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# LINKING ECOLOGICAL FOOTPRINT WITH ECONOMIC GROWTH. EVIDENCE FROM CENTRAL EUROEPAN COUNTRIES

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**Purpose:** The aim of this paper is to examine the relationship between economic growth and ecological footprint in Central European countries in the years 1990-2022.
**Design/methodology/approach**: In order to examine the relationship between economic growth and ecological footprint, the following tools were used: literature analysis, analysis of the dynamics of the variables, descriptive statistics, Pearson correlation coefficient, and graphical construction of the environmental Kuznets curve.
**Findings:** The analysis of the relationship between economic growth and ecological footprint in Central European countries indicated its diversification both over time and between the analyzed countries. Analysis of values calculated using descriptive statistics showed diversification of the results obtained for selected countries and variables. The use of Pearson correlation coefficient provided a basis for confirming the existence of a relationship between economic growth and economic footprint. The obtained results also confirm the presence of a non-linear relationship between economic growth and ecological footprint and the possibility of describing it using EKC, which for the Slovak Republic and the Czechia takes the shape of an inverted-U, while for Hungary and Poland the EKC curve was N-shaped.
**Practical implications:** This paper promotes the problem of economic growth. They can assist in the development of policies and practices that both support economic growth and reduce its negative environmental impact.
**Social implications:** The subject of the article concerns economic growth, which contributes to improving the quality of life of societies.
**Originality/value:** The article analyzes using the most current statistical data of selected variables and statistical tools.
**Keywords:** economic growth, ecological footprint, environmental Kuznets curve.
**Category of the paper:** Research paper.

## 1. Introduction

Economic growth is the basis for the efficient functioning of the economy and satisfying human needs. The concept of economic growth refers to quantitative changes in the economy that are a consequence of the constant increase in economic capacity, both of a material and human nature (Harrod,1973; Lewis, 1963; Kuznets,1971; Rostow, 1953; Solow, 2000; Barro, Sala-i-Martin, 2004; Romer, 2005; Woźniak, 2004). In the definition of economic growth referred to, it can be seen that natural, human and capital resources are required to ensure the economic well-being of society. The pursuit of ever-increasing prosperity therefore contributes to an increased demand for these resources. But also, the resources determine the volume of production in the economy and thus the level of satisfaction of societies. Over the last 200 years, the main focus of economics has been on maximizing profits and production, which was associated with a continuous increase in the exploitation of available resources (Rogall, 2010). However, starting from the 1970s, the emergence of studies focusing on the problem of natural resources consumption can be noticed. One can be mentioned: neoclassical environmental economics, ecological economics, new ecological economics, or the concept of sustainable development (Rogall, 2010). Emerging research points to the importance of measuring resource exploitation, along with the need to use them efficiently in the production of goods. The 21st century poses challenges to economies such as increasing demand for natural resources in order to achieve economic growth. Until recently, carbon dioxide emissions (along with sulfur dioxide and nitrogen oxide emissions) were the main measure of environmental degradation because of the production (Babu, Datta, 2013). However, these only measure the effects on air, which represents just one facet of pollution and thus they ignore other important dimensions of environmental impacts (Al-Mulali et al., 2015; Jha, Murthy, 2003). An increasing number of papers point to the importance of measuring the state of the environment through the analysis of the ecological footprint, which provides a better understanding than $CO_2$ emissions (Aydin et al., 2019; Destek, Sarkodie, 2019; Wang, Dong, 2019; Ozturk, Acaravci, 2013; Saud et al., 2018; Yin et al., 2019). The ecological footprint measures the demand for the natural resources of the biosphere in hectares of land and sea surface that are used for consumption and waste absorption (Kłos, 2014; Wackernagel, Kitzes, 2008). This demand translates into the demand for six main types of land – cropland, grazing land, fishing grounds, forest product, built-up land and carbon (Borucke et al., 2013; Wackernagel, Rees, 1996). The first four of these land types produce food, fiber and wood products for direct or indirect human consumption. The fifth type of land, built-up land, represents the area required for physical infrastructure such as cities and roads. The sixth type of land is carbon, representing the amount of biologically productive space required to absorb one of the most important waste products of the human economy: carbon dioxide ($CO_2$). The analysis of global data on the ecological footprint (https://data.footprintnetwork.org) leads

to the conclusion that in many countries value of ecological footprint exceeds the production capacity of their economies. The question therefore arises whether and to what extent the state of the state of the environment is correlated with the level of economic growth. In recent decades, many studies have been written examining this relationship. Their time range, subject, and methodological scope varies widely. Many of them are subject to developing and emerging countries. Most often, they are concerned about time periods up to the year 2015 and use carbon dioxide emissions as an indicator of the state of the environment degradation. Hence, to fill this gap, the aim of this paper is to examine the relationship between economic growth and ecological footprint in Central European countries between 1990 and 2022. The research statement posed in this way is reflected in the structure of the paper. The literature review presents the results of research conducted for the search for the relationship between economic growth and ecological footprint in the last decade. The next part presents the research method along with the data source. Then, an analysis is carried out and then a discussion of the obtained results regarding the relationship between economic growth and ecological footprint in Central European countries with those presented in the literature review.

## 2. Literature review

This section reviews existing research on the relationship between economic growth and environmental quality. Over the past three decades, many studies have investigated the relationship between these variables, including their determinants. The relationship between economic growth and environmental pollution was first introduced to the literature by (Grossman, Krueger, 1991) and first used by (Panayotou, 1993) and called the environmental Kuznets curve (EKC). The concept of the curve referred to the relationship between income inequality and economic development described by Kuznets in the mid-1950s (Kuznets, 1955) and assumed that the environmental Kuznets curve is most often inverted U-shaped. This means that at a low level of income, the intensity and degree of environmental degradation are low. Then, intensive agricultural development and industrialization cause the consumption of natural resources at a faster rate than their renewal. At a higher level of economic development, where ecological knowledge and awareness are used, government instruments and environmentally friendly technologies cause a gradual reduction in degradation. In many studies, the environmental Kuznets curve takes the form of the letter N. This means that the previously described improvement of the environment, following the crossing of the turning point, occurs only up to a certain level of economic development, after which environmental degradation increases again (Gruszecki, Jóźwik, 2019). Despite many doubts and criticism, the environmental Kuznets curve remained in the center of researchers' interest and was systematically developed in the following years (Genstwa, 2020). Initially, the main measure

of the state of environmental degradation was $CO_2$ emissions. The studies, analyzing relation between economic growth and $CO_2$ can be mentioned are as follow: Acaravci, Ozturk (2010), Al-Mulali et al. (2013), Dogan (2020), Osabuohien et al. (2014), Jammazi, Aloui (2015) (Chaabouni, Zghidi, Mbarek, Ben, 2016; Zaidi, Saidi (2018), Acheampong et al. (2023), Wang (2013), Osabuohien et al. (2014). The ecological footprint has emerged as a new indicator of environmental degradation and is currently considered as a more comprehensive indicator than $CO_2$ emissions. This literature review refers to studies that address the issue of the relationship between economic growth and ecological footprint. Table 1 contains a list of authors who have analyzed the relationship between these variables in the last decade. It can also be seen that most of the studies concern developing economies, mainly from Africa and Asia. Only a small number of papers refers to European countries or Central European countries. The diversity of the comparison also concerns the time period of variables. Only half of them analyzed variables collected for a period of more than 30 years. The rest concern shorter periods. Most studies confirm the existence of a relationship between economic growth and ecological footprint. The works supporting the EKC concept are as follow: Aşici, Acar (2016), Charfeddine, Mrabet (2017), Ulucak, Bilgili (2018), Bello et al. (2018), Destek et al. (2018), Altıntaş, Kassouri (2020), Ulucak, Khan (2020), Dardouri, Smida (2023), Alruweili (2023), Feng, Wu (2011). In most studies, the authors confirmed the inverted-U-shaped relationship between GDP and ecological footprint: Feng, Wu (2011), Nesrine et al. (2023), Destek et al. (2019), Mehmet et al. (2018), Mrabet et al. (2017). N-shaped ECK has been confirmed in works: Destek et al., 2018 and Dardouri, Smida (2023), Lazar et al. (1019). However, the EKC concept was not confirmed in the following works: Usman et al. (2020), Ozturk, Avaravci (2010). Among the large group of studies examining the relationship between economic growth and ecological footprint, there are also those analyzing European countries. The paper of Destek et al. (2018) referred to 15 Western European countries, in which the authors confirmed the existence of U-shaped EKC for data from 1980-2013. Alola et al. (2019) confirmed the relationship between gross domestic product and ecological footprint for 16 Western European countries for the period 1997-2014. Altintas et al. (2020) collected data from 14 European countries for the period 1990–2014, based on which they proved the existence of EKC sensitivity to environmental degradation. Lazăr et al. (2019) confirmed the nonlinear relationship between GDP and carbon dioxide emissions for the Central and Eastern European countries, confirming the N-shaped, inverted-N, U-shaped, inverted-U, monotonic, or no statistical link. In their study, they proved that Czechia and Hungary displayed traditional inverted-U-shaped EKC, and Poland and Slovak Republic inverted-N-shaped. Also, the authors as Raihan et al. (2024), Jamel et al. (2017), and Addai et al. (2023) confirmed the positive relationship between economic growth and carbon dioxide emissions. Such a relationship was also studied by Saud et al. (2019) for 18 Central and Eastern European countries for the period 1980-2016. Based on the analysis, they confirmed the existence of a relationship between these variables only for five countries: Croatia, Poland, Serbia, the Slovak Republic and Ukraine. To sum up the

literature analysis, it can be stated that most of the studies examining the relationship between economic growth and ecological footprint refer to developing countries. Only a small part of them concerns the description of the situation in European economies, especially in Central European countries. However, the vast majority of researchers confirmed the existence of a relationship, mainly non-linear, between these two variables.

**Table 1.**
*Literature review on economic growth – ecological footprint relationship*

| Author | CHARACTERISTICS | |
|---|---|---|
| | **time period** | **region/country** |
| Feng, Wu (2011) | 1996–2008 | China |
| Al-Mulali and Ozturk (2015) | 1996–2012 | 14 MENA countries |
| Aşıcı and Acar (2016) | 2004–2008 | 116 countries: high, middle and low-income |
| Charfeddine andMrabet (2017) | 1975–2007 | 15 MENA countries |
| Marbet et al. (2017) | 1980-2011 | Qatar |
| Uddin et al. (2017) | 1991–2012 | 27 highest emitting countries |
| Bello et al. (2018) | 1971–2016 | Malaysia |
| Destek et al. (2018) | 1980–2013 | 15 European Union countries |
| Ulucak and Bilgili (2018) | 1961–2013 | 15 high-, 15 middle-and 15 low-income countries |
| Destek and Sarkodie (2019) | 1977–2013 | Newly industrialized countries South Korea, Singapore, Brazil, China, Turkey, Thailand, Malaysia, Mexico, India, South Africa and Philippines |
| Ahmed et al. (2019) | 1971–2014 | Japan |
| Alola et al. (2019) | 1997–2014 | 16 European Union countries |
| Baloch et al. (2019) | 1990–2016 | 59 Belt and Road countries |
| Chen et al. (2019)?? | 1991–2014 | 16 Central and Eastern European countries |
| Danish et al. (2019) | 1971–2014 | Pakistan |
| Danish et al. (2019) | 1992–2016 | BRICS countires |
| Dogan et al. (2019) | 1971–2013 | Mexico, Indonesia, Nigeria, Turkey |
| Wang and Dong (2019) | 1990–2014 | 14 Sub-Sahara African countries |
| Altıntaş and Kassouri (2020) | 1990–2014 | 14 European countries |
| Dogan et al. (2020) | 1980–2014 | Brazil, Russia, India, China, South Africa, Turkey |
| Nathaniel et al. (2020) | 1990–2016 | MENA countries |
| Sharif et al. (2020) | 1965–2017 | Turkey |
| Usman et al. (2020) | 1994–2017 | 33 upper-middle-income countries |
| Jahanger et al. (2022) | 1990–2016 | 73 developing countries |
| Faris Alruweili (2023) | 1981–2017 | Saudi Arabia |
| Eissa (2023) | 1971-2022 | Egypt |
| Javeed et al. (2023) | 1990–2017 | Asian countries |
| Mehmood et al. (2023) | 1990–2022 | Pakistan, India, Bangladesh, Nepal, and Sri Lanka |
| Dardouri and Smida (2023) | 1961–2018 | G7 countires |
| Magazzimo (2024) | 1969–2019 | China |
| Minh-Quang Nguyen et al. (2024) | 1970–2018 | Vietnam |

Source: own elaboration.

## 3. Methodology

The article examined the annual economic growth rates and ecological footprint of the Central European countries, also known as the Visegrad Group countries: Poland, Czechia, Hungary, and Slovak Republic. The level of economic growth is measured by the size of the gross domestic product (GDP) per capita taken from the World Bank Indicators (https://databank.worldbank.org). This variable was calculated in constant prices from 2015 in USD (American dollars). Ecological footprint (EFP) data were extracted from the Global Footprint Network (https://data.footprintnetwork.org). This variable was calculated in global hectares per person (ghp per person). Both variables were collected from the 32-year period from 1990 to 2022. In order to examine the relationship between economic growth and ecological footprint, the following methods were used: analysis of the dynamics of the variables along with the determination of the trend line, descriptive statistics, Pearson correlation coefficient, and graphical construction of the environmental Kuznets curve. The analysis of the dynamics of variables was carried out by designating time intervals for those characterized by an upward trend and those with a downward trend. In addition, an attempt was made to designate a trend line that best describes the changes in both variables in the years 1990-2022, along with providing the value of the $R_2$ coefficient of determination. The closer the $R_2$ value to 1, the better the fit of the trend line. The following elements of descriptive statistics were selected for the comparative analysis of asymmetry and concentration measures of the distribution of GDP per capita and the ecological footprint per capita: mean, standard deviation, kurtosis, skewness, maximum and minimum values. Standard deviation is a measure of concentration, the high values of which indicate a high dispersion of variables. The second measure of concentration is kurtosis, the negativity of which indicates a platykurtic distribution (flattening less than normal), and positivity - a leptokurtic distribution (flattening greater than normal) (Puławska-Turyna, 2011). Skewness is a measure of the asymmetry of the distribution. Positive skewness means right-sided asymmetry, i.e. the existence of many values of the variable smaller than the mean, and negative means left-sided asymmetry, i.e. many variables are larger than the mean (Sobczak, 2007). Pearson correlation coefficient is a measure used to describe linear interdependence between two variables. Negative values of the coefficient mean an inverse relationship between variables, and positive values mean a positive relationship. The interpretation of the calculated absolute values of the coefficient is as follows: a) when smaller than 0,3 – weak correlation, b) when it is in the range of 0,4-0,6 – moderate correlation, c) when it is in the range of 0,7-0,9 – strong correlation, d) when = 1 – perfect correlation (Puławska-Turyna, 2011). An attempt was also made to construct EKC in order to deny or confirm the relationship between economic growth and ecological footprint for individual countries. For this purpose, an attempt was made to fit a trend line for the economic growth-ecological footprint relationship for each analyzed country. The trend line allowed to determine

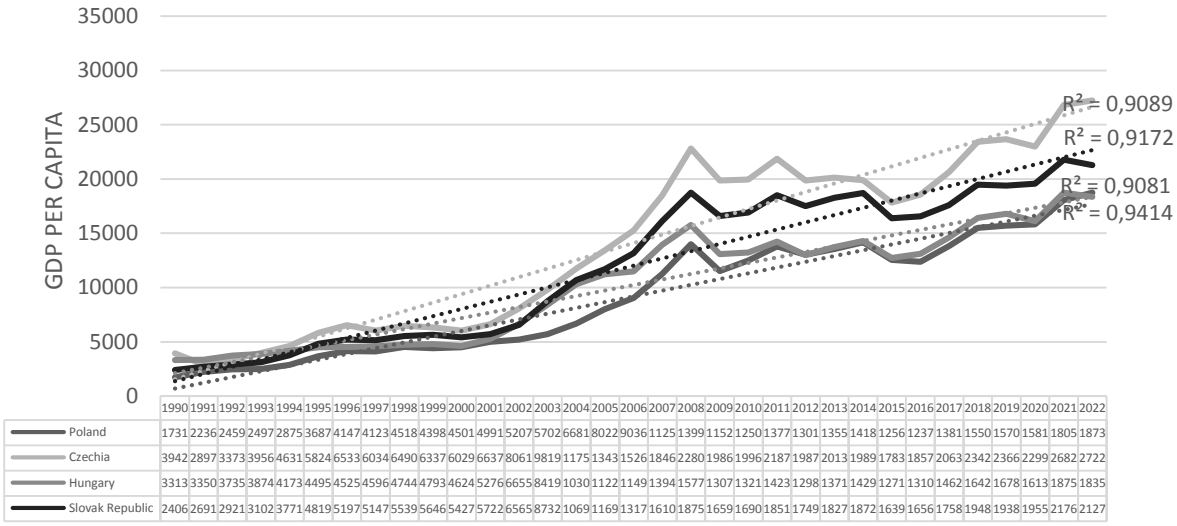
whether the relationship studied in individual countries is inverse-U-shaped, U-shaped, or N-shaped.

## 4. Results and discussion

The analysis of the relationship between economic growth and ecological footprint indicates its differentiation both over time and between the countries analyzed. In the analyzed period, both variables were not constant values in any of the countries. The dynamics of changes in economic growth measured by changes in GDP per capita between 1990 and 2022 were respectively in decreasing order: for Poland 9,8% for Slovakia 7,8%, for the Czechia 5,9% and for Hungary 4,5%. Although the increase in the growth of GDP per capita was the highest for Poland, the country was characterized by the lowest values of GDP per capita throughout the analyzed period, while the Czech economy was characterized by the highest values compared to other countries (Figure 1). Throughout the period analyzed, the ranking of countries, due to the level of economic growth, did not change. Figure 1 shows three characteristic time periods in which GDP per capita grew until 2008, then decreased until 2016. From 2016 to the end of the analyzed period, an upward trend can again be observed, with a noticeable decrease in this variable in the Hungarian and Slovak economies in 2022, compared to 2021. Despite these dynamics of change, a fairly strong linear trend in changes in GDP per capita could be matched for all economies, as shown in Figure 1. For all countries, the $R_2$ coefficient of determination for the linear trend line was over 0,9. The analysis of the dynamics of variables together with the determination of the trend line indicates the diversity of the variables studied in the analyzed countries. Table 2 presents the elements of descriptive statistics. Polish GDP per capita was characterized by the lowest value of this variable throughout the analyzed period: USD 1731,21 in 1990. The highest values of this variable occurred in the Czech economy: USD 27227 in 2022. In addition, the Czech economy experienced the greatest diversity in the level of this variable, having the highest standard deviation value. The Hungarian economy was characterized by the lowest variability, with the lowest standard deviation among the analyzed countries. The calculated kurtosis in all countries is negative, which means the platykurtic distribution of this variable. The calculated skewness was positive for Poland, the Czechia and Hungary, which means a right-skewed distribution. On the other hand, the Slovak economy was characterized by negative skewness, which means a left-skewed distribution.

The characteristics of the ecological footprint per capita for individual countries are completely different (Figure 2). The dynamics of changes in this variable between 1990 and 2022 were very small and amounted to, respectively, in decreasing order: for Czechia 0,9%, for Slovak Republic 0,6%, Poland 0,03%. Only for Hungary the dynamics of the ecological footprint was negative, at the level of -0,1%, which can be considered a positive phenomenon,

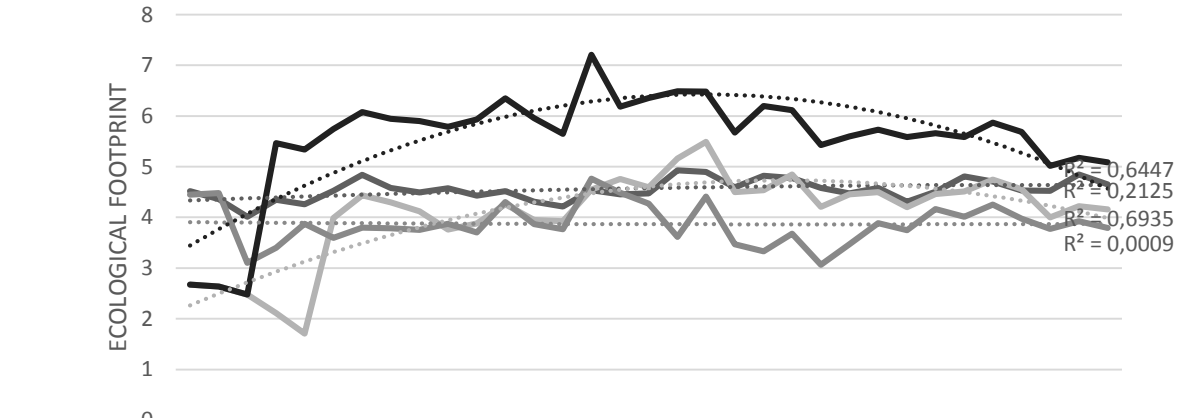
especially since this economy was characterized by the highest values of this variable at the beginning of the analyzed period, compared to other countries, and the lowest at the end. The opposite situation occurred in the Czech economy, where the ecological footprint value at the beginning of the analyzed period was the lowest, and the highest at the end. On the other hand, the lowest value of the ecological footprint per capita during the entire period was recorded by the Slovak economy: 1,70 ghp per capita in 1994, and the highest by the Czechia: 7,20 ghp per capita in 2004.




| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Poland | 1731 | 2236 | 2459 | 2497 | 2875 | 3687 | 4147 | 4123 | 4518 | 4398 | 4501 | 4991 | 5207 | 5702 | 6681 | 8022 | 9036 | 1125 | 1399 | 1152 | 1250 | 1377 | 1301 | 1355 | 1418 | 1256 | 1237 | 1381 | 1550 | 1570 | 1581 | 1805 | 1873 |
| Czechia | 3942 | 2897 | 3373 | 3956 | 4631 | 5824 | 6533 | 6034 | 6490 | 6337 | 6029 | 6637 | 8061 | 9819 | 1175 | 1343 | 1526 | 1846 | 2280 | 1986 | 1996 | 2187 | 1987 | 2013 | 1989 | 1783 | 1857 | 2063 | 2342 | 2366 | 2299 | 2682 | 2722 |
| Hungary | 3313 | 3350 | 3735 | 3874 | 4173 | 4495 | 4525 | 4596 | 4744 | 4793 | 4624 | 5276 | 6655 | 8419 | 1030 | 1122 | 1149 | 1394 | 1577 | 1307 | 1321 | 1423 | 1298 | 1371 | 1429 | 1271 | 1310 | 1462 | 1642 | 1678 | 1613 | 1875 | 1835 |
| Slovak Republic | 2406 | 2691 | 2921 | 3102 | 3771 | 4819 | 5197 | 5147 | 5539 | 5646 | 5427 | 5722 | 6565 | 8732 | 1069 | 1169 | 1317 | 1610 | 1875 | 1659 | 1690 | 1851 | 1749 | 1827 | 1872 | 1639 | 1656 | 1758 | 1948 | 1938 | 1955 | 2176 | 2127 |

**Figure 1.** GDP per capita between 1990 and 2022.

Source: own elaboration.




| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| POLAND | 4,51 | 4,36 | 4,01 | 4,35 | 4,26 | 4,52 | 4,84 | 4,58 | 4,49 | 4,57 | 4,43 | 4,52 | 4,31 | 4,22 | 4,54 | 4,45 | 4,47 | 4,93 | 4,89 | 4,59 | 4,82 | 4,78 | 4,58 | 4,47 | 4,58 | 4,31 | 4,51 | 4,8 | 4,71 | 4,53 | 4,52 | 4,85 | 4,65 |
| SLOVAK REPUBLIC | 2,68 | 2,63 | 2,48 | 2,11 | 1,71 | 3,99 | 4,44 | 4,3 | 4,12 | 3,76 | 3,88 | 4,26 | 3,95 | 3,93 | 4,55 | 4,76 | 4,59 | 5,16 | 5,49 | 4,5 | 4,53 | 4,85 | 4,21 | 4,46 | 4,5 | 4,2 | 4,46 | 4,51 | 4,74 | 4,55 | 4 | 4,22 | 4,16 |
| HUNGARY | 4,45 | 4,48 | 3,11 | 3,4 | 3,87 | 3,59 | 3,8 | 3,78 | 3,75 | 3,87 | 3,7 | 4,3 | 3,87 | 3,76 | 4,76 | 4,48 | 4,27 | 3,61 | 4,41 | 3,47 | 3,33 | 3,68 | 3,06 | 3,47 | 3,89 | 3,75 | 4,16 | 4,01 | 4,25 | 3,97 | 3,77 | 3,92 | 3,79 |
| CZECHIA | 2,68 | 2,63 | 2,48 | 5,47 | 5,34 | 5,74 | 6,08 | 5,94 | 5,9 | 5,79 | 5,93 | 6,35 | 5,95 | 5,65 | 7,21 | 6,19 | 6,36 | 6,49 | 6,48 | 5,68 | 6,19 | 6,11 | 5,42 | 5,59 | 5,73 | 5,59 | 5,66 | 5,59 | 5,87 | 5,68 | 5,02 | 5,18 | 5,08 |

**Figure 2.** Ecological footprint per capita between 1990 and 2022.

Source: own elaboration.

**Table 2.**
*Descriptive statistics for GDP per capita*

| VARIABLES | COUNTRIES | | | |
|---|---|---|---|---|
| | **Poland** | **Czechia** | **Hungary** | **Slovak Republic** |
| MEAN | 9567.361 | 14572.44 | 10584.41 | 12384.77 |
| STANDARD DEVIATION | 5666.822 | 8315.069 | 5466.345 | 6955.877 |
| KURTOSIS | -1.06988 | -1.40482 | -1.2008 | -1.58551 |
| SKEWNESS | 0.264226 | 0.066633 | 0.094323 | -0.09031 |
| MIN VALUE | 1731,21 | 2896,609 | 3312,698 | 2405.535 |
| MAX VALUE | 22112.86 | 30427.42 | 22147.21 | 24470.24 |

Source: own elaboration.

**Table 3.**
*Descriptive statistics for ecological footprint per capita*

| VARIABLES | COUNTRIES | | | |
|---|---|---|---|---|
| | **Poland** | **Czechia** | **Hungary** | **Slovak Republic** |
| MEAN | 4.544061 | 5.546837 | 3.873667 | 4.080691 |
| STANDARD DEVIATION | 0.208283 | 1.045493 | 0.40066 | 0.847133 |
| KURTOSIS | 0.184548 | 4.246947 | -0.13495 | 1.674282 |
| SKEWNESS | -0.15262 | -2.01189 | 0.148992 | -1.36718 |
| MIN VALUE | 4.0126 | 2.479515 | 3.063932 | 1.708239 |
| MAX VALUE | 4.926065 | 7.2074 | 4.763823 | 5.490977 |

Source: own elaboration.

Analyzing the changes in the ecological footprint value in the time series, four periods of increasing and decreasing trends was observed. The first period, in which the largest increases in the value of the variable occurred, lasted until 2004. After that year, the value of the ecological footprint per capita systematically decreased until 2012, and then increased until 2019. From 2020, lower and lower values of this variable were observed until the end of the period analyzed. The variability characteristics of the distribution of the ecological footprint per capita make determining a linear trend line ineffective. The $R_2$ values describing the linear trend oscillated around very low value: 0,1. A better fit was obtained by fitting a polynomial trend line. At that time, the $R_2$ values were at a level of about 0,6. The greatest variation in the ecological footprint value, with the simultaneous occurrence of the highest standard deviation value among the analyzed countries, characterized the economy of Czechia (Table 3), while the lowest variability of this variable was related to the Polish economy, with the lowest standard deviation value among the analyzed countries. The calculated measures of concentration and asymmetry of the distribution for the ecological footprint also yield values different from those of the distribution of GDP per capita. The economies of Poland, Czechia and the Slovak Republic were characterized by positive kurtosis and negative skewness, which means the leptokurtic distribution and its left sidedness. The inverse values of kurtosis and skewness calculated for the Hungarian economy indicate the platykurtic distribution of the analyzed variable and its right-sidedness. The analysis of the values calculated using descriptive statistics shows the diversification of the results obtained for the selected countries and variables.

Table 4 presents the relationships between changes in GDP per capita and changes in the ecological footprint per capita and the Pearson correlation coefficients between these variables in the analyzed period. The results varied both in terms of time and country. In most cases, the coefficient values were higher than 0,5, which indicates a moderate correlation. The highest values of the coefficient, above 0,7, indicating a strong correlation, referred to the period 2009-2016. In the years 1990-2016, a positive correlation can be observed in all analyzed countries. In the years 2017 to 2022, the correlation between the variables was negative, with moderate strength. For the Polish economy, the values of the correlation coefficient for all distinguished periods were positive, although very low. Therefore, smaller time ranges were distinguished, which increased the values of this coefficient, especially for the years 2020-2022. The separation of four periods for the other economies did not bring better results than the separation of three ones. The use of Pearson correlation coefficient provides a basis for confirming the existence of a relationship, positive mostly, between economic growth and economic footprint. This is consistent with many works showing the existence of a relationship between economic growth and ecological footprint.

**Table 4.**
*GDP per capita, ecological footprint per capita and Pearson correlation coefficients*

| CONUNTRY | VARIABLES | PERIODS | | | |
|---|---|---|---|---|---|
| | | 1990-2008 | 2009-2016 | 2017-2022 | |
| POLAND | GDP PER CAPITA | 7.08 | -0.12 | 0.51 | |
| | FOOTPRINT PER CAPITA | 0.08 | -0.08 | 0.03 | |
| | CORRELATION COEFFICIENT | 0.60 | 0.32 | 0.34 | |
| | | 1990-2004 | 2005-2012 | 2013-2019 | 2020-2022 |
| | | 0.24 | 0.69 | 0.46 | 0.73 |
| CZECHIA | GDP PER CAPITA | 4.79 | -0.19 | 0.47 | |
| | FOOTPRINT PER CAPITA | 1.42 | -0.13 | -0.10 | |
| | CORRELATION COEFFICIENT | 0.57 | 0.75 | -0.55 | |
| HUNGARY | GDP PER CAPITA | 3.76 | -0.17 | 0.40 | |
| | FOOTPRINT PER CAPITA | -0.01 | -0.06 | -0.09 | |
| | CORRELATION COEFFICIENT | 0.37 | 0.63 | -0.52 | |
| SLOVAK REPABLIC | GDP PER CAPITA | 6.80 | -0.12 | 0.28 | |
| | FOOTPRINT PER CAPITA | 1.05 | -0.19 | -0.07 | |
| | CORRELATION COEFFICIENT | 0.79 | 0.60 | -0.45 | |

Source: own elaboration.

Figure 3 presents the graphical relationships between GDP per capita and ecological footprint per capita in the years 1990-2022 in analyzed countries. An attempt was made to fit a trend line for the economic growth-ecological footprint relationship for each analyzed economy. The best fit for all countries turned out to be a polynomial trend line. Although it is not a perfect fit, especially for the Hungarian economy. Analyzing the graphs, it can be seen that for Slovak Republic and Czechia the curve was inverted-U-shaped, and for the economies of Hungary and Poland the curve was N-shaped.

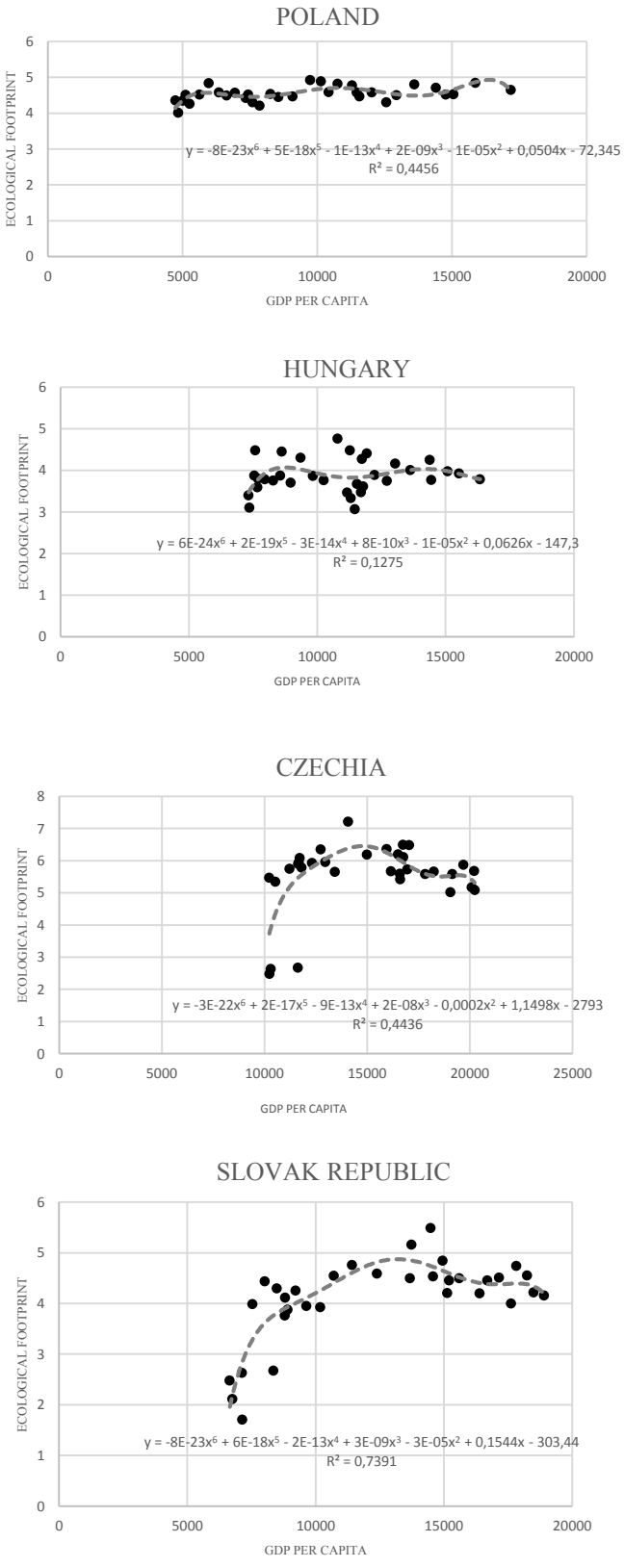



**Figure 3.** Relation between GDP per capita and ecological footprint and EKC.
Source: own elaboration.

The results obtained confirm the presence of the economic growth-ecological footprint relationship and the possibility of describing it using EKC. This conclusion is consistent with most works examining this relationship. The research conducted in this work also confirmed the non-linear relationship of both variables, which is also consistent with the work of other researchers. In addition, it was proven that the environmental Kunzets curve can be U-shaped and N-shaped, which is also confirmed by other authors referring to many economies around the world. The existence of differentiation of the analyzed relationship between the Eastern European countries was also confirmed. However, the conclusions regarding the shape of the EKC were not fully confirmed. The N-shaped EKC of Poland and the inverted-U-shaped EKC of the Czechia coincide with the conclusions obtained by Lazar et al. (2019). Saud et al. (2019) who also confirmed its existence, but only for Poland and the Slovak Republic. The obtained positive values of the Pearson coefficient confirm the existence of a positive relationship between economic growth and ecological footprint in the initial time range, which is consistent with the results obtained by Jamel et al. (2017) and Destek et al. (2018).

## 5. Summary

This article analyzed the annual indicators of gross domestic product per capita and ecological footprint of Central European countries: Poland, Czechia, Hungary and Slovak Republic. Both variables were collected over a 32-year period from 1990 to 2022. In order to examine the relationship between economic growth and ecological footprint, the following were used: analysis of the dynamics of the course of variables, descriptive statistics, Pearson correlation coefficient and graphical construction of the environmental Kuznets curve. The analysis of the relationship between economic growth and ecological footprint in Central European countries indicates its diversification both over time and between the analyzed countries. Analysis of values calculated using descriptive statistics showed diversification of the results obtained for selected countries and variables. The use of Pearson correlation coefficient provided a basis for confirming the existence of a relationship between economic growth and economic footprint. In the years 1990-2016, a positive correlation could be observed in all countries analyzed. In the years 2017 to 2022, the correlation between variables was negative. The obtained results also confirm the presence of a non-linear relationship between economic growth and ecological footprint and the possibility of describing it using EKC, which for the Slovak Republic and Czechia took shape of an inverted-U, while for the economies of Hungary and Poland the EKC curve was N-shaped.

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