

The Performance of EU Member States in Terms of Industry 5.0

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DOI: 10.24818/mer/2026.02-05

ABSTRACT

Industry 5.0 has the role of addressing the fundamental limitations of Industry 4.0, its development positively influencing the competitiveness of a state by stimulating the technological innovation, human capital development, sustainability, and economic resilience. Thus, the main objective of this paper is to examine the situation of the European Union Member States in terms of Industry 5.0 degree of development and to propose possible development measures accordingly. The research methodology is based on building an indicator that measures aggregate performance on the three basic pillars of Industry 5.0: human-centricity, sustainability, and resilience, based on which the states are subsequently grouped into four performance clusters. The main results indicate high performances in the case of Denmark, Finland, and the Netherlands, while at the opposite pole is Bulgaria. The paper presents certain practical implications by proposing an index for measuring Industry 5.0 and highlighting which states have effective policies and development models, which can be considered as best practice. The paper also has some limitations, especially in terms of the number of the constituent variables of Industry 5.0 index.

KEYWORDS: *EU Member States, Industry 5.0, human-centricity, sustainability, resilience*

JEL CLASSIFICATION: *B21, O30*

1. INTRODUCTION

The global economy is in an accelerated transition process of digitalisation, with more activities being adapted to technological progress. This exponential technological development, which is the foundation of Industry 4.0, however, presents certain limitations, as essential aspects such as certain human needs and environmental responsibility are not effectively considered.

In response to these limitations, the European Commission introduced the concept of Industry 5.0 (I5.0), which extends the features of Industry 4.0 by strengthening the role of people in innovative production processes, with a real focus on sustainability and resilience (European Commission, 2021).

The development based on the Industry 5.0 pillars is a complex process, which involves resources and important transformations at the level of national economies (both at the macroeconomic and microeconomic levels), and those states that manage to achieve a sustainable implementation of the principles of the new industrial revolution will be able to obtain long-term competitive advantages.

Thus, the main objective of this paper is to analyse the current situation of the European Union (EU-27) Member States, with a focus on Romania, from the point of view of Industry 5.0 development and to propose on this basis certain potential measures for its development. Also, considering that Industry 5.0 is currently in a fairly early stage of research, the paper proposes

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an example of an index for measuring Industry 5.0 (which has not been identified by the author in another research) in order to achieve the established objective.

The relevance of this research is determined by the index proposed to analyse Industry 5.0 (aggregated on the three fundamental pillars using specific variables), developed within the work and calculated for the year 2025, as well as by the results obtained, which show a current picture of the grouping of EU-27 Member States into different clusters depending on the level of development of Industry 5.0.

2. LITERATURE REVIEW

The scientific literature analysing Industry 5.0 is in continuous development, with more and more researchers trying to identify and highlight various fundamental aspects of it for its implementation and obtaining benefits in an extended area of economic areas, such as the construction industry (Tunji-Olayeni et al., 2023), food industry (Malik et al., 2025), healthcare (Ambrogio et al., 2025) or smart manufacturing (Sarkar et al., 2024).

Regarding the main enablers of Industry 5.0, authors such as Bongomin et al. (2025) and Barata and Kayser (2024) show that digital twin is one of the foundational technologies for the transition from Industry 4.0 to Industry 5.0.

Ivanov (2023) is one of the authors who have conducted complex studies on Industry 5.0, highlighting, among other things, the fact that the new industrial revolution involves human well-being, social sustainability, and resilience.

Regarding human-centricity, Padovano et al. (2024) show that public opinion emphasises soft and hard skills, gender equity, and comfort at work. On the other hand, Pinto et al. (2024) highlight the need for upskilling and continuous learning, as well as the imminent need to adapt educational systems to current demands and changes and present the Self-Made Programme as a solution. The idea is supported by Carminati et al. (2025), who propose partnerships between academia and industry for skills development, while Helker et al. (2024) propose challenge-based learning programs as a way to obtain transdisciplinary skills.

Further, Salvadorinho et al. (2026) discuss the motivational factors and expectations of employees related to the labor market depending on the generation they belong to, and their results contribute to shaping future scholarships and HR strategies.

Moving to the next important pillar, Rame, Purwanto and Sudarno (2024) analyse the link between Industry 5.0 and sustainability, demonstrating the potential of advanced technologies in stimulating sustainable industries, and Fatima, Gupta and Hossain (2025) showed that Industry 5.0 is increasingly integrated into natural resource intensive industries. Similarly, Singh et al. (2025) demonstrate that Industry 5.0 contributes to increasing sustainability, efficiency and the degree of personalisation in the food system.

Industry 5.0 also has positive implications for companies' ESG performance, Asif, Searcy and Castka (2023) showing the capacity of the new industrial revolution to increase ESG disclosure. To obtain the desired benefits, Ghobakhloo et al. (2022) identified 16 functions through which Industry 5.0 contributes to sustainable development, emphasising that they must be developed in a certain order.

Regarding resilience, Brückner et al. (2025) highlight the need to develop advanced IT systems so that the implementation of Industry 5.0 can withstand various shocks.

Considering these aspects, the paper attempts to contribute to the scientific literature by showing what is the current situation of EU Member States in terms of Industry 5.0 development based on a proposed index that aggregately measures the three pillars of Industry 5.0.

3. METHODOLOGY AND DATA

The applied research methodology is mainly based on quantitative analysis, descriptive analysis and comparative analysis.

To build the index that defines Industry 5.0, the three fundamental pillars have been taken into account: human-centricity (HC), sustainability (S) and resilience (R), according to equation (1):

$$I5.0 = w_{HC} * HC + w_S * S + w_R * R \tag{1}$$

where,

w_{HC} , w_S , w_R are the weights of each pillar in the index

Each pillar is treated as having the same importance for the development of Industry 5.0, so $w_{HC} = w_S = w_R = 0.33$

To calculate HC, S and R pillars for every country, the following variables were used:

- % of individuals with basic or above basic overall digital skills (HC_1);
- % of individuals with basic or above basic information and data literacy skills (HC_2);
- % of enterprises using ICT systems or solutions to reduce the energy consumption (S_1);
- % of enterprises using ICT systems or solutions to reduce the materials used (including consumables) or to enhance the use of recycled materials (S_2);
- % of enterprises using at least one of the AI technologies (R_1);
- % of enterprises using Business Intelligence (BI) software (R_2).

For S_1 , S_2 , R_1 and R_2 , the Eurostat size class in number of persons employed was 10 persons employed or more, and the statistical classification of economic activities in the European Community was all activities (with related exceptions).

For the index to be statistically balanced, the variables were initially standardised using Z-score:

$$Z - score = \frac{X - \mu}{\sigma} \tag{2}$$

- X – standardised value
- μ - mean
- σ - standard deviation

Thus, the variables became (ZHC_1 , ZHC_2 , ZS_1 , ZS_2 , ZR_1 , and ZR_2).

Using the standardised variables, the three pillars of I5.0 were calculated according to formulas (3), (4) and (5)

$$HC = \frac{ZHC_1 + ZHC_2}{2} \tag{3}$$

$$S = \frac{ZS_1 + ZS_2}{2} \tag{4}$$

$$R = \frac{ZR_1 + ZR_2}{2} \tag{5}$$

Based on the calculated I5.0 values, the states included in the analysis were divided into four performance clusters using the K-Means Cluster Analysis (classify only method).

The data series are for the year 2025 and are collected from the Eurostat database. Croatia was excluded due to no data related to S_2 .

Data processing was performed using Microsoft Excel and IBM SPSS Statistics.

4. RESULTS

Figure 1 highlights the situation of EU Member States in terms of the determined value of the I5.0 index in 2025.

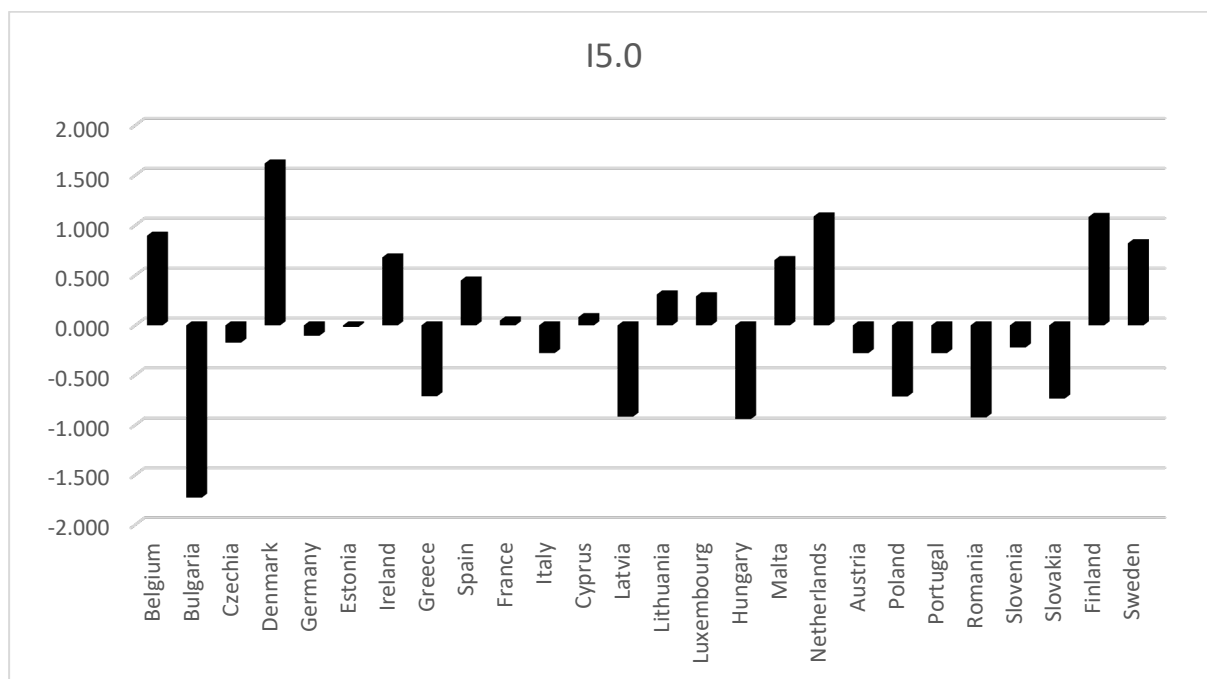


Figure 1. I5.0 value for UE Member States, 2025

Source: Author's calculations based on Eurostat data (2025)

The values indicate that the highest performance in terms of Industry 5.0 development is recorded by Denmark, while at the opposite pole is Bulgaria.

For a more relevant picture, the EU-27 Member States were grouped into four clusters according to I5.0 values (Table 1).

Table 1. Clustering EU Member States based on I5.0

Case Number	GEO (Labels)	Cluster	Distance
1	Belgium	2	0.448
2	Bulgaria	4	0
3	Czechia	3	0.537
4	Denmark	1	0
5	Germany	2	0.554
6	Estonia	2	0.465
7	Ireland	2	0.23
8	Greece	3	0
9	Spain	2	0
10	France	2	0.4

Case Number	GEO (Labels)	Cluster	Distance
11	Italy	3	0.433
12	Cyprus	2	0.367
13	Latvia	3	0.205
14	Lithuania	2	0.14
15	Luxembourg	2	0.158
16	Hungary	3	0.23
17	Malta	2	0.204
18	Netherlands	1	0.53
19	Austria	3	0.432
20	Poland	3	0.002
21	Portugal	3	0.432
22	Romania	3	0.213
23	Slovenia	3	0.489
24	Slovakia	3	0.024
25	Finland	1	0.535
26	Sweden	2	0.372

Source: Author's calculations in IBM SPSS based on Eurostat data (2025)

Cluster 1 includes the countries with the highest performance in terms of Industry 5.0 development. In addition to Denmark, this cluster also includes Finland and the Netherlands. The results of these states demonstrate a solid structure for the accelerated development and implementation of Industry 5.0, with both a high percentage of enterprises implementing some of the new and most representative digital technologies (AI and BI), and human resources that have the necessary skills for the transition.

Denmark is the EU leader in terms of sustainability and resilience, while the Netherlands ranks first regarding human-centricity.

Bulgaria's results are significantly lower than the other countries included in the analysis, which is why it falls into a cluster that no other countries are part of (Cluster 4, with the worst performance regarding Industry 5.0).

The second performance cluster is Cluster 2 and includes the following countries: Belgium, Germany, Estonia, Ireland, Spain, France, Cyprus, Lithuania, Luxembourg, Malta, and Sweden. Romania falls into the third cluster (Cluster 3), which groups, among others, several states in Eastern Europe.

The results obtained are similar to those obtained by Brodny and Tutak (2026), who, based on a similar study, demonstrated that Denmark and the Netherlands are among the countries most prepared for the transition to Industry 5.0, while Poland, Greece, Bulgaria, and Romania are at the opposite pole.

If we analyse the situation of Romania in detail, we notice that it records one of the lowest values of 15.0 compared to the other countries in this cluster (Table 2).

Table 2. Cluster 3 description

GEO (Labels)	HC	S	R	I5.0
Czechia	0.75	-0.99	-0.29	-0.174
Greece	-0.54	-0.52	-1.09	-0.711
Italy	-1.03	0.58	-0.40	-0.278
Latvia	-0.87	-1.14	-0.76	-0.916
Hungary	-0.26	-1.57	-1.03	-0.941
Austria	0.26	-1.42	0.31	-0.279
Poland	-0.74	-0.42	-1.00	-0.713
Portugal	-0.41	0.35	-0.78	-0.279
Romania	-1.85	0.39	-1.33	-0.924
Slovenia	-0.53	0.13	-0.27	-0.222
Slovakia	-0.57	-1.25	-0.40	-0.735

Source: Author's calculations based on Eurostat data

This situation is associated with the fact that for two of the I5.0 pillars (human-centricity and resilience), Romania ranks last in this cluster. In the case of HC, these low performances of Romania are determined mainly by the low percentage of individuals with basic or above basic overall digital skills, while in the case of the R pillar, the ranking is influenced both by the very low percentage of enterprises using at least one of the AI technologies, and that of enterprises using BI software.

To improve the situation of Romania (and other states with similar results), it is necessary, first of all, to develop digital infrastructure, for instance, through investments in the development of 5G networks and improving cybersecurity.

In terms of human resources, it is necessary to reform and adapt the educational systems to the new requirements of the economy based on digitalisation and innovation through academic programs that help the development of the technical and creative skills necessary for human-machine collaboration. Thus, universities must introduce new courses into their educational offerings, such as AI, robotics, sustainability management, data analytics, and cybersecurity, and the curriculum must be reviewed at short intervals of time following consultations with the business sector.

The development of people's skills must be supported also by companies, through lifelong learning programs for employees. In this regard, the state can stimulate such programs through tax benefits for companies that invest in upskilling.

On the other hand, it is imperative to design and implement programs to support people who have difficulties adapting to changes and/or related to professional retraining, carried out by both the business sector and the public administration. These programs include offering free courses, ensuring an income during the reconversion period, and professional coaching.

Additionally, to increase sustainability-related performance, it is recommended to place a high emphasis on granting government guarantees to companies accessing loans for the acquisition of high-performance equipment with high energy efficiency. At the same time, it might be appropriate to apply tax cuts to increase the share of renewable energy in total energy consumption in industry and for the development of industrial resource recovery and reuse

systems, as well as establishing and implementing specific key performance indicators to evaluate the degree of achievement of sustainability objectives by companies.

Regarding the R pillar, as it was constructed in this paper, private investments are needed in developing AI capacity and BI solutions, as well as government incentives to encourage these innovations and continuous R&D.

5. CONCLUSIONS

Industry 5.0 is a concept that is developing rapidly, being the answer to the challenges generated by economic development based on technological progress. The faster and more inclusively an economy, an industry, or even a company integrates the principles of the new industrial revolution, the more it will succeed in obtaining competitive advantages in the medium and long term.

Also, development based on Industry 5.0 principles can contribute to increasing people's living standards and reducing income and opportunity inequalities.

Through this work, an overview of the level of development of EU Member States in terms of Industry 5.0 was obtained, based on which certain measures have currently been proposed, which can improve the situation of countries at the bottom of the ranking according to performance.

The paper has certain limitations, the most relevant being the small number of variables included in the constructed Industry 5.0 index. This limitation can be addressed in future research by adding additional relevant variables to the structure of each of the three pillars of I5.0. At the same time, in order to test the consistency of the results, the work can be extended by establishing alternative hypotheses regarding the allocation of weights for each pillar.

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