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# INTEGRATION OF SUSTAINABLE DEVELOPMENT GOALS INTO THE QUALITY MANAGEMENT SYSTEM OF ENTERPRISES IN INDUSTRY 4.0

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*Sustainable Development Goals (SDGs), Integration of the SDGs into Management, Quality Management System, Enterprises of Industry 4.0, Quality 4.0.*

A B S T R A C T

*The article aims to determine the current level, reveal the prospects and justify the advantages of further integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action". Global monitoring of the practice of integrating the SDGs into the quality management system of enterprises in industry 4.0 based on the international statistics of the United Nations and the World Bank for 2019-2021 has been carried out. Correlation analysis showed that in both categories of countries considered, the degree of integration of the SDGs into quality 4.0 is moderate. In 2021, it is estimated at 22.83% in developing countries, and at 7.54% in developed countries. The key conclusion of the study is that the SDGs are not yet fully integrated into quality 4.0, which, in particular, has been hindered by the pandemic and the COVID-19 crisis – more serious changes in the information system and product quality management in industry 4.0 are needed to solve this problem. In particular, the following conclusions have been made. The prospects for sustainable development of developed and developing countries in the "Decade of Action" are associated with further efforts to fully integrate the SDGs into the quality management system of enterprises in industry 4.0. This conclusion is supported by the authors' forecast, which in turn is based on an econometric model obtained using the regression analysis method. The theoretical significance of the author's conclusions is that they have formed a reliable evidence base that, unlike other sectors of the economy, the degree of integration of the SDGs into the product quality management system in industry 4.0 is much lower and insufficient for the implementation of the 17 UN SDGs in the "Decade of Action". The practical significance of the results of the study is explained by the fact that they allow taking into account the specifics of developed and developing countries when integrating the SDGs into management practices of quality 4.0.*



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## 1. INTRODUCTION

Historically, scientific and technological progress and initiatives in the field of sustainable development have been two parallel processes, not only independent, but also hindering each other. With technological advances, industrial revolutions increased production capacities, accelerated the pace of economic growth to respond more fully to the growing demands of consumers, but at the same time, they entailed ever greater social and environmental costs.

The social costs of industrial revolutions are associated with the release of personnel due to the automation process, as well as with the need for social adaptation to more technically complex production, sales and consumption of products (Shevyakova et al., 2019). Environmental costs consist in an increase in the energy and resource intensity of industrial production, as well as the growth of industrial waste that contaminates the environment (Steblyakova et al., 2022). The higher was the level of industrial development of the economy, the wider was the gap between technology and economy, on the one hand, and society with nature, on the other hand (Mavlyanova et al., 2015; Turginbayeva and Shaikh, 2022).

Accordingly, with the development of initiatives in the field of sustainable development, requests and expectations for improving the state of the environment and its associated social well-being have increased. Their achievement was viewed through the limitations of industrial economic growth and the slowdown of scientific and technological progress. These initiatives reached their apogee, acquiring a global scale in 2015 in connection with the adoption by the United Nations of the seventeen Sustainable Development Goals (17 UN SDGs). It is not a coincidence that this happened in the conditions of the dominance of the post-industrial (specializing in the service sector) economy.

The problem is that by the "Decade of Action" (starting in 2020), the scale of the contradiction of the processes under consideration has become critical, which is why their further parallel implementation has become fundamentally impossible. The contradiction of the processes under consideration can be resolved either in favor of one of them, or through their integration. Since both of these processes are extremely important for the socio-economic development of modern economic systems, it is impossible to make a choice in favor of one of them.

Thus, further industrial growth of the economy in the context of industry 4.0, while disregarding initiatives in the field of sustainable development, is fraught with climate and other environmental crises that have a detrimental impact on agriculture, healthcare and the quality of life in general (Popkova and Sergi, 2022). Similarly, artificial deceleration of scientific and technological progress and de-industrialization in the interests of sustainable development will disrupt the natural course of human civilization, exacerbate the shortage of industrial products and increase social inequality. (Sergi and Popkova, 2022).

In this regard, the most optimal solution to the problem is seen through the transition from inhibition to catalysis of the processes under consideration. It is noteworthy that this decision is seen in the 17 UN SDGs themselves, which include the social block (SDG1,3-5,10,16), the environmental block (SDG2,6,7,11-15,17) and the economic and technological block (SDG8,9). This determines the relevance of integrating the SDGs into the quality management system of enterprises in industry 4.0.

In the existing literature, the issues of the implementation of the SDGs, as well as the issues of information systems and product quality management in industry 4.0 are studied separately. Publications on the topic of integrating the SDGs into business management represent a separate layer of quite numerous studies (Liang et al., 2023; Wang et al., 2023). Although this topic has been worked out quite thoroughly (Abdul Latif et al., 2023; Litvaj et al., 2023; Chairina and Tjahjadi, 2023), it is distantly related to the problem posed in the article and therefore does not provide its solution. Thus, the degree of integration of the SDGs into the quality management system of enterprises in industry 4.0 remains unknown, which acts as a gap in the literature. In an effort to fill the identified gap in the literature, this article aims to determine the current level, reveal the prospects and justify the advantages of further integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action". The chosen purpose determines the research tasks of this article.

The first task is to conduct global monitoring of the practice of integrating the SDGs into the quality management system of enterprises in industry 4.0 and to establish the particularities of developed and developing countries. The second task is to determine the prospects for sustainable development of developed and developing countries with the "Decade of Action" depending on the integration of the SDGs into the quality management system of enterprises of industry 4.0. The third task is to propose a vision of the integration of the SDGs into the quality management system of enterprises of industry 4.0 in the "Decade of Action".

## 2. LITERATURE REVIEW

The theoretical basis of this research is the fundamental provisions of the scientific concept of information systems and product quality management in industry 4.0 (Sharma, 2023; Stefanović et al., 2019). Various issues of integrating the SDGs into the practice of product

quality management are discussed in the publications of Banjanin et al. (2022), Fonseca and Carvalho (2019), Henriques et al. (2022), Khan et al. (2022), Saini et al. (2023), Wang et al. (2022), Gamaliel et al. (2023) in which they note both the successes achieved and the limitations on the way of this integration, mainly driven by the continuing contradiction of the ideas of technological and sustainable development.

The management system of quality 4.0, taking into account the specifics of products in industry 4.0 related to the use of automated production facilities for its production, "smart" technologies for distribution, as well as the high-tech nature of these products, is considered in the available works of Misita and Milanovic, D.D. (2019), Popkova (2019), Popkova and Giyzov (2021), Thach et al. (2021), Woźniak et al. (2022), Zimon et al. (2022).

The literature review makes it possible to conclude that the issues of integrating the SDGs into product quality management, as well as the issues of quality 4.0, have been studied in sufficient detail in the available publications, but mainly separately. Due to the lack of existing literature, there is **a gap** at the boundary of the issues mentioned, which is associated with insufficient knowledge and therefore with the uncertainty to what extent the SDGs are integrated into the quality management system of enterprises in industry 4.0, how the degree of this integration changes over time, how it differs among countries and what benefits it provides for sustainable development. In order to fill the identified gap in the literature, the following four research questions are formulated in this article (RQs).
**$RQ_1$:** To what extent are the SDGs integrated into the quality management system of enterprises in industry 4.0? The available works of Luttikhuis and Wiebe (2023), Zhilin et al. (2020) on the topic of general quality management indicate a strong integration of the SDGs into the practices of this kind of management. However, these publications do not take into account the specifics of quality 4.0, which is why $RQ_1$ remains open.

Based on the publications of Barquet et al. (2022), Dionisio et al. (2023), which note the contradiction of the Fourth Industrial Revolution to the interests of sustainable development, this article puts forward **the hypothesis $H_1$** that the SDGs are poorly integrated into the quality management system of enterprises in industry 4.0. The logic of the hypothesis is that to achieve a more complete integration of the SDGs into quality 4.0, targeted management measures are necessary, which require serious justification and scientific study – this article seeks to provide them.
**$RQ_2$:** Which category of countries demonstrates a higher degree of integration of the SDGs into the quality management system of enterprises in industry 4.0? Available publications by Van Tulder et al. (2021), Yu et al. (2022) state that the degree of integration of the SDGs into the quality management system of enterprises in industry 4.0 is higher in developed countries due to the general logic of a higher level of socio-economic and technological development of developed countries, as well as their leadership in the field of "green" economic growth and sustainable development.

Nevertheless, based on the works of Baffoe et al. (2021), Zhou et al. (2022), which note the significant successes of developing countries in recent years in the field of sustainable development, this article puts forward **the hypothesis $H_2$** that the degree of integration of the SDGs into the quality management system of enterprises in industry 4.0 is the highest in developing countries. The logic of the hypothesis is that the peculiarity of developing countries is the most dynamic development, accelerated economic growth and active support for international social and environmental initiatives, which allows them to quickly expand their achievements in these areas.

Special attention should be paid to the special context of the COVID-19 pandemic and crisis, which had a strong impact on the sustainable development of the world economic system at the very beginning of the "Decade of action". In this regard, **$RQ_3$** is posed: How has COVID-19 affected the degree of integration of the SDGs into the management system of quality 4.0? The published works of Elavarasan et al. (2022), Srinivasan and Eden (2021) indicate that under the influence of the pandemic and the COVID-19 crisis, the degree of integration of the SDGs into the management system of quality 4.0 has increased.

As an argument, it is pointed out that additional environmental initiatives in the field of sustainable development have been launched to prevent future environmental crises and epidemics, and additional social initiatives are aimed at mitigating the social consequences of pandemics and lockdowns. In contrast to this position, in the works of Colombage et al. (2023), van Zanten and van Tulder (2020), which note a shortage of financial resources for intensifying sustainable development initiatives due to the COVID-19 crisis, **the hypothesis $H_3$** is put forward that the degree of integration of the SDGs into the management system of quality 4.0 has decreased in the context of the pandemic and the COVID-19 crisis.

**$RQ_4$:** What is the significance of integration into the quality management system of enterprises in industry 4.0 for the implementation of the SDGs in the "Decade of action"? The available evidence in the scientific literature of authors such as Palomares et al. (2021), Singh and Ru (2023) suggests that integration into quality 4.0 is of minor importance: the SDGs will be achieved in any case during the "Decade of Action", and therefore no additional measures are required.

However, based on the works of Khalid et al. (2020), Montiel et al. (2021), which indicate the barriers to the implementation of the SDGs in the "Decade of Action" caused by the recession of the world economic system, in particular, against the background of the COVID-19 pandemic and crisis, this article puts forward **the hypothesis $H_4$** that integration into the quality management system of enterprises in industry 4.0 is important for the implementation of the SDGs in the "Decade of Action".

The logic of the hypothesis is that rapidly developing high-tech industries largely determine the growth of modern digital economies. The significant scale of industry 4.0 can greatly sustain the achievements in the field of sustainable development when integrating the SDGs into quality 4.0. The successful experience of industry 4.0 can also serve as a landmark example for enterprises from other sectors of the economy – a powerful incentive to integrate the SDGs into the industry practices of quality management.
To verify hypotheses, this article examines in detail the international experience of integrating SDGs into the quality management system of enterprises in industry 4.0. The authors conduct a comprehensive analysis of official international statistics in the context of a cluster of developed countries and a cluster of developing countries, which makes it possible to identify their specifics. High-precision economic and mathematical modeling of the global experience based on a reliable methodology of econometrics allows us to form a convincing evidence base for testing all hypotheses put forward in the article.

## 3. MATERIALS AND METHODOLOGY

The sample of this study includes 192 countries for which statistics of the World Bank (2023) and the UN (2023) are available. Developing countries predominate among them (their combined share is 80.73%), of which 25.52% are Africa countries (49 countries), 13.54% are E. Europe & C. Asia countries (26 countries), 10.94% are East & South Asia countries (21 countries), 15.63% are LAC countries (30 countries), 8.85% are MENA countries (17 countries), 6.25% – Oceania countries (12 countries). The share of developed countries (OECD) is 19.27% (37 countries).

The time frame of the study covers 2019-2021. This makes it possible to take into account the experience of the pre-pandemic (2019), the pandemic period (2020) and the post-pandemic (2021) period. The following control variables are used during the study: 1) Sustainable Development Index (UN, 2023), high-technology exports (% of manufactured exports) (World Bank, 2023), as well as the results of the implementation of the SDGs (Goal 1-17 Scores) (UN, 2023). The factual basis of the study is given in tabular form in the Microsoft Excel file attached to this article.

The first task of this study is to conduct global monitoring of the practice of integrating SDGs into the quality management system of enterprises in industry 4.0 and to identify the particularities of developed and developing countries. To solve this problem, arithmetic averages are calculated and the dynamics of the implementation of the SDGs (sustainable development index), the development of industry 4.0 (high-technology exports) and the degree of their integration in 2019-2021 are determined – separately in developing and developed countries.

The degree of integration ofsustainable development goalsinto quality 4.0 is determined using the correlation analysis method. To do this, the correlation of the sustainable development index with high-technology exports ($r_{sdi,hte}$) is calculated. The dynamics of the degree of integration of the SDGs into quality in industry 4.0 in 2019-2021 in each category of countries is also determined. To do this, there is a correlation of high-technology exports with the results of the implementation of each of the 17 UN SDGs (Goal 1-17 Scores).

The hypothesis $H_1$ is considered proven if $r_{sdi,hte}$ is below 50%. The hypothesis of $H_2$ is considered as proven if $r_{sdi,hte}$ is higher in developing countries. An additional confirmation of the hypothesis $H_2$ is the lower values of the correlation coefficients of high-technology exports with the results of the implementation of each of the 17 UN SDGs (Goal 1-17 Scores) in developed countries or a greater number of negative correlation coefficients than in developing countries. The hypothesis $H_3$ is considered as proven if $r_{sdi,hte}$ in 2021 is lower than in 2019.

The second task is related to determining the prospects for sustainable development of developed and developing countries in the "Decade of Action" depending on the integration of the SDGs into the quality management system of enterprises in industry 4.0. To solve it, the dependence of the sustainable development index on high-technology exports is determined in a complete sample of countries, including both developed and developing countries, using the regression analysis method. The research model has the following form:

$$SDI=\sigma+\omega*HTE \quad (1)$$

where SDI – sustainable development index (UN, 2023), points from 1 to 100;
HTE – high-technology exports (World Bank, 2023), % of manufactured exports;
$\sigma$ – constant;
$\omega$ – regression coefficient for the factor variable.

Possible options for change of variables from model (1) in the "Decade of Action" are determined by the method of random number generation. On the basis of this,

forecasts are made for the sustainable development of developing and developed countries (separately, taking into account their specifics) in the "Decade of Action" due to the integration of the SDGs into quality in industry 4.0. The $H_4$ hypothesis is recognized as proven if the comprehensive growth (subject to the integration of the SDGs into quality 4.0) of the sustainable growth index in the "Decade of Action" exceeds its isolated growth (without taking into account the integration of the SDGs into quality 4.0), which is below 100 points.

The third task is to offer a vision of the integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action". The authors' vision is a schematic representation of the organization of the quality management process of enterprises in industry 4.0 in the "Decade of Action", taking into account the SDGs. For this purpose, the impact of each economic subsystem on the integration of the SDGs into the management system of quality 4.0 is taken into account.

## 4. RESULTS

### 4.1. Global monitoring of the practices of integration of the SDGs into the quality management system of enterprises in industry 4.0, taking into account the characteristics of developed and developing countries

In order to solve the first task of this study, global monitoring of the practices of integration of the SDGs into the quality management system of enterprises in industry 4.0 and the identification of the characteristics of developed and developing countries is carried out. For this purpose, arithmetic averages are calculated and the dynamics of the implementation of the SDGs (sustainable development index), the development of industry 4.0 (high-technology exports) and the degree of their integration in 2019-2021 are determined. The degree of integration of the SDGs into quality 4.0 is determined using the correlation analysis method ($r_{sdi,hte}$). The results for developing countries are shown in Fig. 1, and the results for developed countries are illustrated in Fig. 2.

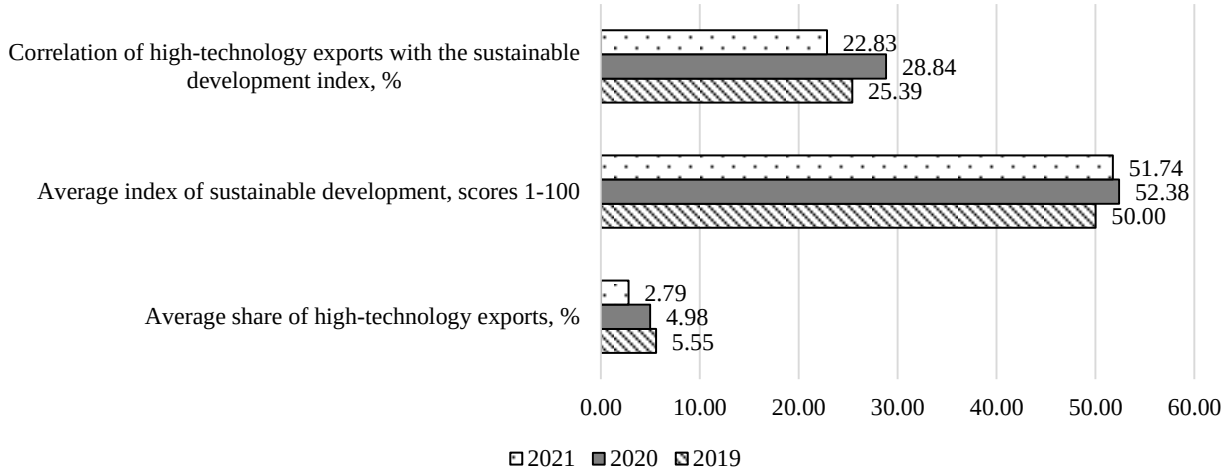


**Figure 1**. Dynamics of the implementation of the SDGs, the development of industry 4.0 and the degree of their integration in 2019-2021 in developing countries

*Source: calculated and constructed by the authors.*

The results obtained in Fig. 1 indicate that in developing countries the index of sustainable development in the pre-pandemic period (2019) scored 50.00 points. In the conditions of the pandemic (in 2020), it increased to 52.38 points, and in the post-pandemic period (2021) it decreased to 51.74 points, but was still higher than in 2019. This is in the obvious contrast to the revealed trend of slowing down the pace of neoindustrialization 4.0 in developing countries. Thus, in 2019, the share of high-tech exports in this category of countries was estimated at 5.55% on average. Thus, in 2019, the share of high-tech exports in this category of countries was estimated at 5.55% on average. In 2020 it reduced to 4.98%, and in 2021 it decreased to 2.79%.

The correlation of the sustainable development index with high-technology exports ($r_{sdi,hte}$) is positive and amounted to 25.39% in 2019, 28.84% in 2020 and 22.83% in 2021.Consequently, the degree of integration of the SDGs into quality 4.0 increased under the influence of the pandemic and the COVID-19 crisis, but this effect proved to be short-lived and disappeared after a year. For comparison, it is advisable to refer to the experience of developed countries (Fig. 2).

The results obtained in Fig. 2 indicate that in developed countries the index of sustainable development in the pre-pandemic period showed steady growth. In 2019, it was estimated at 77.48 points. In the conditions of the pandemic (in 2020), it increased to 78.11 points, and in the post–pandemic period (2021) it increased even more - to 79.02 points.

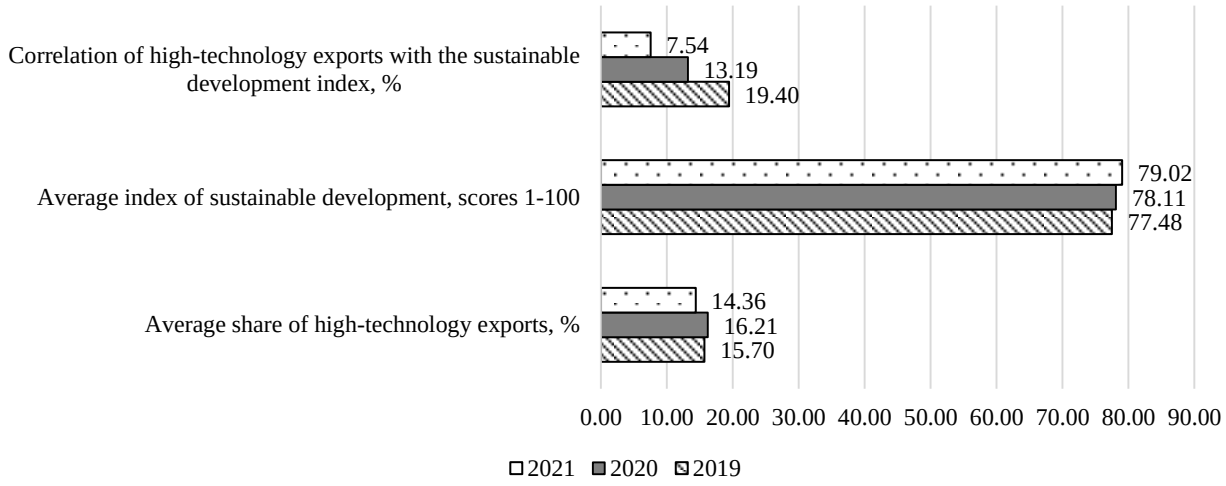


**Figure 2**. Dynamics of the implementation of the SDGs, the development of industry 4.0 and the degree of their integration in 2019-2021 in developed countries

*Source: calculated and constructed by the authors.*

This is in sharp contrast to the revealed trend of slowing down the pace of neoindustrialization 4.0 in developed countries. Thus, in 2019, the share of high-tech exports in this category of countries was estimated at 15.70% on average. In 2020 it increased to 16.21%, and in 2021 it decreased to 14.36%. Consequently, the level of development of industry 4.0 increased under the influence of the pandemic and the COVID-19 crisis, but this effect was temporary and disappeared after a year.

The correlation of the sustainable development index with high-technology exports ($r_{sdi,hte}$) is positive, but shows a downward trend. This correlation was 19.40% in 2019, 13.19% in 2020 and 7.54% in 2021. Consequently, under the influence of the pandemic and the COVID-19 crisis, the degree of integration of the SDGs into quality 4.0 has decreased, and this effect has long-term consequences.

The dynamics of the degree of integration of the SDGs into quality in industry 4.0 in 2019-2021 in each category of countries has also been determined. To do this, the correlation of high-technology exports with the results of the implementation of each of the 17 UN SDGs (Goal 1-17 Scores) has been calculated. The result for developing countries is shown in Fig. 3.

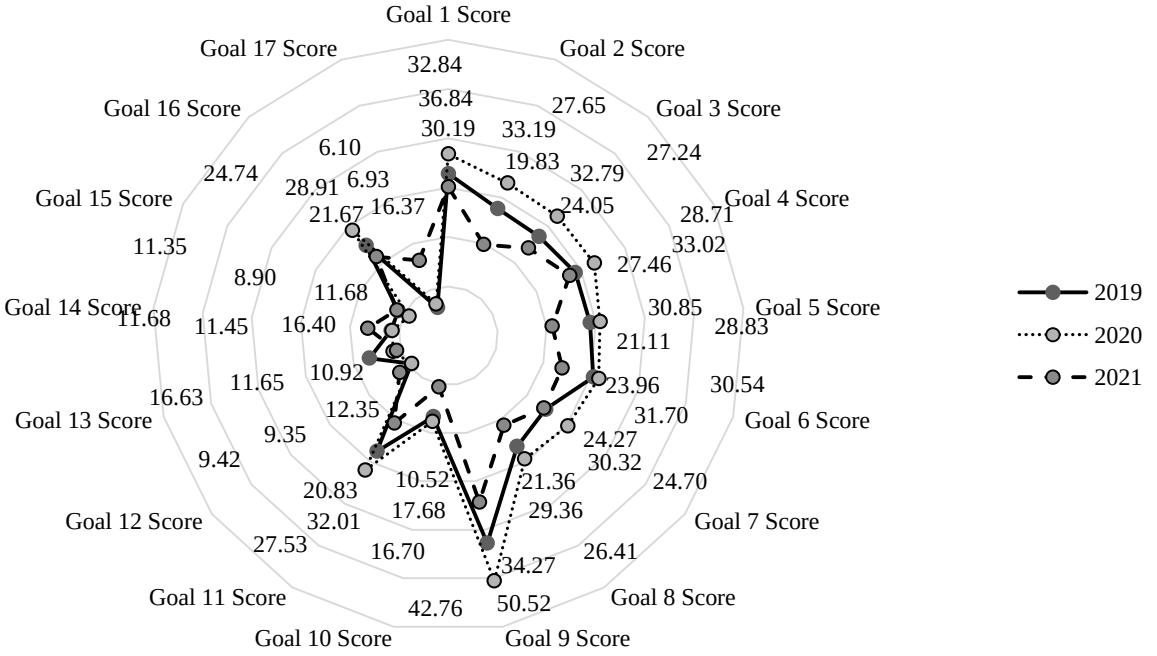


Figure 3. Dynamics of the degree of integration of the SDGs into quality in industry 4.0 in 2019-2021 in developing countries, %

*Source: calculated and constructed by the authors.*

As shown in Fig. 3, in developing countries, all 17 UN SDGs are integrated into quality 4.0 as a whole. SDG9 is the most strongly integrated (correlation: 42.76% in 2019; 50.52% in 2020 and 34.27% in 2021). SDG17 is the least integrated (correlation: 6.10% in 2019; 6.93% in 2020, but already 16.37% in 2021). For comparison, it is advisable to refer to the results for developed countries (Fig. 4).

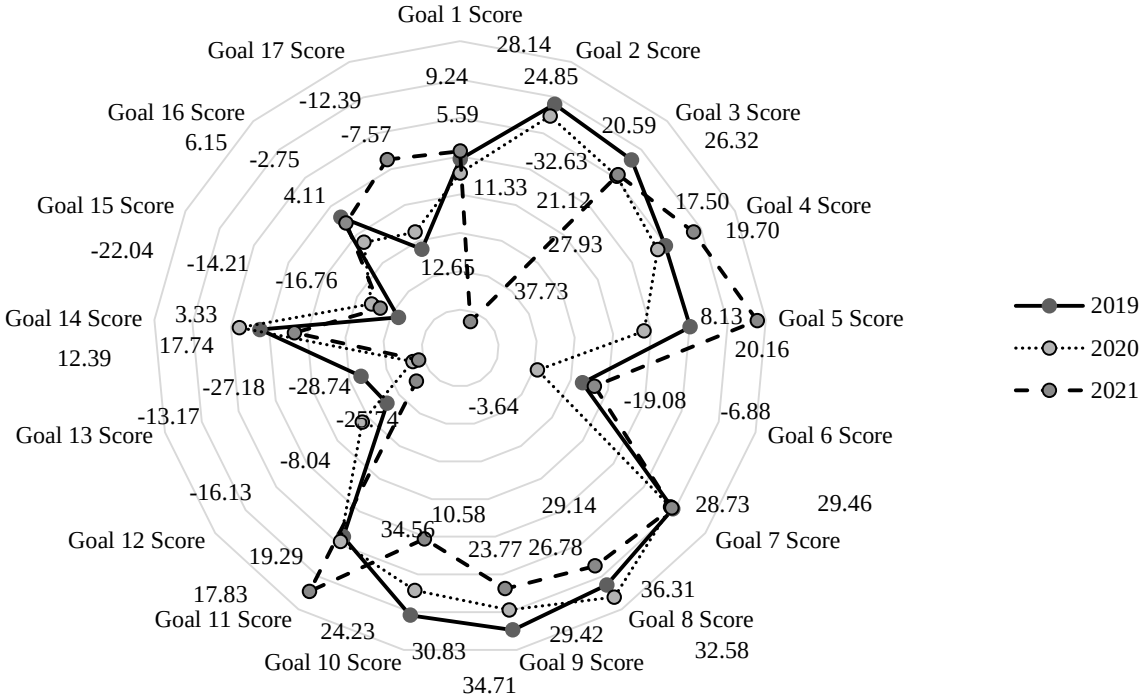


Figure 4. Dynamics of the degree of integration of the SDGs into quality in Industry 4.0 in 2019-2021 in developed countries, %

*Source: calculated and constructed by the authors.*

As shown in Figure 4, most, but not all, of the 17 UN SDGs are integrated as 4.0 in developed countries. SDG5 (correlation: 20.16% in 2019; 8.13% in 2020 and 37.73% in 2021) and SDG9 (correlation: 34.71% in 2019; 29.42% in 2020 and 23.77% in 2021) are most strongly integrated. Not integrated into quality 4.0 (as of 2021) were SDG2 (-32.63%), SDG6 (-3.64%), SDG12 (-25.74%), SDG13 (-28.74%), SDG15 (-16.76%) and SDG17 (12.65% in 2021, but -12.39% in 2019 and -7.57% in 2020).

Thus, the results obtained allow us to draw the following conclusions. Firstly, the correlation of the sustainable development index with high-technology exports ($r_{sdi,hte}$) is below 50% in both categories of countries considered. In developing countries in 2021, the degree of integration of the SDGs into quality 4.0 is estimated at 22.83%, and in developed countries – at 7.54%. It is noteworthy that as industrialization progresses 4.0 in developed countries, the support for the SDGs of the environmental block decreases. This proves both the hypothesis $H_1$ and the hypothesis $H_2$.
Secondly, the correlation of the sustainable development index with high-technology exports ($r_{sdi,hte}$) in both categories of countries in 2021 is lower than in 2019.In developing countries, the degree of integration of the SDGs into quality 4.0 decreased from 25.39% in 2019 to 22.83% in 2021, and in developed countries – from 19.40% in 2019 to 7.54% in 2021. This proves the hypothesis $H_3$.

### 4.2. Prospects for sustainable development of developed and developing countries with the "Decade of Action" depending on the integration of the SDGs into the quality management system of enterprises in industry 4.0

In order to solve the second task of this study, the prospects for sustainable development of developed and developing countries with the "Decade of Action" are determined, depending on the integration of the SDGs into the quality management system of enterprises in industry 4.0. To do this, in accordance with the research model (1), a regression analysis of the dependence of the sustainable development index on high-technology exports is carried out in a complete sample of countries, including both developed and developing countries. The following equation of paired linear regression is obtained:

$$SDI=51.5726+1.0809*HTE \quad (2)$$

Equation (2) indicates that the sustainable development index increases by 1.0809 points with an increase in the share of high-tech exports by 1%. Regression statistics and analysis of variance are shown in Table 1.

**Table 1.**Regression statistics and analysis of variance

| *Regression statistics* | |
|---|---|
| Multiple R | 0.3783 |
| R-Square | 0.1431 |
| Adjusted R-Square | 0.1386 |
| Standard Error | 23.7037 |
| Observations | 192 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 17834.4736 | 17834.4736 | 31.7416 | $6.3*10^{-8}$ |
| Rsidual | 190 | 106754.1282 | 561.8638 | | |
| Total | 191 | 124588.6018 | | | |

| | *Coeffi-cients* | *Standard Error* | *t-Stat* | *P-Value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Constant | 51.5726 | 1.9627 | 26.2763 | $3.5*10^{-65}$ | 47.7011 | 55.4441 |
| HTE | 1.0809 | 0.1919 | 5.6340 | $6.3*10^{-8}$ | 0.7025 | 1.4593 |

*Source: calculated and compiled by the authors.*

The results from Table 1 show that the change in the global average of the sustainable development index by 37.83% is due to the influence of high-tech exports - this is the global degree of integration of the SDGs into quality 4.0 (relatively small). Fischer's F-test and Student's t-test have been passed at a significance level of 0.001, which has confirmed the reliability of equation (2).

For each variable from equation (2), 100 random numbers have been generated taking into account arithmetic averages (SDI: 51.74 and 79.02; HTE: 2.79 and 14.36, respectively) and standard deviations (SDI: 25.71 and 3.85; THE: 7.73 and 7.55, respectively) in developed and developing countries. Histograms of the normal distribution of the obtained random numbers and their probabilities have been constructed in Fig. 5-8.

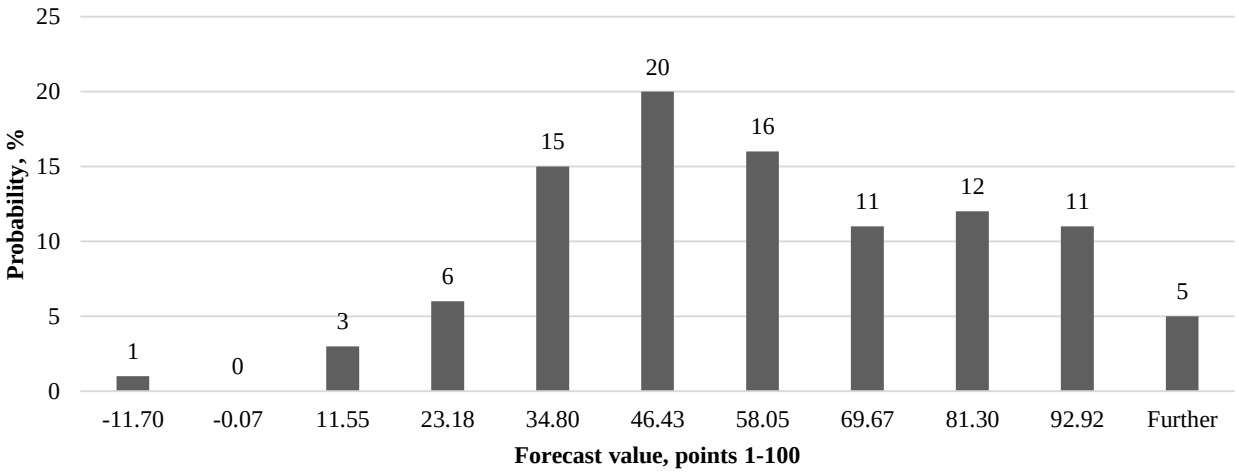


Figure 5. Forecast of the sustainable development index in developing countries in the "Decade of Action"
*Source: calculated and constructed by the authors.*

Fig. 5 shows that with a probability of 16%, the index of sustainable development in developing countries at the end of the "Decade of Action" (by 2030) will reach 92.92 points or exceed this value – this is an optimistic scenario. The pessimistic scenario, in which the sustainable development index will be in the range from 58.05 points to 81.30 points, will be implemented with a probability of 39%.

Fig. 6 shows that the index of sustainable development in developed countries at the end of the "Decade of Action" (by 2030) will reach 85.60 points or exceed this value with a probability of 10% – this is an optimistic scenario. The pessimistic scenario, in which the sustainable development index will be in the range from 80.02 points to 83.74 points, will be implemented with a probability of 51%.

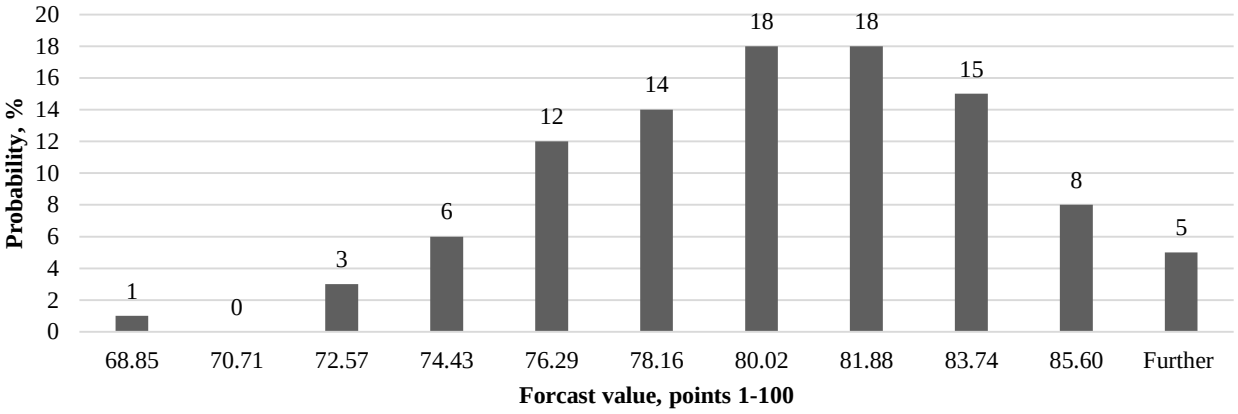


Figure 6. Forecast of the sustainable development index in developed countries in the "Decade of Action"
*Source: calculated and constructed by the authors.*

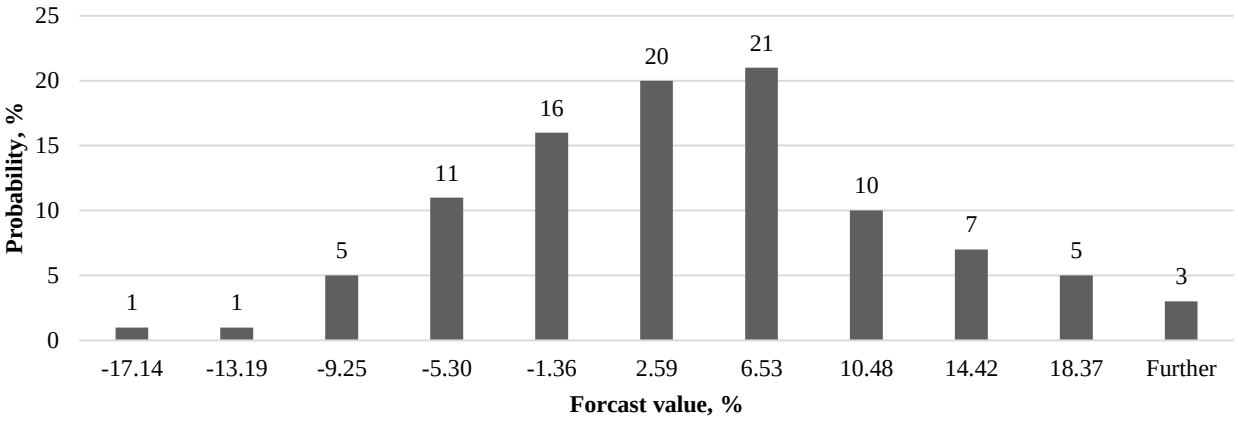


Figure 7. Forecast of high-tech exports in developing countries in the "Decade of Action"
*Source: calculated and constructed by the authors.*

Fig. 7 shows that the share of high-tech exports in developing countries at the end of the "Decade of Action" (by 2030) will reach 18.37% or exceed this value with a probability of 8% - this is an optimistic scenario. The pessimistic scenario, in which the share of high-tech exports will be in the range from 6.53% to 14.42%, will be implemented with a probability of 38%.

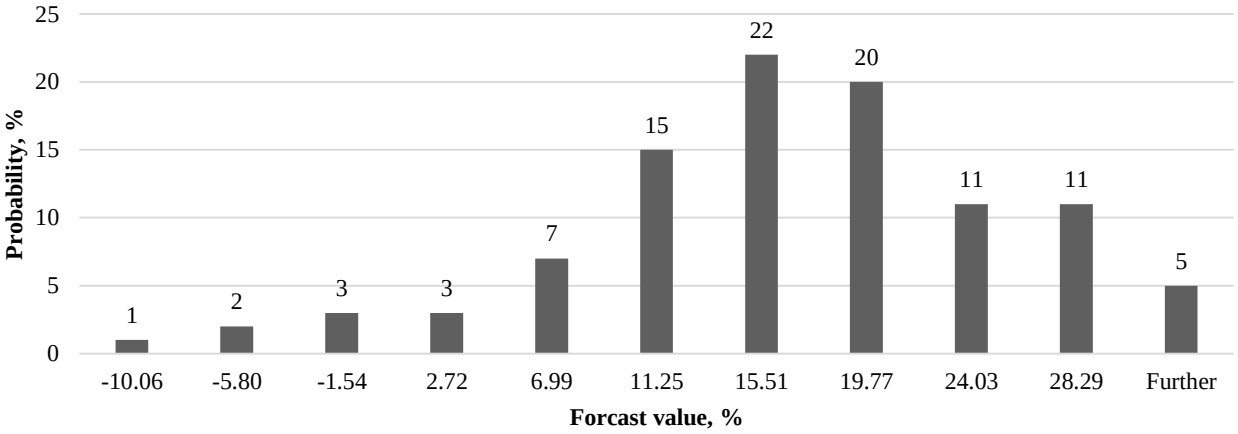


Figure 8. Forecast of high-tech exports in developed countries in the "Decade of action"
*Source: calculated and constructed by the authors.*

Fig. 8 shows that the share of high-tech exports in developed countries at the end of the "Decade of Action" (by 2030) will reach 28.29% or exceed this value with a probability of 16% - this is an optimistic scenario. The pessimistic scenario, in which the share of high-tech exports will be in the range from 15.51% to 24.03%, will be implemented with a probability of 53%.

Based on the developed scenarios, forecasts of the sustainable development of developing and developed countries (separately, taking into account their specifics) in the "Decade of Action" due to the integration of the SDGs into quality in industry 4.0 have been compiled. For this purpose, the values of the indicators for the scenarios have been substituted into equation (2). The forecast for developing countries is reflected in Table 2.

**Table 2.** Forecast of sustainable development of developing countries in the "Decade of action" by integrating the SDGs into quality in industry 4.0

| **Indicators** | | **The base value in 2021** | **Forecast values for the "Decade of Action" (until 2030)** | | |
|---|---|---|---|---|---|
| | | | **Pessimistic scenario** | | **Optimistic scenario** |
| | | | **from** | **to** | |
| High-technology exports, % | | 2.79 | 6.53 | 14.42 | 18.37 |
| Isolated growth due to industry 4.0 | Sustainable development index, points 1-100 | 51.74 | 58.63 (1.13 compared 2021) | 67.16 (1.30 compared 2021) | 71.43 (1.38 compared 2021) |
| Isolated index growth | | | 58.05 | 81.30 | 92.92 |
| Comprehensive growth | | | **65.78** (58.05*1.13) | **100.00** (81.30*1.30) | **100.00** (92.92*1.38) |

*Source: calculated and compiled by the authors*.

The forecast in the Table 2 has shown that in developing countries, the isolated growth of the sustainable development index due to industry 4.0 alone ranges from 1.13 to 1.30 (58.63 points - 67.16 points) under the pessimistic scenario and 1.38 (71.43 points) under the optimistic scenario. Isolated growth of the sustainable development index (without support from industry 4.0) will be from 58.05 to 81.30 points under the pessimistic scenario and up to 92.92 points under the optimistic scenario.

The comprehensive growth of the sustainable development index (provided that the SDGs are integrated into quality 4.0) will be up to 65.78 points under the pessimistic scenario and up to 100 points under the optimistic scenario, that is, it will allow the full implementation of the 17 UN SDGs by 2030. The forecast for developed countries is reflected in Table 3.

**Table 3.** Forecast of sustainable development of developed countries in the "Decade of Action" by integrating SDGs into quality in industry 4.0

| **Indicators** | | **The base value in 2021** | **Forecast values for the "Decade of Action" (until 2030)** | | |
|---|---|---|---|---|---|
| | | | **Pessimistic scenario** | | **Optimistic scenario** |
| | | | **from** | **to** | |
| High-technology exports, % | | 14.36 | 15.51 | 24.03 | 28.29 |
| Isolated growth due to industry 4.0 | Sustainable development index, points 1-100 | 79.02 | 68.34 (at the level of 2021) | 77.55 (at the level of 2021) | 82.15 (1.04 compared 2021) |
| Isolated index growth | | | 80.02 | 83.74 | 85.60 |
| Comprehensive growth | | | **83.19** (80.02*1.04) | **87.06** (83.74*1.04) | **88.99** (85.60*1.04) |

*Source: calculated and compiled by the authors*.

The forecast in Table 3 showed that in developed countries the isolated growth of the sustainable development index only due to industry 4.0 is 1.04 (82.15 points) according to the optimistic scenario. Isolated growth of the sustainable development index (without support from industry 4.0) will be from 80.02 to 83.74 points under the pessimistic scenario and up to 85.60 points under the optimistic scenario. The comprehensive growth of the sustainable development index (provided that the SDGs are integrated into quality 4.0) will be from 83.19 to 87.06 points according to the pessimistic scenario and up to 88.99 points according to the optimistic scenario.

Thus, the results obtained allow us to conclude that the comprehensivy growth (under the condition of integrating the SDGs into quality 4.0) of the sustainable development index in the "Decade of Action" (up to 100 points in developing countries and up to 88.99 points in developed countries) exceeds its isolated growth (without taking into account the integration of the SDGs into quality 4.0), which is below 100 points and amounts to up to 92.92 points in developing countries and up to 85.60 points in developed countries. This proves the hypothesis $H_4$.

### 4.3. Vision of the integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action"

To solve the third task of this study, the authors propose a vision of the integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action". It is a schematic representation of the organization of the quality management process of enterprises in industry 4.0 in the "Decade of Action", taking into account the SDGs. To develop the authors' vision, the influence of all economic subsystems - the state, society, consumers, nature, technologies, suppliers and employees - on the integration of the SDGs into the quality management system 4.0 is taken into account (Fig. 9).

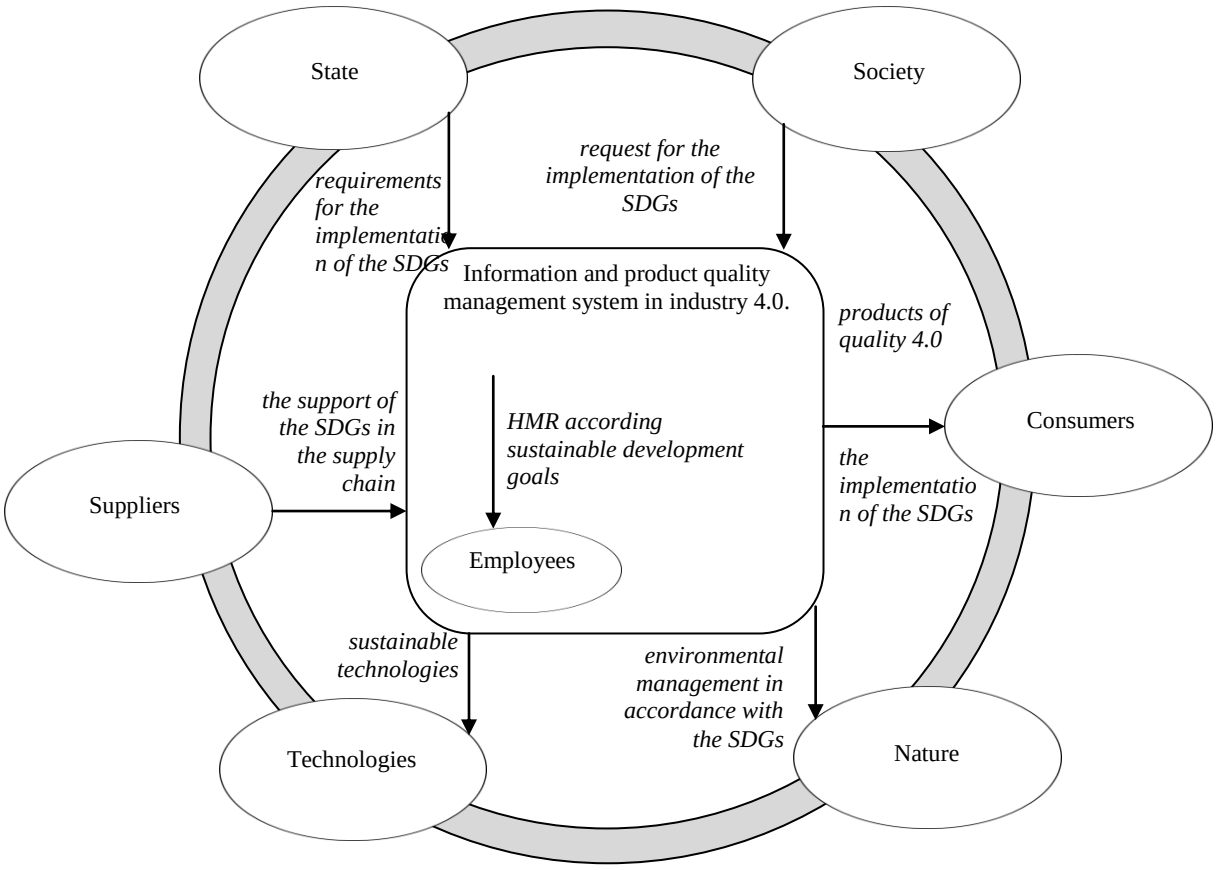


Figure 9. Vision of the integration of the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action"

*Source: developed by the authors.*

As shown in Figure 9, the state imposes requirements for the implementation of the SDGs, and the society places a request for the implementation of the SDGs. Thanks to sustainable technologies and the support of the SDGs by all participants in the supply chain in the information and product quality management system in industry 4.0, sustainable HRM is implemented and sustainable environmental management is practiced in accordance with the SDGs. Consumers receive not only products of 4.0 quality, but also 17 UN SDGs, which have been implemented with the support of enterprises of industry 4.0.

## 5. DISCUSSION

The results obtained in the article develop and complement the provisions of the scientific concept of information systems and product quality management in industry 4.0This is the contribution of the article to the literature. In particular, the article has clarified to what extent the SDGs are integrated into the quality management system of enterprises in industry 4.0, how the degree of this integration changes over time, how it differs among countries and what benefits it provides for sustainable development. The received answers to RQs are given in Table 4 in comparison with the literature.

**Table 4.** Answers to RQs: Existing literature vs this article

| Alternative sources of answers to RQs | | Research questions (RQs) | | | |
|---|---|---|---|---|---|
| | | **$RQ_1$:** To what extent are the SDGs integrated into the quality management system of enterprises in industry 4.0? | **$RQ_2$:** Which category of countries demonstrates a higher degree of integration of the SDGs into the quality management system of enterprises in industry 4.0? | **$RQ_3$:** How has COVID-19 affected the degree of integration of the SDGs into the management system of quality 4.0? | **$RQ_4$:** What is the significance of integration into the quality management system of enterprises in industry 4.0 for the implementation of the SDGs in the "Decade of action"? |
| **Literature** | **Existing answer** | the SDGs are highly integrated | developed countries have a higher degree of integration of the SDGs | the degree of integration has increased | small value: the SDGs will be achieved in the "Decade of Action" anyway |
| | **Source** | Luttikhuis and Wiebe (2023), Zhilin et al. (2020) | Van Tulder et al. (2021), Yu et al. (2022) | Elavarasan et al. (2022), Srinivasan and Eden (2021) | Palomares et al. (2021), Singh and Ru (2023) |
| **This article** | **New answer** | the SDGs are poorly integrated into the quality management system of enterprises in industry 4.0 | the degree of integration of the SDGs into the quality management system of enterprises in industry 4.0 in developing countries | the degree of integration of the SDGs into the quality management system 4.0 has decreased in the context of COVID-19 | of great importance: the independent implementation of the SDGs is not sufficient – the integration into the quality management system of enterprises of industry 4.0 is advisable for their full achievement |
| | **Quantitative interpretation of the answer** | − the SDGs are integrated by 22.83% in developing countries;<br>− the SDGs are integrated by 7.54% in developed countries. | | − from 25.39% to 22.83%: developing countries;<br>− from 19.40% to 7.54%: developed countries. | − developing countries: the forecast of the implementation of the SDGs is up to 71.43 points, but up to 100.00 points with integration;<br>− developed countries: the forecast of the implementation of the SDGs is up to 82.15 points, but up to 88.99 points with integration; |

*Source: developed by the authors.*

As shown in Table 4, unlike Luttikhuis and Wiebe (2023), Zhilin et al. (2020), it has been proved that the SDGs are poorly integrated into the quality management system of enterprises in industry 4.0. They are integrated by 22.83% in developing countries and by 7.54% in developed countries. This has provided an answer to **$RQ_1$**, confirming the hypothesis **$H_1$**.

In contrast to Van Tulder et al. (2021), Yu et al. (2022), it has been proved that the degree of integration of SDGs into the quality management system of enterprises in industry 4.0 is higher in developing countries. This has provided an answer to **$RQ_2$**, confirming the hypothesis **$H_2$**.

In contrast to Elavarasan et al. (2022), Srinivasan and Eden (2021), it has been proved that the degree of integration of SDGs into the quality management system 4.0 has decreased under the conditions of COVID-19: from 25.39% to 22.83% in developing countries; from 19.40% to 7.54% in developed countries. This has provided an answer to **$RQ_3$**, confirming the hypothesis **$H_3$**.

Unlike Palomares et al. (2021), Singh and Ru (2023), it has been proved that the integration into the quality management system of enterprises of industry 4.0 is of great importance for the implementation of the SDGs in the "Decade of Action": the independent implementation of the SDGs is not sufficient – their full achievement requires the integration into the quality management system of enterprises of industry 4.0. In developing countries, the forecast of the implementation of the SDGs is up to 71.43 points, but up to 100.00 points with their integration. In developed countries, the forecast for the implementation of the SDGs is up to 82.15 points, but up to 88.99 points with their integration. This has provided an answer to **$RQ_4$**, confirming the hypothesis **$H_4$**.

## 6. CONCLUSION

The key conclusion based on the results of the study is that today the SDGs are not fully integrated into quality 4.0, to which, in particular, the pandemic and the COVID-19 crisis have become an obstacle – more serious changes in the information system and product quality management in industry 4.0 are needed to solve

this problem. In particular, the following conclusionsconclusions are made.

1) The global monitoring of the practices of integration of the SDGs into the quality management system of enterprises in industry 4.0 has shown that in both categories of countries considered, the degree of integration of the SDGs into quality 4.0 is moderate. In developing countries in 2021, it is estimated at 22.83%, and in developed countries – at 7.54%. As the industrialization of 4.0 progresses in developed countries, the support for the SDGs of the environmental block decreases, which is an alarming trend, indicating the disintegration of the SDGs with the quality of 4.0 in developed countries in the context of the Fourth Industrial Revolution.

2) The degree of integration of SDGs into quality 4.0 has decreased under the influence of the pandemic and the COVOD-19 crisis. It decreased from 25.39% in 2019 to 22.83% in 2021 in developing countries, and it reduced from 19.40% in 2019 to 7.54% in 2021 in developed countries. This is another alarming trend of deepening the gap between technological and sustainable development that impedes the implementation of the 17 UN SDGs in the "Decade of Action".

3) The prospects for sustainable development of developed and developing countries in the "Decade of Action" are associated with further and more complete integration of the SDGs into the quality management system of enterprises in industry 4.0. This conclusion is based on the fact that the comprehensive growth (assuming the integration of the SDGs into quality 4.0) of the sustainable development index in the "Decade of Action" (up to 100 points in developing countries and up to 88.99 points in developed countries) has exceeded its isolated growth (excluding the integration of the SDGs into quality 4.0), which is below 100 points and amounts to up to 92.92 points in developing countries and up to 85.60 points in developed countries.

The theoretical significance of the authors' conclusions is that they have formed a reliable evidence base that, unlike other sectors of the economy, the degree of integration of the SDGs into the product quality management system in industry 4.0 is much lower and insufficient for the implementation of the 17 UN SDGs in the "Decade of Action".

The practical significance of the results of the study is explained by the fact that they allow taking into account the specifics of developed and developing countries when integrating the SDGs into the management of quality 4.0. The managerial significance is related to the fact that the developed new vision of integrating the SDGs into the quality management system of enterprises in industry 4.0 in the "Decade of Action" will ensure more complete integration and will bridge the gap between technological and sustainable development in the "Decade of Action" through the sustainable development of industry 4.0 as a new dimension of quality 4.0.

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