow by 0.4625% of manufactured exports with an increase of ISO 14001 environmental certificates/bn PPP$ GDP by 1 point.

Thus, the regression coefficients in equations (8)-(10) have taken positive values. This proves the hypothesis H1 and confirms that environmental quality certification accelerates the development of industry 4.0, providing an increase in: 1) medium and high-tech manufacturing value added; 2) ICT goods exports and 3) medium and high-tech exports. Correlation coefficients in Tables 1-3 (59.91%; 32.91%; 28.51% respectively) are similar correlation coefficients in Tables 4-6 (25.55%; 32.69%; 42.53% respectively).

Table 9. Regression in the function $I_{40(3)}$=F(EnvSert)

Regression Statistics						
Multiple R	0.3968					
R-Square	0.1574					
Adjusted R-Square	0.1504					
Standard Error	21.9523					
Observations	122					
ANOVA						
	df	*SS*	*MS*	*F*	*Signi-ficance F*	
Regression	1	10805.9181	10805.9181	22.4233	$6*10^{-6}$	
Residual	120	57828.6462	481.9054			
Total	121	68634.5644				
	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	29.9261	2.5021	11.9603	$3.5*10^{-22}$	24.9721	34.8801
EnvSert	0.4625	0.0977	4.7353	6E-06	0.2691	0.6558

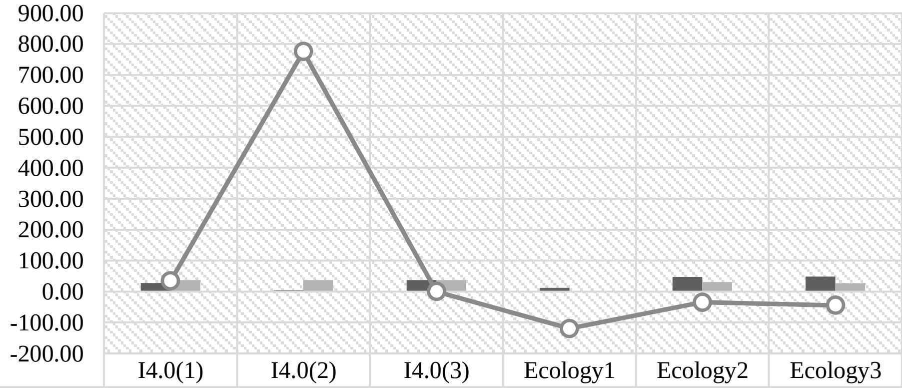
Source: calculated and compiled by the authors.

This proves the hypothesis of H_2 and confirms that environmental quality certification has almost as much impact on the environment as the development of industry 4.0.

4.2. Environmental scenarios of entrepreneurship development in industry 4.0 depending on the approach to TQM

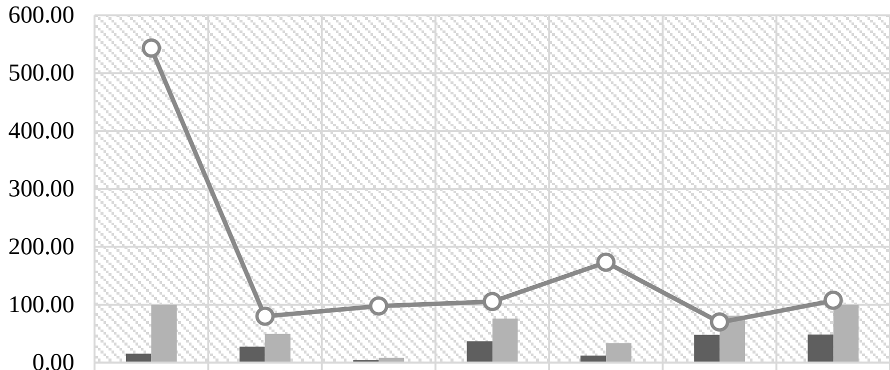
To solve the second task and create environmental scenarios for the development of entrepreneurship in industry 4.0, depending on the approach to TQM, the results of econometric modeling have been used. To make a scenario of industrial development, the values of factor variables at the maximum level among them have been substituted into equations (1)-(3) (the maximum is observed at $I_{4.0(3)}$ and is 37,12) (Fig. 1).

As shown in Fig. 1, the environmental consequences of the scenario of industrial development of entrepreneurship in industry 4.0 are extremely unfavorable. Thus, carbon pricing score at EUR60/tCO_2 reduces from 12.25 points in 2022 to 0 (-119.91%). Mean area that is protected in terrestrial sites important to biodiversity decreases from 47.72% in 2022 to 31.17% (-34.67%). Mean area that is protected in freshwater sites important to biodiversity decreases from 48.32% to 26.82% (-44.50%).To create an alternative scenario for sustainable development, the maximum possible value of the factor variable (EnvSer=100) has been substituted into equations (4)-(9) (Fig. 2).



	I4.0(1)	I4.0(2)	I4.0(3)	Ecology1	Ecology2	Ecology3
The global average value in 2022	27.73	4.24	37.12	12.25	47.72	48.32
The global average value according to the scenario	37.12	37.12	37.12	0.00	31.17	26.82
The increase in the global average value according to the scenario compared to 2022, %	33.87	775.45	-0.01	-119.91	-34.67	-44.50

Figure 1. Ecological scenario of industrial development of entrepreneurship in industry 4.0
Source: calculated and constructed by the authors



	EnvSert	I4.0(1)	I4.0(2)	I4.0(3)	Ecology1	Ecology2	Ecology3
The global average value in 2022	15.56	27.73	4.24	37.12	12.25	47.72	48.32
The global average value according to the scenario	100.00	49.83	8.38	76.17	33.46	80.89	100.00
The increase in the global average value according to the scenario compared to 2022, %	542.51	79.69	97.52	105.19	173.10	69.53	107.00

Figure 2. Ecological scenario of sustainable entrepreneurship development in industry 4.0
Source: calculated and constructed by the authors.

As shown in Fig. 2, the environmental consequences of the scenario of sustainable entrepreneurship development in industry 4.0, on the contrary, are very unfavorable. Thus, the carbon pricing score at EUR60/co2 rises to 33.46 points (+173.10%). Mean area that is protected in terrestrial sites important to biodiversity increases to 80.89% (+69.53%). Mean area that is protected in freshwater sites important to biodiversity rises to 100% (+107%)

At the same time, the development of industry 4.0 is also achieved. Thus, medium and high-tech manufacturing value added increases from 27.73% of manufacturing value added in 2022 to 49.83% of manufacturing value added (+79.69%). ICT goods exports grow from 4.24% of total goods exports in 2022 to 8.38% of total goods exports (+97.52%). Medium and high-tech exports increase from 37.12% of manufactured exports in 2022 to 76.17% of manufactured exports (+105.19%). Therefore, the scenario of sustainable entrepreneurship development in industry 4.0 is preferable.

4.3. "Green 4.0": a new dimension of product quality in industry 4.0

To solve the third problem and substantiate "Green 4.0" as a new measurement of the quality of products of business entities in industry 4.0, different measurements of product quality are compared through the prism of the stages of the life cycle of products of industry 4.0 in Table 10.

Table 10. Comparison of quality measurements of products of business entities in industry 4.0 through the prism of stages of their life cycle

Stages of the life cycle of products in industry 4.0	**Quality measurement of products of business entities in industry 4.0**	
	Quality 4.0	**«Green 4.0»**
Purchase of raw materials	mainly primary raw materials	if possible – secondary raw materials
Design (industrial and manufacturing engineering)	with a focus on the technical properties of the products	taking into account also the environmental properties of the products
Production	cost-effective (the most profitable)	environmentally friendly
Transportation/delivery (management information systems)	cost-effective logistics; promotion with a focus on the technical properties of products	environmentally responsible logistics (eco-transport); promotion with a focus on the environmental properties of products
Consumption	non-ecological consumption	environmentally responsible consumption (energy efficient, with bio-packaging)
Final processing and/or recycling	sorting of production and consumption waste	recycling
Final disposal	if possible, environmentally-safe disposal of waste	environmentally-safe disposal of non-recyclable waste
Result: compliance with quality standards	ISO-9001	ISO-9001 and ISO-14001

Source: developed by the authors.

As shown in Table 10, at the stage of purchasing raw materials, Quality 4.0 assumes the use of mainly primary raw materials, and "Green 4.0" – secondary raw materials, if possible. At the design stage (industrial and manufacturing engineering), Quality 4.0 involves designing with a focus on the technical properties of products, and "Green 4.0" – taking into account also the environmental properties of products.

At the production stage, Quality 4.0 implies cost-effective (the most profitable) production and "Green 4.0" assumes environmentally friendly production. At the stage of transportation/ delivery (management information systems), Quality 4.0 implies cost-effective logistics, as well as promotion with a focus on the technical properties of products, and "Green 4.0" presupposes environmentally responsible logistics (preference for eco-transport), as well as promotion with a focus on the environmental properties of products.

At this stage of use, quality 4.0 presupposes non-ecological consumption, and "Green 4.0" implies environmentally responsible consumption (energy-efficient, with bio-packaging).

At the stage of final processing and/or recycling, Quality 4.0 presupposes sorting of production and consumption waste, and "Green 4.0" implies recycling. At the stage of final disposal, Quality 4.0 assumes, if possible, environmentally safe disposal of waste, and "Green 4.0" involves the environmentally safe disposal of non-recyclable waste.

Thus, Quality 4.0 corresponds only to the ISO-9001 standard, and "Green 4.0" complies with the ISO–9001 and ISO-14001 standards, and therefore is more preferable.

4.4. The new approach to TQM of entrepreneurship in industry 4.0 to achieve the quality of "Green 4.0"

To solve the fourth task, the authors have developed a new approach to TQM of entrepreneurship in industry 4.0 to achieve the quality of "Green 4.0". Alternative approaches to product quality management in industry 4.0 are compared from the standpoint of differences in the implementation of TQM principles in Table 11.

Table 11. Comparison of the alternative approaches to product quality management of industry 4.0 from the standpoint of differences in the implementation of the principles of TQM

Principles of TQM	Application of principles in the approach to TQM in industry 4.0	
	Standardization of Quality 4.0	**Environmental standardization of the quality of "Green 4.0"**
1. Customer orientation	only to the information society	also to sustainable communities
2. Leadership	only in the field of digital competitiveness of products	also in the field of corporate environmental responsibility
3. Interaction of people	digital personnel	"green" digital personnel
4. Process approach (management of processes and systems as a whole according to the PDCA cycle: "Plan - Do - Check – Act")	P: planning of optimal utilization of production capacity ("economies of scale", profit); D: optimization of economic parameters of production; C: checking the economic efficiency of production; A: actions to improve the technical properties of products.	P: environmentally responsible production planning; D: introduction of environmental innovation; C: environmental quality control, monitoring of consequences for nature; A: actions to improve the environmental properties of products.
5. Improvement	only technical properties of products and processes	also environmental properties of products and processes
6. Evidence-based decision-making	economic criteria for decision-making	a set of environmental, social and economic criteria for decision-making
7. Relationship Management	in the ecosystem "industry 4.0-consumers of its products"	in the ecosystem "industry 4.0-sustainable communities-nature"

Source: developed by the authors.

As shown in Table 1, the principle of consumer orientation in the existing approach assumes an orientation only towards the information society, and in the new approach, in addition, there is an orientation towards sustainable communities. The principle of leadership in the existing approach assumes leadership only in the field of digital competitiveness of products, and in the new approach, this principle is also implemented in the field of corporate environmental responsibility. The principle of interaction of people in the existing approach involves the interaction of digital personnel, and the new approach also implies the interaction of "green" digital personnel.

The principle of managing processes and systems as a whole according to the PDCA cycle: "Plan - Do - Check – Act") in the existing approach assumes P: planning for optimal utilization of production capacity ("economies of scale", profit); D: optimization of economic parameters of production; C: checking the economic efficiency of production; A: actions to improve technical properties of products. In the new approach – P: environmentally responsible production planning; D:

introduction of environmental innovations; C: environmental quality control, monitoring of consequences for nature; A: actions to improve the environmental properties of products.

The principle of improvement in the existing approach involves improving only the technical properties of products and processes, and the new approach also involves improving the environmental properties of products and processes. The principle of evidence-based decision-making in the existing approach assumes consideration of exclusively economic criteria for decision-making, and the new approach also includes consideration of a set of environmental, social and economic criteria for decision-making. The principle of relationship management in the existing approach implies relationship management in the ecosystem “industry 4.0-consumers of its products”, and in the new approach – in the ecosystem “industry 4.0-sustainable communities-nature”.

5. DISCUSSION

The article contributes to the literature through the development of the TQM concept, justifying the expediency of choosing environmental certification of product quality as a new vector of sustainable entrepreneurship development in industry 4.0. The increment of scientific knowledge achieved in the article is indicated in Table 12.

As reflected in Table 12, the increment of scientific knowledge has been achieved in the article, firstly, due to the formation of a new vision of quality and the way to achieve it in the implementation of the vector of sustainable development of industry 4.0. In contrast to Ali and Johl (2023), Maganga and Taifa (2023), the authors of this article have proposed a new approach to TQM of entrepreneurship in industry 4.0: environmental standardization of the product quality in industry 4.0 instead of the standardization of quality 4.0 characteristic of the industrial vector. In contrast to the position of such authors as Alketbi et al. (2022) Anvari and Anvari (2023), a new approach to the TQM of entrepreneurship in industry 4.0 has been proposed - environmental standardization of product quality in industry 4.0 - instead of standardization of Quality 4.0, characteristic of the industrial vector.

Table 12. Increment of scientific knowledge achieved in the article

Comparison of vectors of entrepreneurship development in industry 4.0		**The vector of entrepreneurship development in industry 4.0**	
		Existing: industrial development	**New proposed: sustainable development**
Vision of quality and ways to achieve it	**Quality measurement** of products of business entitites in industry 4.0	Quality 4.0 (Ali and Johl, 2023; Maganga and Taifa, 2023)	“Green 4.0”
	Approach to TQM of entrepreneurship in industry 4.0	Standardization of Quality 4.0 (Alketbi et al., 2022; Anvari and Anvari, 2023)	Environmental standardization of product quality in industry 4.0
Answers to RQs	**RQ₁:** What are the implications of environmental quality certification for industry 4.0?	Environmental quality certification hinders the development of industry 4.0 (Bashir et al., 2022; Castillo-Martinez et al., 2021)	Environmental quality certification accelerates the development of industry 4.0, explaining the growth: • Medium and high-tech manufacturing value added by 30.04%; • ICT goods exports by 12.15%; • Medium and high-tech exports by 39.68%.
	RQ₂: To what extent can the advantages of environmental quality certification mitigate the environmental damage caused by industry 4.0?	Industry 4.0 has a much greater impact on the environment than environmental quality certification (Bravi et al., 2020; Steblyakova et al., 2022; Yarahmadi and Soleimani-Alyar, 2021)	Environmental Quality Certification (Ecocert) has almost as much impact on the environment as the development of industry 4.0 ($I_{4.0}$): • Correlation of Carbon Pricing Score at EUR60/tCO_2 with EnvSert: 25.55%, with $I_{4.0}$: 59.91%; • Correlation of Mean area that is protected in terrestrial sites important to biodiversity with EnvSert: 32.69%, with $I_{4.0}$: 32.91%; • Correlation of Mean area that is protected in freshwater sites important to biodiversity with EnvSert: 42.53%, with $I_{4.0}$: 28.51%.

Source: developed by the authors.

Secondly, the article has achieved the growth of scientific knowledge due to the received new answers to RQs. In contrast to the opinion of Bashir et al. (2022), Castillo-Martinez et al. (2021), it has been proved that environmental quality certification does not restrain, but accelerates the development of industry 4.0, explaining the increase: 1) Medium and high-tech manufacturing value added by 30.04%; 2) ICT goods exports by 12.15%; 3) Medium and high-tech exports by 39.68% (this is a new answer to RQ_1, which has proved the hypothesis H_1).

In contrast to Bravi et al. (2020), Steblyakova et al. (2022), Yarahmadi and Soleimani-Alyar (2021), who argue that industry 4.0 has a much greater impact on the environment than environmental quality certification, which is why the latter is not able to mitigate the damage of industry 4.0 to the environment, it has been proved that environmental quality certification (EnvSert) has almost as much impact on the environment as the development of industry 4.0 ($I_{4.0}$) (this is a new answer to RQ_1, which has proved the hypothesis H_1). The correlation of Carbon Pricing Score at EUR60/tCO_2 with EnvSert: 25.55%, with $I_{4.0}$: 59.91%. The correlation of Mean area that is protected in terrestrial sites important to biodiversity with EnvSert: 32.69%, with $I_{4.0}$: 32.91%. The correlation of Mean area that is protected in freshwater sites important to biodiversity with EnvSert: 42.53%, with $I_{4.0}$: 28.51%

6. CONCLUSION

So, a new vector of entrepreneurship development in industry 4.0 has been proposed – the vector of its sustainable development based on environmental certification of product quality. Its preference has also been justified. The authors' main conclusion is that environmental quality certification accelerates the development of industry 4.0 and has almost as much impact on the environment as the development of industry 4.0.

The considered environmental scenarios of entrepreneurship development in industry 4.0, depending on the approach to TQM, have shown that in the industrial scenario, environmental costs are very high and include: 1) reduction of carbon pricing score at EUR60/tCO_2 by 119.91%; 2) reduction of mean area that is protected in terrestrial sites important to biodiversity decreases by 34.67%; 3) reduction of mean area that is protected in freshwater sites important to biodiversity by 44.50%.

The alternative to it is the scenario of sustainable entrepreneurship development in industry 4.0, which is preferable, since it allows not only to enhance the results of industry 4.0 – to increase medium and high-tech manufacturing value added by 79.69%, ICT goods exports – by 97.52%, medium and high-tech exports – by 105.19% – but also to improve the state of the environment through: 1) increase in carbon pricing score at EUR60/tCO_2 by 173.10%; 2) increase in mean area that is protected in terrestrial sites important to biodiversity by 69.53%; 3) increase in mean area that is protected in freshwater sites important to biodiversity by 107%.

The theoretical significance of the results of this article is related to the fact that it has proposed a new dimension of product quality of business entities of industry 4.0: “Green 4.0”, and has also developed a new approach to TQM of entrepreneurship in industry 4.0 to achieve the quality of “Green 4.0” and the implementation of the vector of sustainable development of industry 4.0. The practical significance of the authors' conclusions and recommendations is that they will allow the fullest disclosure of the potential of entrepreneurship development in industry 4.0 due to the systemic improvement of the quality of its products in unity and consistency of its technical and environmental properties.

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