https://doi.org/10.52326/jss.utm.2024.7(2).13
UDC 001.89:338

SCIENTOMETRIC APPROACH IN DETERMINING THE ROLE OF SCIENCE IN SOCIOECONOMIC DEVELOPMENT OF SOCIETY

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Received: 06. 05. 2024
Accepted: 06. 23. 2024

Abstract. This study investigates the relationship between scientific advancement and socioeconomic progress using a scientometric methodology. The research examines publication activity and the Science Development Index (SDI) in different countries, utilizing statistical methods to evaluate the reciprocal impact of science and socioeconomic metrics, namely the Human Development Index (HDI). The results demonstrate a significant, nonlinear association between SDI and HDI, emphasizing the essential role of international cooperation and funding in fostering scientific development. The study emphasizes the importance of scientometric indicators in informing policy-making and fostering sustainable socioeconomic progress.

Keywords*: scientometrics, correlation analysis, human development index, science development index, publication activity, R&D funding, international cooperation.*

Rezumat. Acest studiu investighează relația dintre progresul științific și dezvoltarea socioeconomică utilizând o metodologie scientometrică. Cercetarea examinează activitatea de publicare și indicele de dezvoltare științifică (SDI) în diferite țări, utilizând metode statistice pentru a evalua impactul reciproc al științei și al indicatorilor socioeconomici, și anume indicele de dezvoltare umană (HDI). Rezultatele demonstrează un nivel de corelare semnificativ și neliniar între SDI și HDI, subliniind rolul esențial al cooperării și finanțării internaționale în dezvoltarea științifică. Studiul subliniază importanța indicatorilor scientometrici în fundamentarea elaborării politicilor și în promovarea progresului socioeconomic durabil.

Cuvinte-cheie: *scientometrie, analiză de corelație, indicele dezvoltării umane, indicele dezvoltării științifice, activitatea de publicare, finanțarea cercetării și dezvoltării, cooperarea internațională.*

1. Introduction

The slogan "Science is the direct productive force of society" was popular in the Soviet Union, where its validity remained unquestioned due to the remarkable scientific and technological advancements achieved by the nation. Following the dissolution of the USSR, the necessity to foster scientific and technological progress in the smaller ex-Soviet republics became less apparent and more challenging due to financial constraints. Consequently, there is a pressing need to establish methodologies for evaluating the significance of science for society and its influence on socioeconomic development. Addressing this issue is of paramount importance for governmental bodies and policymakers. Therefore, it is imperative to devise methods or frameworks for assessing the correlation between science and the socioeconomic status of a society.

The development of such methods has been made possible through the application of quantitative approaches to describe processes in science development, known as scientometrics. While some quantitative methods for describing patterns in science, as well as its structure and extent, were utilized earlier in the 20th century [1−4], the term 'scientometrics' (rus: наукометрия) was first introduced by Nalimov in 1966 [5]. The term gained recognition following the publication in 1969 by Nalimov & Mul'chenko of the renowned book titled The Study of the Development of Science as an Information Process [6]. In this book, scientometrics is defined as a branch of the Science of Science (rus: науковедение) that examines science using quantitative methods based on an information model. According to this model, science is a self-organizing system, the advancement of which is regulated by its information flows. Since these information flows are generated by scientific publications, which serve as sources of information, one can analyze the progress of science by tracking the increase in the number of scientific publications over time.

Another term for the quantitative approach to analyzing scientific publications is bibliometrics. Coined by Pritchard in 1969 [7], bibliometrics is defined as application of mathematical and statistical methods to books and other forms of communication. Bibliometrics encompasses various types of literature, not limited to academic works. Despite this, scientometrics and bibliometrics are frequently used interchangeably to denote the measurement of the quantity, impact, or quality of academic publications [8−10].

A quantitative analysis of the correlation between a society's level of socioeconomic development and its scientific advancement requires the utilization of quantitative indicators, preferably those that are comprehensive and relative, for various aspects of the system. One such indicator is the Science Development Index (SDI), introduced in 1999 for the first time [11]. The SDI is defined as the ratio of a country's contribution to the global information process to its share of the world's total population:

$$SDI = Ps / Pn, \quad (1)$$

Where *Ps* represents the share of the contribution of researchers from a specific country to the global information process (%), calculated on the based of the number of publications indexed in the WoS or Scopus databases published over a defined period of time. While *Pn* represents the share of this country's population in the world's population (%).

The proposed indicator can be seen as an equivalent of GDP per capita, but in the realm of science. Essentially, SDI is a measure of the scientific publication output of researchers in a specific country per capita.

It was shown in [11−14] that there is a pronounced relationship between SDI and the level of socioeconomic development of society, with a fairly high correlation coefficient. This relationship, however, depends on the level of development of science in a particular country. Quantitatively, the integral indicator of the level of socioeconomic development in a specific country is determined by the Human Development Index (HDI) published in the Human Development Reports [15]. HDI is calculated annually by a special UN Commission and takes into account the country's economy level (GNI per capita, considering purchasing power parity), the level of healthcare (life expectancy), and the education level (years of schooling). In the works [11−14], it has been emphasized that the observed dependence is non-linear, in the sense that science is characterized by positive feedback that leads to mutual influence or interdependence of SDI and HDI.

The study of the dynamics of analyzed relationships, as well as the assessment of various scientometric indicators, is important not only for obtaining purely scientific outputs but also for determining the trends of scientific development. These trends hold significant importance and priority for making appropriate managerial decisions.

It should be mentioned that SDI is not the only one indicator that describes the development of science, just as HDI is far from the only indicator for assessing the level of socioeconomic development of society.

Thus, this work aims to explore the feasibility of using various quantitative indicators (in contrast to SDI) to evaluate the level of scientific development in various countries based on publication activity (PA). It focuses on the number of academic works published annually in top journals per million inhabitants of a country. This metric serves as an equivalent to the indicator of innovation activity (IA).

Innovation activity indicator have been considered by several authors. Svensson's paper [16] examines different patent value indicators, such as citation frequency and patent family size, to assess their correlation with technological innovation.

Zoltan J. Acs and David B. Audretsch [17] explored the validity of using patents as an indicator of innovative output. Although they critically analyzed the relationship between patent counts and actual innovation, considering factors such as industry differences, firm size, and the quality versus quantity of patents, the authors concluded that patents can be a useful measure of innovative activity.

So, even if the comparison of PA and IA represents interest, what is more intriguing is to analyze the dynamics of PA. Therefore, another objective of this work is to determine the feasibility of using PA as a quantitative indicator to assess the interdependence between the level of scientific development and the level of socioeconomic development.

2. The methodology of the study

The study utilized quantitative methods, such as statistical analysis, comparative analysis, and correlation analysis. As mentioned in [18], scientific publications need to adhere to professional standards to be truly informative and serve as a robust foundation for science and technology indicators. Therefore, the primary data for this study were sourced from the internationally recognized Scopus database [19]. Additional data were obtained from the World Bank's Databank (population) [20] and the UNDP Human Development Reports (HDI) [15].

The analysis focused on different groups of countries: the top 10 countries in the world based on the number of documents published across all subject areas in 2000 and 2023. The list of top countries varied between these years, reflecting the changing dynamics of countries' contributions to the global information process. The study also analyzed a group of Eastern European countries and conducted a special analysis on the ex-Soviet countries, which encompassed both Eastern European and Asian countries.

Two indicators were calculated: Science Development Index (SDI) and Publication Activity (PA). Despite the similarity of these indicators in terms of physical meaning, they differ significantly. SDI is a dimensionless value; moreover, it is the ratio of relative values, while *PA* is a relative value but a dimensional indicator (the number of publications per million inhabitants per year).

The level of socioeconomic development was collected from [15], as well as in earlier works [11–14]. The obtained ratios of PA to HDI were compared with those described for a previous period.

3. Results and Discussion

3.1 The Dynamics of Publication Activity

Below there is some data for the top 10 countries on the number of documents (nPb) indexed in Scopus in 2000 (Table 1) and 2022 (Table 2) with at least one author from a specific country, along with two calculated indicators: PA and SDI. Table 2 also shows the ratios of PA in 2022 to PA in 2000 and SDI in 2022 to SDI in 2000. Several key points need to be highlighted: 1) The leader for nPb among the top 10 countries has changed. In 2000, the United States was the clear leader in the total number of documents (US researchers published over three times as many papers as the UK, the second-ranked country). However, in 2022, Chinese researchers have taken the lead. 2) The total number of publications (nPb) is increasing in all countries, but to varying degrees. If researchers from the USA and leading European countries published about two to three times more works in 2022 compared to 2000, then for Australia this ratio increased by 30 times, for China by almost 18 times, and for India by 8.5 times. 3) Additionally, at the beginning of the 21st century, 73% of all new knowledge was by the top 10 countries, which comprised 35% of the Earth's population. In 2022, 79% of new knowledge was "produced" by the top 10 countries, which now account for 46% of the world's population. This phenomenon is attributed to the significant growth of science in Asian countries and Australia.

Table 1

Scientometric indicators of leading countries, 2000

No.	Country	$nPb\cdot10^{-3}$	$PA\cdot10^{-3}$	SDI
1.	United States	376.4	1.33	6.23
2.	United Kingdom	108.5	1.84	8.61
3.	Japan	105.3	0.83	3.88
4.	Germany	90.7	1.10	5.16
5.	France	64.4	1.06	4.94
6.	China	51.9	0.04	0.19
7.	Canada	45.8	1.49	6.97
8.	Italy	44.8	0.79	3.68
9.	Russia	34.7	0.24	1.11
10.	Spain	31.5	0.78	3.63

Data source: nPb - [19]; PA, SDI calculated by authors based on [19,20]. nPb - number of publications; PA - Publication Activity; SDI - Science Development Index.

Table 2

Scientometric indicators of leading countries, 2022 and some comparisons with 2022

No.	Country	nPb·10⁻³	PA·10⁻³	SDI	$\frac{PA_{2022}}{PA_{2000}}$	$\frac{SDI_{2022}}{SDI_{2000}}$
1.	China	1041.5	0.74	1.43	17.9	7.4
2.	United States	738.5	2.22	4.29	1.7	0.7
3.	India	285.7	0.20	0.39	8.5	3.5
4.	United Kingdom	246.0	3.63	7.03	2.0	0.8
5.	Germany	214.1	2.55	4.95	2.3	1.0
6.	Italy	160.5	2.72	5.28	3.5	1.4
7.	Japan	145.8	1.17	2.26	1.4	0.6
8.	Canada	134.5	3.45	6.69	2.3	1.0
9.	France	130.1	1.91	3.71	1.8	0.8
10.	Australia	126.1	4.85	9.39	30.1	12.5

Data source: nPb - [19]; PA, SDI calculated by authors based on [19,20]. nPb - number of publications; PA - Publication Activity; SDI - Science Development Index.

The group of countries studied above is characterized by the interdependence (mutual influence) of the level of development of science assessed by the SDI and the level of socio-economic development described by HDI (Figure 1).

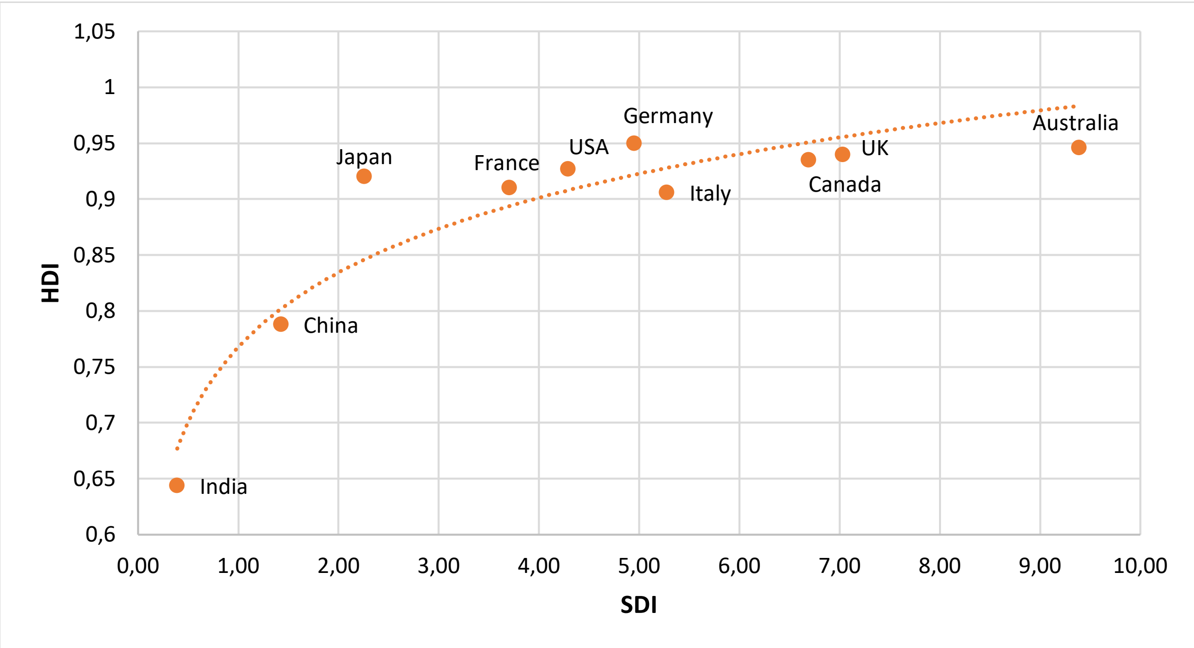


Figure 1. Correlation between *SDI* and *HDI* for leading countries in science, 2022 (cumulative contribution to the global information process 79%).
SDI – Science Development Index; HDI – Human Development Index.

Quantitatively, the relationship between HDI and SDI is expressed by the Equation (2):

$$HDI = a\ lgSDI + b, \quad (2)$$

Where: the correlation coefficient R = 0.94 ± 0.12, coefficient *a* = 0.12 ± 0,03 and coefficient *b* = 0.76 ± 0,02. It is worth mentioning two features: 1) The value of the correlation coefficient for 2022 is higher than for the earlier period (2013), however, not for the leading countries in publishing, but for the EU states [14, 26]. At the same time, the correlation coefficient calculated and presented earlier in (Dikusar Alexandr and Cujba Rodica, 2015b) was the maximum (R = 0.86) for different groups of countries. Its increase to a value of 0.94 should be considered as evidence of the growing over time of the degree of mutual influence of the considered quantitative indicators. 2) The value of HDI for Japan significantly exceeds the average for the studied group of countries, while the highest value of *SDI* is observed for Australia, Figure 1.

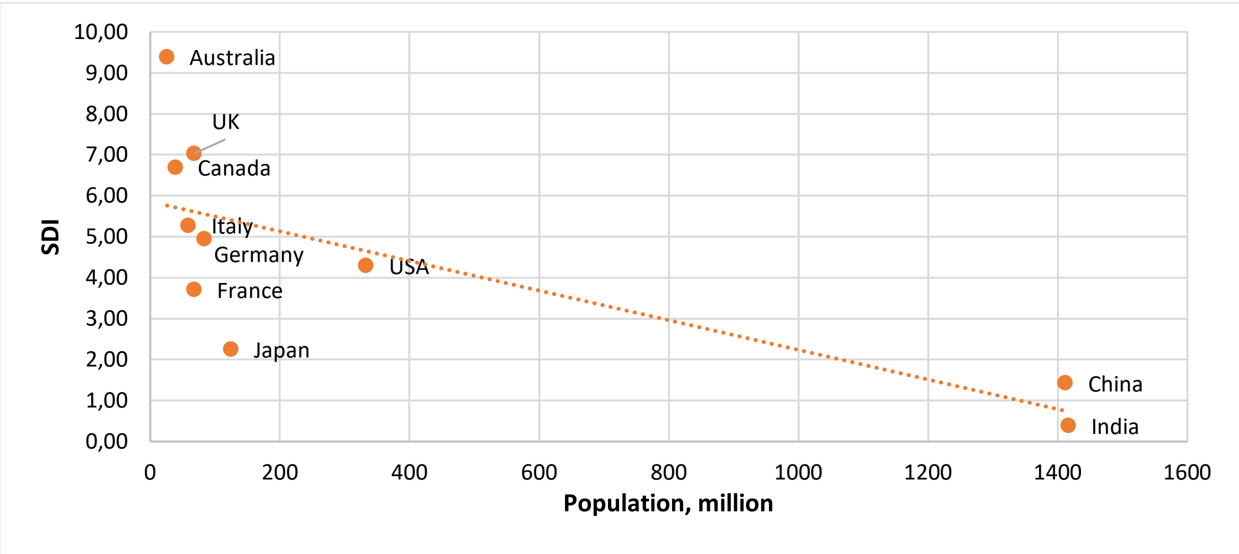
The replacement of SDI with PA in Equation (2) leads to the following relation:

$$HDI = 0.06\, lgPA + 0.74 \qquad (3)$$

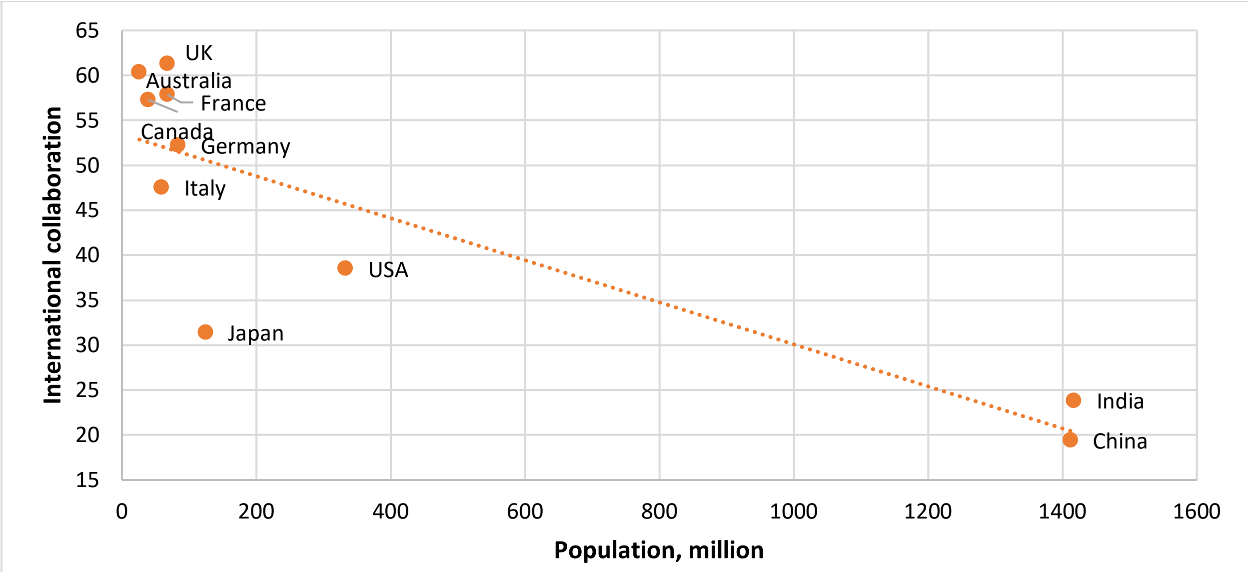
With the correlation coefficient R = 0.79 ± 0.04 and corresponding coefficients for a = 0.06 ± 0.02 and b = 0.74 ± 0.02. These values can justify the applicability of SDI instead of PA for the quantitative analysis of the relationship. The main reason for this conclusion is that, unlike PA, SDI reflects the mutual influence of the components of the system (e.g., with the increase of the SDI value for one country, it can decrease in another (see Table 2). Therefore, PA is only suitable for systems with linear dependencies, not for the non-linear dependencies characteristic to system "science – socio-economic development".

3.2 The Role of International Cooperation

SDI, as a measure of the level of scientific development of the society, has an interesting feature: this value decreases with the growth of the population (Figure 2a). However, a similar dependence can be observed for the share of international cooperation (Figure 2b), collected for every examined country from [22]. The share of international collaboration is also related to publication activity because it represents the proportion of works published and presented in a specific database with international participation, i.e., when the same authors of works are affiliated with organizations from different countries. This indicator also shows an increasing trend over time in most countries. For example, from 2000 to 2022, it increased among Chinese researchers from 16% to 20%, United States researchers from 19% to 39%, researchers from the UK from 27% to 61%, German researchers from 31% to 52%, researchers from France from 34% to 58%, etc.



a)



b)

Figure 2. Correlation of SDI (a) and international cooperation (b) with the number of population in leading countries by publishing research articles (2022). SDI – Science Development Index.

The observed dependence of the SDI on the population is clearly a result of the impact of the level of international cooperation on the effectiveness of scientific research. This, in turn, mirrors the extent of mutual influence among the components of the system "science development level – socio-economic development level".

3.3 The role of funding R&D

The effects of the mutual influence of the level of development of science and the level of socio-economic development of society, as described earlier [11–14] and above, are certainly related to its financing. This can be clearly demonstrated using examples from Eastern European countries: EU member states, non-members, and post-Soviet countries. In [13] it was shown that *SDI* of post-Soviet countries is dependent on the level of science funding (as a percentage of GDP). On the other hand, it was also demonstrated that the degree of mutual influence of the *HDI* and *SDI* (the coefficient *a* in Equations (2) and (3)) significantly increased for EU countries after the adoption of the Lisbon Strategy in 2000. This strategy aimed to increase overall Research and Developmen (R&D) expenditures to 3% of GDP by 2010, with the goal of becoming "the most competitive and dynamic knowledge-based economy in the world" [23].

Table 3 presents scientometric indicators for some EU/Eastern European/post-Soviet countries. The data show that the maximum values of both *SDI* and *PA* are in the EU member states. The *SDI* ranges from around 2 (Romania) to 7.72 (Slovenia), with a mean *SDI* value of 4.2. In contrast, for Eastern European countries outside the EU (with significantly lower R&D funding levels), the *SDI* ranges from 0.76 (Macedonia) to around 3 (Serbia), with a mean value of 1.7.

For the post-Soviet countries, the *SDI* value varies from 0.4 (Azerbaijan) to the maximum value of *SDI* 1.57 (Russia) for this group of countries, with a mean value of 0.9. The *SDI* value for Russia is attributed, on one hand, to the maximum level of R&D funding among these countries (approximately 1.2% of GDP) and, on the other hand, to the relatively low level of international cooperation (23%), which explains the lower *SDI* value compared to, for instance, Serbia (52% of international cooperation). It seems obvious that the impact of the level of funding and international cooperation is not unambiguous, but represents a certain trend (see Figure 2).

Another observation on the post-Soviet countries is that despite the very different levels of international cooperation between Russia (23%) and Moldova (62%), a significant difference in the level of funding for R&D (1.2% of GDP for Russia and 0.22% of GDP for Moldova) is one of the reasons for the significant disparity in *SDI* (1.57 and 0.43 respectively).

Table 3

Scientometric indicators of some EU/Eastern-European/post-Soviet countries, 2022

No.	Country	nPb*10^{-3}	PA*10^{-3}	SDI
1.	Slovenia	8.4	3.98	7.72
2.	Estonia	4.6	3.44	6.67
3.	Croatia	10.5	2.73	5.30
4.	Czech Rep.	27.7	2.60	5.03
5.	Lithuania	5.7	2.02	3.92
6.	Slovakia	9.8	1.81	3.50
7.	Latvia	3.3	1.77	3.44
8.	Poland	61.4	1.67	3.23
9.	Hungary	15.7	1.63	3.15
10.	Bulgaria	7.9	1.23	2.38
11.	Romania	20.0	1.05	2.04
12.	Serbia	10.4	1.56	3.03
13.	Montenegro	0.6	0.99	1.91
14.	Bosnia and Herzegovina	2.1	0.66	1.27
15.	Albania	1.1	0.39	0.76
16.	Macedonia	1.4	0.78	0.76
17.	Russia	117.0	0.81	1.57
18.	Georgia	2.4	0.64	1.23
19.	Ukraine	21.3	0.56	1.09
20.	Armenia	1.5	0.55	1.07
21.	Belarus	2.9	0.32	0.62
22.	Moldova	0.7	0.22	0.43
23.	Azerbaijan	2.1	0.21	0.40

Data source: nPb - [19]; PA, SDI calculated by authors based on [19,20]. nPb - number of publications; PA - Publication Activity; SDI - Science Development Index

The combined effect of science funding and the level of international cooperation on publication activity leads to *SDI* values (Figure 3) that correlate with the level of socio-economic development, expressed through *HDI*. This relationship is observed not only in scientifically advanced countries (see Figure 1), but also in relatively small Eastern European countries that are members of the EU, as well as in the post-Soviet countries (Figure 3).

The corresponding quantitative relation for post-Soviet countries is described by Equation (4).

$$HDI = 0.11\, lgSDI + 0.80 \quad (4)$$

With the correlation coefficient R = 0.85 ± 0.18 and a coefficient of mutual influence of 0.11 ± 0.02.

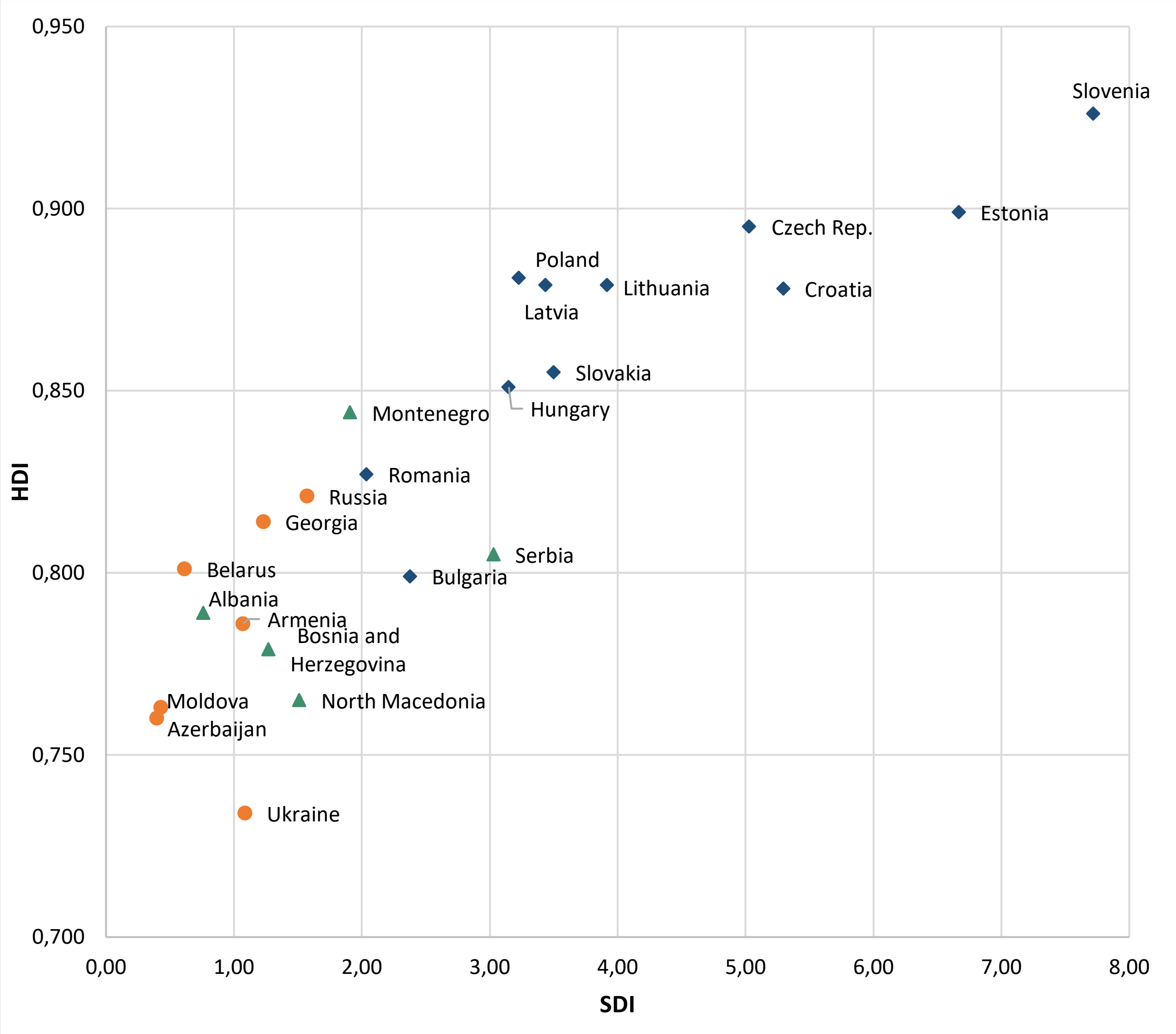


Figure 3. Dependence between *SDI* and *HDI* for some EU/Eastern European/post-Soviet countries. SDI – Science Development Index, HDI – Human Development Index.

Equation (5) describes the relationship between HDI and SDI for EU member states from the Eastern European region.

$$HDI = 0.13\, lgSDI + 0.79 \quad (5)$$

This relationship is characterized by a correlation coefficient of R = 0.86 ± 0.17 and a coefficient of mutual influence of 0.13 ± 0.13.

Despite the similarity of the coefficients in equations (4) and (5), the higher average values of both HDI and SDI for the EU member states compared to post-Soviet countries indicate the significant role of financing, which currently corresponds to approximately 3% of GDP for the EU countries. Additionally, according to the data presented in Figure 3, post-Soviet countries with their own energy resources (or preferential access to them) exhibit higher SDI compared to countries without their own energy resources. Therefore, socio-economic development levels depend not only on the advancement of science.

The analysis of the obtained results allows us to conclude that there is a correlation between the level of scientific development and the socio-economic development of both scientifically leading countries and smaller ones (particularly ex-Soviet countries). The level of scientific development in a country is evidently influenced by its funding. Despite this, active international cooperation among researchers from less funded R&D systems can notably enhance the level of scientific development. Consequently, with the presence of positive feedback, this can also boost the level of socio-economic development.

The high level of correlation between the components of the system: science development and level of socio-economic development, and the presence of non-linear, synergetic links in this system are determined by the very nature of science. Science is not only a self-organized system but also multifunctional, actively influencing various aspects of society.

4. Conclusions

The analysis demonstrates a significant correlation between *SDI* and *HDI*, indicating that countries with higher scientific output tend to have better socioeconomic indicators. The study identifies a non-linear relationship between scientific development and socioeconomic progress, suggesting that the growth of scientific activity can lead to reciprocal advancements in societal development. The study finds significant differences in scientific development and socioeconomic progress among various countries and regions, with Eastern European and post-Soviet countries generally lagging behind their Western counterparts.

International collaboration in scientific research plays a vital role in enhancing a country's scientific output and, consequently, its socioeconomic development.

Adequate funding for R&D is crucial for the advancement of science. Countries that invest more in R&D tend to demonstrate better performance in both *SDI* and *HDI*.

Policymakers should prioritize increasing investments in R&D and promoting international collaborations to improve scientific output, which can subsequently stimulate socioeconomic development.

Further studies should explore additional scientometric indicators and their impact on socioeconomic variables to enhance the understanding of the science-society relationship.

Conflict of interest: The authors declare no conflict of interest.

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Citation: Dikusar, A.; Cujba, R. Scientometric approach in determining the role of science in socioeconomic development of society. *Journal of Social Sciences* 2024, 7 (2), pp. 159-169. https://doi.org/10.52326/jss.utm.2024.7(2).13.

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