

Kichurchak, Marianna

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Human capital in the sustainable development of EU countries: A longitudinal data analysis

Marianna Kichurchak*

Doctor of Economic Sciences, Professor
Ivan Franko National University of Lviv
79000, 1 Universytetska Str., Lviv, Ukraine
<https://orcid.org/0000-0002-1927-5704>

Abstract. One of the prominent areas focused on identifying the key trends and factors of human capital formation for sustainable development in the EU countries is the use of panel data. This study specified the dependence of human capital in the EU countries on four factor attributes that affect its place and role in sustainable development using longitudinal data analysis. The methodological framework of this study included the econometric modelling toolkit for constructing multivariate regression equations of three types: pooled regression, fixed effects, and variable effects. To determine the parameters of multivariate regression equations, the study employed Eurostat statistics for 21 EU countries for 2013-2021, based on the completeness of the statistical indicators presented for the resultant and factor attributes and the incompleteness of such data for 2022-2024. For the three types of multivariate regression equations, the endogenous variable describing human capital is the number of students enrolled in higher education institutions in the EU and four exogenous variables. The analysis found that the best specification of the impact on human capital in the EU countries is an econometric model described by a multivariate fixed-effects regression equation. It includes three factor variables: total government spending on higher education, employment with higher education, and total environmental taxes. Considering the parameters of this equation, human capital in the sustainable development of EU countries depends on the situation on the labour market for highly skilled individuals, government policy in higher education, and environmental taxation. It was found that the values of the fixed effects for each of the EU countries are positive, specifying the differences in these countries in the formation of human capital. The multivariate regression equation of human capital in the EU countries will help to improve understanding of approaches to building partnerships in the EU countries for the implementation of sustainable development policy measures

Keywords: higher education institutions; panel data; econometric modelling; fixed and variable effects; pooled regression; employment

Introduction

Human capital (HC) is one of the key drivers of sustainable development (SD) in the EU, contributing to strengthening economic potential, innovation, and improving social conditions. Due to changes in the economy, technological shifts, and the use of SD principles, the need to identify the main patterns of HC formation in the EU countries is becoming increasingly relevant. For Ukraine, consideration of the factors of influence on the HC available in the EU is significant due to its

European integration aspirations and post-war economic reconstruction.

In the EU, SD is defined as a priority goal of Ukrainian and foreign policy, and progress towards achieving 17 goals is monitored (EU "whole-of-government approach," 2024). The development of the new European Agreement for the Future, which identifies 10 priority areas, is also linked to the SD. Due attention is paid to HC because of the need to reduce the risk of poverty and

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*Corresponding author

social exclusion, strengthen the European Education Area, and increase scientific literacy (Lafortune *et al.*, 2024). Accordingly, the successful formation and use of HC in EU countries is the basis for ensuring sustainable development and achieving positive changes in society.

In EU countries, there has been a growing scientific debate on the significance of investing in HC at the local level, based on a panel regression model with municipal fixed effects (Biedka *et al.*, 2022) and a dynamic longitudinal microsimulation model (Myrskylä *et al.*, 2024). Using cross-sectional autoregression with a distributed lag, the researchers identified the direct and moderate impact of HC on carbon emissions in nine leading countries and proposed a roadmap for sustainable growth based on individual Sustainable Development Goals (SDGs) (Payab *et al.*, 2023). In addition, for 21 EU countries, it was found that HC increases carbon emissions at low levels of HC financial development and reduces them at high levels (Çakar *et al.*, 2021). In other words, it is important to transform HC into a factor that facilitates the transition to environmentally sustainable economic development. Based on econometric modelling methods, K. Kluza *et al.* (2021) found that the implementation of SDG4 (ensuring inclusive and equitable quality education and promotion of lifelong learning opportunities) and SDG17 (strengthening of the means of implementation and enhancement of global partnerships for SD) in the EU directly contribute to the achievement of environmental policies. Using the statistical model "method of moments of quantile regression", G. Han & X. Cai (2024) found that the presence of HC plays a significant role in maintaining environmental quality, but the economic globalisation has a negative impact on environmental indicators in the N-11 countries. In other words, it is crucial to ensure that HC contributes to the transition to environmentally sustainable economic development.

There is a range of scientific and methodological approaches that consider the role of HC, education, and employment in the country's transition to the SD. Using quantitative methods, M. Simionescu *et al.* (2021) found that HC has a positive impact on economic development through the innovative skills of people that increase the productivity of physical capital and can determine the adoption of external technologies by absorbing new equipment and ideas from these factors. In terms of SD, J. Wyrwa *et al.* (2020) found that there is moderate variation in the level of social development in EU countries and considerable variation in the level of development of Industry 4.0. In other words, there is a multifaceted impact of HC on SD and structural transformation in the analysed countries.

HC is considered in close connection with educational, cultural, and institutional factors of SD. B. Égert *et al.* (2020) found that for European and OECD countries, higher pre-school attendance, greater autonomy of schools and universities, and other factors contribute to the growth of the HC through increased public spending

on education. E.O. Özbal (2021) assessed the long-term dynamic impact of higher education expenditure in OECD countries and higher education enrolment rates on the HC to accelerate economic growth. In this way, the development of education and cultural values form the basis for improving labour market outcomes and employment growth.

Notably, scientific and methodological developments of scientists in the field of SD and HC propose measures to formulate effective policies in the field of employment, education, and ecologisation of national economies. However, in EU countries, there is a need to identify the key factors that influence the HC for SD using panel data.

The purpose of this study was to assess the place and role of HC in the EU countries' SD based on longitudinal data analysis by specifying the types of dependencies that influence its formation.

Materials and Methods

This study was conducted within the framework of the research area of the Department of Economics of Ukraine at the Ivan Franko Lviv National University, and the statistical data were collected and analysed in January-April 2024 on the Eurostat (2024). To reveal the influence of factor attributes on the LC for SD of the EU countries on the main panel data, it is necessary to specify multivariate pooled regression equations with fixed and random effects. In general, the multivariate pooled regression equation can be written as follows:

$$Y_{it} = a_0 + a_1 * X_{1it} + a_2 * X_{2it} + \dots + a_j * X_{jit} + \dots + a_m * X_{mit} + \varepsilon_{it}, \quad (1)$$

where X_{jit} – j exogenous variable for observation i in time period t ; parameters a_j are constant for all values of t and i , $i = \overline{1, n}$, $j = \overline{0, m}$, $t = \overline{1, T}$.

This model is a panel data model without effects, which assumes that the relationships between the exogenous variables are constant over time and across all cross-sectional units in the sample. For a multivariate regression equation with fixed effects, the function will have the following form:

$$Y_{it} = \beta_{it} + \beta_1 * vX_{1it} + \beta_2 * X_{2it} + \dots + \beta_j * vX_{jit} + \dots + \beta_m * X_{mit} + v_{it}, \quad (2)$$

where $\beta_1, \beta_2, \dots, \beta_m$ are unknown parameters of the model, β_{it} are different values of the intercept (fixed effects) for each EU country, $i = \overline{1, n}$, $j = \overline{0, m}$, $t = \overline{1, T}$.

In Model 2, different values of intercepts β_{it} are introduced; this dependence is constant for different time periods. The specific feature of Equation 2 is that different values of β_{it} are estimated for different EU countries, which reflect the influence of factors specific to these countries. The model parameters $\beta_1, \beta_2, \dots, \beta_m$ are the same for all EU countries and for all time periods. The multivariate regression equation with random effects will look as follows:

$$Y_{it} = \mu + \eta_1 * X_{1it} + \eta_2 * X_{2it} + \dots + \eta_j * X_{jit} + \dots + \eta_m * X_{mit} + \vartheta_{it}, \quad (3)$$

where $\eta_{2it}, \eta_{2it}, \dots, \eta_{jit}, \dots, \eta_{mit}$ are unknown parameters of the model, μ is the constant, ϑ_{it} is the random error, invariant in time for each EU country.

Model 3 accommodates the fact that the formation of HC for one EU country may differ from the existing conditions in another EU country. The specific feature of Equation 3 is that the constant μ is estimated for different EU countries and errors ϑ_{it} individual for each object of observation, it has the same parameters $\eta_{2it}, \eta_{2it}, \dots, \eta_{jit}, \dots, \eta_{mit}$ for all EU countries and time periods.

The sample includes 21 EU countries ($i = \overline{1, 21}$), the time period covers 2013-2021 ($t = \overline{1, 9}$), 189 observations, statistics taken from Eurostat (2024). Given the completeness of officially available statistics, the following countries were considered: Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Greece, Ireland, Italy, Latvia, Lithuania, Germany, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Hungary, and the United Kingdom. A limitation of the analysis was the lack of complete data for the presented endogenous and exogenous variables for the EU countries included in the sample for 2022-2023 on the Eurostat (2024). Furthermore, annual statistics were used, which makes it impossible to include operational statistics for 2024 in the analysis. Additionally, it should be borne in mind that the submission of statistical data to Eurostat (2024) is delayed due to the nature of statistical reporting by EU countries.

In the study, HC is represented as the outcome variable Y_{it} – students studying in higher education institutions in EU countries, people. This can be explained by the fact

that the growth of HC in a country's economy is due to the accumulation of knowledge through learning. Independent variables are X_{1it} – resource productivity in EU countries, EUR/kg; X_{2it} – total budget expenditures on higher education (levels 5-8) in EU countries, EUR mn; X_{3it} – employment with higher education (levels 5-8) in countries aged 15 to 64, thsd people; X_{4it} – total environmental taxes, EUR mn.

Results and Discussion

The study resulted in the following theses: there may be spatial differences in the development of the HC in the EU countries; the HC in the EU countries, which is associated with the number of students enrolled in higher education institutions, may be influenced by the state of employment after graduation, the conditions of state funding of higher education, the dynamics of resource productivity and environmental taxation; differences between EU countries in the formation of the HC may be due to fixed and random effects.

As presented in Table 1, the selected endogenous and exogenous variables for the EU HC panel data model have their specific features. In 2013-2021, there was a tendency to increase differences among EU countries in the formation of HC in terms of average values, range of variation, standard deviation, and coefficient of variation. In other words, the dynamic of the number of students pursuing higher education in the EU countries suggests that spatial differences in the formation of HC have gradually increased in the population under study. The growing differences in HC may indicate heterogeneity and different conditions for achieving the SDGs across the EU.

Table 1. Descriptive statistics for dependent and independent variables

Indicator	Variable	2013	2015	2016	2017	2018	2019	2020	2021
Average	Y_{it}	743231.2	737770.0	738224.8	743677.3	750852.4	763179.4	772632.9	794060.5
	X_{1it}	1.5816	1.6908	1.7364	1.7560	1.7890	1.8599	1.8900	1.9879
	X_{2it}	4008.6	4196.6	4063.0	4141.4	4309.5	4418.9	4547.7	4853.5
	X_{3it}	2404.7	2548.7	2630.4	2714.1	2802.6	2891.3	2944.5	3056.9
	X_{4it}	12224.6	12808.5	13292.3	13570.4	13874.0	13988.3	12717.2	13848.1
Scope of variation	Y_{it}	2715207.0	2922567.0	2992489.0	3044304.0	3082154.0	3250765.0	3235160.0	3306634.0
	X_{1it}	2.7094	28247	2.8547	3.0106	3.0099	2.8533	2.8570	3.0479
	X_{2it}	24081.0	26413.0	25577.2	26348.5	26791.0	26865.4	28311.0	29112.0
	X_{3it}	11057.0	10799.0	11283.0	11448.0	11624.0	12062.0	12309.7	12773.6
	X_{4it}	57462.4	57510.2	58835.8	58578.2	59022.1	60229.5	56818.6	63996.9
Standard deviation	Y_{it}	828787.3	847281.3	859048.9	873113.1	891484.2	922825.5	935285.4	959208.8
	X_{1it}	0.7744	0.8626	0.8698	0.8837	0.9098	0.9048	0.9438	0.9814
	X_{2it}	5500.0	5951.6	5793.1	5956.1	6070.0	6122.6	6337.3	6562.8
	X_{3it}	3116.6	3173.4	3281.1	3355.4	3452.8	3579.8	3641.7	3779.1
	X_{4it}	17048.7	17523.9	18159.3	18340.1	18772.1	18903.5	17023.9	18663.4
Variation coefficient	Y_{it}	1.1151	1.1484	1.1637	1.1740	1.1873	1.2092	1.2105	1.2080
	X_{1it}	0.4896	0.5102	0.5009	0.5032	0.5085	0.4864	0.4994	0.4937
	X_{2it}	1.3720	1.4182	1.4258	1.4382	1.4085	1.3856	1.3935	1.3522
	X_{3it}	1.2961	1.2451	1.2474	1.2363	1.2320	1.2381	1.2368	1.2363
	X_{4it}	1.3946	1.3682	1.3661	1.3515	1.3530	1.3514	1.3386	1.3477

Source: calculated based on data from Eurostat (2024)

This is conditioned by the existence of differentiated approaches to policy measures to ensure access to education, coverage of different segments of the population and employment. In 2013-2021, comparable trends of increasing differences among EU countries were recorded for resource productivity, employment of people with higher education, public funding of higher education, and approaches to environmental taxation (Table 1). The growing gaps in the social, financial, and environmental conditions of EU countries suggest the presence of a certain element of competition in achieving the SDGs. Although the EU has defined common SDGs (EU “whole-of-government approach”, 2024), key targets and indicators by goal, it is important to consider the current social, environmental, and economic situation in each country.

The following multivariate econometric pooled regression model was obtained (Table 2). The parameters of the regression equation are adequate according to Fisher and Student's criteria, i.e., the selected factor

variables of this equation have an impact on the HC of EU countries. From the economic standpoint, this equation (Table 2) explains 97.33% of the impact on the HC in EU countries of such factors as resource productivity, total budget expenditures on higher education, employment of individuals with higher education, and general environmental taxes.

The multivariate regression equation (Table 2) contains a common intercept α_0 for different EU countries, i.e., it does not accommodate individual specific features of HC formation for SD by EU countries. In this multivariate econometric model, the values of the dependent and independent variables for the EU countries are combined into one sample and interpreted as observations of one generalised abstract country. However, the social and economic development of each EU country, environmental conditions and natural resource endowment, and traditions of higher education may have different impacts on the HC. This means that the role of HC in the SD of EU countries may vary.

Table 2. Multiple regression equations for panel data and estimation results

Variables	Slope and intercept parameters	Standard error*	t-test	p-level (p<0.05)	Confidence interval, 95%		
					Lower limit	Upper limit	
Pooled regression							
Y _{it} -intercept	131066.5934	26344.4106	4.975	0.0001	79090.6	183042.9	
X _{1it}	-58141.8516	16653.3105	-3.491	0.0006	-90997.8	-25285.9	
X _{2it}	-17.6606	4.2461	-4.159	0.0001	-26.0380	-9.2833	
X _{3it}	217.9539	8.2034	26.569	0.0001	201.769	234.139	
X _{4it}	15.8218	1.4505	10.908	0.0001	12.9601	18.6835	
Regression statistics			Variance analysis				
R	0.9866		df	SS	MS	F	p-level
R ²	0.9733	Regression	4	1.443E+14	3.607E+013	1676.683	0.0000
Normalised R ²	0.9727	Balance	184	3.958E+12	2.151E+10		
Standard error**	146668.5	Total	188	1.482E+014			
Fixed effects (4 variables)							
Y _{it} intercept	429971.6835	55546.6	7.741	0.0001	320293	539650	
X _{1it}	-26284.1298	29591.9	-0.888	0.3757	-84714.4	32146.1	
X _{2it}	59.4237	15.5437	3.823	0.0002	28.7321	90.1153	
X _{3it}	95.3799	22.7225	4.198	0.0001	50.5136	140.246	
X _{4it}	-10.8797	3.86419	-2.816	0.0055	-18.5096	-3.2497	
Regression statistics			Variance analysis				
LSDV R	0.9979		df	SS	MS	LSDV F	p-level
LSDV R ²	0.9957	Regression	4	3.768E+11	9.421E+10	1596.780	0.0000
Within R ²	0.3737	Balance	184	6.316E+11	3.433E+09		
Standard error**	62060.4	Total	188	1.008E+12			
Y _{it} -intercept	410463.4259	50987.3	8.050	0.0000	309792	511135	
Fixed effects (3 variables)							
X _{2it}	55.3429	14.8397	3.729	0.0003	26.0427	84.6432	
X _{3it}	92.2241	22.4286	4.112	0.0000	47.9400	136.508	
X _{4it}	-10.9427	3.8611	-2.834	0.0052	-18.5662	-3.31924	
Regression statistics			Variance analysis				
LSDV R	0.9979		df	SS	MS	LSDV F	p-level

Table 2, Continued

Variables	Slope and intercept parameters	Standard error*	t-test	p-level (p<0.05)	Confidence interval, 95%		
					Lower limit	Upper limit	
Regression statistics			Variance analysis				
LSDV R ²	0.9957	Regression	3	3.738E+11	9.345E+10	1668.305	0.0000
Within R ²	0.3707	Balance	184	6.347E+11	3.449E+09		
Standard error**	62020.64	Total	187	1.008E+12			

Note: * – slope and intercept parameters; ** – regression

Source: calculated based on data from Eurostat (2024)

Above are the parameters of the fixed-effects econometric model and its estimation (Table 2). With the same values of the model factors, there are differences in the formation of the HC of the EU countries compared to the average level of the regression equation intercept (Table 3). In terms of SD, such differences in fixed effects suggest different capacities of EU countries to develop HC due to variations in social and economic conditions, efficiency of natural resource use, education policies, etc. For instance, it was noted that the EU average conceals considerable differences between European sub-regions and countries, with the average SDG index ranging from over

80% in some Northern European countries to around 60% in some Eastern European countries and 50% in some candidate countries (Lafortune *et al.*, 2024). This multivariate regression equation captures the impact of the specified factors on the EU countries' HC quite well. With a probability of 99.57% (Table 2), it can be argued that the development of HC in EU countries depends on resource productivity, total budget expenditures on higher education, employment of individuals with higher education, and general environmental taxes (Eurostat, 2024). For the exogenous variable X_{1it} , the Student's t-test is not fulfilled, i.e., the parameter β_{1it} is not statistically significant.

Table 3. Cross-sectional values (fixed effects) for EU countries

Country	Effect*	Effect**	Country	Effect*	Effect**	Country	Effect*	Effect**
Austria	281252.09	236151.69	France	1284170.77	1302577.86	Lithuania	80675.73	61204.51
Belgium	280745.93	223565.88	Germany	1099686.01	1180944.68	Poland	840497.83	864632.66
Croatia	141077.70	113772.90	Greece	628792.43	604389.77	Portugal	252073.39	229790.13
Czech Republic	232717.17	211821.80	Hungary	170887.38	154987.88	Slovakia	129802.84	100400.06
Denmark	104541.01	70407.81	Ireland	154838.98	90342.76	Slovenia	81062.74	42964.08
Estonia	35016.49	19795.62	Italy	1820533.89	1770151.58	Spain	1189362.37	1171754.22
Finland	53085.24	49019.24	Latvia	75850.66	50689.56	Sweden	92734.72	70367.27

Note: * – for four exogenous variables; ** – for three exogenous variables

Source: calculated based on data from Eurostat (2024)

In the equation (Table 2), the independent variable X_{1it} was removed to construct a multivariate regression equation with fixed effects containing the factors X_{2it} , X_{3it} , and X_{4it} . This resulted in a refined econometric model and its estimates (Table 2, fixed effects with 3 variables). The values of the fixed effects for each EU country (Table 3) suggest that the conditions for HC formation in the respective country are higher or lower than the average value of the intercept of the multivariate regression equation. Given the same values of the factors in this model, HC has a better position in those countries whose fixed effects are higher than the average values of the intercept. In other words, EU countries are developing individualised approaches to policy measures related to the accumulation of HC for SD.

The multivariate regression equation (Table 2) reflects the impact of the identified factors on the HC of the

EU countries. Specifically, it can be argued that the formation of HC in the EU countries depends on the amount of total budget expenditures on higher education, employment of individuals with higher education, and general environmental taxes by 99.57% (Eurostat, 2024). The values of F - and t -statistics are higher than the critical ones, which indicates the adequacy of the built model. According to the identified relationships between the endogenous and exogenous variables of the fixed-effects regression equation (Table 2), improving HC for SD in the EU should accommodate policy measures defined at the EU and country level. Creating favourable conditions for attracting more people in the EU to higher education requires considering the state's budgetary capacity to develop higher education, the situation on the labour market for people with higher education, and the state of the environment in the context of environmental taxation.

A multivariate regression equation was obtained, with its estimates for HC in EU countries with random effects (Table 4). With the same values of the regression equation parameters, HC is influenced by random effects that reflect the uniqueness of the environment of its formation in each EU country, which is invariant over time. For the SD and the completion of its objectives related to the HC in EU countries, this requires the coordination of common policy measures. The multivariate regression equation (Table 4) properly shows the impact of the identified factors on the HC of the EU countries. The Belsley-Kuh-Welsch collinearity test suggests that there is no evidence of excessive collinearity, with the number of condition indices greater than 30 or 10 being zero.

The random-effects model (Table 4) should be tested for the significance of these effects in comparison with the multivariate pooled regression equation and the multivariate fixed-effects model (Table 2). According to the Breusch-Pagan test, the calculated value $\chi^2(1) = 373.333$, which corresponds to the $p_{\text{-value}} = 3.520\text{E-}83$. The $p_{\text{-value}}$ is less than 0.05, the hypothesis is accepted that the parameters of the model with random effects better describe the factors influencing the development of HC in the EU countries. According to the Hausman test, the calculated value $\chi^2(3) = 78.804$, which has a $p_{\text{-value}} = 5.540\text{E-}17$. This means that the parameters of the multivariate fixed-effects regression equation (Table 2) better specify the factors influencing HC in EU countries.

Table 4. Multiple random effects regression equations for panel data and estimation results

Variables	Slope and intercept parameters	Standard error*	z	p-level (p<0.05)	Confidence interval, 95%	
					Lower limit	Upper limit
Y_{it} -intercept	139999.6421	44815.6	3.124	0.0018	51583.3	228414
X_{2it}	32.5073	10.7614	3.021	0.0025	11.277	53.738
X_{3it}	146.3365	19.2084	7.618	0.0000	108.441	184.232
X_{4it}	5.8199	2.9916	1.945	0.0517	-0.0822	11.722

Note: * – slope and intercept parameters

Source: calculated based on data from Eurostat (2024)

However, the Belsley-Kuh-Welsch collinearity test for the model (Table 2) revealed that the number of state indices greater than 30 is 1, and the number of indices greater than 10 is 3. To eliminate collinearity, the data were standardised by dividing by the standard

deviation of the sample. The new parameters of the multivariate fixed-effects regression equation were specified (Table 5). The Belsley-Kuh-Welsch test showed that the number of state indices greater than 30 or 10 is zero.

Table 5. Multiple fixed effects regression equations for standardised panel data and estimation results

Variables	Slope and intercept parameters	Standard error*	t-test	p-level (p<0.05)	Confidence interval, 95%	
					Lower limit	Upper limit
Y_{it} -intercept	753996	4511.34	167.1	0.0001	745088	762903
sX_{2it}	333213	89348.1	3.729	0.0003	156800	509625
sX_{3it}	314385	76457.6	4.112	0.0001	163424	465347
sX_{4it}	-197642	69736.7	-2.834	0.0052	-335333	-59950.5
Regression statistics			Variance analysis			
LSDV R	0.9979		df	SS	MS	LSDV F
LSDV R ²	0.9957	Regression	4	3.738E+11	9.345E+10	1668.305
Within R ²	0.3707	Balance	184	6.347E+11	3.449E+09	
Standard error**	62020.64	Total	188	1.008E+12		

Note: * – slope and intercept parameters; ** – regression

Source: calculated based on data from Eurostat (2024)

The multivariate regression equation (Table 5) reflects the influence of the factor attributes on the HC of the EU countries. With a probability of 99.57%, it can be argued that the HC of EU countries depends on the standardised amounts of total budget expenditures on higher education, employment of individuals with higher education, and total environmental taxes (Eurostat, 2024). The economic meaning of the coefficients

in the factor characteristics of the multivariate model is that they determine the contribution of exogenous variables to the development of HC in the EU countries.

An assessment of the factual and theoretical values obtained based on the multivariate regression equation (Table 5) showed that this model can be used to predict the key trends in the development of HC in the EU countries. The mean error (ME) is $3.080\text{E-}012$; root

mean square error (RMSE) is 57949; mean absolute error (MAE) is 30.934; mean percentage error (MPE) is -0.6053; mean absolute percentage error (MAPE) is 6.8136; Theil's U is 0.0249. The ability to identify and measure effects, considering social and economic differences between countries, is being improved to assess the prospects for SD in the EU.

HC is important for the EU's SD because an educated population is turning into a driver of various changes in the economy. However, according to the multivariate regression equation (Table 5), it is important for the HC in the EU to improve their investment approaches by expanding the possibilities of budget financing of higher education. Therewith, the findings obtained may also suggest that increasing employment opportunities for people with higher education is one of the significant factors that stimulates individuals to improve their educational qualifications. In this context, using a non-radial DEA model, M. Cyrek & B. Fura (2019) also pointed to this aspect of employment, arguing that employment in agriculture is one of the factors that slows down SD. Other researchers have emphasised that education to improve HC has a significant impact on the SD and competitiveness of national economies due to the synergistic effect (Aleksejeva, 2016; Sart, 2022). In this way, the quality of labour is improved, and the SDGs focused on decent work are achieved. The findings obtained by the researchers confirm the significance of state measures in the educational sphere for improving the quality of life and achieving the SDGs, complementing the approaches based on the fixed-effects regression equation.

The identified positive effect of employment of people with higher education on labour productivity in the EU countries may also suggest the expediency of creating favourable socio-economic conditions for increasing labour productivity. From this standpoint, the specified dependencies of HC and factor variables in a fixed-effects regression equation complement the findings of M. Conti & G. Sulis (2016) and M.-A. Georgescu & E. Herman (2019) regarding the significance of ensuring high labour productivity and improving the employment structure in national economies for the SD. Therewith, E. Pelinescu *et al.* (2019), using fixed and random effects models, emphasised that in the EU countries, to grow human capital, it is advisable to pay attention to efforts to improve research and development. In this way, EU countries that seek to attract as many people as possible to higher education will be able to ensure sustainable growth of HC. According to S. Vaitkevičius *et al.* (2015) and A.P. Balcerzak (2016), the existence of differences in the development of HC in the EU countries indicates different mechanisms of its formation, which are based on a range of political and institutional factors. This correlates with the fact that in the EU countries, such factors may include the distribution and redistribution of the total budget of each

EU country for higher education, the existing network of higher education institutions (Kichurchak, 2022). Accordingly, deepening the approaches to identifying the links between HC, tertiary employment and labour productivity in the EU could provide a better basis for implementing SD policies.

One of the crucial policy vectors for the EU's SD is to increase the efficiency of using available natural resources. The regression analysis revealed the existence of an inverse relationship between HC and policy measures related to environmental taxation. Accordingly, it is necessary to find a reasonable balance between public investment in forestry and environmental protection. For instance, based on the PMG co-integration analysis, T. Yildiz *et al.* (2022) noted that to increase the impact of HC on the ecological footprint in the EU countries, it is advisable to develop educational infrastructure and accelerate technological development by increasing technological activities. Additionally, it demonstrates the multifaceted and interdependent nature of the interaction between HC and SD in terms of environmental protection, rational use of available natural resources, and policy measures in this area. According to the results of the fixed-effects regression equation, EU countries need to make certain choices in their policies on investment in forestry and environmental taxation. M. Kichurchak (2020) also pointed to the limited financial resources in the SD policy measures in the cultural sector. Considering the multiplicity of factors related to HC and SD, their significance for environmentally oriented economic growth, formation of cultural values and environmental awareness, further research in this area could complement the links of HC in EU countries with environmental taxation and other factors for the development of SD policies.

However, in the EU, the war in Ukraine has created new challenges for HC and SD. For instance, as of 1 February 2024, 4.2 mn Ukrainian citizens were registered as temporary asylum seekers in the EU, of whom only 5% were over the age of 65 (Eurostat, 2024). According to T.V. Yasinska (2022), the events of 2020-2022 are not conducive to the development of HC in Ukraine, especially due to the Russian-Ukrainian war, which made the educational process in many regions of the country impossible for a long time. At the same time, L.M. Zomchak (2023) and O. Hrynevych *et al.* (2023) noted that 2022 saw the deepest recession in the Ukrainian economy, the out-migration of economically active Ukrainians, a considerable reduction in household income, and additional concerns about the environmental consequences of the war. The war in Ukraine is significantly changing approaches to the formation of HC in the EU in the medium and long term, due to the forced migration of economically active and highly educated Ukrainian citizens and the socialisation of their children in recipient countries. According to D. Pudryk *et al.* (2023), the return of forced migrants to Ukraine requires the

implementation of state programmes to stimulate the return migration of HC. For the SD of the EU countries, this also means that it is advisable to continue investigating the factors affecting the HC, considering forced migration and the growing burden on the social sphere of recipient countries, while Ukraine needs to modernise its approaches to the implementation of the SDGs and develop effective policy measures to return the HC to the country after the war.

Conclusions

It was found that the development of HC in the EU countries is a complex and multifactorial process, which is based on the influence of different social, environmental, and political conditions in each country. The multivariate pooled regression model proved that the growth of the HC in the EU countries is sustainable in the period under study (2013-2021), depending on the common policy of the EU countries in the field of highly skilled employment, financial support for higher education, rational use of available natural resources, and their taxation. Based on a comparison of the parameters of the specified multivariate regression models of pooled regression, fixed effects, random effects, describing the dependence of HC in the EU countries on a range of factors, it was found that the best fit for analysis is the regression equation with fixed effects for three variables. Accordingly, the factors that stimulate the development of the HC, which is based on an increase in the number of students pursuing higher education, are the conditions of budget financing of higher education and the situation on the labour market, which is associated with better job opportunities for individuals with higher

education in the EU. On the contrary, the factor that hinders the development of HC in the EU countries is the state's measures in the field of environmental taxation. Furthermore, the specified parameters of the multivariate fixed-effects regression models for HC in the EU countries showed that there are differences in HC formation policies between the EU countries. This suggests not only differences in the social and economic development of the EU countries themselves, but also differentiated approaches to understanding the place and role of HC in ensuring the country's SD. Although the fixed effects contain different cross-sectional coefficients for each EU country, they are not negative. Additionally, this points to the individual capacities of each EU country to increase HC to achieve the SD. Considering the specified factors, the implementation of policies to improve the quality of life in the EU will contribute to the achievement of the SDGs related to decent work, quality education, and reduction of social inequality. Since 24 February 2022, the HC of the EU countries has been considerably affected by the war in Ukraine and the unprecedented increase in the number of forced migrants. At the same time, the assessment of these impacts in the short term has a range of limitations caused by incomplete statistical data. This forms the basis for further research on the significance of HC for the sustainable development of EU countries.

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Conflict of Interest

None.

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Людський капітал у сталому розвитку країн ЄС: лонгитюдний аналіз даних

Маріанна Кічурчак

Доктор економічних наук, професор
Львівський національний університет імені Івана Франка
79000, вул. Університетська, 1, м. Львів, Україна
<https://orcid.org/0000-0002-1927-5704>

Анотація. Одним з важливих напрямів, орієнтованих на виявлення головних тенденцій та чинників формування людського капіталу для сталого розвитку в країнах ЄС, є підходи з використанням панельних даних. У статті специфіковано залежність людського капіталу в країнах ЄС від чотирьох факторних ознак, які впливають на його місце і роль у сталому розвитку, за допомогою лонгитюдного аналізу даних. Методологічною основою дослідження був інструментарій економетричного моделювання для побудови багатофакторних регресійних рівнянь трьох видів: об'єднаної регресії, з фіксованими і змінними ефектами. Для визначення параметрів багатофакторних регресійних рівнянь використано статистичні дані Eurostat для 21 країни ЄС за 2013-2021 роки, підґрунтям чого є повнота представлених статистичних показників за результуючими і факторними ознаками та неповнота таких даних для 2022-2024 років. Для трьох видів багатофакторних регресійних рівнянь ендегенною змінною, що описує людський капітал є кількість студентів, які навчаються у вищих навчальних закладах країн ЄС, та чотири екзогенні змінні. Аналіз виявив, що найкраще специфікує вплив на людський капітал країн ЄС економетрична модель, яка описується багатофакторним регресійним рівнянням з фіксованими ефектами. До його складу входять три факторні змінні – загальні державні видатки на вищу освіту, зайнятість з вищою освітою та загальні екологічні податки. З огляду на одержані параметри такого рівняння людський капітал у сталому розвитку країн ЄС залежить від ситуації на ринку праці для високо-кваліфікованих індивідів, державної політики у сфері вищої освіти та екологічного оподаткування. Визначено, що значення фіксованих ефектів для кожної з країн ЄС є додатними, специфікуючи відмінності у даних країнах з формування людського капіталу. Багатофакторне регресійне рівняння людського капіталу країн ЄС допоможе поліпшити розуміння підходів до розбудови партнерських відносин у країнах ЄС щодо реалізації заходів політики сталого розвитку

Ключові слова: вищі навчальні заклади; панельні дані; економетричне моделювання; фіксовані та змінні ефекти; об'єднана регресія; зайнятість