PANOECONOMICUS, 2017, Vol. 64, Issue 1, pp. 93-112
Received: 23 April 2015; Accepted: 22 January 2016.

UDC 330.34: 504.7
DOI: 10.2298/PAN150423012G
Preliminary report

Romualdas Ginevičius

Vilnius Gediminas Technical University, Lithuania

✉ romualdas.ginevicius@vgtu.lt

Giedrė Lapinskienė
Corresponding author

Vilnius Gediminas Technical University, Lithuania

✉ giedre.lapinskiene@vgtu.lt

Kęstutis Peleckis

Vilnius Gediminas Technical University, Lithuania

✉ kestutis.peleckis@vgtu.lt

The Evolution of the Environmental Kuznets Curve Concept: The Review of the Research

Summary: The paper aims to describe the evolution of the environmental Kuznets curve, from its origin up to its present status, and to systemise the results of the empirical studies of the relationship between the emissions of greenhouse gases and economic growth. The environmental Kuznets curve indicates that at the early stages of economic growth, pollution increases with the growing use of resources, but when a certain level of income *per capita* is reached, the trend reverses so that, at a higher development stage, further economic growth leads to the improvement of the environment. The paper starts with a description of the most influential theories of the environmental economics that helps to highlight an effective environmental approach. The article may be useful for scientists and policy makers, analysing the trends of the economic development of various countries and the problems of the relationship between the environmental indicators and economic growth.

Key words: Environment, Environmental Kuznets curve, Economic growth, Greenhouse gases.

JEL: Q56.

At the highest political level, the environmental problems have been viewed as an important factor in the development of any country since 1972, when Stockholm Conference on the Human Environment was held and sustainable development as the leading paradigm resurfaced. Despite the growing efforts, the environmental problems are still acute, while the natural environment has been destroyed beyond repair in many places. This supported the idea of the critics saying that to sustain and develop is an oxymoron. In the scientific world, the question of how a continuous economic growth affects various environmental indicators is very important and has been analysed by many scientists. The authors of some studies demonstrated the necessity of slowing down economic growth and moving to the steady state economy (Donella H. Meadows et al. 1972; Meadows, Randers, and Meadows 2004; Randers 2012). The second large group of authors stated that the relationship between the economic growth and the environment changes demonstrates the inverted-U trajectory (Gene M. Grossman and Alan B. Krueger 1991, 1995; Nemat Shafik and Sushenjit Bandyopadhyay 1992; Douglas Holtz-Eakin and Thomas M. Selden 1995; Theodore Panayotou 2003; Marzio Galeotti, Alessandro Lanza, and Francesco Pauli 2006; Rachel S. Franklin and Matthias Ruth 2012; Giedrė Lapinskienė, Manuela Tvaronavičienė, and Pranas Vaitkus 2013, 2014; Kuan M. Wang 2013; Nicholas

Apergis and Ilhan Ozturk 2015; Lapinskienė, Kęstutis Peleckis, and Marijus Radavičius 2015). These researchers believe that at the early stages of economic growth, which can be called the period of pre-industrial economies, the degradation and pollution are increasing, but beyond a particular level of income *per capita* (reaching the turning point in industrial economies), the trend reverses so that at high income levels (the stage of post-industrial economies), the economic growth leads to the environmental improvement. This implies that the environmental impact indicator is the inverted-U shape function of income *per capita*. In their studies, Partha Dasgupta and Karl-Goran Maler (1994) called this empirical relationship between the national income per head and concentration levels of industrial pollutants the environmental Kuznets curve. The environmental Kuznets curve (EKC) should be viewed as the hypothesis of the interrelation between the economic growth and the environmental quality. Hence, the EKC might be useful for the analysis of additional instruments for reducing its height based on the experience of other countries and the policies, allowing for "tunnelling" through the curve and providing scientific information for sustainable policy design (Remigijus Čiegis, Dalia Štreimikienė, and Edmundas Kazimieras Zavadskas 2008).

This paper aims to describe the evolution of the environmental Kuznets curve, from its origin up to its present status. It also aims to summarise and systemise the results of empirical studies. The article may be useful for scientists and policy makers in analysing the trends of the economic development of the countries and dealing with the problems of the relationship between the environmental indicators and economic growth.

The paper has the following structure: Section 1 describes the most influential theories of the environmental economics to highlight the environmental aspect; Sections 2 and 3 present thorough analysis of the EKC evolution from start up to present. The last section, Section 4, summarizes the results by providing the concluding remarks and defining possible areas for further research.

1. The Interrelationship between the Economic Growth and the Indicators of Environmental Degradation: The Environmental Approach

The most influential theories of the environmental economics are presented to highlight the environmental aspect of the study. In 1798, Thomas R. Malthus wrote a book "An Essay on the Principle of Population". In this book, the author assumed that food supply grew only arithmetically, while a healthy population grew geometrically. It was called the Malthusian population trap where long-run human progress would be very dim. The author did not assess the technological progress, and the land was defined as an irreplaceable source of natural capital.

In 1968, another book, "The Population Bomb", warned about the overpopulated Earth. As man changed the axe into the machine, the environment lost the battle, because a man is so brutal with the infinity of his needs. The author asked people to recognize that the growing population would change the living standards and the natural beauty of the environment. The necessity to plan for a stable population of

optimum size was thought of. Otherwise, it was believed that the environmental deterioration would pose a colossal threat to mankind survival (Paul R. Ehrlich 1968).

Most of the theoretical considerations referring to the relationship between the environment and economic growth started with the presentation of the famous book "The Limits to Growth" (Meadows et al. 1972) inspired by the informal organization called "The Club of Rome". It was observed that the rates of variables such as population growth, usage of resources, level of pollution, and material consumption grew according to the trajectory of the exponential function. The authors warned that the patterns of production had to be changed from quantity to quality and noted that it was impossible to satisfy the infinite needs of every human, therefore, the necessity of choice would be inevitable. Various scenarios were built in examining the growth of the selected variables, according to which the limits of the planet would have stopped the economic growth in the 21th century.

In 1992, "The Limits to Grow", a new book of the authors called "Beyond the Limits" was published. Using the updated results, the authors emphasized that the natural processes of the planet were broken, therefore it was very important to recognize that and make changes to alter the current path. Later, the scientists continued to study the possible scenarios for the world, comparing the results presented in the previous studies. Meadows, Randers, and Meadows (2004) updated their studies and published the book "The Limits to Growth: The 30-Year Update". In this new book, the authors acknowledged many positive things that were done in order to preserve the environment during the past years. However, the rate of population, production and pollution were still rising, despite the emergence of new technologies and innovations. Modelling the World 3-3 scenarios, the scientists included new components of rates. One of their conclusions emphasized the importance of managing an orderly reduction of their activities back down below the limits of the Earth's resources.

In 2012, Randers, one of the authors of "The Limits to Growth", published the book "2052 Global Forecast and Report to the Club of Rome", where he forecasted the future in order to answer the so frequent question given to him during the forty years: "What would happen in another forty years?". He noticed that the real challenge was to estimate how much (or how little) of what needs to be done would actually be done. He believed that the transition to sustainability would be only half complete by 2052, because the human response to the environmental degradation is too slow. In the book, the most critical factor was highlighted as greenhouse gas emissions caused by human activities. The transition to sustainability will require a fundamental change to a number of the systems that govern the current world development, such as capitalism, economic growth, democracy, intergenerational equity and our relationship with the earth's climate. The author chose to forecast or trace the big lines of what he saw to be the probable global evolution toward 2052. Technically, the trends and tendencies that are rooted in stable causal feedback structures in the world system are described. As the author pointed out, his forecast did not eliminate free will, but rather was based on the belief that human decision making was influenced by the conditions under which the decision was being made. The book includes about thirty-five glimpses of different experts in the described areas. The author, building his forecast on the system dynamic models, embodied a lot of academ-

ic theories drawn from economics, political science, sociology, engineering, biology, agriculture and environmental science.

Environmentalists and other researchers aiming at preservation of the natural environment feel disappointed by the behavioural patterns of human beings. Despite the fact that sustainable development has been a strategic aim for forty recent years, the environmental problems are acute, and in many places, the natural environment has been destroyed beyond repair, which supports the idea of the critics saying that to sustain and develop is an oxymoron.

2. The Evaluation of the First Wave of Environmental Kuznets Curve Studies till the End of the 20th Century

The relationship between the economic growth and the environmental quality presented by the inverted-U has been widely studied since 1990s. Originally, the environmental Kuznets curve was derived from the Kuznets curve. In 1955, Simon Kuznets became interested in the character and causes of the changes in inequality of personal distribution of income in the course of the economic growth of a country. In general, Kuznets hypothesized that at the early stages of development, when the income *per capita* was growing, income inequality had to increase, but above some income level, the inequality would decline, thereby demonstrating the inverse-U-shaped relationship between the level of income inequality and income growth. This relationship is now known as the Kuznets curve.

Environmental economists have built on this concept by hypothesizing the same type of relationship between the level of the environmental degradation and income growth. Many researchers have agreed that Gene Grossman and Alan Krueger were the scientists who boosted the research. In the article published in 1991, the authors used the comparable measures of three air pollutants, sulphur dioxide, dark matter and suspended particles, in a cross-section of urban areas located in 42 countries, to study the relationship between the air quality and economic growth in the context of liberalization of trade between the United States and Mexico. The study was inspired by the discussion on the potential North American Free Trade Agreement (NAFTA). It was stated that the country's weak regulatory infrastructure would not be able to control the industrialization processes due to the liberalization of trade and investment. According to the authors, the elimination of trade barriers generally affects the environment by expanding the scale of economic activity, as well as altering its composition and bringing about a change in the methods of production. These explanations have become the classical theory of the relationship between the economic growth and environmental indicators, which is known as the EKC (Grossman and Krueger 1991).

This concept was popularized through the 1992 World Bank Development Report. In this report, the protection of the environment was defined as an essential part of development, and it was emphasized that without adequate environmental protection the development would be undermined. On the other hand, in the absence of development, the resources required for investments would be inadequate, and the environmental protection would fail. Hence, a positive effect of growth on the envi-

ronment was determined. The authors used some additional environmental indicators and examined more countries to find that the environmental quality was monotonically improving. This is due to the reduction of the amount of pollutants except for the amount of the dissolved oxygen in rivers and CO_2 when the level of income was rising. It was found that CO_2 emissions *per capita* had been increasing monotonically during the income growth with unidentified income turning point (Shafik and Bandyopadhyay 1992).

In 1994, Selden and Daqing Song continued to study the relationship between the environmental quality and the development, following the above mentioned studies. The authors made the assumption that industrialization and agricultural modernization might lead to increased pollution, while other factors might cause its decrease. Selden and Song (1994) emphasized the role of the following factors: positive income elasticity for the environmental quality, the changes in the patterns of production and consumption, as well as the increasing levels of education and environmental awareness and the development of more open political systems. The researchers limited their study to air quality indicators (sulphur dioxide, suspended particulates, oxides of nitrogen and carbon monoxide). They hypothesized that urban air pollution would be lower than aggregate emissions at lower levels of *per capita* income. The reasons behind this hypothesis were the importance of the urban quality for public health: lower cost of urban quality improvement and reallocation of the dirty industries to other areas by rising land rents or using the political power. The authors contributed to the environment and growth debate by making forecasts of global emissions for various scenarios of income and population growth. They highlighted three interrelated factors, which could be important for the future scenario of global pollution, as follows: the distribution of global income, the pattern of income growth rates among various nations and the pattern of the population growth rates among the nations. The authors used the quadratic regression equation to integrate into a single model the emissions *per capita*, real GDP *per capita* and an additional variable, the population density. In the frame of this model, a meaningful Kuznets relationship between the emissions and GDP was expressed *via* possible signs of regression coefficients.

The acute problem of global warming induced the scientists Holtz-Eakin and Selden (1995) to carry out the research based on CO_2 and GDP. In 1995, the researchers debated the future path of greenhouse gas emissions and global economic development. This discussion is still important and on going up to this day. The authors concentrated their analysis on two emission functions: the first one is quadratic in levels, while the second one is quadratic in the natural logarithms. They determined that endogenous variables could be the composition of output, regulations and taxes, as well as patterns of urbanization. Some country-specific factors, including climate, geography, resources, and land area were mentioned as exogenous variables of emissions. The panel data covered completely 108 countries from 1951 to 1986. The estimation results increased with *per capita* GDP, but, eventually, decreased consistently with the inverted-U shape. The researchers used the estimated relationship to forecast the global emissions due to fossil fuel consumption and cement manufacturing over the period of 1986-2100.

Later, Grossman, and Krueger (1995) continued to search for the answer to a difficult and complex question about the effect of economic growth on ecological problems. The scientists believed that their findings could be very useful for creating the appropriate development strategies for other countries. They made an assumption that the development gave rise to structural changes in production, and the societies could find ways to conserve scarce resources. They believed that the forces of innovation would be so strong that they could compensate for the harmful effects of economic growth on the environment. They also believed that the damage to the environment would be directly linked to the scale of economic activities. In order to test this, they examined the reduced-form relationship between *per capita* income and various environmental indicators, such as urban air pollution, the state of the oxygen regime in river basins, the faecal contamination and heavy metal contamination of river basins. In general, the research demonstrated that national income was an important determinant of local air and water pollution. The authors found that for the most indicators, the pollution increased at the initial stage, but in the course of the economic growth, a subsequent phase of improvement could be observed. The authors suspected that these improvements were the results of the increased demand and supply for environmental protection at higher levels of national income.

Based on empirical research, the first studies highlighted the turning points; when positive changes were caused by structural transformation, dirty technologies by more environmentally-friends techniques were changed and more stringent environmental standards and laws were implemented. The concluding remarks of the first influential studies allow this study to sum up that countries have to be very innovative in creating and implementing various mechanisms to preserve the environment.

The works of the author on the EKC hypothesis discussed above can be referred to as classics in this area. After their publication, the EKC concept was criticised from two perspectives, i.e. the economic point of view and econometric methodology used for empirical research. According to the critics, the changes in trade relationship associated with the development were not included in the previous models. The neutral effect of trade in the models caused fundamental problems associated with the EKC hypothesis. The researchers noticed that the EKC was built on the economic assumption, not taking into account the feedback, showing how the state of the environment affects the economic growth. The decreased quality of the environment could lead to a lower quality of life, but not to the reduction of production. The critics noticed that estimation of a single equation did not cover various causal chains and could not be the main instrument for achieving the sustainable development policy, which, in reality, was described by many criteria. A structural model might be more suitable than a single regression. The countries importing raw materials might be exporting the environmental impacts to other countries. The authors of the critical papers concluded that the historical experience of some economies could not be extrapolated to the future global economy. The quality of the environmental data was also mentioned as unsatisfactory and this could be a cause for the occurrence of heteroskedasticity cases. They suggested that the analysis of the relationship between economic growth and environment should be based on the historical experience of individual countries (David I. Stern 1998).

In 1997, J. Timmons Roberts and Peter E. Grims presented the research covering the data from 1962 to 1991 for the groups of the countries, which, in 1970, had been referred by the World Bank to high, middle and low levels according to income levels. The researchers used the environmental indicator called National Carbon Intensity, which was based on carbon intensity divided by GDP. This variable was taken as the log dependable in the quadratic regression analysis. The authors checked if there had been an inverted-U curve relationship for CO_2 emissions per unit of GDP over the period of 30 years and tracked the changes in the selected groups of the countries. The authors thought that the existence of the inverted-U curve for CO_2 emissions intensity would suggest that the reduction of pollution might be expected to occur as a natural by-product of economic development, improving the efficiency, particularly, of energy consumption. They expected that their analysis would help to assess the causal importance of abatement policies, the improvement of technical production efficiency and the reallocation of energy and pollution intensive industries to poorer countries. Their analysis showed that the relationship between National Carbon Intensity and GDP changed from the essentially linear in 1965 to strongly curvilinear in 1990 for all countries. Hence, they proved the existence of the inverted-U relationship. Examining the path of National Carbon Intensity in different groups of countries for the selected period, they noticed that the higher income countries demonstrated a decrease in CO_2 emission, while other groups showed its increase.

In 1998, G. C. Unruh and W. R. Moomaw analysed the EKC behaviour and raise a question if the phenomenon of the decreasing pollution in the countries with higher income was the result of economic growth or were there some other underlying changes. The researchers could not find any convincing evidence that all countries could replicate the experience of the presently industrialized countries. They were reflecting whether EKC was a useful model for the analysis of policy determining the development purposes. Had the highlighting of the turning points been so valuable? Was it possible to replicate the best practice without reaching a certain level of income? In an effort to evaluate whether income was the determining variable, the authors had applied the techniques of nonlinear dynamical analysis. According to the authors, the research into these techniques was known as the "chaos" studies because the latter were characterised by multiple or even an infinitive number of solutions. The authors generated phase diagrams for sixteen countries. The analysis showed that there was a group of countries that demonstrated EKC-like behaviour because the emissions first rose and then stabilized around an attractor in the period from 1970 to 1980, or declined as the income grew. Having analysed many cases, the authors concluded that it was inappropriate to choose a single income turning point because CO_2 emissions originated almost entirely from fossil fuel usage. In 1970, however, the oil crisis led to the decrease in the level of emission. In the case of France, it induced the authorities to change the electric power production from coal to a program of the combined nuclear electric power and efficiency gains. These changes marked temporal, historic events and confirmed that it was not a specific income level, which was at the root of this transition. The nonlinear systems' dynamics in the emissions data suggested that the changes in CO_2 emission trajectories

could be due to some shocks or special events in the socio-economic systems. The shocks appeared to provide a sufficient incentive for new policy initiatives, both at the private and public levels.

In 1999, Galeotti and Lanza used a panel data model for 110 countries to estimate the relationship between CO_2 and GDP and to forecast emissions in the period from 1971 to 1996. The sample covered 88% of the CO_2 emissions generated by fuel combustion. The authors chose a non-linear functional form, which was known in the statistical literature as Gamma-Weibull function. They motivated their choice by the fact that this decision could not restrain the range of possible shapes. Besides, it better performed econometrically, outperforming the log-linear specification, as a preferable method, on statistical testing groups. In the first part of the study, the estimated results confirmed the EKC hypothesis. In the second part, the researchers forecasted the level of emission until 2020. They mentioned that the main advantage of forecasting, based on the environmental Kuznets curve, was its simplicity. Their prediction showed that the future global emissions would grow, but they also emphasized that, in many cases, their projections predicted a lower level of total emissions. The authors advised to create effective technological cooperation in this field.

From the analyses of the first studies, it could be seen that the established EKC relationship between the environmental indicators and economic growth left many unresolved problems and areas for further research. It can be observed that, in spite of the great number of investigations, there is no definite answer to the question about the EKC existence and the causes of its occurrence. Further analysis of the empirical studies presented in this paper will be mainly concentrated on the relationship between the economic growth and air quality, which captures CO_2 emission due to global climate change.

3. The Evaluation of the Modern EKC Studies Conducted in the 21st Century

Similar to the researchers of the 20th century, the scientists of the 21st century were interested in the economic growth and the environmental quality. However, researchers highlighted that the analyses of the relationship between the economic growth and the environmental indicators could not be based on the developmental stages as there were no reasons to believe that most countries could ever reach the hypothesized turning point. They highlighted that factors, such as effective technologies, the reallocation of energy and pollution intensive industries to poorer countries, as well as the choice of policy, prices of resources and special shocks, determined the level of the environmental degradation in a particular country. Hence, worldwide cooperation is very important in implementing international environmental standards and enforcement mechanisms, which can be an effective instrument in managing the climate change issue around the world. In the last decade, the main problems considered in the EKC literature had not changed considerably. The influential and critical articles written by David I. Stern, Soumyananda Dinda, and Richard T. Carson are described below.

Based on the reviewed studies, Stern (2004) concluded, that despite the performed analysis, some problems of EKC evaluation still remained. The author sum-

marised the theoretical errors in the latest studies as follows: the income is assumed to be an independent variable, therefore, there is no feedback from the environmental degradation to GDP; trade impact and regulatory differences have not been estimated; transition to new pollutants has not been discussed; unequal distribution of income *per capita*, with a large number of people below the mean, makes the median, but not the mean, a more relevant variable; the authors mentioned that the environmental problems could not be solved separately because other social aspects are also very important; the main econometric issues include heteroskedasticity, simultaneity, the omitted variable bias and cointegration.

Soumyananda Dinda (2004) summarized the results obtained in the analysis and presented his evaluation of the main findings, which could be useful for further studies. Firstly, he emphasized, that many researchers found the EKC for local pollutants, which have local impacts. Most of the EKC studies concluded that the EKC level was significantly affected by national and local policies. It was believed that fruitful analysis could be based on the analysis of the historical experience of individual countries. The analysed sources of EKC were classified into two major groups based on structural changes and technological progress. Structural changes comprised factors such as production structure, migration from the areas with high environmental problems, the sectorial structure, and the external important events, such as oil crises and the corruption level. Technological progress embodied the level of R&D and innovation at all stages of the considered processes.

One of the most interesting critical observations was presented by Richard T. Carson (2010). Analysing the literature on the EKC hypothesis, the author pointed out the aspects that were not widely cited in other literature. He highlighted that famous EKC researchers, such as Grossman and Krueger, had not cited the important books, such as "The Limits to Growth" and "The Population Bomb". The EKC theory limited itself by not including the environmental economists' studies. The EKC was promoted by trade/development economists in the context of an international trade agreement rather than by environmental/resources economists in the pollution control context. The author noticed that after appearance of the EKC studies, the economic growth per person began to be touted as the answer to environmental problems in popular publications. Nobody cared that environmental policy was highlighted as the main prerequisite. In analysing the theoretical literature on the EKC, he considered the empirical issues and evidences presented in the observed theories based on the data collected for Mexico, the United States, Malaysia and China. He contributed to other EKC critique by noting that the pollution data used in the EKC studies were not as comparable across countries as one might hope because different methods and procedures could have been used in each country. He also concluded that the environmental data were very poor in quality. Econometric issues of the EKC were presented as uncertain and fragile. Statistical tests usually rejected random effects' specification due its correlation with the included covariates. The fundamental problem was formulated because of the need to show causality between income and the environmental variables of interest. The cubic function trend with respect to income led to the conclusion that the environmental conditions eventually took a turn for the worse with the income increase. The main critique of a general EKC frame-

work is focused on the fact that, for some time, this theory made it easy to believe that the developing countries might grow out from the environmental problems, while, in reality, the developing countries can take many active actions to improve the environmental conditions. While there are many articles focusing on the EKC theory, only a few took a serious look at the problem of how changes in regulatory systems and incentives placed across political jurisdictions could be used to improve the environmental quality and avoid unnecessary environmental degradation.

In today's world, climate change is assumed to be caused by human activities (the so-called anthropogenic effects) and is widely discussed and considered to be a major threat to the environment. Over the period of about 150 years (beginning with the industrial revolution), large amount of carbon dioxide and other gases, producing the so-called greenhouse effect, were released into the atmosphere. Based on the assumption that the harmful effects produced by human activities cause climate change, researchers are trying to find the methods and ways of interrupting this causal relationship between human activities and climate.

Galeotti, Lanza, and Pauli (2006), set themselves a task to reassess the robustness of the EKC for CO_2 emissions by performing the analysis in a different parametric setup and using the alternative emission data supplied by the International Energy Agency. The study used the data from the International Energy Agency and covered the period from 1960 to 1998. The authors highlighted that other researchers used the data from the Carbon Dioxide Information Analysis Centre of the Oak Ridge National Laboratory that covered CO_2 from fossil fuel burning, cement production and gas flaring on the global, regional and national scale. The data were obtained based on the methodologies used by the United Nations and the U.S. Department of Energy. The authors detailed the differences between the two sources and noted that the data might be more precise because they used specific emission coefficients for different energy products. Despite using larger numbers, the differences were not that significant. The economic indicators were taken from the OECD Main Economic Indicators, while others used the World Bank database. The sample was divided into high-income (OECD) countries and low-income (non-OECD) countries. The estimation based on two different data sources (panel data) was made by using a standard cubic log-linear EKC relationship for the comparable number of the countries and the period. The obtained coefficients were rather stable across two data sets. Some differences could be observed with the non-OECD group. The EKC relationship could be observed for the OECD countries. The non-OECD sample was characterized by the increasing slightly concave relationship. For the second check of robustness, they proposed an alternative functional form with some appealing features. They employed a three-parameter Weibull function. Graphically presented results demonstrated a bell-shaped curve with reasonable turning points for the group of the OECD countries and a less pronounced curve without reasonable turning points for the non-OECD countries.

Jack Fosten, Bruce Morley, and Timothy Taylor (2012) considered the emissions of gases with respect to the environmental Kuznets curve relationship in the United Kingdom. The analysis of the data was based on the relationship between the emissions of CO_2 and SO_2 gases and GDP *per capita*. The sample covered the data

from 1830 to 2003 for the CO_2 model and from 1850 to 2002 for the SO_2 model. The research showed that long-run results were in favour of the EKC hypothesis, with *per capita* CO_2 and SO_2 emissions, having an inverse-U relation with real GDP *per capita*. This suggests that mitigating of CO_2 or greenhouse gas as well as SO_2 emissions should rely more on legislation than the reduction in economic growth. The researchers also used the gas price as an additional variable, which had partially explained the results. The authors suggested that the EKC model should be estimated by specifying and incorporating various measures of technological changes.

Vicente Esteve and Cecilio Tamarit (2012) renewed the research for EKC evidence in Spain, using a linear integrated regression model with multiple structural changes. The authors used time-series data on the Spanish economy spanning from 1857 to 2007. In order to avoid the econometric problems mentioned in the previous empirical literature, the authors made use of recent developments in cointegrated regression models with multiple structural changes. They emphasized that the turning point in Spain was dated 1986 and could be explained by the oil crisis of the 70s, caused by the political instability at the end of the Spanish dictatorship in 1975-78, and by the shift in the energy mix that took place only at the beginning of the 80s. The coefficient of the relationship estimated between *per capita* CO_2 and *per capita* income (or long-run elasticity) in the presented model showed a tendency to decrease over time. They found that the "income elasticity" coefficient with regard to CO_2 was smaller than one. This implies that even if the shape of the EKC does not follow an inverted-U, it shows a decreasing growth path, pointing to a prospective turning point.

Franklin and Ruth (2012) contributed to time series studies, using the U.S. emission of CO_2 in the additional explanation of the potential impact of population and the economic structure on it. The researchers used the log squared regression equation. The existence of the inverted-U shaped EKC was confirmed by a smaller number of data for a hundred-year period with the variables divided by the population size. The total CO_2 emission may continue to increase. The results suggested that there should have been some relevant relationships between the demography and the productive structure of the economy and CO_2 emissions. The authors offered to choose the strategies that foster consumption choices consistent with those seen in a society with high elderly dependency ratios as they would more strongly guarantee the sustainable way.

Hidemichi Fujii and Shunsuke Managi (2013) assumed that CO_2 emission for an entire country was unclear and did not show individual industrial characteristics or fuel choices. Following the ideas that economic scale, technology level and composition are the factors influencing the shape of the EKC, the authors chose to estimate the EKC relationship separately, controlling the produced effects by considering particular types of industry and fuel. They hypothesized that the existence of the EKC relationship between CO_2 and economic growth would be possible for the wood and paper industries, as well as pulp and printing industries, which do not use fossil fuels as intermediate fuels and whose product value per weight is lower than that of the others. For other industries, particularly to steel and metal, which use coal as their main intermediate fuel, the emission of CO_2 would increase proportionally with the

production growth. They considered that the EKC relationship observed in the previous studies could be explained by industrial structural changes. The authors relied on a panel regression analysis based on quadratic or cubic relationship between CO_2 and GDP, incorporating in the model the type of energy, industry, country, year and specifying energy efficiency (the total energy use per sale) and the variables of the share of each industry in GDP (the share of the industrial sector's value added in the total GDP). They supposed that these control variables would positively impact CO_2. The industries were chosen based on the data available from the International Energy Agency and the level of CO_2 emissions. The authors found that overall CO_2 emissions demonstrated the N-shape trend. The EKC hypothesis was supported by the study of the industries producing wood and its by-products, paper and pulp, as well as printing and construction industries. The CO_2 emissions from burning coal and oil increased with economic growth in upstream industries. Hence, a conclusion was made that three industries of the nine ones analysed with respect to CO_2 emissions were greener than the others.

Tetsuya Tsurumi and Managi (2010) examined the environmental Kuznets curve hypothesis for carbon dioxide, using generalized additive models with a generic flexible functional form, allowing for a potentially non-linear non-monotonic relationship. A sample covered 30 OECD countries for the period 1960-2003. The authors classified 30 OECD countries into three groups. The dependent variables covered the log of CO_2, while independent variables covered the real log of GDP *per capita*. The results imply that, in this case, economic growth was not sufficient to decrease CO_2 emissions. The first group had a negative slope for the high-income levels, while the second group demonstrated a monotonically increasing trend at all income levels, and the third group displayed other trends or had confidence intervals which were too wide to interpret. The results obtained by these authors suggested that economic growth was not sufficient to decrease CO_2 emissions.

The standard analysis was also performed by the authors from the developing countries. It can be noted that they often followed the research path of the developed countries. For example, the authors from Malaysia tested the EKC hypothesis about the existence of the relationship between the environmental quality (i.e. CO_2, SO_2, BOD, SPM10, and GHG) and GDP to find any similarities or differences between two sample groups, including the developed and developing countries in the period from 1961 to 2009. The sample was divided into several parts consistent with the World Bank methodology. The analysis performed was based on panel data analysis and the cubic regression model. The estimation of the coefficients led the authors to the conclusion about the EKC existence. The results revealed that CO_2 and SPM10 were the environmental indicators which demonstrated the existence of the EKC. They showed that the developed countries had higher turning points than those of the developing countries and allowed the authors to conclude that a higher economic growth might produce different effects on the environmental quality in different economies (Ahmad R. M. Al Sayed and Siok Kun Sek 2013).

It can be seen that the EKC hypotheses also interested the Chinese researchers. Their studies emphasized the specific behaviour of the EKC in their country compared to that in the developed world. For example, Wei Ming Huang, Grace W. M.

Lee, and Chih-Cheng Wu (2008) studied 38 industrialized countries in order to test their correspondence to the Kyoto Protocol in this respect. They divided the selected sample of these countries into two parts, including the economies in transition (for example Russia, the Baltic States) and the developed countries (for example Norway, Austria). The authors used time series linear, quadratic and cubic equations. The research revealed that the economic development and GHG in the economies in transition exhibited a hockey-stick curve trend. The statistical analysis of the developed countries did not provide any evidence to support the EKC hypothesis for GHG. The authors emphasized that, to achieve the Kyoto Protocol objectives, the parties should implement the policies, which specifically limit GHG with the aim of retarding the climate change.

Hua Liao and Huai-Shu Cao (2013) examined the historical relationship between the economic development and carbon dioxide emission in 132 countries for the period of 1971-2009 and evaluated the robustness of the results based on three criteria: data sources, model specification and estimation methods. They included in their empirical analysis such factors as urbanisation, population density, trade and energy mix. The linear spline econometric model, specified in the functional form and including different covariates, was used. Before choosing the quadratic or cubic functional forms, the authors tested whether the results were sensitive to a different number of segments of income elasticity of CO_2 in order to check the robustness of the income effect. The second step was to test the sensitivity of the results by using some additional factors. Six models were estimated based on the chosen econometric methodology. It was concluded, that while the economic development continued to drive up CO_2 emission, urbanisation, population density, trade and energy mix would potentially contribute to the reduction of the absolute level of CO_2 *per capita* emission. The authors noted that their results had not supported the inverted-U shape concept, but rather described the trend observed in high income segments as a saturation of trend. As most of the countries are still below some threshold income *per capita* level, the economic policy mix, helping to foster green technology development and the additional CO_2 emission reduction measures should be implemented to offset a negative stage of income and CO_2 relationship. Otherwise, consistent with a historical trend, poorer countries will still need considerable emission volumes to outweigh their economic backwardness.

Wang (2013) performed a panel data analysis of carbon dioxide emissions and economic growth in 138 countries in the period of 1971-2010. The chosen sample was divided into five quintiles according to the level of CO_2 emissions in every country. The estimation of several models suggested that income elasticity dropped with the raising quintiles. With the increasing CO_2 emissions' quintiles, the growth of GDP will be higher than CO_2 emissions, when income elasticity decreases from more than one to below zero. The author performed a panel data analysis to estimate the long-run elasticity relationship by using regression. The empirical results showed that the long-run relationship between the global carbon dioxide emissions and GDP was stable. The paper suggested that the top priority to mitigate global warming had primarily to refer to the countries with a high economic growth and a strong increase in carbon dioxide emission. If the appropriate technologies and policies of reducing

CO_2 emissions could be identified, national income would not have to decline in order to limit emissions.

Table 1 presents the summarized empirical findings of the later studies, where carbon dioxide or GHG were considered to be the dependable variables of the environmental quality. Some of these studies supported the EKC hypothesis.

Table 1 Summarized Findings of the Studies, where Carbon Dioxide or GHG Represented the Environmental Quality

Authors	Year of publication	The obtained functional form	Sample and time period	Model
Shafik and Bandyopadhyay	1992	Monotonically rising	149 countries, 1960-1990.	Three different functional forms: log-linear, log-quadratic and, in the most general case, a logarithmic cubic polynomial in GDP *per capita*.
Holtz-Eakin and Selden	1995	EKC	130 countries, 1951-1986.	Nonlinear dynamic system analysis. Time evolving space phase that compares emissions in the previous year with those in the current year.
Roberts and Grims	1997	EKC for high income countries; monotonically rising for low and middle income countries.	Constant groups of countries (high, middle and low levels of GDP *per capita*), 1962-1991.	Generic flexible functional form allowing a potentially non-linear non-monotonic relationship.
Unruh and Moomaw	1998	EKC	16 countries, 1950-1992.	Quadratic regression analyses.
Galeotti and Lanza	1999	EKC	110 countries, 1960-1990.	Quadratic regression analyses.
Galeotti, Lanza, and Pauli	2006	EKC for OECD countries, not clear for non-OECD.	Countries of the UN Framework Convention on Climate Change for 1960-1998; other countries 1971-1998.	Panel data, standard cubic log-linear regression analyses.
Huang, Lee, and Wu	2008	No clear trend in developed countries, while economies in transition exhibited a hockey-stick curve trend.	38 countries, 1990-2003.	Time series linear, quadratic and cubic equitations.
Tsurumi and Managi	2010	The high-income levels - negative slope, the second group - a monotonically increasing trend, the third group - other trends which are too wide to interpret.	30 OECD countries, 1960-2003.	Two models - quadratic and quadratic in the natural logarithms.
Franklin and Ruth	2012	EKC, showing the "rebound effect", which suggests the continued upward trend.	United States , 1800-2000.	Non-linear functional forms, which in the statistical literature are known as Gamma-Weibull functions.
Fosten, Morley, and Taylor	2012	EKC	United Kingdom, 1830 to 2003 –200.	Log-squared regression.
Esteve and Tamarit	2012	It shows a decreasing growth path behaviour and an improvement in relative terms.	Spain, 1857 to 2007.	Time series, cubic regression.
Wang	2013	EKC	138 countries,1971-2007.	Standard cubic log-linear.

Liao and Cao	2013	Trend saturation	132 countries, 1971-2009.	Time series, cubic regression.
Fujii and Managi	2013	EKC for paper, pulp, wood, construction industries; the increasing trend in other sectors.	OECD countries, 1970-2005.	Quadratic or cubic panel regression.
Al Sayed and Kun Sek	2013	EKC	Developed and developing countries in the period 1961 to 2009.	Panel data cubic regression.
Lapinskienė, Tvaronavičienė, and Vaitkus	2014	EKC	27 states of the European Union as well as Switzerland and Norway in the period 1995-2010.	Panel data cubic regression.
Olugbenga A. Onafowora and Oluwole Owoye	2014	EKC (in Japan and South Korea); N-shaped trajectory (others).	Brazil, China, Egypt, Japan, South Korea, Mexico, Nigeria and South Africa over the period 1970-2010.	Log-cubic regression.
Apergis and Ozturk	2015	EKC	14 Asian countries spanning the period 1990-2011.	Panel data cubic regression.

Source: The authors.

There is an extensive literature on EKC and most of the results are mixed. The analysed results can be divided into several groups. The majority of the reviewed studies identified the inverted-U relationship (13 cases out of 17 studies analysed), some revealed the increasing trends (5 cases), other works described a decreasing trend (2 cases), while in one case, a hockey-stick trend trajectory was found, and, in three cases, the relationship was not clear. A larger number of studies used panel data, including samples of various sizes, starting from fourteen countries to those covering one hundred forty nine countries. Time series analysis was performed in the United States, the United Kingdom and Spain. The most common equations were quadratic, cubic or log-squared/cubic regressions. In general, it can be observed that the model has remained the same as that used the first classical studies on EKC, but the latest models have been supported by various statistical tests in order to prove the robustness of the empirical results.

4. Conclusion and Discussions

The history of the EKC studies started in the 1990s, and many of these works analysing the relationship between various indicators of the environmental degradation and income *per capita* had been published. From the historical perspective, this period is rather short, but the rapid growth of industrial development caused the economic growth, which entailed a parallel rapid growth of resource consumption and various forms of environmental degradation, leading to climate change. Hence, this external political and economic environment stimulated the growth of the number of the EKC studies. In these studies, researchers used various indicators of the environmental degradation, such as air pollutants (CO_2, later GHG, SO_2, suspended particulate matter and others), as well as water indicators, waste, deforestation and other specific environmental indicators from the environment related databases, such as Global Environmental Monitoring System (GEMS), OECD, the Oak Ridge National labora-

tory, Eurostat and national statistics. Later (in the 21th century) the inverse relationship between pollution and *per capita* income has been explored using a variety of indexes, such as earth footprint, energy intensity, GINI index and others.

Since it is an empirical phenomenon, the approaches to the EKC studies have been closely related to the evolution in the science of statistics, specifically, when new data sources were being introduced. The modern studies expanded a classical model of EKC in order to test the impact of the particular factors expressed by specific proxy variables. The latest studies use modern statistical techniques for enhancing the statistical properties of the analysis.

After the publication of the first classical EKC studies, some critical articles considering econometric statistical methods, data sources and the usefulness of turning points calculations have emerged. The first studies attempted to estimate the average income level corresponding to the turning point of the common EKC-pattern. Some critics noted that in many countries the calculated turning points were far from the average income and the usefulness of such calculations were doubtful. Moreover, there were doubts about the ability of the developing countries to follow the growth-patterns of the developed countries in Europe and North America. Many critical remarks were related to the implicit assumptions of the EKC-speculation, such as of the income normal distribution. Their authors noted that the solution of a single equation had not covered various causal chains, therefore, a structural model might be more suitable in the considered case. The quality of the environmental data was also mentioned as unsatisfactory, and this could be a cause for the occurrence of heteroskedasticity issues. Carson (2010) emphasized that famous EKC researchers had not cited the fundamental books, such as "The Limits to Growth" and "The Population Bomb", and the EKC theory limited itself by not including the data described in the environmental economists' studies.

In the last decade, the calculations were mostly made for assessing the impact of particular factors. Based on the empirical studies, general theoretical causes and factors determining the relationship between the environmental indicators and economic activity could be divided into several categories. Those categories were the scale of economic activity, the structure of economy, technological development, international trade and the pollution haven hypothesis, income inequality of income distribution, political-governance factors, social-demographical factors, historical events or shocks, and country-specific factors. It is difficult to identify the primary cause in the analysis of some particular cases since all these are interrelated. Some latest developments include new factors which have not been considered important in classical studies. Among other factors, political-governance factors and the impact of shocks were analysed. The analysis of the political-governance factors, covering the development of more open political systems, quality of institutions, regulations, effective international environmental standards, enforcement mechanisms and the implementation of the described issues, might help to prevent the environmental degradation resulting from the continuing economic growth. The various shocks are at the root of the EKC, when the future path of pollution cannot be predicted. Shocks can lead to the reduction of pollution. It might result from price changes, policy measures or technological innovations. The appropriate policy measures include the removal of

energy subsidies, the introduction of more secure property rights over natural resources and the internalization of externalities.

The executed systemic analysis of the empirical studies, where the EKC analysis was extended to include some additional variables, has led to the idea that different locations and different time series may be significantly impacted by special factors. Note that even if the validity of EKC has been proved for emissions *per capita*, pollution still remains a problem for the following reasons:

- According to the environmentalists, population growth is one of the main driving forces behind the environmental decay.
- Even if emissions *per capita* are decreasing, overall concentrations can still be above the assimilative capacity of nature.
- The effectiveness of implementing the green economy might change the direction of the EKC studies from the analysis of special factors to measuring the greenness of GDP, because it might be impossible to separate growth from the environmental degradation, which means that growth has to be green to be sustainable.

References

Al Sayed, Ahmad R. M., and Siok Kun Sek. 2013. "Environmental Kuznets Curve: Evidences from Developed and Developing Economies." *Applied Mathematical Sciences*, 7(22): 1081-1092.

Apergis, Nicholas, and Ilhan Ozturk. 2015. "Testing Environmental Kuznets Curve Hypothesis in Asian Countries." *Ecological Indicators*, 52(May): 16-22. http://dx.doi.org/10.1016/j.ecolind.2014.11.026

Carson, Richard T. 2010. "The Environmental Kuznets Curve: Seeking Empirical Regularity and Theoretical Structure." *Review of Environmental Economics and Policy*, 4(1): 3-23. http://dx.doi.org/10.1093/reep/rep021

Čiegis, Remigijus, Dalia Štreimikienė, and Edmundas Kazimieras Zavadskas. 2008. "The Use of Environmental Kuznets Curve: Environmental and Economic Implications." *International Journal of Environment and Pollution*, 33(2/3): 313-335. http://dx.doi.org/10.1504/IJEP.2008.019401

Dasgupta, Partha, and Karl-Goran Maler. 1994. "Poverty, Institutions, and the Environmental-Resource Base." World Bank Environment Paper 9.

Dinda, Soumyananda. 2004. "Environmental Kuznets Curve Hypothesis: A Survey." *Ecological Economics*, 49(4): 431-455. http://dx.doi.org/10.1016/j.ecolecon.2004.02.011

Ehrlich, Paul R. 1968. *The Population Bomb*. New York: Ballantine Books.

Esteve, Vicente, and Cecilio Tamarit. 2012. "Is there an Environmental Kuznets Curve for Spain? Fresh Evidence from Old Data." *Economic Modelling*, 29(6): 2696-2703. http://dx.doi.org/10.1016/j.econmod.2012.08.016

Fosten, Jack, Bruce Morley, and Timothy Taylor. 2012. "Dynamic Misspecification in the Environmental Kuznets Curve: Evidence from CO2 and SO2 Emissions in the United Kingdom." *Ecological Economics*, 76(C): 25-33. http://dx.doi.org/10.1016/j.ecolecon.2012.01.023

Franklin, Rachel S., and Matthias Ruth. 2012. "Growing Up and Cleaning Up: The Environmental Kuznets Curve Redux."*Applied Geography*, 32(1): 29-39. http://dx.doi.org/10.1016/j.apgeog.2010.10.014

Fujii, Hidemichi, and Shunsuke Managi. 2013. "Which Industry Is Greener? An Empirical Study of Nine Industries in OECD Countries." *Energy Policy*, 57(C): 381-388. http://dx.doi.org/10.1016/j.enpol.2013.02.011

Galeotti, Marzio, and Alessandro Lanza. 1999. "Richer and Cleaner? A Study on Carbon Dioxide Emissions in Developing Countries." *Energy Policy*, 27(10): 565-573. http://dx.doi.org/10.1016/S0301-4215(99)00047-6

Galeotti, Marzio, Alessandro Lanza, and Francesco Pauli. 2006. "Reassessing the Environmental Kuznets Curve for CO2 Emissions: A Robustness Exercise." *Ecological Economics*, 57(1): 152-163. http://dx.doi.org/10.1016/j.ecolecon.2005.03.031

Grossman, Gene M., and Alan B. Krueger. 1991. "Environmental Impact of a North American Free Trade Agreement." National Bureau of Economic Research Working Paper 3194.

Grossman, Gene M., and Alan B. Krueger. 1995. "Economic Growth and the Environment." *The Quarterly Journal of Economics*, 110(2): 353-377. http://dx.doi.org/10.2307/2118443

Holtz-Eakin, Douglas, and Thomas M. Selden. 1995. "Stoking the Fires? CO2 Emissions and Economic Growth." *Journal of Public Economics*, 57(1): 85-101. http://dx.doi.org/10.1016/0047-2727(94)01449-X

Huang, Wei Ming, Grace W. M. Lee, and Chih-Cheng Wu. 2008. "GHG Emissions, GDP Growth and the Kyoto Protocol: A Revisit of Environmental Kuznets Curve Hypothesis." *Energy Policy*, 36(1): 239-247. http://dx.doi.org/10.1016/j.enpol.2007.08.035

Lapinskienė, Giedrė, Manuela Tvaronavičienė, and Pranas Vaitkus. 2013. "Analysis of the Validity of Environmental Kuznets Curve for the Baltic States." *Environmental and Climate Technologies*, 12(1): 41-46. http://dx.doi.org/10.2478/rtuect-2013-0015

Lapinskienė, Giedrė, Manuela Tvaronavičienė, and Pranas Vaitkus. 2014. "The Emissions of Greenhouse Gases and Economic Growth - The Evidence of the Presence of the Environmental Kuznets Curve in the European Union Countries." *Technological and Economic Development of Economy*, 20(1): 65-78. http://dx.doi.org/10.3846/20294913.2014.881434

Lapinskienė, Giedrė, Kęstutis Peleckis, and Marijus Radavičius. 2015. "Economic Development and Greenhouse Gas Emissions in the EU Countries." *Journal of Business Economics and Management*, 16(6): 1109-1123. http://dx.doi.org/10.3846/16111699.2015.1112830

Liao, Hua, and Huai-Shu Cao. 2013. "How Does Carbon Dioxide Emission Change with the Economic Development? Statistical Experiences from 132 Countries." *Global Environmental Change*, 23(5): 1073-1082. http://dx.doi.org/10.1016/j.gloenvcha.2013.06.006

Malthus, Thomas R. 1798. *An Essay on the Principle of Population*. London: J. Johnson.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. 1972. *Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books.

Meadows, Donella H., Jorgen Randers, and Dennis L. Meadows. 2004. *Limits to Growth: The 30-Year Update*. Vermont: Chelsea Green Publishing.

Onafowora, Olugbenga A., and Oluwole Owoye. 2014. "Bounds Testing Approach to Analysis of the Environment Kuznets Curve Hypothesis." *Energy Economic*, 44(C): 47-62. http://dx.doi.org/10.1016/j.eneco.2014.03.025

Panayotou, Theodore. 2003. "Economic Growth and the Environment." In *Economic Survey of Europe*, ed. United Nations Economic Commission for Europe, 45-72. New York: United Nations Publishing.

Randers, Jorgen. 2012. *2052: A Global Forecast for the Next Forty Years*. Vermont: Chelsea Green Publishing.

Roberts, J. Timmons, and Peter E. Grims. 1997. "Carbon Intensity and Economic Development 1962-91: A Brief Exploration of the Environmental Kuznets Curve." *World Development*, 25(2): 191-198. http://dx.doi.org/10.1016/S0305-750X(96)00104-0

Selden, Thomas M., and Daqing Song. 1994. "Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics and Management*, 27(2): 147-162. http://dx.doi.org/10.1006/jeem.1994.1031

Shafik, Nemat, and Sushenjit Bandyopadhyay. 1992. "Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence." World Bank Policy Research Working Paper 904.

Stern, David I. 1998. "Progress on the Environmental Kuznets Curve?" *Environment Development Economics*, 3(2): 173-196.

Stern, David I. 2004. "Rise and Fall of the Environmental Kuznets Curve." *World Development*, 32(8): 1419-1439. http://dx.doi.org/10.1016/j.worlddev.2004.03.004

Tsurumi, Tetsuya, and Shunsuke Managi. 2010. "Decomposition of the Environmental Kuznets Curve: Scale, Technique, and Composition Effects." *Environmental Economics and Policy Studies*, 11(1): 19-36. http://dx.doi.org/10.1007/s10018-009-0159-4

Unruh, Gregory C., and William R. Moomaw. 1998. "An Alternative Analysis of Apparent EKC-Type Transitions." *Ecological Economics*, 25(2): 221-229. http://dx.doi.org/10.1016/S0921-8009(97)00182-1

Wang, Kuan M. 2013. "The Relationship between Carbon Dioxide Emissions and Economic Growth: Quantile Panel-Type Analysis." *Quality & Quantity*, 47(3):1337-1366. http://dx.doi.org/10.1007/s11135-011-9594-y