ENTREPRENEURSHIP, TRADE AND EXCHANGE ACTIVITIES

RECEIVED:
11 July 2024
ACCEPTED:
19 September 2024
RELEASED:
20 October 2024

UDC 004.8:658.114

DOI 10.26661/2522-1566/2024-3/29-12

ADOPTION OF ARTIFICIAL INTELLIGENCE IN EUROPEAN ENTERPRISES: A MATHEMATICAL MODEL BASED ON SOCIOECONOMIC AND TECHNOLOGICAL INDICATORS

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Abstract. This study examines the factors influencing the adoption of Artificial Intelligence (AI) by enterprises across European countries, with a particular focus on the role of digital infrastructure and human capital. Using a linear regression model, the analysis explores the relationship between AI adoption and several key indicators, including the Digital Economy and Society Index (DESI), Human Development Index (HDI), Global Innovation Index (GII), Technology Readiness Index (TRI), and GDP per capita. The results reveal that DESI and HDI are the most significant drivers of AI adoption, highlighting the importance of digital ecosystems and educated workforces in facilitating AI integration.

The model explains 64.9% of the variance in AI adoption, with DESI contributing to a 0.26% increase in AI adoption for every unit of improvement. HDI, representing the quality of human capital, plays an even larger role, suggesting that countries with higher levels of education and social development are better equipped to integrate AI into their industries. While innovation and technological readiness contribute to AI adoption, their effects are less pronounced compared to infrastructure and workforce readiness. GDP per capita, though positive, has only a marginal impact on AI adoption, indicating that economic strength alone does not guarantee widespread use of AI technologies.

The study also provides a country-specific analysis, identifying Germany, Finland, and Ireland as leaders in AI adoption due to their strong digital and human resource foundations. Conversely, Bulgaria and Greece lag behind, primarily due to weaker digital infrastructure and lower levels of workforce readiness. Policy recommendations for these countries include targeted investments in digital infrastructure, education, and workforce training programs, as well as fostering public-private partnerships and supportive regulatory environments for AI development.

The findings emphasize the critical role of digital infrastructure and human capital in driving AI adoption. Countries aiming to enhance their AI capabilities should focus on these key areas to remain competitive in the rapidly evolving global economy.

Keywords: AI, Artificial Intelligence adoption, digital infrastructure, human capital, AI Drivers in Europe, Digital Economy and Society Index, Human Development Index, Innovation and Technology Readiness.

JEL: A11, C45, O33, O52.

Antoniuk, D. & Kolyada, O. (2024). Adoption of artificial intelligence in European enterprises: a mathematical model based on socioeconomic and technological indicators. Management and Entrepreneurship: Trends of Development, 3(29), 130-139. https://doi.org/10.26661/2522-1566/2024-3/29-12

INTRODUCTION

The rapid development and integration of Artificial Intelligence (AI) across industries have transformed the global economic and technological landscape. AI is not only reshaping traditional industries but also acting as a catalyst for new business models and innovations. European enterprises, in particular, are embracing AI to enhance productivity, optimize operations, and create competitive advantages in an increasingly digitalized economy (Antoniuk & Kolyada, 2024). However, the adoption of AI across different countries is uneven, and the degree of its utilization varies significantly depending on several socioeconomic and technological factors.

In last years, Europe saw a marked increase in AI implementation across various sectors, driven by advancements in digital infrastructure, increased investments in AI research and development (R&D), and growing awareness of AI's potential among enterprises (European Court of Auditors, 2024). Nevertheless, several challenges persist, including gaps in digital literacy, insufficient technological infrastructure in certain regions, and regulatory and ethical concerns surrounding AI deployment.

LITERATURE REVIEW

The level of AI adoption by enterprises is influenced by a wide range of factors, both quantitative and qualitative. These factors include the availability of digital infrastructure, human capital readiness, innovation capacity, economic development, regulatory frameworks, and governmental support (Kabalisa & Altmann 2021; Brey & van der Marel, 2024; Hooks D. et al., 2022). Understanding the dynamics between these factors is crucial for explaining why AI adoption varies significantly across different regions and sectors. Therefore, conducting both quantitative and qualitative analyses of these indicators is essential for identifying the key drivers behind AI implementation and for developing strategies to enhance AI readiness in lagging countries.

One of the most critical factors is the state of a country’s digital infrastructure. Countries with robust digital ecosystems, characterized by widespread high-speed internet access, well-developed data centers, and access to advanced cloud computing resources, are generally more capable of integrating AI technologies into their industries. The Digital Economy and Society Index (DESI), which measures digital infrastructure and performance, provides a comprehensive view of a country’s preparedness for AI adoption (European Comission, 2023). Nations with higher DESI scores, such as Germany and Denmark, have created technological environments that support the widespread use of AI.

Human capital also plays a pivotal role in AI adoption, particularly the availability of skilled workers in fields such as science, technology, engineering, and mathematics (STEM). Countries with a strong focus on education and workforce development are better positioned to leverage AI technologies. The Human Development Index (HDI) provides insights into a country’s educational and societal capacity to integrate AI (Hooks D. et al., 2022). Higher HDI scores, as seen in countries like Finland and the Netherlands, are associated with more educated workforces, enabling better integration of AI into enterprises.

In addition to human capital, a nation’s capacity for innovation is a critical predictor of AI adoption. The Global Innovation Index (GII) measures how well countries foster innovation, with high-scoring nations leading in AI research and development (TheGlobalEconomy.com, 2023). Countries like Switzerland and Sweden benefit from strong public and private sector partnerships, fostering a favorable environment for technological advancements. These innovation-oriented nations invest heavily in AI-related research, which facilitates faster adoption of these technologies.

Economic resources, particularly Gross Domestic Product (GDP) per capita, are also crucial in determining a country’s ability to adopt AI. Wealthier nations, such as the United Kingdom and France, with higher GDP per capita can allocate more resources to AI infrastructure and development (CBS, 2024). This enables them to accelerate the integration of AI technologies across

industries. Research from McKinsey Global Institute (2018) emphasizes that economic power is a key determinant in AI adoption.

Furthermore, regulatory frameworks and governmental support are important factors that influence the pace and success of AI implementation. Countries with well-defined regulatory systems that address the ethical, privacy, and safety aspects of AI use are more likely to see higher adoption rates. The existence of national AI strategies, as seen in France (French National Artificial Intelligence Research Program, 2024) and the United Kingdom (UK AI Strategy Beyond, 2024) provides clarity and direction for both public and private sector investments in AI. Governments that actively promote AI development through incentives, public-private partnerships, and funding for AI research help create a conducive environment for adoption.

Cultural attitudes towards technology and risk aversion also play a role. In some countries, industries may be more open to experimentation and the adoption of cutting-edge technologies, while others may demonstrate reluctance due to concerns about job displacement, ethical considerations, or cybersecurity risks. Nations that foster a culture of innovation and embrace change, such as Estonia and Finland, tend to adopt AI technologies faster than more conservative or risk-averse countries.

Despite these positive factors, significant disparities in AI adoption exist across Europe. Western and Northern European countries are leading the way in AI integration, while Southern and Eastern European nations face challenges. For instance, Germany, Sweden, and Finland excel due to their strong digital infrastructure, innovation ecosystems, and educated workforces. Meanwhile, countries like Bulgaria and Romania face substantial hurdles, including weaker infrastructure, lower levels of governmental support, and insufficient investment in AI (Statistics Explained, 2024).

Research indicates that a combination of well-defined regulatory frameworks, investment in digital infrastructure, human capital development, and innovation-driven policies is essential for overcoming these disparities. Countries that lack these factors encounter significant barriers such as regulatory uncertainty, limited access to technology, and resistance from traditional industries. A comprehensive analysis of these factors is necessary to understand the reasons behind the uneven adoption of AI across Europe.

PAPER OBJECTIVE

This study aims to provide a mathematical model that highlights the interplay of these indicators, offering insights into how countries can improve their AI readiness and competitiveness.

METHODOLOGY

This study employs a quantitative modeling approach to explore the relationship between various socioeconomic and technological indicators and the level of Artificial Intelligence (AI) adoption by enterprises across different European countries. The goal of this analysis is to identify the key factors driving AI implementation and to assess their relative impact.

The data used in this study were gathered from publicly available sources, including international reports and databases such as the OECD, United Nations Development Programme (UNDP), and World Bank. The following key indicators were selected as independent variables in the model (Table 1):

- Digital Economy and Society Index (DESI). Measures a country’s digital infrastructure, including internet access, data centers, and cloud computing availability. This index is a key indicator of technological readiness for AI adoption.
- Human Development Index (HDI). Reflects a country’s level of education, healthcare, and overall quality of life. Higher HDI scores indicate better preparedness of the workforce to integrate AI technologies.

- Global Innovation Index (GII). Assesses a country's capacity for innovation and technological advancements. Countries with higher GII scores are expected to have more favorable conditions for AI research and development.
- Network Readiness Index (Technology). Measures the technological infrastructure and access to communication tools necessary for AI adoption.
- Gross Domestic Product (GDP) per capita. Represents the economic resources available to a country, reflecting its ability to invest in AI infrastructure and development.

The dependent variable in the model is the percentage of enterprises that have adopted AI technologies, which was collected from relevant sources detailing AI implementation across European countries.

A linear regression model was employed to estimate the impact of these independent variables on AI adoption. The general form of the model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \epsilon, \quad (1)$$

where: Y – represents the percentage of AI adoption by enterprises (dependent variable),

X_1 to X_5 represent the independent variables (DESI, HDI, GII, Technology, GDP per capita),

β_0 is the intercept, and β_1 to β_5 are the coefficients that estimate the influence of each variable on AI adoption,

ϵ is the error term.

The regression analysis was conducted using the Ordinary Least Squares (OLS) method, which minimizes the sum of the squared residuals between the observed and predicted values of the dependent variable. This approach allows for the identification of statistically significant relationships between the independent variables and the level of AI adoption.

Table 1.

Inputs for mathematical modeling, 2023

Country	Digital Economy and Society Index (DESI)	Human Development Index (HDI)	Global Innovation Index (GII)	Network Readiness Index (Technology)	Gross Domestic Product (GDP) per capita, adjusted for price level differences, thousand €	Percentage of enterprises that have adopted AI technologies, %
Austria	56,9	0,926	53,25	60,19	46,2	10,8
Belgium	54,7	0,942	49,94	57,11	44,4	13,8
Bulgaria	42,7	0,799	-	42,69	24,1	3,6
Greece	44,6	0,893	37,53	53,39	25,3	4
Denmark	74,8	0,952	60,7	-	48	15,2
Estonia	59,1	0,899	53,38	51,33	30,7	5,2
Ireland	63,2	0,95	50,42	56,58	79,6	8
Spain	51,7	0,911	45,93	56,34	33,3	9,2
Italy	47,8	0,906	46,61	53,08	39,5	5
Cyprus	49,4	0,907	46,29	46,26	35,8	4,7

Latvia	53,7	0,879	39,73	44,53	26,6	4,5
Lithuania	55,7	0,879	41,95	49,55	32,6	4,9
Luxembourg	60,1	0,927	50,6	62,47	90,2	14,4
Malta	61,8	0,915	49,08	49,71	36,7	13,2
Netherlands	68,9	0,946	64,5	71,59	49,1	13,4
Germany	61	0,95	58,76	69,45	43,3	11,6
Poland	45,5	0,881	37,75	48,95	30	3,7
Portugal	56,4	0,874	44,88	56	31,1	7,9
Romania	40,3	0,827	34,66	42,76	29,4	1,5
Slovakia	44,8	0,855	36,21	48,42	27,3	7
Slovenia	54,2	0,926	42,24	51,25	34,4	11,4
Hungary	45,3	0,851	41,34	51,36	28,7	3,7
Finland	69,9	0,942	64,8	65,5	40,7	15,1
France	54,5	0,91	56,02	62,96	38	5,9
Croatia	50	0,878	37,07	38,8	25,8	7,9
Czech Republic	52,4	0,895	44,83	53,39	34,2	5,9
Sweden	68,6	0,952	59,5	67,21	43,9	10,4

Source: compiled by (European Comission, 2023, The Facts Institute. 2023, TheGlobalEconomy.com. 2023, CBS. 2024, Statistics Explained, 2024).

To evaluate the model, we examined the R-squared value, which indicates the proportion of the variance in the dependent variable explained by the independent variables. Additionally, the F-statistic was used to test the overall significance of the model, while the p-values for each independent variable determined the statistical significance of individual predictors. A confidence level of 95% was used to assess the significance of the coefficients.

While the model provides valuable insights into the factors influencing AI adoption, certain limitations should be acknowledged. Multicollinearity, or the correlation between independent variables, may affect the stability of the estimated coefficients. Furthermore, unobserved factors such as cultural attitudes towards technology, regulatory frameworks, and risk aversion, which may also play a significant role in AI adoption, were not directly included in the model but could be explored in future research.

RESULTS AND DISCUSSION

The regression analysis produced a model describing the relationship between AI adoption by enterprises and several key socioeconomic and technological factors. The mathematical model is as follows:

$$Y = -50.39 + 0.2646X_1 + 50.7303X_2 - 0.1565X_3 + 0.0937X_4 + 0.0105X_5, \quad (1)$$

where:

Y – represents the percentage of enterprises adopting AI, %,

X_1 – Digital Economy and Society Index (DESI),

X_2 – Human Development Index (HDI),

X_3 – Global Innovation Index (GII),
X_4 – Technology Readiness Index,
X_1 – GDP per capita, adjusted for price level differences, thousand €.

The statistical significance of the model, confirmed by the F-statistic of 7.022 and a p-value of 0.000718, demonstrates that the independent variables, when taken together, play a crucial role in explaining AI adoption patterns. Among the key drivers, DESI and HDI emerge as the most influential, both showing positive and significant effects on AI adoption. In contrast, GII, Technology Readiness, and GDP per capita showed weaker and statistically insignificant impacts in this model, suggesting that while they play a role, they are secondary to infrastructure and human capital.

The positive coefficient (0.2646) suggests that as the DESI score increases (X_1), indicating improved digital infrastructure, the percentage of enterprises adopting AI also rises. Countries with well-developed broadband networks, cloud computing resources, and overall digital readiness are better equipped to integrate AI into their industries. For example, Germany and Denmark, with high DESI scores (56.9 and 58.7, respectively), are among the leaders in AI adoption, while countries such as Bulgaria and Romania (DESI = 42-43) are struggling due to weaker digital infrastructure.

The large positive coefficient (50.7303) near X_2 (Human Development Index (HDI)) highlights the crucial role that human capital plays in AI adoption. Countries with higher HDI scores, reflecting better education systems, healthcare, and quality of life, are better positioned to integrate AI technologies. For instance, Finland and Netherlands, with high HDI scores (0.94 and 0.95), demonstrate strong AI adoption, leveraging their highly educated workforces. Conversely, countries like Bulgaria and Greece (HDI around 0.79-0.89) face challenges due to lower levels of workforce readiness.

The coefficient for GII was slightly negative (-0.1565), which was unexpected. This suggests that innovation alone is not a strong predictor of AI adoption in the presence of other factors such as digital infrastructure and human capital. While countries like Switzerland and Sweden invest heavily in AI research, the relationship between innovation and adoption appears to be more complex, possibly due to variations in how quickly innovations are commercialized and adopted in the market.

The positive coefficient (0.0937) suggests a slight positive effect of technological readiness on AI adoption, though it is not statistically significant in this dataset. Countries with more advanced communication technologies and infrastructure, such as Ireland (Technology Index = 56.58) and Austria (60.19), are well-positioned for AI adoption, but the readiness alone does not guarantee widespread implementation without strong human capital and innovation ecosystems.

The small coefficient (0.0105) for GDP per capita shows that economic wealth has a limited effect on AI adoption compared to other factors. While wealthier countries such as Ireland (€79600) and Austria (€46200) can allocate more resources to AI, economic strength alone is insufficient without supporting infrastructure and workforce capabilities. Lower-income countries, such as Greece and Bulgaria, could still make significant strides in AI adoption by focusing on improving their digital infrastructure and education systems.

The scatter plots of AI adoption against DESI, HDI, GII, Technology Readiness, and GDP per capita reveal (Fig. 1) that DESI and HDI exhibit clear positive correlations with AI adoption, confirming their status as key drivers. The relationship between AI adoption and innovation, however, is less well-defined, reflecting the complexity of the innovation ecosystem in driving real-world AI use.

Country-specific analysis highlights Finland's, Denmark's, Belgium's, Germany's leadership in AI adoption, supported by high DESI and HDI scores. Finland, too, benefits from its emphasis on human capital, with its educated workforce playing a pivotal role in the integration of AI technologies.

For countries that are lagging in AI adoption, such as Bulgaria, Greece, and Romania, it is essential to develop strategies focused on improving infrastructure and enhancing human capital.

First and foremost, it is crucial to strengthen digital infrastructure. Investments in high-speed internet, cloud technologies, and modern networks will create the foundation for successful AI adoption. For countries like Bulgaria (DESI = 42.7), improving digital infrastructure should be a top priority.

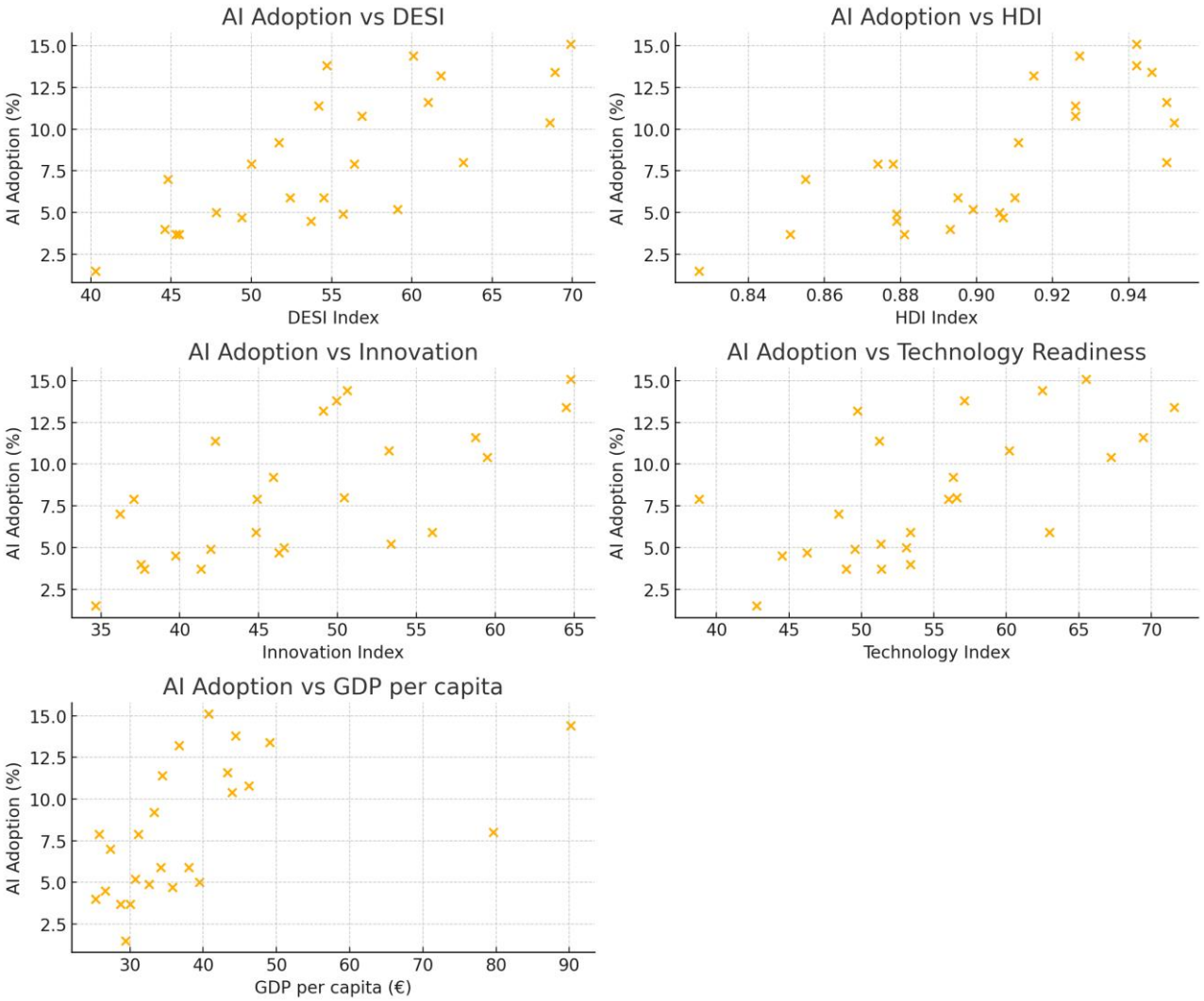

Figure 1. Scatter plots of AI adoption against DESI, HDI, GII, Technology Readiness, and GDP per capita reveal

Source: compiled based on statistical data using ChatGPT [European Comission, 2023, The Facts Institute. 2023, TheGlobalEconomy.com. 2023, CBS. 2024, Statistics Explained, 2024].

The second step is to invest in education and human capital development. Countries with lower HDI scores, such as Bulgaria (HDI = 0.79), need to expand educational programs, particularly in STEM fields, and introduce reskilling and upskilling programs to prepare the workforce for AI-related tasks. Building a competent and educated workforce is key to ensuring successful technology integration.

Additionally, it is important to promote innovation and foster public-private partnerships. While innovation alone is not decisive, creating an environment that encourages collaboration between government, businesses, and educational institutions will help accelerate AI adoption. This is particularly relevant for countries like Greece, where there is potential for innovation but a lack of conditions for widespread commercialization of new technologies.

Furthermore, countries should focus on establishing favorable regulatory frameworks for AI development. Addressing issues such as data privacy, ethics, and security will help build trust in AI technologies and encourage enterprises to adopt them. Countries like Romania and Greece, for example, would benefit from revising their regulatory approaches to AI development.

CONCLUSION

1. This study investigated the factors influencing the adoption of Artificial Intelligence (AI) by enterprises across European countries, focusing on the roles of digital infrastructure and human capital. The research provided a clear and comprehensive analysis of key socioeconomic and technological indicators such as the Digital Economy and Society Index (DESI), Human Development Index (HDI), Global Innovation Index (GII), Technology Readiness, and GDP per capita, and their relationship with AI adoption.

2. The regression model developed in the study explains 64.9% of the variance in AI adoption, indicating a strong correlation between the chosen factors and the extent of AI implementation in enterprises. The results of the analysis highlight two primary drivers of AI adoption: digital infrastructure (DESI) and human capital (HDI). Countries with advanced digital ecosystems, such as Germany and Denmark, have higher rates of AI adoption, illustrating the critical importance of having robust digital foundations for enabling the effective use of AI technologies. Similarly, countries like Finland and the Netherlands, with high HDI scores, show that an educated and skilled workforce is fundamental to the successful integration of AI into business processes.

3. Contrary to expectations, the Global Innovation Index (GII) had a weaker, and even slightly negative, effect on AI adoption, suggesting that while innovation capacity is essential for developing AI technologies, it alone does not drive adoption. This finding points to the complexity of AI implementation, where even the most innovative countries may face barriers to translating innovation into widespread use of AI. Additionally, Technology Readiness and GDP per capita demonstrated minimal influence, underscoring that neither economic wealth nor technological infrastructure can independently accelerate AI adoption without strong human capital and adequate digital infrastructure.

4. Country-specific analysis revealed that while Western and Northern European countries are leading in AI adoption, Southern and Eastern European countries, such as Bulgaria, Greece, and Romania, are lagging behind. These countries face significant challenges, particularly in terms of weaker digital infrastructure and lower levels of human capital readiness.

5. The study underscores several recommendations for countries lagging in AI adoption: (1) enhancing digital infrastructure (countries with lower DESI scores should prioritize investments in broadband networks, cloud computing, and modern digital infrastructure to create the foundation necessary for AI integration); (2) investing in human capital (the development of a skilled workforce through enhanced educational programs, particularly in STEM fields, and reskilling initiatives is crucial for successful AI implementation); (3) promoting innovation and collaboration (fostering public-private partnerships, as well as encouraging collaboration between the government, businesses, and educational institutions, can help accelerate AI adoption and create a more favorable environment for technology commercialization); (4) establishing favorable regulatory frameworks (governments should implement clear and supportive regulatory policies addressing data privacy, ethics, and security concerns related to AI; this will help build trust in AI technologies and encourage their adoption by enterprises).

Countries aiming to enhance their AI capabilities must focus on building strong digital infrastructure and investing in human capital. Digital readiness and workforce development are critical for ensuring that enterprises can effectively adopt and integrate AI technologies, ultimately enabling them to remain competitive in the rapidly evolving global economy.

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ВПРОВАДЖЕННЯ ШТУЧНОГО ІНТЕЛЕКТУ НА ЄВРОПЕЙСЬКИХ ПІДПРИЄМСТВАХ: МАТЕМАТИЧНА МОДЕЛЬ НА ОСНОВІ СОЦІАЛЬНО-ЕКОНОМІЧНИХ ТА ТЕХНОЛОГІЧНИХ ПОКАЗНИКІВ

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У дослідженні розглядаються фактори, що впливають на впровадження штучного інтелекту (ШІ) підприємствами в європейських країнах, з особливим акцентом на ролі цифрової інфраструктури та людського капіталу. З використанням лінійної регресійної моделі, встановлено взаємозв'язок між рівнем впровадженням ШІ та кількома ключовими показниками, зокрема Індексом цифрової економіки та суспільства (DESI), Індексом людського розвитку (HDI), Глобальним інноваційним індексом (GII), Індексом технологічної готовності (TRI) та ВВП на душу населення. Результати показують, що DESI та HDI є найбільш значущими рушійними силами впровадження ШІ, підкреслюючи важливість цифрових екосистем та освіченої робочої сили для сприяння інтеграції ШІ.

Модель пояснює 64,9% дисперсії у впровадженні ШІ, причому DESI сприяє збільшенню впровадження ШІ на 0,26% на кожну одиницю вдосконалення. ІЛР, що відображає якість людського капіталу, відіграє ще більшу роль, що свідчить про те, що країни з вищим рівнем освіти та соціального розвитку краще підготовлені до інтеграції ШІ у свої галузі. Хоча інновації та технологічна готовність сприяють впровадженню ШІ, їхній вплив є менш вираженим порівняно з інфраструктурою та готовністю робочої сили. ВВП на душу населення, хоча і має позитивний вплив, має лише незначний ефект на впровадження ШІ, що свідчить про те, що економічна сила сама по собі не гарантує широкого використання технологій ШІ.

У дослідженні також представлений аналіз по країнах, який визначає Німеччину, Фінляндію та Ірландію як лідерів у впровадженні ШІ завдяки їхньому потужному цифровому та кадровому потенціалу. І навпаки, Болгарія та Греція відстають, насамперед через слабшу цифрову інфраструктуру та нижчий рівень готовності робочої сили. Рекомендації для цих країн включають цільові інвестиції в цифрову інфраструктуру, освіту та програми підготовки кадрів, а також сприяння державно-приватному партнерству та створенню сприятливого регуляторного середовища для розвитку ШІ.

Результати дослідження підкреслюють вирішальну роль цифрової інфраструктури та людського капіталу у впровадженні ШІ. Країни, які прагнуть розширити свої можливості у сфері ШІ, повинні зосередитися на цих ключових сферах, щоб залишатися конкурентоспроможними в глобальній економіці, що швидко розвивається.

Ключові слова: ШІ, впровадження штучного інтелекту, цифрова інфраструктура, людський капітал, драйвери ШІ в Європі, Індекс цифрової економіки та суспільства, Індекс людського розвитку, інноваційна та технологічна готовність.