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CO_2 Emissions and Macroeconomic Indicators: Analysis of the Most Polluted Regions in the World

Nestor Shpak [1], Solomiya Ohinok [1], Ihor Kulyniak [1], Włodzimierz Sroka [2,3,*], Yuriy Fedun [4], Romualdas Ginevičius [5] and Joanna Cygler [6]

1 Institute of Economics and Management, Lviv Polytechnic National University, 79013 Lviv, Ukraine; nestor.o.shpak@lpnu.ua (N.S.); solomiia.v.ohinok@lpnu.ua (S.O.); ihor.y.kulyniak@lpnu.ua (I.K.)
2 Department of Management, Faculty of Applied Sciences, WSB University, Cieplaka 1c, 41-300 Dąbrowa Górnicza, Poland
3 School of Management Sciences, North-West University, Private Bag X1290, Potchefstroom 2520, South Africa
4 Department of International Economic Relations, Faculty of International Relations, Ivan Franko National University Lviv, 79000 Lviv, Ukraine; yuriy.fedun@lnu.edu.ua
5 International Department of Logistics and Service Engineering, Białystok University of Technology, Wiejska 45A, 15-351 Bialystok, Poland; r.ginevicius@pb.edu.pl
6 Collegium of Management and Finance, SGH Warsaw School of Economics, Al. Niepodległości 162, 02-554 Warsaw, Poland; cygler@sgh.waw.pl
* Correspondence: wsroka@wsb.edu.pl

Abstract: There is no sector of the economy that is not dependent on the state of development of the energy sector. This sector produces a significant share of global CO_2 emissions. Harmful CO_2 emissions and greenhouse gas emissions accelerate global warming. Therefore, more and more countries are adopting a strategy for the transition to carbon-neutral energy. However, energy independence and economic competitiveness are closely linked. One cannot analyze them separately. Given these facts, we focused on conducting an econometric study of the impact of key macroeconomic indicators on the level of CO_2 emissions into the air in the United States and the Asia-Pacific region as the regions with the largest CO_2 emissions. The modeling was carried out using the method of a correlation–regression analysis with the subsequent construction of econometric models. The quality of the built econometric models was checked using the coefficient of determination and Fisher's criterion. The sample of statistics was formed from all the available values of the World Bank's annual indicators for the period 1970–2020. The findings achieved showed that: (i) The results of our study confirmed the dependence of CO_2 emissions on macroeconomic factors such as GDP, exports and imports, the rate of inflation, and unemployment. It allows the governments of many countries to use research findings to diagnose, monitor, and forecast macroeconomic outcomes to reduce or maintain allowable CO_2 emissions. (ii) Identifying and assessing economic losses from environmental pollution by CO_2 emissions using econometric models will allow to ensure effective public environmental and economic policies aimed at reducing harmful CO_2 emissions into the air. It may be regarded as the practical importance of our study.

Keywords: CO_2 emissions; energy sector; GDP; exports; imports; inflation; unemployment; correlation and regression analysis; USA; Asia-Pacific region

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Citation: Shpak, N.; Ohinok, S.; Kulyniak, I.; Sroka, W.; Fedun, Y.; Ginevičius, R.; Cygler, J. CO_2 Emissions and Macroeconomic Indicators: Analysis of the Most Polluted Regions in the World. *Energies* **2022**, *15*, 2928. https://doi.org/10.3390/en15082928

Academic Editors: Attilio Converti and Marek Szarucki

Received: 21 March 2022
Accepted: 12 April 2022
Published: 15 April 2022

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1. Introduction

Global environmental problems are caused by the growing level of damage that people are doing to the planet. They include economic activities, irrational and wasteful uses of nature, overpopulation, urbanization, wars, and armed conflicts. The role of carbon dioxide (CO_2) in the life of the biosphere is primarily to support the process of photosynthesis carried out by plants. As carbon dioxide is a greenhouse gas, it affects the heat exchange of the planet with the surrounding space, effectively blocking the reflected infrared radiation at several frequencies, and thus participates in the formation of the planet's climate [1]. However, an increase in the concentration of carbon in the atmosphere is one of the main factors of global warming [2–4]. The main source of carbon emissions is the burning of fossil natural resources: coal, oil, gas, etc.

The deterioration of the ecological situation in the world is influenced by several economic and legal factors. They function in different spheres and vary in the scale of their impact and the severity of their consequences. These factors include: a macroeconomic policy, which leads to the extensive use of natural resources; an investment policy, focused on the development of the exploitation of natural resources; an inefficient sectoral policy, namely in the fuel and energy complex; agriculture and forestry; the imperfect legislative framework; a lack of ecologically balanced long-term strategy; the insufficient consideration of the indirect effect of nature protection; and the existence of an effective incentive in the form of significant and rapid profits from overexploitation or the sale of natural resources such as oil, gas, timber, and ore.

The pollution and depletion of resources has a long history, beginning with the fact that man inhabited the Earth and actively explored it. These factors intensified during the periods of nascent industrial production, urban growth, and population growth and were stimulated by industrial revolutions. Anthropogenic pressure on the Earth's environment has reached its peak, resulting in some irreversible consequences [5]. Today, three major ecologically destabilized areas, covering about 20 million square kilometers of land, have sprung up in Europe, Asia, and America, while less than 10% of natural ecosystems can still be considered untouched. Some countries located in these areas are developing rapidly and constantly increasing pollutant emissions. Meanwhile, environmental conditions continue to deteriorate. The United Nations itself has spent several trillion dollars on environmental programs over the twenty years of implementing the sustainable development strategy. China and the United States are among the world's largest sources of carbon emissions, with both countries announcing a plan to work together to reduce greenhouse gas emissions over the next decade [6]. The COVID-19 pandemic helped to reduce emissions. However, one expects that once the pandemic is over, the world economy will recover, which will cause an increase in CO_2 emissions [7].

The implementation of environmentally friendly technologies is in line with the Sustainable Development Goals and the Lisbon Agenda [8]. Therefore, companies strive for technological progress, having in mind a balance between business, environment, and society [9,10]. There is a need to ensure the application of environmental conservation principles, empower the community, improve education, sustain ecology, and reduce damage to the environment [11–13]. Moreover, one should adjust the industrial structure to meet the needs of environmental protection [14,15].

Analyzing the report of the European Environment Agency, the main market instruments in force include trade permits introduced to reduce emissions (CO_2 emission quotas) and save natural resources (fishing quotas), environmental taxes introduced to change prices that shape the policy of both consumers and producers, environmental contributions to fully or partially cover the costs of environmental services, measures to reduce the pollution of water basins and their resources, environmental subsidies and benefits to stimulate the development of new technologies [16], capturing new markets for environmental products, as well as establishing high standards of the environment protection, the creation of a system of compensation for losses due to the activity dangerous to nature, and also, the expenses to prevent these consequences [17].

The conflict between interests of socioeconomic development and energy transition to the path of low-carbon development requires a balanced theoretical and methodological approach to their balancing, which can be achieved by identifying the impact of macroeconomic factors on CO_2 emissions. Most studies are devoted to studying the nature of the impact of one of the factors on CO_2 emissions, but the outlined issues are complex. All economic factors act in a complex on a certain result, so they need to be analyzed together [18]. That is why modeling the relationships between many parameters is necessary to identify further steps towards decarbonization that need to be ensured in the national economy without hampering its socioeconomic development. Statistics show that the regions with the highest CO_2 emissions are the USA and Asia-Pacific regions. The economic development of these regions is not the same, which makes it impossible to implement economic solutions in one of them to simulate another region. In other words, there is a need for further studies of these regions, taking into account the specifics of their development. Given the relevance and inadequacy of the study of the stated topics, the purpose of the article is to analyze the impact of macroeconomic indicators on CO_2 emissions in the world (USA and Asia-Pacific region) while determining the quantitative regularity and relationships between "CO_2 emissions" (resulting feature) and "exports volume", "imports volume", "inflation rate", and "unemployment rate" (explanatory variables).

Pollution is damaging the whole world, which is why we should do everything to improve the situation. Any innovative approach is necessary to measure it, analyze, and then allow it to be implemented. Our approach is one of these solutions, because a detailed analysis of macroeconomic factors will allow us to understand what policies should be implemented to reduce environmental pollution and how to reduce CO_2 emissions. Considering that 50 years was chosen for the analysis, the simulation results will allow us to more accurately obtain the trajectory of the studied variables, determine the optimal parameters, and predict the behavior of the studied indicators. In other words, our research is aimed at closing the gaps caused by the short-term research of other scientists, which, in our opinion, is important, because human and human macroeconomic activities have long-term and complex impacts on the environment and economic and other factors may not appear immediately.

The article is structured as follows. First, the literature review and the theoretical foundations of the study are presented. They focus on determining the relevance of the study. Secondly, the research methodology is presented. The next part of the article highlights the results achieved. Finally, we present the conclusions and practical significance of the study.

2. Literature Review

2.1. Theoretical Background

The impact of the economy on the environment is becoming increasingly visible with the development of the world economy. Accordingly, there are a large number of studies that have tried to explain and analyze this relationship [19–22]. However, the report of the Club of Rome, which was proposed in 1992, deserves the highest attention. The purpose of the Club is to solve current problems based on the development of a new direction called global modeling, which can be used to scientifically analyze the problems of mankind related to the limited resources of the Earth, the rapid growth of production, and consumption, as well as to warn humanity about the critical situation in the world, to achieve a global balance [23].

Back in 1970–1971, Dennis Meadows, together with an international team of researchers from the Massachusetts Institute of Technology (USA), at the request of the Club of Rome conducted research on the long-term effects of the current global trends. They studied the relationship between population growth, the development of industrial and agricultural production, and the consumption of natural resources and environmental pollution [24]. Dennis Meadows' model was developed using Jay Forrester's methodology of system dynamics and covered in the work "*The Limits to Growth*" in 1972. The conclusions of this model are quite similar to the views of Thomas Malthus. They were built on the five main parameters [25]: (1) the population of the Earth, (2) industrialization, (3) food production, (4) depletion of natural resources, and (5) environmental pollution. This laid out the foundations of the modern concept of "sustainable development" and justified the need to move to zero growth, i.e., to reduce production and consumption to simple reproduction.

Recently environmental issues are becoming more and more visible and stimulate politicians to take action [26]. No wonder then that the pollution of the atmosphere by harmful emissions like greenhouse gases is a problem of the research of many scholars [27–29]. To change these trends and move to a state of economic, social, and environmental stability, it is necessary to change the consciousness of people and their perceptions of the environmental and economic values of society [30,31].

Georgescu-Roegen was one of the first economists to argue that the economy is facing constraints on growth due to resource depletion. Relying on the works of Georgescu-Roegen, Daly [32] developed a model by editing the anthology "*Towards a Sustainable Economy*", which was published in 1973. In 1990, Daly was a co-founder of the International Society for Environmental Economics (ISEE) [33].

The analysis of the relationship between globalization and changes in the quality of the environment also deserves attention. There is evidence in the modern literature that political globalization has a direct effect on the environment, but the same cannot be said for economic globalization, which is detrimental to the environment [34,35].

Today, more and more researchers are paying attention to environmental pollution by CO_2 emissions. Rapid urbanization, widespread energy use, and free trade are the most common causes of rising CO_2 emissions [36,37]. Several studies are proving that, with the increasing economic activity, CO_2 emissions increase [38,39]. Modern production conditions require an increase in energy use, which directly leads to increased CO_2 emissions [40,41]. The level of carbon dioxide in the air is 50% higher than in preindustrial times, and the average rate of CO_2 growth is faster than ever. Industrial carbon emissions far exceed what plants can consume. In general, CO_2 emissions are higher in developed countries. In the United States, energy consumption has increased over the past five years, most likely due to greater heating and cooling needs and lower oil prices, increasing travel. This increase comes after almost a decade of declining energy consumption. The world is looking to these developed countries to lead the initiatives to reduce CO_2 emissions.

The OECD identifies five main economic sectors related to the development of the energy sector, which is the main source of CO_2 emissions: industry, agriculture, transport, services, and other sectors of green growth [42]. Researchers argue that the strongest direct correlation is observed in the transport sector, which means that, with increasing energy consumption in this sector, the efficiency of CO_2 production increases [43]. The key emitters of CO_2 emissions in the industry are ferrous metallurgy, the chemical industry, and cement production. The dynamics of production of three key product groups fully correlate with the dynamics of emissions by the industry, which indicates a significant dependence of emissions on several major products [44]. Power engineering is a strategically important sector that ensures the functioning of the country's economy, its energy, and economic independence from other countries. Electricity generation is growing every year, as the electricity demand is constantly increasing. However, it is the power engineering industry that pollutes the environment with CO_2 emissions the most. The contradiction of high-quality energy supply for the needs of the population and the industry, on the one hand, and the environmental friendliness of energy production, on the other hand, comes to the fore. That is why Germany and some European countries have changed the development trend to more expensive, unstable, but environmentally renewable energy [45,46]. Saudi Arabia and Belarus began building nuclear power plants to reduce the share of thermoelectric power stations. Norway and countries with developed river systems have started to develop hydroelectric power plants. Each country has chosen its path according to its natural, economic, and political capabilities [47,48].

China has the highest level of CO_2 emissions. China is the world's largest emitter of carbon dioxide. Fossil fuels, especially coal-fired fuels, are China's main source of CO_2 emissions. More than 50% of China's total energy comes from coal, and because coal is rich in carbon, burning it in Chinese power plants and industrial plants and boilers releases large amounts of CO_2 into the atmosphere. In addition, China is one of the largest importers of oil, contributing to significant CO_2 emissions through the use of motor vehicles. The United States occupies second place. The US economy is heavily dependent on the oil-burning transportation sector. American consumers are particularly dependent on their cars, and this also contributes to CO_2 emissions from gasoline and diesel fuel. Another major contributor to CO_2 emissions in the United States is the fossil fuel industry. In addition, the US chemical sector uses a variety of chemical reactions required to produce goods from raw materials that emit CO_2 in the process.

2.2. GDP, Export, Import, and CO_2 Emissions

Increased economic activity and increased GDP has led to increased energy consumption and, consequently, CO_2 emissions [49]. In other words, the rapid growth of the global economy merged with human activities has become the reason for the environmental deterioration. The hypothesis of the dependence of GDP on greenhouse gas emissions was confirmed by [44]. This cited the example of Ukraine, which is among the world leaders in reducing greenhouse gas emissions compared to 1990. In the last 30 years, the greenhouse gas emissions in Ukraine have decreased significantly, which is explained by a decrease in GDP (especially typical of the period of a rapid decline until the end of the 1990s), a change in the structure of the economy (where the share of the industry decreased significantly), and an increase in energy efficiency and carbon modernization. In the works [50–53], the mathematical models of processes of ecological and economic interactions in the space of indicators of the economic structure of society, prices, and environmental pollution are developed. These models are formalized by the systems of ordinary differential equations and contain several parameters, the numerical specification of which leads to parameterization (identification) tasks.

Analyzing the relationship between a sustainable environment and economic growth in the European and Central Asian Countries between 1971 and 2016, Mohsin et al. (2022) [54] found a significant negative relationship in the long run and a positive relationship for the short run between CO_2 emissions and GDP. The data confirm the thesis that it is economic growth that deteriorates environmental sustainability. Furthermore, Daysi et al.'s (2021) [55] research showed that the impact on emissions decreased, while the GDP per capita has an increasing relationship with high-tech exports. In other words, emissions continue to increase.

A group of researchers such as Menyah and Wolde-Rufael (2010) [56], Nazirah Wahid et al. (2013) [57], Razak et al. (2013) [58], and Zhou and Li (2011) [59] emphasized measuring the impacts of economic growth on CO_2 emissions. Among them, a positive and significant relationship between CO_2 emissions and economic growth in South Africa was revealed by Menyah and Wolde-Rufael (2010) [56]. In turn, the study performed by Razak et al. (2013) [58] to investigate air pollution in Malaysia revealed that GDP and air pollution have a positive relationship, while the country's industrial manufacturing activities have an insignificant effect on CO_2 emissions. On the other hand, the research of Zubair et al. (2020) [60] in Nigeria brought about the opposite results. The impact of economic growth on carbon emissions was negative. It ensures that the higher the total performance, the economy will be subjected to the implementation of advanced technologies for efficient production. These findings are in line with the research results of Do & Dinh (2020) [61]—acc. to them, in the long run, the GDP growth per capita has a negative influence on CO_2 emissions in Vietnam. One should also add that Chinese researchers discovered that the GDP—among other factors, such as industrial infrastructure and the price of energy—had a positive influence on CO_2 emissions (Zhou & Li 2011) [59]. Another group of researchers analyzes the impact of exports and imports on CO_2 emissions. One should remember that, especially, developing countries depend on international trade and Foreign Direct Investments (FDI) to support their economies. Analyzing five North African countries from 1990 to 2014, Mahmood et al. (2020) [62] showed evidence of the negative effect of exports on CO_2 emissions. On the other hand, their spillover effects in the neighboring countries were found to be positive. In turn, the effects of imports and total trade openness were found positive on local economies, and their spillovers were negative. It was interesting that the said research did not confirm FDI to be affecting CO_2 emissions.

Al-mulali Usama & Sheau-Ting (2014) [63] conducted an analysis of trade, exports, imports, energy consumption, and CO_2 emissions in 89 countries from six different regions, including Asia Pacific, Eastern Europe, the Americas, the Middle East and North Africa, Sub-Saharan Africa, and Western Europe (in the period of 1990–2011). The results showed that all the regions, excluding Eastern Europe, showed a long run positive relationship between the trade variables and energy consumption and between the trade variables and CO_2 emissions. However, at the country level, the results revealed that the feedback long run positive relationship between the trade variables, energy consumption, and CO_2 emission takes place in most cases when the share of the trade of goods and services to the GDP is significant at the level of the countries.

Haug & Ucal (2019) [64] examined the effects of foreign trade and FDI on CO_2 emissions in Turkey. They found significant asymmetric effects of exports, imports, and FDI on CO_2 emissions per capita. In addition, they discovered that FDI have no statistically significant long-run effects (which confirms the findings of Mahmood et al. 2020) [62]. Additionally, in the long-term period, decreases in exports reduce CO_2 emissions per capita, but increases in exports have no statistically significant effects. Increases in imports raise CO_2 emissions per capita, while decreases in imports have no long run effects.

Several conclusions can be drawn from the analysis made. Firstly, there is no one universal answer regarding the impact of macro-indicators on CO_2 emissions, and the results achieved by the particular researchers vary substantially (and sometimes, they are even the opposite). One of the reasons may be the country (or region) being analyzed (developing vs. developed economies; however, it seems that the studies in the former ones prevail). This shows how complicated and complex said phenomenon is and how many factors influence it. Secondly, the researchers employ different methodologies to analyze these phenomena that also may have an impact on the findings. Thirdly, economic growth in low-income countries is associated with negative consequences. This is not necessarily the case in developed countries that can afford to implement high advanced environmentally friendly technologies. Fourthly, exports and imports (or, generally, foreign trade) have a diversified impact on CO_2 emissions.

Based on the analysis conducted, the following hypotheses were formulated:

Hypothesis 1 (H1). *There is a significant direct impact of GDP on CO_2 emissions in the United States and the Asia-Pacific region.*

Hypothesis 2 (H2). *There is a significant direct impact of exports on CO_2 emissions in the United States and the Asia-Pacific region.*

Hypothesis 3 (H3). *There is a significant direct impact of imports on CO_2 emissions in the United States and the Asia-Pacific region.*

2.3. Inflation and CO_2 Emissions

The inflation rate influences all the countries, and this impact may be negative or positive. This term may be defined as "*a rise in the price level of a good or service or market basket of goods and/or services*" [65]. It relates to the percentage increase or decrease in the price of goods or services at a certain time, mostly annually [66]. A rise in the inflation rate is associated with the rise in materials cost, where workers will also demand an increase in wages to compel the higher living cost [67]. While the matter of inflation and its impact on the countries was analyzed from different points of view, the issue becomes much more problematic when taking into account other aspects, e.g., the impact of inflation on CO_2 emissions. Few studies that have analyzed this topic. First of all, one cannot calculate the effect directly; therefore, researchers use different indirect methods to analyze it. For example, the research of Musarat et al. (2021) [68] in the Malaysian construction industry showed that the reduction in the inflation rate caused an increase in CO_2 emissions. They used an indirect assessment of the correlation coefficient between the inflation rate (independent variable) and construction rates, i.e., built material prices and the value of construction work (dependent variables). According to the researchers, the reduction of inflation stimulates economic growth, and the increase in construction work requires more materials, and when the manufacturing industry starts production, a significant amount of additional CO_2 is emitted.

Setyadharma et al. (2021) [69] analyzed the impact of inflation on air pollution in Indonesia in the period between 1981 and 2017. Their research indicates that both in the long and the short run, higher inflation is causing a lower level of air pollution. In other words, these findings show a positive impact of inflation in the country analyzed, i.e., that higher inflation can reduce air pollution. A similar view was presented by Ronaghi et al. (2019) [70], who claimed that inflation has a negative, significant relationship with CO_2 emissions. Rising inflation is accompanied by higher prices of products and services. As the result, consumer demands for goods will fall, and by decreasing production, CO_2 emissions will fall. Furthermore, the impact of climate change and COVID-19 on inflation in Indonesia was studied by Wahidah & Antriyandarti (2021) [71]. Different analyses showed that, because of the pandemic, greenhouse gas emissions decreased by at least several percent, but since countries have relaxed their lockdown policies for economic recovery, the level of CO_2 emissions has increased again. Their findings indicate that an increase in the number of COVID-19 cases will lower inflation and food inflation.

Given these deliberations, we hypothesize that:

Hypothesis 4 (H4). *There is a significant indirect impact of inflation on CO_2 emissions in the United States and the Asia-Pacific region.*

2.4. Unemployment and CO_2 Emissions

Mrabet & Jarboui (2017) [72] studied the impact of institutional factors on the efficiency of the GDP and CO_2 emissions in Gulf and Maghreb countries from the period 1995–2013. They revealed a positive effect of inputs such as labor on CO_2 emission efficiency for Arabic countries. For Maghreb countries, the capital is a determinant of the GDP efficiency. The huge investment of the Gulf countries leads to job creation and, hence, lower unemployment. Furthermore, Liu & Feng (2022) [73] examined the potential effects of unemployment on global CO_2 emissions by using the panel data of 77 countries and regions from 1991 to 2020. Their findings indicated that, at the global level, unemployment has negative effects on CO_2 emissions; however, at the regional level, it looks different. Additionally, unemployment has a positive effect on CO_2 emissions in the Middle East and a negative effect on CO_2 emissions in Africa, the Americas, Europe, and the Asia-Pacific regions. There is no evidence that unemployment has certain effects on CO_2 emissions in the Middle East and the Asia-Pacific regions.

In turn, Naqvi et al. (2022) [74] studied the impact of renewable energy production on the unemployment rate of European countries from 1991 to 2019. The results revealed that renewable energy production significantly reduced the unemployment level in European countries in the long-term period. Moreover, a positive change in renewable energy production has a negative significant impact on unemployment, and a negative change in renewable energy production has a positive significant impact on unemployment in the long run. However, Ibrahiem & Sameh (2020) [75], who analyzed the situation in Egypt, achieved other results. The results showed that clean energy resources hurt unemployment.

One should add that some researchers study the impact of the COVID-19 pandemic—which undoubtedly reduced CO_2 emissions in the world—on unemployment [76]. In general, an increase in the number of COVID-19 cases will lead companies to reduce the number of employees. As the result, one can observe many jobs terminations and, as the result, unemployment increases.

Based on this, we formulated the following hypothesis:

Hypothesis 5 (H5). *There is a significant indirect impact of unemployment on CO_2 emissions in the United States and the Asia-Pacific region.*

3. Materials and Methods

In scientific and practical economic research, there are two main types of relationships: functional (determinate) and correlation (stochastic). At a functional dependence, phenomena show dynamic regularity and harsh mechanical causality, which is expressed in the form of a mathematical equation. A relationship in which each value of the argument corresponds to several values of the function, and between the argument and the function a clear relationship cannot be established, is called correlation. It is described using econometric regression models [77], which allow quantifying the existing regularity of socioeconomic processes and phenomena [78,79]. The regression model is the one-way stochastic dependence of one random variable (dependent variable) on one or more other random variables (independent variables) [80].

To substantiate the hypotheses and analyze the impact of macroeconomic indicators on CO_2 emissions in the world, the research methodology used in our paper consists of the following main stages:

Stage 1. Selection of indicators and sampling for modeling. The authors selected the following indicators: dependent variable—the amount of CO_2 emissions into the air (CO_2_EMISSIONS)—and independent variables—gross domestic product (GDP), the volume of exports (EXPORTS), the volume of imports (IMPORTS), inflation rate (INFLATION), and unemployment rate (UNEMPLOYMENT). The sample of statistics is formed from all the available values of the annual indicators of the World Bank for the period 1970–2020 [81]. The study was conducted according to the data of the United States and the Asia-Pacific region.

Stage 2. Graphic display of indicators and analysis of their dynamics for the period 1970–2020.

Stage 3. Formation of a correlation matrix to assess the relationship between indicators.

Stage 4. Construction of a regression equation.

The general equation of the multiple regression model is as follows:

$$Y = b0 + b1x1 + b2x2 + \ldots + bnxn, \tag{1}$$

where:
Y—dependent variable;
b—parameter (coefficient) of regression;
x—factor of influence;
n—number of factors in the model.

The dependent variable Y is also called an explanatory one, an endogenous variable; independent variables Xj are explanatory, exogenous variables.

Stage 5. Estimation sof the parameters of econometric models using the method of least squares. Checks the quality of constructed econometric models using the coefficient of determination and Fisher's criterion. Conclusions.

Given these considerations, the study aims to econometrically model the impact of key macroeconomic indicators (GDP, exports and imports volumes, the rate of inflation, and unemployment) on the CO_2 emission volume in the air in the United States and the Asian Pacific as the regions with the highest CO_2 emissions in 1970–2020.

4. Results

4.1. The Impact of Macroeconomic Indicators on CO_2 Emissions in the United States

The United States is one of the most environmentally destabilized areas. That is why it was decided to conduct an econometric study of the impact of US macroeconomic indicators on the level of CO_2 emissions in the air to confirm or refute the hypotheses.

According to the statistical data (Figure 1), a positive point can be identified for the United States: CO_2 emissions have been declining since 2009; GDP, the volume of exports and imports, tended to increase throughout the study period, and the rate of inflation and unemployment fluctuated significantly.

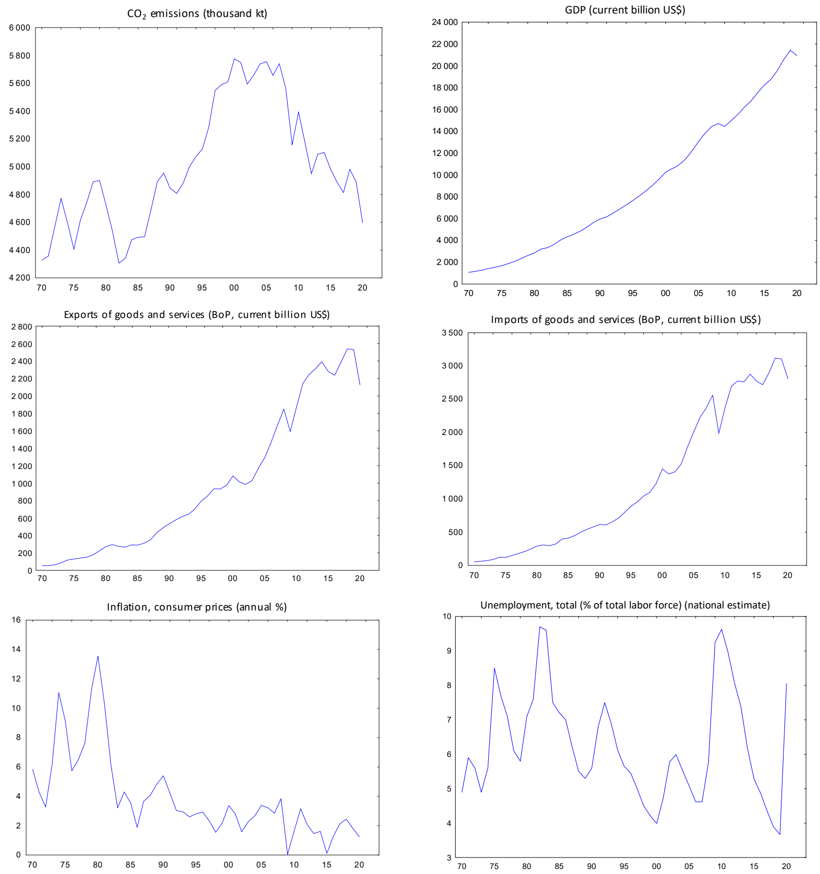

Figure 1. Graphical representation of the dynamics of changes in CO_2 emissions and US macroeconomic indicators. Made by the authors based on [81].

The authors formed a correlation matrix to assess the relationship between CO_2 emissions and the values of US macroeconomic indicators (Table 1).

Table 1. Correlation matrix for the USA.

	CO_2 Emissions (kt)	**Exports of Goods and Services (BoP, Current USD)**	**Imports of Goods and Services (BoP, Current USD)**	**Inflation, Consumer Prices (Annual %)**	**Unemployment, Total (% of total Labor Force) (National Estimate)**	**GDP (Current USD)**
CO_2 emissions (kt)	1.000000	0.427974	0.483338	−0.406354	−0.431853	0.481560
Exports of goods and services (BoP, current USD)	0.427974	1.000000	0.992203	−0.612493	−0.151669	0.984062
Imports of goods and services (BoP, current USD)	0.483338	0.992203	1.000000	−0.615909	−0.168782	0.988240
Inflation, consumer prices (annual %)	−0.406354	−0.612493	−0.615909	1.000000	0.115266	−0.658768
Unemployment, total (% of total labor force) (national estimate)	−0.431853	−0.151669	−0.168782	0.115266	1.000000	−0.192127
GDP (current USD)	0.481560	0.984062	0.988240	−0.658768	−0.192127	1.000000

The matrix graph of the correlations between indicators is given in Figure 2.

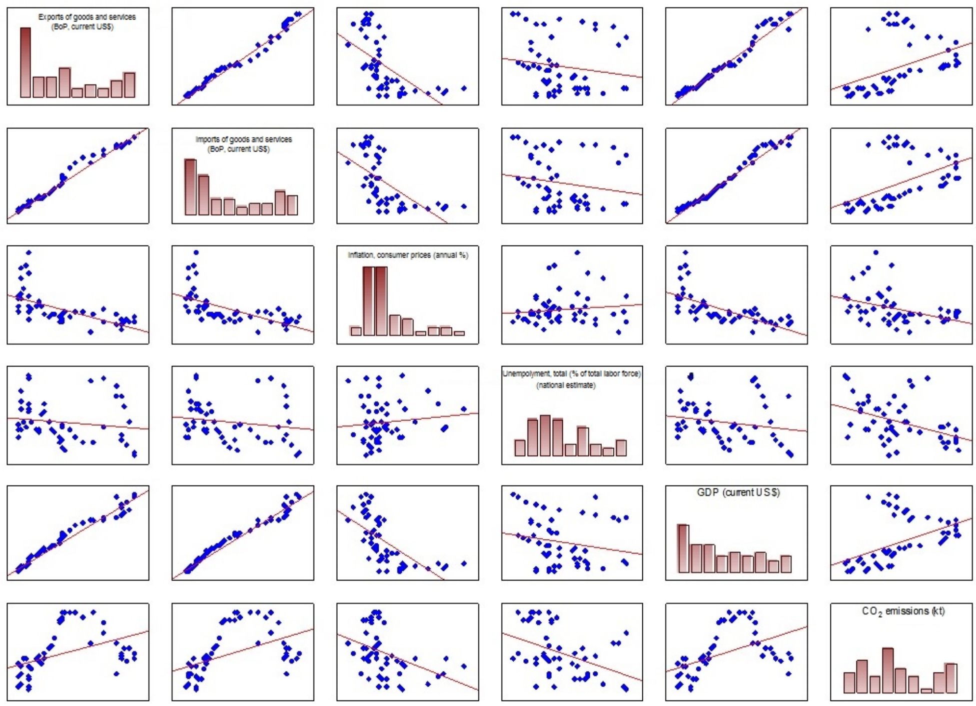

Figure 2. Matrix graph of the correlations between indicators.

The formation of a correlation matrix allowed obtaining the following results:

1. The correlation between CO_2 emission volumes and the exports volume is 0.427974.
2. The correlation between CO_2 emission volumes and GDP is 0.481560.
3. The correlation between CO_2 emission volumes and the imports volume is 0.483338.
4. The correlation between CO_2 emission volumes and the inflation rate is −0.406354.
5. The correlation between CO_2 emission volumes and the unemployment rate is −0.431853.

Analyzing the obtained values, one can conclude that the correlation coefficient is similar for all the independent variables. Its value is average, which indicates that there is a relationship between the indicators for the GDP; the volume of exports and imports—direct (with an increase in one determinant, CO_2 emissions increase, and vice versa); and for the rate of inflation and unemployment—indirect (with an increase in determinants, CO_2 emissions decrease, and vice versa).

However, there is a significant correlation between the independent variables, which is why when forming the regression equation, it was decided not to take into account the GDP to avoid the problem of multicollinearity. A regression equation is presented in Table 2.

Table 2. Parameters of the regression equation of the dependence of CO_2 emissions on macroeconomic indicators in the United States.

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample: 1970–2020 Included Observations: 51				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Exports of goods and services (BoP, current USD)	-1.70×10^{-6}	4.53×10^{-7}	−3.64576	0.000677
Imports of goods and services (BoP, current USD)	1.42×10^{-6}	3.58×10^{-7}	3.98296	0.00024
Inflation, consumer prices (annual %)	−27,190.6	20,075.87	−1.35439	0.182227
Unemployment, total (% of total labor force) (national estimate)	−87,566.8	29,676.71	−2.95069	0.004974
C	5,507,272	238,311.1	23.11	0

Table 2. *Cont.*

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample: 1970–2020 Included Observations: 51				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Multiple R	0.719077			
R-squared	0.517072			
Adjusted R-squared	0.475079			
S.E. of regression	323,724.6			
F-statistic	12.3131			
Prob(F-statistic)	0.000001			

Using the STATISTICA program, a multiple regression equation was formed, where the dependent variable was the volume of CO_2 emissions in the air and the independent variables included the volumes of exports and imports, the rate of inflation, and unemployment.

The following empirical multiple regression equation was obtained:

$$CO_2\_EMISSIONS = 5{,}507{,}271.9816 - 1.7 \times 10^{-6} \times EXPORTS + 1.42 \times 10^{-6} \times IMPORTS - 27{,}190.6 \times INFLATION - 87{,}566.8 \times UNEMPLOYMENT$$

Let the authors check the quality of this econometric model using the coefficient of determination and Fisher's criterion.

The coefficient of determination $R^2 = 0.52$ indicated that 52% of the value of the resulting feature (CO_2 emission) was defined by the values of explanatory variables (the volumes of exports and imports, the rate of inflation and unemployment), and 48% was determined by the other indicators. Given a large number of factors that affect the volume of CO_2 emissions, the result was considered quite significant.

The estimated value of Fisher's criterion $F_{estimated} = 12.31310$. The corresponding tabular value $F_{tabular} = 2.53$ for the confidence probability $P = (1 - 0.05) = 0.95$. Since the estimated value of Fisher's criterion exceeded the tabular one, the model was adequate.

While analyzing the regression equation, one can draw the following conclusions:

1. If all the independent variables equal zero, US CO_2 emissions will be 5,507,271.9816 kt.
2. If the volume of exports increases by USD 1, CO_2 emissions will decrease by 1.7×10^{-6} kt.
3. If the volume of imports increases by USD 1, CO_2 emissions will increase by 1.42×10^{-6} kt.
4. If the inflation rate increases by 1%, CO_2 emissions will decrease by 27,190.6 kt. However, as it can be seen from the regression equation, this figure is insignificant (Prob. > 0.05).
5. If the unemployment rate increases by 1%, CO_2 emissions will decrease by 87,566.8 kt.

After analyzing the first regression equation, the second regression equation was developed, in which the dependent variable was the volume of CO_2 emissions in the air, and the independent one was the US GDP (Table 3). The purpose of such a correlation and regression analysis is to verify the impact of the economic indicator of GDP on CO_2 emissions. The GDP indicator was excluded when forming the first regression equation, which allowed checking the impact on CO_2 emissions.

Table 3. Parameters of the regression equation of the dependence of CO_2 emissions on the GDP in the United States.

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample: 1970–2020 Included Observations: 51				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDP (current USD)	3.44×10^{-8}	8.95×10^{-9}	3.846273	0.000347
C	4,690,573	98,091.21	47.81848	0

Table 3. *Cont.*

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample: 1970–2020 Included Observations: 51				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Pearson's r	0.48156			
R-squared	0.2319			
Adjusted R-squared	0.216225			
S.E. of regression	395,570.9			
F-statistic	14.79382			
Prob(F-statistic)	0.000347			

The relationship between the studied indicators had a direct and medium density, as the correlation coefficient r = 0.48156. The coefficient of determination R^2 = 0.23 indicated that 23% of the value of the resulting feature (CO_2 emission) was defined by the values of the explanatory variable (GDP), and 77% was determined by the other indicators. The low value of R-squared indicated the low accuracy of the selection of indicators to build the model.

The estimated value of Fisher's criterion $F_{estimated}$ = 14.79382. The corresponding tabular value $F_{tabular}$ = 4.03 for the confidence probability P = (1 − 0.05) = 0.95. Since the estimated value of Fisher's criterion exceeded the tabular one, the model was adequate. According to the built model, if the GDP increased by USD 1, CO_2 emissions will increase by 3.44×10^{-8} kt.

To increase the accuracy of the model, the relationship between CO_2 emissions and GDP was constructed in the form of a nonlinear regression equation—the third degree polynomial spline, for which the coefficient of determination R^2 = 0.72 (Figure 3). The regression equation was obtained:

$$CO_2\_EMISSIONS = 4.2881 \times 10^6 + 1.0864 \times 10^{-7} \times GDP + 4.2468 \times 10^{-21} \times GDP^2 - 4.1365 \times 10^{-34} \times GDP^3$$

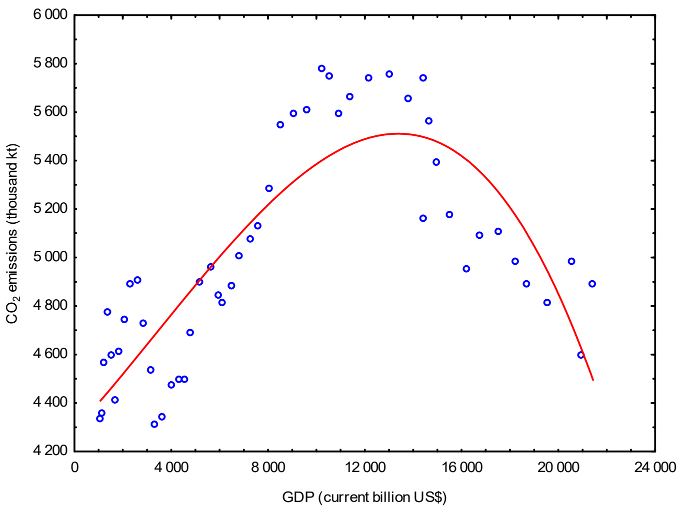

Figure 3. Graphic representation of the dependence of CO_2 on the GDP.

4.2. The Impact of Macroeconomic Indicators on CO_2 Emissions in the Asia-Pacific Region (APAC)

Another region with an ecologically destabilized zone is the Asia-Pacific region. Similarly, an econometric study of the impact of macroeconomic indicators of the Asia-Pacific region on CO_2 emissions into the air was conducted.

Having analyzed the dynamics of changes in the indicators (Figure 4), the authors could conclude that, unlike the USA, CO_2 emissions in the Asia-Pacific region have begun to increase, which suggests that all economic, environmental, and social processes occurring within the Asia-Pacific region have an indirect impact on the environmental indicator—CO_2 emissions in the air. The GDP and the volumes of the exports and imports tended to increase throughout the study period, and the inflation rate was characterized by fluctuations with a marked downward trend. The unemployment rate after a significant increase changed the direction of movement ever since 2006 in a declining direction.

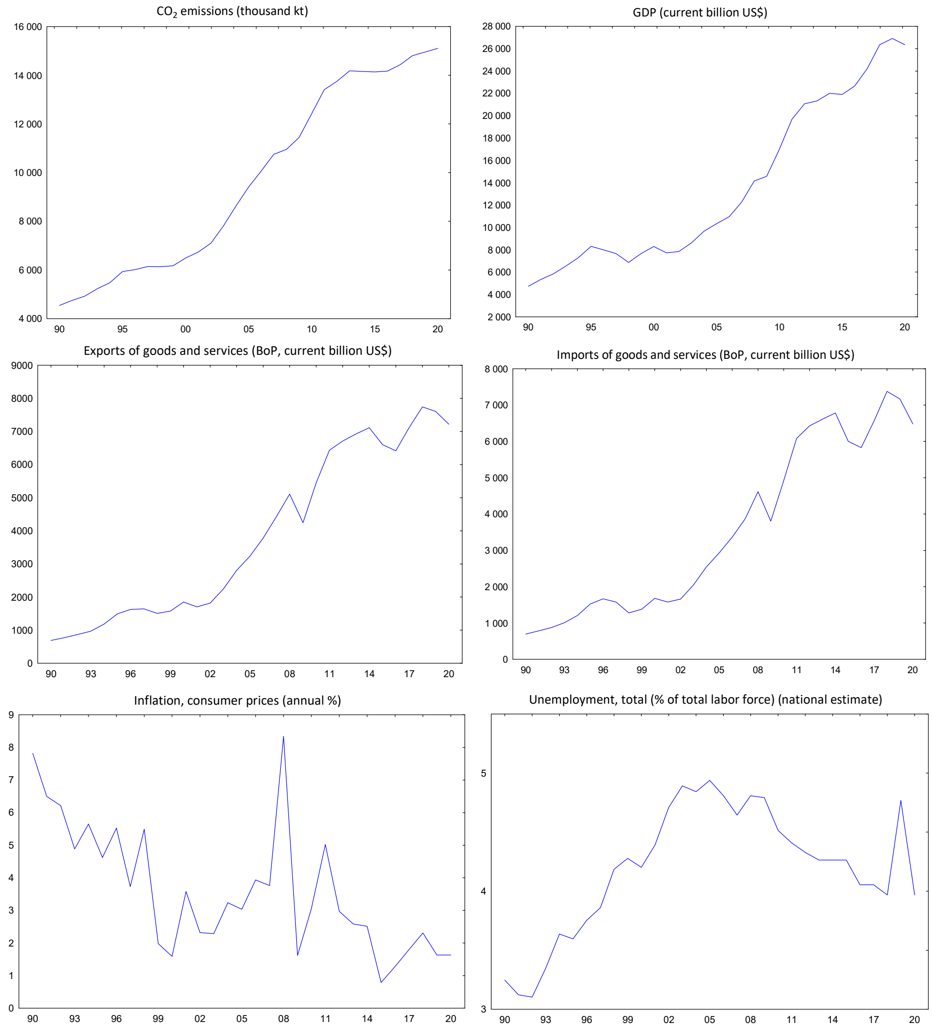

Figure 4. Graphical representation of the dynamics of the changes in CO_2 emissions and macroeconomic indicators of the Asia-Pacific region. Made by the authors based on [81].

Then, we formed a correlation matrix to assess the existence of relationships between the volume of CO_2 emissions and the values of the macroeconomic indicators of the Asia-Pacific region (Table 4).

Table 4. Correlation matrix for the APAC.

	CO_2 Emissions (kt)	**Exports of Goods and Services (BoP, Current USD)**	**Imports of Goods and Services (BoP, Current USD)**	**Inflation, Consumer Prices (Annual %)**	**Unemployment, Total (% of Total Labor Force) (National Estimate)**	**GDP (Current USD)**
CO_2 emissions (kt)	1.000000	0.993555	0.988110	−0.565898	0.441368	0.970408
Exports of goods and services (BoP, current USD)	0.993555	1.000000	0.998500	−0.514987	0.384849	0.980044

Table 4. *Cont.*

	CO_2 Emissions (kt)	Exports of Goods and Services (BoP, Current USD)	Imports of Goods and Services (BoP, Current USD)	Inflation, Consumer Prices (Annual %)	Unemployment, Total (% of Total Labor Force) (National Estimate)	GDP (Current USD)
Imports of goods and services (BoP, current USD)	0.988110	0.998500	1.000000	−0.503368	0.360731	0.981295
Inflation, consumer prices (annual %)	−0.565898	−0.514987	−0.503368	1.000000	−0.448818	−0.559441
Unemployment, total (% of total labor force) (national estimate)	0.441368	0.384849	0.360731	−0.448818	1.000000	0.274526
GDP (current USD)	0.970408	0.980044	0.981295	−0.559441	0.274526	1.000000

The matrix graph of correlations between indicators is given in Figure 5.

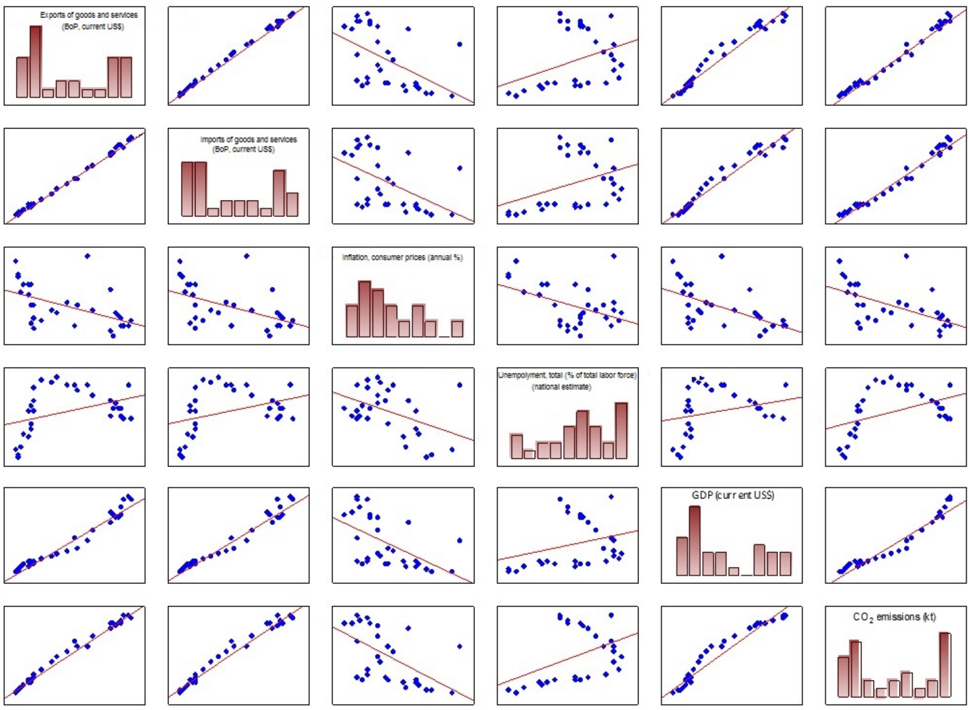

Figure 5. Matrix graph of correlations between indicators.

The formation of a correlation matrix allowed obtaining the following results:

1. The correlation between CO_2 emission volumes and the volume of exports equals 0.993555.
2. The correlation between CO_2 emission volumes and GDP equals 0.970408.
3. The correlation between CO_2 emission volumes and the volume of exports imports equals 0.988110.
4. The correlation between CO_2 emission volumes and the rate of inflation is −0.565898.
5. The correlation between CO_2 emission volumes and the unemployment rate is 0.441368.

Analyzing all the obtained values, one can conclude that the correlation coefficient between the volume of exports (imports and GDP) and CO_2 emissions in the air is the highest compared to the USA. The value of the correlation coefficient is significant, which indicates that there is a strong direct relationship between the indicators (for GDP, the volume of exports and imports, the unemployment rate is direct (with an increase in one determinant, CO_2 emissions increase, and vice versa), and for the inflation rate, it is indirect (with an increase in the inflation rate, CO_2 emissions decrease, and vice versa).

However, there is a significant correlation between independent variables, which is why when forming a regression equation, it was decided not to take into account the GDP to avoid the problem of multicollinearity.

Let the authors form a regression equation (Table 5).

Table 5. Parameters of the regression equation of the dependence of CO_2 emissions on macroeconomic indicators in the Asia-Pacific region.

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample (Adjusted): 1990–2020 Included Observations: 31				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Exports of goods and services (BoP, current USD)	2.81×10^{-6}	4.31×10^{-7}	6.51957	6.53×10^{-7}
Imports of goods and services (BoP, current USD)	-1.50×10^{-6}	4.58×10^{-7}	−3.21664	0.003457
Inflation, consumer prices (annual %)	−98,154.3	32,696.88	−3.00195	0.005858
Unemployment, total (% of total labor force) (national estimate)	208,544.1	121,696.8	1.713636	0.098496
C	3,968,322.2	852,329.3	4.6559	0.0001
Multiple R	0.9976096			
R-squared	0.9952249			
Adjusted R-squared	0.9942699			
S.E. of regression	288,708.5			
F-statistic	1042.096			
Prob(F-statistic)	0			

Using the STATISTICA program, a multiple regression equation was formed, where the dependent variable is the volume of CO_2 emissions in the air, and the independent variables include the volumes of exports and imports, the rate of inflation, and unemployment.

The following empirical multiple regression equation is obtained:

$$CO_2\_EMISSIONS = 3{,}968{,}322.1983 + 2.81 \times 10^{-6} \times EXPORTS - 1.5 \times 10^{-6} \times IMPORTS - 98{,}154.3 \times INFLATION + 208{,}544.1 \times UNEMPLOYMENT$$

Let the authors check the quality of this econometric model using the coefficient of determination and Fisher's criterion.

The coefficient of determination $R^2 = 0.99$ indicates that 99% of the value of the resulting feature (CO_2 emissions) is defined by the values of the explanatory variables (the volume of exports and imports, the rate of inflation, and unemployment), and 1% is determined by the other indicators. This is the highest figure among all the regions. Thus, the authors can conclude that the macroeconomic indicators of the Asia-Pacific region have the greatest impact on the CO_2 emissions.

The estimated value of the Fisher's criterion $F_{estimated} = 1042.096$. The corresponding tabular value $F_{tabular} = 2.74$ for the confidence probability $P = (1 - 0.05) = 0.95$. Since the estimated value of the Fisher's criterion exceeds the tabular one, the model is adequate.

Analyzing the regression equation, one can draw the following conclusions:

1. If all independent variables equal zero, the CO_2 emissions in the Asia-Pacific region will be 3,968,322.1983 kt.
2. If the volume of exports increases by USD 1, the CO_2 emissions will increase by 2.81×10^{-6} kt.
3. If the volume of imports increases by USD 1, the CO_2 emissions will decrease by 1.5×10^{-6} kt.
4. If the inflation rate increases by 1%, the CO_2 emissions will decrease by 98,154.3 kt.
5. If the unemployment rate increases by 1%, the CO_2 emissions will increase by 208,544.1 kt. However, as it can be seen from the regression equation, this figure is insignificant (Prob. > 0.05).

After analyzing the first regression equation, the second regression equation was developed, in which the dependent variable is the volume of CO_2 emissions in the air, and the independent one is the GDP of the Asia-Pacific region (Table 6). The purpose of such a correlation and regression analysis was to verify the impact of the economic indicator of the GDP on CO_2 emissions. The GDP indicator was excluded when forming the first regression equation, which allowed checking the impact on CO_2 emissions.

Table 6. Parameters of the regression equation of the dependence of CO_2 emissions on the GDP in the Asia-Pacific region.

Dependent Variable: CO_2 Emissions (kt) Method: Least Squares Sample: 1970–2020 Included Observations: 51				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDP (current USD)	5.24×10^{-7}	1.30×10^{-8}	40.27305	0
C	2,453,665	157,671.2	15.56191	0
Pearson's r	0.985228			
R-squared	0.970675			
Adjusted R-squared	0.970076			
S.E. of regression	751,972.9			
F-statistic	1621.918			
Prob(F-statistic)	0			

The relationship between the studied indicators has a direct and significant density, as the correlation coefficient r = 0.985228. The coefficient of determination $R^2 = 0.97$ indicates that 97% of the value of the resulting feature (CO_2 emission) is defined by the values of explanatory variable (GDP), and 3% is determined by the other indicators. The value of R-squared indicates the significant accuracy of the selection of indicators to build the model.

The estimated value of Fisher's criterion $F_{estimated} = 1621.918$. The corresponding tabular value $F_{tabular} = 4.03$ for the confidence probability $P = (1 - 0.05) = 0.95$. Since the estimated value of Fisher's criterion exceeds the tabular one, the model is adequate. According to the built model, if the GDP increases by USD 1, the CO_2 emissions will increase by 5.24×10^{-7} kt (Figure 6).

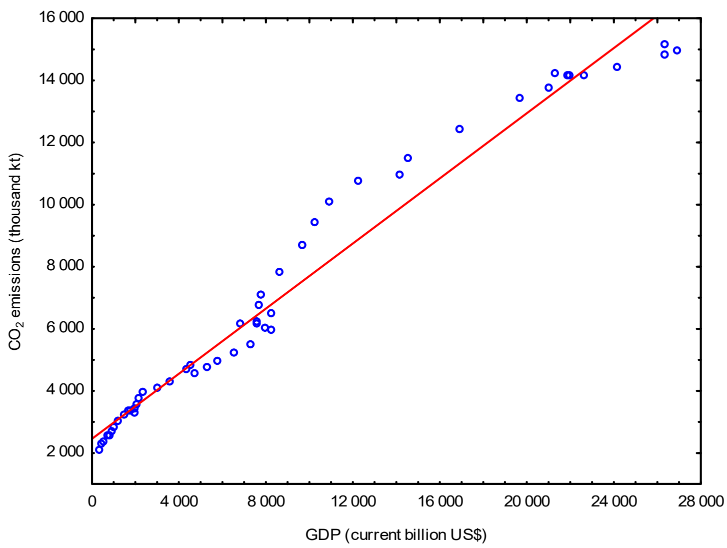

Figure 6. Graphic representation of the dependence of CO_2 on the GDP.

The Asia-Pacific region, like the United States, faces a challenge: whether to reduce its trade balance and GDP to reduce CO_2 emissions or to improve economic performance, thereby increasing CO_2 emissions.

5. Discussion

Based on the results of the study, we can conclude that:

H1. The hypothesis is confirmed. There is a significant direct impact of GDP on CO_2 emissions in the United States and the Asia-Pacific region.

H2. The hypothesis is partially confirmed. There is a significant direct impact of exports on CO_2 emissions in the Asia-Pacific region and a medium direct impact in the United States.

H3. The hypothesis is partially confirmed. There is a significant direct impact of imports on CO_2 emissions in the Asia-Pacific region and a medium direct impact in the United States.

H4. The hypothesis is partially confirmed. There is a medium indirect impact of inflation on CO_2 emissions in the United States and the Asia-Pacific region.

H5. The hypothesis is confirmed only for the United States. There is a significant indirect impact of unemployment on CO_2 emissions in the United States and a significant direct impact in the Asia-Pacific region.

Besides the factors mentioned in our study, the CO_2 emissions are also affected by other economic, social, and environmental parameters that are difficult to measure. For example, the level of CO_2 emissions in the electricity sector is likely to be affected by some factors, including the electricity generation portfolio, relative fossil fuel prices, federal and/or state policy development, economic impact, and energy efficiency on demand [82–84]. One can add that the development of US domestic policy is of interest to current and projected levels of CO_2 emissions. In December 2015, delegations from 195 countries, including the United States, adopted in Paris an agreement establishing an international framework for countries committed to reducing greenhouse gas emissions; adapting to climate change; and working together to achieve these goals, including financial, economic, and other. Under the agreement, the United States has promised (in 2015) to reduce greenhouse gas emissions by 26–28% by 2025 compared to its 2005 levels [82]. However, the relationship between macroeconomic indicators and CO_2 emissions in the United States and the Asia-Pacific region poses a dilemma for governments and businesses, as well as other economies, to reduce trade and the GDP to reduce CO_2 emissions or improve macroeconomic performance, thereby increasing CO_2 emissions? The answer to this question is complex and difficult.

The results of the research [85–87] confirm the positive correlation between CO_2 emissions and economic parameters—in particular, the GDP per capita. These works are in line with our study. A positive ratio indicates an increase in CO_2 emissions as a result of economic growth. The theoretical concept that most likely explains the increase in CO_2 emissions is the effect of the scale. The theory underlying the effect of scale is based on the assumption that increased production leads to increased pollution and damage to the environment. The effect of the scale is included in other theories and considered by scientists to explain the interdependence of CO_2 emissions and the level of macroeconomic development of the state—in particular, the Kuznets Ecological Curve, the Brundtland Curve, and the Daily Curve.

Understanding the sources of CO_2 emissions and the main factors influencing the level of emissions can help in the discussion among politicians on reducing CO_2 emissions. The question for politicians is whether US greenhouse gas emissions will remain at current levels, be reduced to meet the 2025 targets, or increased to previous (or even higher) levels. Many of the factors analyzed, including the economy, exports and imports, technology, and climate policy, are likely to play a role in future levels of CO_2 emissions. To make informed decisions about how best to limit future CO_2 emissions, policymakers and the public need high-quality data on [88]:

- which sectors of the economy are responsible for CO_2 production;
- how macroeconomic indicators change over time;
- in which economic sectors there is the greatest change in CO_2 in terms of their production;

- how changes in production in one sector of the economy affect emissions not only in this sector but also (through the purchase of raw materials) in other sectors.

The US and Asia-Pacific governments must pursue environmental policies and take international measures to reduce environmental degradation. An effective environmental policy can be achieved by increasing the energy efficiency through the use of less carbon fuel, especially with the use of renewable energy sources. The use of renewable energy sources in all sectors of the economy leads to a reduction in other energy sources, especially fossil fuels. This has a significant impact on reducing CO_2 emissions. Countries need to have a model of economic growth that promotes prosperity while ensuring sustainable development.

6. Conclusions and Policy Implications

As it can be seen, the results of the analysis of correlation dependence in different regions differ. For the United States, the correlation coefficients are similar for all the independent variables and indicate that there is an average relationship between the indicators. For the Asia-Pacific region, the correlation coefficients between the volumes of exports (imports and GDP) and CO_2 emissions are the highest compared to the USA, indicating a strong relationship between the indicators for this region.

According to the study results, the authors can draw the following conclusions: with a decrease in the GDP of the USA and the Asia-Pacific region, CO_2 emissions will also decrease; if the GDP of the USA and the Asia-Pacific region increases, so will the CO_2 emissions.

The construction of correlation matrices allowed obtaining the following results:

1. The correlation between CO_2 emission volume and exports volume is medium and direct for the United States, whereas it is significant and direct for the Asia-Pacific region.
2. The correlation between CO_2 emission volume and GDP for the United States and the Asia-Pacific region is significant and direct.
3. The correlation between CO_2 emission volume and imports volume is medium and direct for the United States, whereas it is significant and direct for the Asia-Pacific region.
4. The correlation between CO_2 emission volume and the inflation rate for the US and the Asia-Pacific region is medium and indirect.
5. The correlation between the CO_2 emission volume and the unemployment rate is significant and indirect for the United States, whereas it is significant and direct for the Asia-Pacific region.

The environmental strategy of the analyzed regions should be aimed at limiting global warming by regulating measures to reduce CO_2 emissions. The strategy to reduce CO_2 emissions should be the widespread introduction of environmentally friendly, energy-efficient, energy-saving, and low-carbon technologies, including the improvement of the efficiency of coal energy use [89], increasing the level of technical support [90], and the production of renewable energy [91]. Key measures and policies aimed at preventing climate change include energy saving, energy efficiency, renewable energy, the schemes of emission quota trading [92], carbon emission taxes [93], establishing emission limits, etc. A further innovation is needed, which has a direct impact on initiatives to reduce greenhouse gas emissions in oil-importing countries—in particular, the EU, China, and the US have managed to significantly minimize emissions through innovation [94]. Given that the level of CO_2 emissions depends on the country's economic development, governments must develop a combination of interdependent economic and climate goals that will ensure environmental security [95], economic stability [96], and compliance with the Paris Agreement and will not restrict other sustainable development goals [97].

There are several policy implications in our study. First of all, the practical significance of the problem lies in the diagnosis, monitoring, forecasting, and identification of mechanisms to reduce harmful CO_2 emissions into the air. This is of key importance. Built multifactor regression models in the practice of national governments make it possible to optimize, control, and forecast their macroeconomic performances to reduce or maintain an allowable amount of CO_2 emissions. Secondly, identifying and assessing economic losses from environmental pollution by CO_2 emissions using econometric models will allow governments to ensure effective public environmental and economic policies. Thirdly, it gives useful instruments not only for the representatives of governments but also the local authorities, who, in many cases, are the first line of a fight with harmful CO_2 emissions in the atmosphere and climate change in general. Therefore, such solutions should be regarded as extremely important.

As a limitation, it should be noted that the proposed regression models of the dependence of the CO_2 emissions on macroeconomic indicators are built without taking into account many variables that can also have a significant impact, including those that characterize the social, environmental, and technological components of the problem.

The next stage of the research is to study the scenarios for the use of economic levers in the United States and the Asia-Pacific region that will regulate the changes in CO_2 emissions in the direction of reduction and, at the same time, ensure the economic development of the regions.

Author Contributions: Conceptualization, N.S. and S.O.; methodology, I.K.; software, Y.F.; validation, S.O., W.S. and Y.F.; formal analysis, S.O.; investigation, I.K.; resources, I.K.; data curation, S.O.; writing—original draft preparation, I.K.; writing—review and editing, W.S.; visualization, Y.F.; supervision, N.S.; project administration, N.S.; funding acquisition and final editing, R.G.; and final editing, J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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