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Master thesis

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Analyzing the Impact of Czech Economic Development on Carbon Emissions: VAR Model Approach

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Abstract

The Czech Republic has experienced steady and continuous economic growth since acceded to the European Union. However, at the same time, the increasingly frequent global geological disasters are a constant reminder that the Earth's environment seems to be undergoing even more severe damage. Behind industrial development, technological progress and improving people's lives are increasing carbon emissions. The Czech Republic's carbon emissions are among the highest in Central and Eastern European countries, and the substantial carbon emissions bring serious consequences. The Czech Republic has gradually recognised the seriousness of this problem. It has started introducing a series of relevant policies, laws, and regulations to change the economic growth model, hoping to reduce carbon emissions and improve the natural environment. Based on this, this paper studies the impact of economic growth on carbon dioxide. This paper first selects GDP per capita, industrial structure, and foreign trade dependence as the indicators of economic growth. Then it discusses the theoretical basis and influence mechanism of the impact of economic growth indicators on carbon emissions. By collating the relevant data on economic growth and carbon emissions in the Czech Republic from 1990-2019, the relationship between the two is visually represented by actual data. Afterwards, empirical evidence is used to prove the obtained conclusions further. The article constructs a VAR model to analyse the impact of various factors on carbon emissions from multiple angles. It puts forward relevant suggestions based on the empirical results. The empirical results show that the relationship between GDP per capita and carbon emissions is in line with the environmental Kuznets theory, and the inhibition effect of industrial structure on carbon emissions is noticeable. Overall, economic growth suppresses carbon dioxide emissions.

Based on the conclusion of this study, this paper puts forward some practical suggestions to reduce carbon emissions, such as vigorously developing the service industry and high-tech industry to improve the energy-consuming industry and making trade structural adjustments to encourage the import of resource-intensive products to reduce the production of carbon-intensive products in the country, and so on. The paper also discusses the innovations and limitations.

Abstrakt

Od vstupu do Evropské unie zaznamenává Česká republika stabilní a nepřetržitý hospodářský růst. Současně však stále častější globální geologické katastrofy neustále připomínají, že životní prostředí na Zemi je zřejmě stále vážněji poškozováno. Za průmyslovým rozvojem, technologickým pokrokem a zlepšováním života lidí stojí rostoucí emise uhlíku. Emise uhlíku v České republice patří k nejvyšším v zemích střední a východní Evropy a značné emise uhlíku přinášejí vážné důsledky. Česká republika si postupně uvědomuje závažnost tohoto problému. Začala zavádět řadu příslušných politik, zákonů a nařízení, aby změnila model hospodářského růstu, a doufá, že se jí podaří snížit emise uhlíku a zlepšit přírodní prostředí. Na základě toho se tento článek zabývá vlivem hospodářského růstu na emise oxidu uhličitého.

Tento článek si jako ukazatele hospodářského růstu nejprve vybírá HDP na obyvatele, průmyslovou strukturu a závislost na zahraničním obchodu. Poté se zabývá teoretickým základem a mechanismem vlivu ukazatelů hospodářského růstu na emise uhlíku. Na základě srovnání relevantních údajů o hospodářském růstu a emisích uhlíku v České republice v letech 1990-2019 je vztah mezi nimi vizuálně znázorněn pomocí aktuálních dat. Následně jsou využity empirické důkazy, které získané závěry dále dokládají. V článku je zkonstruován VAR model, který analyzuje vliv různých faktorů na emise uhlíku z více hledisek. Na základě empirických výsledků předkládá relevantní návrhy. Empirické výsledky ukazují, že vztah mezi HDP na obyvatele a emisemi uhlíku je v souladu s Kuznetsovou teorií životního prostředí a že je patrný brzdný účinek průmyslové struktury na emise uhlíku. Celkově lze říci, že hospodářský růst potlačuje emise oxidu uhličitého. Tento článek si jako ukazatele hospodářského růstu nejprve vybírá HDP na obyvatele, průmyslovou strukturu a závislost na zahraničním obchodu. Poté se zabývá teoretickým základem a mechanismem vlivu ukazatelů hospodářského růstu na emise uhlíku. Na základě srovnání relevantních údajů o hospodářském růstu a

emisích uhlíku v České republice v letech 1990-2019 je vztah mezi nimi vizuálně znázorněn pomocí aktuálních dat. Následně jsou využity empirické důkazy, které získané závěry dále dokládají. V článku je zkonstruován VAR model, který analyzuje vliv různých faktorů na emise uhlíku z více hledisek. Na základě empirických výsledků předkládá relevantní návrhy. Empirické výsledky ukazují, že vztah mezi HDP na obyvatele a emisemi uhlíku je v souladu s Kuznetsovou teorií životního prostředí a že je patrný brzdný účinek průmyslové struktury na emise uhlíku. Celkově lze říci, že hospodářský růst potlačuje emise oxidu uhličitého.
Na základě závěrů této studie předkládá tento článek několik praktických návrhů na snížení emisí uhlíku, jako je energický rozvoj průmyslu služeb a průmyslu špičkových technologií s cílem zlepšit energeticky náročný průmysl a provést strukturální úpravy obchodu s cílem podpořit dovoz výrobků náročných na zdroje, aby se snížila výroba výrobků náročných na emise uhlíku v zemi atd. Článek se rovněž zabývá inovacemi a omezeními.

Keywords

Carbon emissions, economic growth, VAR modelling, Czech Republic

Range of thesis: [20500 symbols, 67 pages]

Declaration of Authorship

1. The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

2. The author hereby declares that all the sources and literature used have been properly cited.

3. The author hereby declares that the thesis has not been used to obtain a different or the same degree.

Prague 1.8.2023

Xueyan Shi

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1.Introduction

1.1. Research Background

With the progress of economy and society, the global level of industrialisation has increased rapidly. Energy has become an essential driving force for drive economic and social progress. Also it is the material guarantee for the continuous progress of human society, which has an essential position in the whole national economy. The Industrial Revolution in the 18th century was the prelude to the rapid development of the human society, and it also opened a chapter in which human activities promote climate warming. Fossil energy's unchecked extraction and usage have sparked a dramatic rise in carbon dioxide emissions, gravely harming the natural environment and the carbon emissions brought on by energy exploitation. Additionally, consumerism is now the primary man-made factor contributing to global warming, which poses a severe danger to the realisation of humanity's sustainable development agenda. Climate warming has become the most important environmental problems in human society.

During the human social productivity rapid improvement, the energy source consumption has increased sharply, causing environmental problems such as ecological damage and frequent extreme weather. According to the fifth report of the United Nations Intergovernmental Panel on Climate Change (IPCC) [1], human activities, mainly come from burning fossil fuels, are 'very likely' to be the main section cause of global warming since 1950. Assume that we continue to promote economic growth through 'High-energy consumption and High-energy emissions'. In such event, it would unavoidably hasten the process of global warming, which will result in more irreparable harm to the environment in which people live and the collapse of human civilization. Therefore, there is an imperative need to reform the existing economic growth paradigm and find a development balance between economic growth and CO2-emissions.

The human society and economic rapid development has brought a series of crises to the ecological environment while liberating and developing productive forces. As people gradually realize that besides economic development, protecting the earth on which we

1 Korea.(2018).IPCC. Special Report on Global Warming of 1.5°C[R].

live is the top priority, the concept of a 'Low Carbon Economy' came into being. It is a new economic development model that focuses primarily on reducing high-carbon energy consumption in production and existence through technological innovation, industrial transformation, and new energy development in order to reduce carbon dioxide emissions. The optimized industrial structure completed under this economic model encourages the innovation of environmentally friendly technologies, thereby stimulating employment to form a virtuous circle conducive to the sustainable development of man and nature.

Although the low-carbon economy has been frequently mentioned in past few years. The energy consumption structure in nowadays human society is still led by traditional fossil energy, such as coal resource, oil resource, and natural gas resource. In 1898, Swedish scientists first proposed that carbon dioxide produced by burning coal and oil may cause global warming. However, it was in the 1970s that the issue of the climate change around the global world received all human’s attention from the international community. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations. It continually provides governments with suggestions and measures to combat climate change. It compiles and investigates information regarding global climate change.

In 1990, the 2nd World Climate Conference was held by WMO, which called for forming an international framework convention on climate change to promote the international community's response on this issue. The 1992 'Framework Convention on Climate Change' clearly stipulates that developed countries have the responsibility to reduce emissions and provide developing countries with the technical and financial help needed to promote low-carbon economic transformation. And established the 'common but differentiated responsibilities principle'. In 1997, *the Kyoto Protocol* stated that to avoid the main effects from the global climate change to human society, the content of greenhouse gases in the atmosphere should be stabilized at an appropriate level.

In 2009, the Copenhagen Climate Conference was held. Although the convening of this meeting did not agree on how to control greenhouse gas emissions. However, it has promoted the global transition to a 'Low Carbon Economy' in the future. The Paris Agreement was obtained in 2015, and the Paris Climate Conference made plans for the global response to climate change after 2020.

Due to the energy consumption increase of traditional fossil energy, the total global carbon emissions are still showing a gradual upward trend. According to *BP World Energy statistics*, from 1965 to 2020, global carbon emissions increased from 11.2 billion tons to 32.3 billion tons. According to a report released by *McKinsey & Company* in January 2022[2], between 2021 and 2050, the global capital expenditure required to achieve climate neutrality (Climate-Neutral) and net-zero emission (Net-Zero Emission) is expected to be as high as 275 trillion dollars.

Since the EU recognized the climate issue earlier and actively took relevant measures to deal with global warming, the EU has rich experience and reference significance in carbon emission reduction at this stage and has been an advocate and leader in global climate governance. Since 1 January 1993, the Czech Republic has been an independent and sovereign state, which has successfully transformed itself into a country with sustained economic growth, social harmony and stability; in May 2004, the Czech Republic joined the European Union, and in 2005 it was classified by the World Bank as a high-income country. At the same time, the Czech Republic is a member of the OECD, NATO and the Schengen Agreement. The Czech Republic was reclassified as a developed country in 2006. The Czech Republic is traditionally an industrial nation, and the industrial sector is vital to the national economy. The principal export market for Czech industrial goods is the European Union, particularly Germany. In recent years, the Czech Republic has expanded aggressively into Asian markets including China.

In 1989 the Czech Republic transitioned from a centrally planned economy to a market economy, making the Czech Republic the most prosperous and stable economy in the Central and Eastern European region. Therefore, this paper chooses 1990-2019 as the period for the study. From the energy structure of the Czech Republic in this period, it can be found that coal accounted for the largest share of the total energy consumption of the Czech Republic in the early period because the Czech Republic mainly developed its industry after the Second World War, which was mainly powered by burning coal. At the same time, the Czech Republic was dominated by resource-intensive enterprises, so it relied heavily on fossil fuels.

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2 McKinsey & Company.(2022). The Net-Zero Transition: What It Would Cost, What It Could Bring. https://www.mckinsey.com/business-functions/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring.

The Czech Republic has moved away from energy-intensive growth. By optimising the structure of its energy supply, reducing the energy intensity of the residential and industrial sectors, and enhancing the legal framework for the transition to a green economy, it has achieved significant emission reductions. However, the Czech Republic also faces various challenges at the economic, social and political levels: The country's continued reliance on coal, the difficulty of reducing emissions in the energy-intensive industrial and transportation sectors in the short term, the size of the employment base in energy-intensive industries, and the unsustainable use of natural gas to reduce emissions all contribute to the country's continued dependence on coal.

Based on the Statistical Yearbook of World Energy, the amount of carbon dioxide in the Czech Republic in 2019 was 98.22 million tons. The Czech energy structure dominated by coal consumption not only leads to a large amount of $CO2$ emissions. But also affects the development of Czech foreign trade to a certain extent. In addition, although the Czech Republic's annual carbon dioxide emissions have decreased, the country's total emissions remain the one of the highest in Central and Eastern Europe.
Related literature and theory can be found through the study of carbon dioxide emissions. The factors affecting carbon dioxide depend on economic development, population size, energy structure, technological progress and other aspects, of which economic development is the most critical. It has been found that different stages of economic development have different impacts on carbon emissions. In the early stage of enterprise development, mainly relying on cheap labour, at this time, resource-intensive enterprises and labour-intensive enterprises are, mainly coal as the main factor of production. Hence, the carbon dioxide emissions are more significant. In the middle stage of economic development, investment is introduced, and steel manufacturing enterprises have a competitive advantage, which promotes carbon emissions. In the later stages, technology is upgraded, and technology-intensive firms dominate, suppressing carbon emissions. Therefore, carbon emissions are closely related to economic development.

To sum up, this paper chooses the Czech Republic as the research object, explores the impact of Czech economic growth on carbon dioxide by building a VAR model, and explores the way and the size of the impact of different variables of economic growth on carbon emissions, to put forward a proposal for the Czech Republic to reduce carbon dioxide emissions in the future.

1.2. Significance of the research

As countries worldwide pay more attention to the Ecological-Environment and the future development of human beings, countries pay more and more attention to carbon dioxide emissions while developing their economies.However, country's Different economic development and different geographical locations make the environmental Kuznets curves of countries or regions different. More scholars hope to describe the relationship between the two with more intuitive data relationships.

After analysing a large quantity of data, it has been determined that academics focus on the relationship between economic development and energy emissions. In addition, they are examining the effect of a particular aspect of economic development on carbon emissions.

In this report, economic development is specified, so the content of the research is more comprehensive, and the empirical analysis is carried out in combination with the specific data of the Czech Republic. The strategy of reducing carbon emissions enables the government to take targeted and effective measures to complete the transition mission and build a high efficiency low-carbon economy, so it would be a great significance for study the how the Czech economic growth impact on carbon emissions.

This paper examines the effect of economic growth on CO2 emissions within the context of international economics, environmental economics, and low-carbon economics. On the basis of a large number of published works, the impact mechanism on carbon emissions is analysed through various variables of economic development. This article will choose the VAR model to quantitatively analyze the influence of relevant factors on the of economic growth process on CO2 emissions. The main reasons are:

(1) The VAR model can comprehensively analysis the deep interconnection between each economic variables and carbon emissions. Unlike traditional regression models that focus on one dependent variable, VAR models can simultaneously examine interdependence among multiple variables, providing a more comprehensive view of relationships

(2) Economic systems are inherently dynamic and subject to feedback loops and time lags. VAR models are good at capturing these dynamic effects, allowing researchers to analyze how changes in economic variables affect carbon emissions. The model works for both of the short term run and long term run.

(3) VAR models use impulse response functions to account for each variable's response to shocks to itself or other variables. This capability helps understand immediate and delayed responses of economic indicators to changes in carbon emissions, and vice versa, providing insight into system sensitivity and resilience.

(4) VAR models can quantify the proportion of forecast error variance in each variable that is attributable to its own shocks or shocks on other variables through variance decomposition. Variance decomposition helps assess the relative importance of different economic variables in influencing carbon emissions. It helps identify critical drivers of environmental change.

In summary, VAR modelling plays a key role in providing a nuanced understanding of the internal connection between economic development and carbon emissions.

2.Literature Reviews

As the ecological environment continues to deteriorate, countries around the globe have realised the significance of environmental protection to the advancement of human society. This is required for the implementation of a low-carbon economy environment. The most important aspect of developing a low-carbon economy is reducing carbon emissions from human activities.

Also， the factors affecting carbon emissions have been the focus on research at home and abroad, such as population size, economic development, energy structure, energy consumption, etc.

2.1. Definition of concept

2.1.1 Greenhouse Gases

Greenhouse gases are those gases that absorb and emit infrared radiation in the atmosphere. And the six common greenhouse gases are include:

- Carbon dioxide(CO2)
- Hydrofluorocarbons(HFCS)
- Methane(CH4)
- Sulphur hexafluoride(SF6)
- Nitrous oxide(N2O)
- Perfluorocarbons(PFCS)

Therefore, the greenhouse effect the ability of the atmosphere to trap heat, increasing the temperature of the Earth's surface.

2.1.2 Thoery of Carbon Emission

'Carbon Emission' is synonymous with 'carbon dioxide emissions'. Any human activity can influence carbon dioxide emissions. Such as burning coal, oil, natural gas, or other high-carbon energy sources, as well as by transportation and daily life, and are now intimately associated with our everyday lives. According to the United Nations

Intergovernmental Panel on Climate Change (IPCC)[3], the annual global carbon dioxide emissions caused by human activities are estimated to be 23.7 billion tonnes.

2.2 Theoretical Basis

2.2.1 Sustainable Development Theory

The sustainable development theory, which was initially developed from an ecological perspective, has undergone a long formation process. Environmental pressures from economic growth, population and resources have led to scepticism about the 'growth equals development' paradigm. The World Conservation Programme defines sustainable development as the quality of life that can be pursued without exceeding the carrying capacity of the ecosystem.

In the 1960s, the publication of Silent Spring [4]triggered a debate on the concept of development; in the 1970s, the publication of There is Only One Planet brought people's understanding of survival and the environment to the realm of sustainable development. In the 1980s, the sustainable development model became more and more popular. And the concept of sustainable development was formalised with the publication of Our Common Future[5], a report detailing the environment in which people live and develop. The United Nations Conference on Environment and Development endorsed sustainable development in the 1990s.

So, the formulation of the sustainable development concept is of great significance. First of all, it emerged after humanity had gained a deep understanding of the sustainability of the environment and resources. The formulation of the theory enabled people to change their old modes of production and ways of thinking, and led to re-examine the relationship between human beings and nature. Second, sustainable development theory dispels the long-held misconception that economic growth cannot protect the environment. It encourages people to change the high consumption and wasteful lifestyles of the past and to abandon the wrong way of production, i.e., the polluting and consuming way of production. Finally, the theory of sustainable development calls for the most efficient use of resources to reduce consumption. The aim is to minimise emissions and maximise resource utilisation, thereby reducing the pressure on nature

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3 McKinsey & Company.(2022). The Net-Zero Transition: What It Would Cost, What It Could Bring. https://www.mckinsey.com/ business-functions/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring.

4 **Carson. (1965). Silent spring / Rachel Carson. Penguin in association with H. Hamilton.**

and maintaining the structure and functioning of the ecosystem in order to achieve a higher paradigm of sustainable development in which human beings are in harmony with the natural geographical environment.

2.2.2 Environmental Kuznets Curve (EKC) Theory

The Environmental Kuznets Curve proposed by Krueger (1991) [6]in his study of whether the North American Free Trade Agreement (NAFTA) causes environmental degradation in the United States, explains the relationship between economic growth and environmental pollution in terms of structural, technological, and scale dimensions that vary in tandem and then inversely. i.e., an inverted 'U' relationship.

And the structural effects mainly the input resources structure and the structure of industries. As a country's industrial structure evolves from being predominantly agricultural to being predominantly industrial to being predominantly service orientated, this change in industrial structure significantly reduces the demand for energy, leading to a reduction in the final discharge of pollutants, and environmental problems are somewhat ameliorated. The technology effect focuses primarily on the impact of technology on the environment, economic growth will increase research and development of technology, and research and development will result in the creation of new technology, promote energy-saving and emission-reduction technology, and reduce pollutant emissions. In terms of scale effects, the focus is on destructive impacts, with the increased scale of economic growth increasing the demand for resources, with the immediate consequence being an increase in pollutants. Finally, he pointed out that environmental pollution and GDP per capita show an inverted 'U' curve. During the earliest stages of social development, the economy is less developed. However, its economic growth rate is significant. The relationship between economic prosperity and environmental pollution is cyclical. When the economic scale reaches a certain point, the environment will be sustained by continuous economic growth. On the contrary, it can promote the improvement of the environment and lead to a new healthy development model.

The environmental Kuznets curve reflects a phenomenon of economic and environmental interaction. When people's income level gradually develops from low

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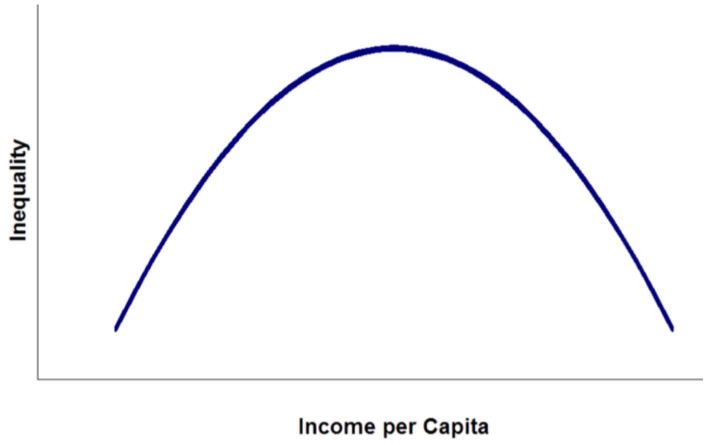
[5] **Carson. (1965). Silent spring / Rachel Carson. Penguin in association with H. Hamilton.**

level to a high level, people will neglect the management of the environment, and the degree of environmental pollution problem will becomes more and more serious. And under the continuous effect of this impact, the environmental quality will continue to decreases. so at a particular stage, high income can lead to the deterioration of the ecological environment; when people's income reaches a peak, environmental pollution problem is also the most serious, but with the income level continuing to rise, the ecological environment is changing from bad to good. The quality of the environment is rising. The environment is polluted to a decreasing degree. The graph below illustrates the correlation between environmental pollution and income per capita.

Figure 1. Environmental Environmental Kuznets Curve



Due to its oversimplification of the relationship between economic growth and income inequality, lack of reference to other well-being indicators, and lack of consideration of the potential negative impact of economic growth on the environment and society, the Kuznets curve has certain limitations.

Nevertheless, as depicted in the preceding diagram, the EKC curve is an inverted 'U' shaped function curve. At the midpoint of per capita income growth, the curve reaches its apex (turning point), at which point the environmental pressure value reaches its maximum; thereafter, the environmental pressure value will continue to decrease as per capita income increases. The curve demonstrates that the effect of per capita income growth on the environment is nonlinear and incorporates both positive and negative correlations.

[6] Krueger, & Grossman, G. M. (1991). Environmental Impacts of a North American Free Trade Agreement. NBER Working Paper Series, 3914.

Therefore, the environmental Kuznets curve theory lays the theoretical foundation for the research content of this paper.

2.2.3 Low-Carbon Economy

The concept of sustainable development underpins a low-carbon economy. It can reduces greenhouse gas emissions through innovative technologies and system upgrade. To reduce energy consumption and greenhouse gas emissions, it employs a variety of strategies, such as the creation of new energy sources and the transformation of industries. Low-carbon economy not only develops the economy but also protects the ecological environment.

The term 'Low Carbon Economy' first appeared in the UK Energy White Paper 'Our Energy Future: Building a Low Carbon Economy' published in 2003. Since the theory was introduced, it has been studied by several researchers. Shimada (2007) [7]established a methodology based on long-term development scenarios of a low-carbon economy at the city scale, found that socio-economic structural changes and technological means are essential for developing a low-carbon economy, and applied this methodology to Shiga Prefecture in Japan.

A low-carbon economy necessitates a balance between economic growth and emissions reductions. It is a crucial effort to combat global warming and the fossil fuel crisis. Low carbon means controlling carbon dioxide emissions while achieving economic growth; The economy is to grow steadily and sustainably as a result of the energy transition. There are four dimensions to the theoretical framework of low-carbon economics as show below:

The industrial dimension of low-carbon economy, i.e. the decomposition of the carbon cycle in the industrial chain, forms the research field of low-carbon economics, which consists primarily of four directions: energy decarbonisation, industrial decarbonisation, consumption decarbonisation, and the development of carbon sink industry.

The development dimension of low-carbon economy, i.e., the low-carbon economy research field, is separated from the spatial organisation of economic development,

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[7] Shimada, Tanaka, Y., Gomi, K., & Matsuoka, Y. (2007). Developing a long-term local society design methodology towards a low-carbon economy: An application to Shiga Prefecture in Japan. Energy Policy, 35(9), 4688–4703.

which primarily comprises the two directions of low-carbon urban development and low-carbon rural development in the binary transformation of the economy.

The production relations dimension of the low carbon economy, i.e, the research field of the low carbon economy, is divided from the form of existence between people in social reproduction. The main body of market resource allocation mainly researches the production relations of marketisation of low carbon economy, i.e., the definition of property rights of carbon emission, carbon trading, carbon finance and carbon law, etc.

The international dimension of the low-carbon economy, i.e., the study of the development of the low-carbon economy in the international context in terms of international low-carbon trade, low-carbon competition, and low-carbon cooperation.

Although many domestic and foreign scholars may have different perspectives, methods and regions for studying a low-carbon economy, the core concept is the same: to reduce carbon emissions and develop a low-carbon economy.

2.2.4 Decoupling Theory

Decoupling was introduced into economic research by the Organisation for Economic Co-operation and Development (OECD) from the field of physics and is defined as 'breaking' the link between economic growth and environmental degradation. And it is divided into two types of relationships: absolute decoupling and relative decoupling.

In his study of decoupling CO2 emissions from GDP in the Finnish transport sector in 1970-2001, Tapio (2005)[8] enriched the decoupling indicator system by refining the decoupling state into eight indicators. In his study, Sorrell (2012) [9]found that relative decoupling of road transport energy from GDP was achieved in the United Kingdom in the period 1989-2004. Vavrek (2016) [10] analysed the decoupling status in the V4 countries in the period 1991-2012 and found that the decoupling status of road transport energy was relatively low. -2012 decoupling status of the V4 countries and the conclusion was that all four countries showed strong decoupling. Roinioti (2017)

8 Tapio. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. Transport Policy, 12(2), 137–151.

9 Sorrell, Lehtonen, M., Stapleton, L., Pujol, J., & Toby Champion. (2012). Decoupling of road freight energy use from economic growth in the United Kingdom. Energy Policy, 41(1), 84–97.

10 Vavrek, & Chovancova, J. (2016). Decoupling of Greenhouse Gas Emissions from Economic Growth in V4 Countries. Procedia Economics and Finance, 39, 526–533.

[11] noted that Greece attained weak decoupling in the majority of years, with the exception of 2006, 2008, and 2009. In recent years, however, this decoupling progress has been hampered by economic contraction. Wu (2018) found during his study by constructing a system of decoupling that among developed and developing countries, developed countries have better decoupling.

In the study of the relationship between economic growth and carbon emissions, various countries, regions, and stages of economic development exhibit different relationships between economic growth and carbon emissions; As described by the EKU curve, for underdeveloped regions with relatively backward economic development, economic growth in the early stage will lead to an increase in carbon emissions. However, when the economy continues to develop until it surpasses a certain threshold, the value of carbon emissions will decrease as the economy grows. For the research of a specific region, it is crucial to analyse the relationship between economic growth and carbon emissions.

2.2.5 Energy-economy-environment (3E) theory

As the ecological environment continues to deteriorate, more and more people are becoming aware of the relationship between the ecological environment and economic development. As a result, energy economics and environmental economics began to be established and valued by everyone, and attracted a large number of scholars to conduct further research on energy economics and environmental economics. Since then, the relationship among environment, economy, and energy has become closer, and a large number of academic research results in this area have also expanded the development of the dual research system.

As a continuance of the concept of a low-carbon economy and sustainable development, the '3E' theory integrates energy, the economy, and the environment into a single research system. In this triadic system, the relationship between energy and the economy is primarily manifested in the following ways: energy is the 'lifeblood' of the development of a country or region, and energy consumption provides the necessary impetus for production, which in turn promotes the development of society as a whole, while economic growth can raise the level of social affluence, and thus society has

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[11] Roinioti, & Koroneos, C. (2017). The decomposition of CO_2 emissions from energy use in Greece before and during the

ample funds to promote research of energy technologies and develop new energy sources. The relationship between energy and the environment is mainly manifested in the fact that energy consumption increases the emission of pollutants, thus causing irreversible damage to the environment . Increased environmental pressures are forcing humanity to reduce the burning of fossil fuels, seek improvements in energy efficiency and optimise the energy mix. The past economic development model of high consumption, high emissions, and low output exacerbated environmental pressures. In contrast, the limited carrying capacity of the environment has forced the transformation and upgrading of the economic development model, which is not only concerned with economic growth but also with environmental protection.

Therefore, the relationship between energy-economy-environment is intricate. It is not possible to study only one or two variables. In order to obtain research results that are closer to the real situation, it is necessary to combine energy-economy-environment and analyze the interaction between them. It is necessary to integrate them into a unified system for comprehensive research, and to grasp the causal relationship among the three and the dynamic balance between them.

2.2.6 Industrial Structure Theory

Industrial structure is the interrelationships between the compositional distribution of primary, secondary, and tertiary industries in an economy. The theory of industrial structure relates to the dynamic transformation of industrial structure in a specific region. The most classical theories in industrial structure theory are the Matey-Clark theorem, Kuznets law and Hoffman's theorem. Based on the theorem, researchers divided industries into primary, secondary and tertiary industries. In 1957, Kuznets put forward the 'Kuznets Law', which studies the mutual changes between the national income of an industry and the distribution of its labour force. The ratio of the output of the primary industry to the labour force decreases annually, while the proportion of the secondary industry remains relatively stable and the proportion of the tertiary industry increases. Hoffmann's theorem states that as the industrialisation of the industrial structure progresses, the capital industry's proportion of the industry increases. In contrast, the output of the consumer goods industry and the output of the investment industry, i.e. Hoffmann's ratio, tends to decrease gradually.

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economic crisis and their decoupling from economic growth. Renewable & Sustainable Energy Reviews, 76, 448–459.

2.2.7 Theory of Externalities

An externality is the effect of an action carried out by an economic agent on a party to which it does not belong. An externality can be positive or negative, i.e., its behaviour can result in favourable or unfavourable consequences for others. At the level of carbon emissions, a comparison of the positive and negative impacts of carbon emissions reveals that carbon emissions have a strong negative externality. On an economic level, personal costs are smaller than social costs in the optimal allocation of carbon emissions when carbon-emitting companies carry out their emission activities according to their wishes so that the realistic level of carbon emissions is higher than reasonable under normal circumstances. Improving the condition of the environment generates employment opportunities in a variety of fields, which is an action with a positive externality from an individual's perspective; on the other hand, the fruits of the labour of those who participate in the protection of the environment have a positive externality. The personal benefits are smaller than the social benefits.

The conduct of foreign trade is not the essential cause of carbon emissions; trade itself does not exacerbate carbon emissions, but the production, processing, and packaging of traded products generate carbon emissions, especially in the early stages of development. Firstly, from the current global international trade pattern, most countries rely on energy- and resource-intensive enterprises to produce traded products at the early stage of trade development. Primary products are a top priority in foreign trade. However, these countries' vast gains in foreign trade have come at the expense of energy and environmental resources. As some enterprises cannot meet the high emission standards set by developed countries, these highly polluting enterprises are more willing to choose to carry out production activities in developing countries with relatively lax emission standards, followed by import trade, which makes developing countries exporting resource-intensive products more and more polluted, and those that need to import developed countries to ease the pressure on carbon emissions in this way. Typically, these developed countries that enjoy services push developing countries to export resource-intensive products using trade policies that further exacerbate carbon pollution in these developing countries.

The above analysis shows that carbon dioxide has significantly negative externalities. The solution to the problem of carbon emissions is not the responsibility of a particular country or region; it should be a matter of cooperation and mutual monitoring among countries.

2.3 Synthesis of research on factors influencing carbon emissions

The study of the factors that influence carbon emissions is of great theoretical and practical importance for addressing climate change, enhancing relevant energy policies, and implementing low-carbon development strategies. Scholars in the United States and abroad began studying the factors influencing carbon emissions at an early stage, and scholars from various nations have analysed the relationship between carbon emissions and economic development.

Ehrlich (1971) [12] proposed the IPAT equation, which links carbon emissions to population, technological means and the level of economic development as the main factors affecting carbon emissions. Kaya (1989) [13] first proposed Kaya's Constant Equation in the IPCC's Working Paper, In it, he argued that the total carbon emissions from socioeconomic activities in a region are equal to the product of factors such as total population, gross domestic product per capita, energy use efficiency, and carbon emissions per unit of energy. Kohler (2013) [14]examined the relationship between energy consumption, carbon emissions and economic growth by analysing trade and energy data for South Africa and found that per capita energy consumption had a significant effect on the increase in carbon emissions, while higher levels of trade favoured a reduction in carbon emissions. Liddle (2014) [15]analysed the impact of age structure, urbanisation rate and population on carbon emissions and found that there is a positive correlation between urbanisation rate and carbon emissions, while population shows a negative correlation with carbon emissions.

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[12] Ehrlich, & Holdren, J. P. (1971). Impact of Population Growth: Complacency concerning this component of man's predicament is unjustified and counterproductive. Science (American Association for the Advancement of Science), 171(3977), 1212–1217.

[13] Kaya Y. (1989).Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios IPCC energy and industry subgroup, response strategies working group[R].

[14] Kohler. (2013). CO2 emissions, energy consumption, income and foreign trade: A South African perspective. Energy Policy, 63, 1042–1050.

[15] Liddle. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. Population and Environment, 35(3), 286–304.

Roy (2017)[16] verified the contribution of affluence to carbon emissions by 24% by performing a ridge regression analysis on the model. Noorpoor (2015) [17] after constructing the research model, applied partial least squares analysis, and the results showed that population, GDP per capita, etc. had a positive effect on carbon emissions in the electricity sector in Iran. Chekouri (2020) [18]used the problem of multicollinearity was eliminated using partial least squares regression, and the results demonstrated that population has a significant positive effect on carbon emissions..

Kais (2016) [19]used the GMM estimation method to demonstrate that in the '3E' system, as per capita energy consumption and per capita GDP increase, so do carbon emissions. Ehigiamusoe (2019)[20] showed that rising income levels and financial development in society have a strong dampening effect on carbon emissions. Lower levels of income and financial development increase carbon emissions, and energy consumption is the leading cause of increased carbon emissions. Bakhsh (2021) [21] incorporates four indicators for measuring carbon emissions and technological innovation and institutional quality into one system to study the impact of FDI on carbon emissions, pointing out that the improvement of institutional quality and technological innovation capacity can promote carbon emission reduction.

Kang (2019) [22] used a VAR model to analyse the dynamic relationship between hydropower consumption and coal consumption, CO2 emissions and economic growth in India. Khoshnevis (2018) [23]used a VAR model to empirically analyse the relationship between CO2 emissions and economic growth, renewable energy consumption and

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[16] Roy, Basu, S., & Pal, P. (2017). Examining the driving forces in moving toward a low carbon society: an extended STIRPAT analysis for a fast growing vast economy. Clean Technologies and Environmental Policy, 19(9), 2265–2276.

[17] Noorpoor, & Kudahi, S. N. (2015). CO2 emissions from Iran's power sector and analysis of the influencing factors using the stochastic impacts by regression on population, affluence and technology (STIRPAT) model. Carbon Management, 6(3-4), 101–116.

[18] Chekouri, Chibi, A., & Benbouziane, M. (2020). Examining the driving factors of CO2 emissions using the STIRPAT model: the case of Algeria. International Journal of Sustainable Energy, 39(10), 927–940.

[19] Kais, & Sami, H. (2016). An econometric study of the impact of economic growth and energy use on carbon emissions: Panel data evidence from fifty eight countries. Renewable & Sustainable Energy Reviews, 59, 1101–1110.

[20] Ehigiamusoe, & Lean, H. H. (2019). Effects of energy consumption, economic growth, and financial development on carbon emissions: evidence from heterogeneous income groups. Environmental Science and Pollution Research International, 26(22), 22611–22624.

[21] Bakhsh, Yin, H., & Shabir, M. (2021). Foreign investment and CO2 emissions: do technological innovation and institutional quality matter? Evidence from system GMM approach. Environmental Science and Pollution Research International, 28(15), 19424–19438.

[22] Kang, Islam, F., & Kumar Tiwari, A. (2019). The dynamic relationships among CO2 emissions, renewable and non-renewable energy sources, and economic growth in India: Evidence from time-varying Bayesian VAR model. Structural Change and Economic Dynamics, 50, 90–101. 6

[23] khoshnevis Yazdi, & Shakouri, B. (2018). The renewable energy, CO2 emissions, and economic growth: VAR model. Energy Sources. Part B, Economics, Planning and Policy, 13(1), 53–59.

energy consumption in Germany for the period 1975-2014. Ali (2023) [24]used a VAR model with the help of the VAR model to study the interaction between oil dependence and Sudan's export diversification and economic growth.

Academics believe that industrial structures will reduce carbon emissions by decreasing energy consumption and fostering technological advancement. Various academicians domestically and internationally examine the relationship between industrial structure and carbon emissions using a variety of research techniques. Brannlund's (2012)[25] study shows that optimising industrial structure will inhibit carbon emissions by affecting changes in the structure and energy consumption efficiency. Zhang (2020) [26]and others conducted an empirical study based on the data of Chinese Zhang (2020) et al. From 2006 to 2016, an empirical study based on data from 281 prefecture-level communities in China revealed that industrial structure indirectly increases carbon intensity by promoting technological change. Tiam (2014) [27]et. Based on data from nine typical provinces in China, showed that the differences in regional CO2 emissions are mainly due to the differences in the regional industrial structure. Zheng (2020) [28]et al. showed that upgrading the regional industrial structure is related to the changes in the development model, and the optimisation of the regional development model can effectively reduce carbon emissions. Talukdar (2001) [29]constructed a random effects regression model of industrial structure and carbon emissions based on panel data from 44 developing countries.

Through the research of domestic and international academicians on the influence factors of carbon emissions, it is evident that the selected influence factors will vary considerably according to the various research perspectives. However, they basically come from economic development, population size, energy structure, technological progress and other aspects. In addition, some scholars have considered industrial structure, urbanisation, climate and other factors in their research. Due to the economic

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24 Ali, Murshed, S. M., & Papyrakis, E. (2023). Oil, export diversification and economic growth in Sudan: evidence from a VAR model. Mineral Economics : Raw Materials Report, 36(1), 77–96.

25 Brannlund, & Persson, L. (2012). To tax, or not to tax: preferences for climate policy attributes. Climate Policy, 12(6), 704–721.

26 Zhang, Deng, X., Phillips, F., Fang, C., & Wang, C. (2020). Impacts of industrial structure and technical progress on carbon emission intensity: Evidence from 281 cities in China. Technological Forecasting & Social Change, 154, 119949–.

27 Tian, Chang, M., Shi, F., & Tanikawa, H. (2014). How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China. Environmental Science & Policy, 37, 243–254.

28 Zheng, Peng, J., Xiao, J., Su, P., & Li, S. (2020). Industrial structure transformation and provincial heterogeneity characteristics evolution of air pollution: Evidence of a threshold effect from China. Atmospheric Pollution Research, 11(3), 598–609.

variables all interacting with each other, there may be problems such as omitted variables and significant statistical errors when building the model, so that the model will have endogeneity problems. At the same time, because carbon emission is a continuous process, the impact of economic growth may not be fully reflected in the carbon emission in the current period, so it is necessary to choose suitable measurement methods to deal with these problems when conducting empirical research.

[29] Talukdar, & Meisner, C. M. (2001). Does the Private Sector Help or Hurt the Environment? Evidence from Carbon Dioxide Pollution in Developing Countries. World Development, 29(5), 827–840.

3. Research content and research methodology

3.1 Research content

On the basis of a review of the research results of scholars from various countries on the relationship between economic growth and carbon emissions, this paper elucidates the interaction and influence modes between economic growth and carbon emissions and introduces the relevant fundamental theories. In addition, the mechanism by which economic growth affects carbon emissions is analysed, with a focus on economic development-related variables. And the VAR model used in this paper was constructed using carbon emission-related data. And the relationship between them is accurately and comprehensively analyzed empirically. In addition, empirical analysis is used to determine the impact of each factor on carbon emissions and their contribution to carbon emissions. Then, relevant policy recommendations for reducing carbon dioxide emissions are provided based on the empirical findings.

Therefore, the main research content of this paper can be divided into the following seven section :

(1) Introduction. This section primarily introduces the paper's research context, research purpose, and research significance.

(2) Literature review. This section mainly reviews the theoretical knowledge and research methods involved in this paper in detail. And according to the relevant theoretical literature reviewed, it specifically analyzes the impact of the single influencing factor of economic growth on economic growth by domestic and foreign scholars. Examples of research on the impact of carbon emissions. In addition, the existing relevant research conclusions are also reviewed. At the same time, the concept is clarified and the theoretical foundation is laid.

This section introduces and analyses the research significance of sustainable development theory, environmental Kuznets curve theory, and other related theories to this paper. Overall, the main significance of this section is to provide a strong theoretical support for the establishment of this paper.

(3) This chapter mainly introduces the research content and research methods used in this paper. It also expounds the main work content involved, the main innovation points related to the work and the establishment of the main structure of this paper.

(4) This chapter focuses on analysing the impact and transmission mechanisms of economic growth on carbon emissions. Especially the analysis of the influence mechanism, this chapter analyzes the influence factors of economic growth on carbon emissions.

(5) This chapter mainly reviews the status quo of Czech's current economic growth and carbon emissions. And its current economic status and carbon emission data are analyzed.

(6) Analysis of the empirical relationship between economic development and carbon emissions. In addition, the primary purpose of the VAR model is to investigate the impact of economic growth-related variables on carbon emissions, their contribution to carbon emissions, and a comprehensive evaluation of the research outcomes.

(7) Conclusions and countermeasures. This section mainly includes the paper's research conclusions and summarizes the impact of economic growth on carbon emissions. Concurrently, suggestions and effective countermeasures are proposed for Czech carbon emissions. Moreover, this section also include the research deficiencies and prospects, hoping to enrich the research content and conclusions effectively.

3.2 Research Methodology

(1) Literature Research method
This method is applied in the process of topic selection, framework construction, content research and so on. First, the topic of this paper is determined by collecting, reading, and organising relevant data on economic development and carbon emissions at home and abroad, combined with the actuality of the Czech Republic; second, the VAR model is chosen as the research method for this paper.

(2) Qualitative analysis method
Before writing this paper, read and sorted out many domestic and foreign literature, and comprehensively sorted out relevant knowledge points. Factors such as per capita GDP, industrial structure, and foreign trade dependence are also considered. Then analyze their impact on carbon emissions separately, and pay attention to the latest policies and regulations, and conduct analysis in combination with reality.

(3) Quantitative analysis method.

After the theoretical analysis, empirical research is conducted in this paper. Using a VAR model, the empirical section investigates the relationship between variables associated with Czech economic development and carbon emissions from 1990 to 2019. In addition, by analysing the impulse response and variance decomposition, we can determine the magnitude and duration of each factor's effect on carbon emissions as well as each factor's contribution to carbon emissions.

3.3 Main work and innovations

(1) From the standpoint of research objects, the majority of domestic and international literature focuses solely on the relationship between financial development or economic growth and carbon emissions. Few researchers have conducted in-depth examinations of the connection between Czech economic growth and ecological environment development. However, the author of this paper took the influence relationship between the two into the scope of research when constructing this paper.

(2) Regarding the selection of indicators for this paper, the author of this paper chose to include the indicators of per capita GDP, industrial structure, and foreign trade dependence into the scope of indicators for measuring economic development. The advantage of doing this is that compared with using a single indicator to measure economic development, the results obtained in this way are more accurate and comprehensive.

(3) In terms of research methodologies, econometric models were predominantly used to examine the relationship between variables in prior studies. But this paper utilises the VAR modal. Utilising the VAR model has the advantage of effectively avoiding the potential two-way causality between economic development and carbon dioxide emissions. Relationships lead to inaccurate results. Compared with the dynamic panel model, the VAR model can regard all factors affecting carbon dioxide emissions as endogenous variables. On the other hand, when using the VAR model for research, impulse response and variance decomposition can be performed. The degree and duration of the effect of each factor on carbon emissions can be seen, and the contribution of each factor to carbon emissions can be seen.

4. Mechanistic analysis of the impact of economic growth on carbon emissions and research hypotheses

Different development stages of economic growth have different mechanisms for influencing carbon emissions：

（1） In the factor-driven stage, the most fundamental factors are capital and workforce. Economic growth relies heavily on land, capital, etc., to create an environment with cheap labour, natural factors suitable for business development, and low cost of access to resources for passive business development. Resource-intensive and labour-intensive enterprises tend to be highly competitive in the market at this stage. They mainly use coal and oil as their factors of production. An unmistakable characteristic of crude economic growth marks the stage. Because the scale of production in this type of industry is limited, even if they cause resource consumption, it will be a minimal emission of pollutants. Therefore, no significant CO2 emissions are generated at this stage.

（2） In the efficiency-driven stage, which relied mainly on investment, firms introduced advanced equipment to improve product quality. In this stage, the competitive advantage of firms such as steel manufacturing gradually came to the fore, so the market was dominated by heavy industry. As a result, the energy consumed increased dramatically during this phase, and the carbon emissions of society as a whole increased dramatically. At the same time, the population has begun to increase its high consumption as a result of a significant rise in living standards, and population growth has accelerated, further contributing to CO2 emissions.

（3） In the innovation-driven stage, the independent innovation capacity of enterprises has been developed, knowledge has become the driving force of economic development, people's quality education has been improved, and investment in human capital has continued to increase. In this phase, technology-intensive industries dominate, consuming significantly fewer resources and causing significantly less carbon emissions than heavy industry.

At the same time, along with the shift from speed to quality in economic development, people's income levels have reached a higher level. Beyond satisfying essential consumption, people care about whether their environment is livable, whether the things they use are harmful, and whether the food they eat is detrimental to their health. These changes have curbed residents' carbon dioxide emissions.

The above analysis shows that along with economic development, carbon emissions increase first and then decrease, which is consistent with the environmental Kuznets curve. Therefore, with financial development, the economy will be in different stages of development, when the relationship between it and carbon emissions is also different.

The development of a low-carbon economy necessitates the reduction of CO2 emissions while simultaneously attaining economic growth. The initial period concentrates on the development of resource-based industries, so industrial scale expansion will increase carbon emissions. When economic growth exceeds a certain threshold, it will provide an economic basis for the adjustment of the industrial structure. Therefore, economic expansion will result in a reduction in carbon emissions. This section analyses the mechanism of economic growth on carbon emissions from three aspects: GDP per capita, import and export trade and industrial structure.

4.1 Economic development affects carbon emissions through industrial structure

Industrial structure refers to the composition of the different productive sectors and the proportions between sectors that drive economic growth. Due to the complexity of demand and the continuous upgrading of production technology, the division of labor has been continuously refined during the economic growth process. As a result, the production sector includes not only the traditional industrial and agricultural industries but also new service industries, such as the financial and electronic information technology industries, because of the differences in inputs and outputs. During the course of economic expansion, the production sector will be influenced by distinct forces. Consequently, the industrial structure is a characteristic of production structure that describes the composition of distinct industries and the proportion of value added by each of them, and the three industrial classifications are commonly used to classify the industrial sectors..

The continuous optimisation of the industrial structure strengthens the industry's demand for finance, which promotes the flow of capital to enterprises with good development prospects. Enterprises with good development prospects can, in turn, upgrade their industrial structure through capital, thus forming a virtuous circle and reducing carbon emissions. The effect of economic development on carbon emissions through its impact on industrial structure varies at different stages. The specific mechanism of action is as follows:

When the level of economic development was low, efforts were made to develop resource-based industries, leading to increased carbon emissions.

As a means of reducing CO2 emissions, the industry optimises and modernises more as the level of economic development increases, incentivizing the gradual transformation of former businesses into environmentally friendly ones.

The transformation and development of the pertinent industrial structure are not identical, however, due to the varying countries and territories, as well as the varying levels of development in various regions. Resources will be prioritised to flow to enterprises that contribute to economic development, and energy-saving and emission-reduction enterprises are not their priority. In this instance, the effect of financial development on reducing carbon emissions through industrial structure is negligible, so the region's economic development must have attained a certain level in order to influence carbon emissions through industrial structure. Only when the degree of economic development is high, under the guidance of relevant policies, with the help of the ‘invisible hand’ on the market to allocate resources to the relevant enterprises to carry out technological progress and industrial reform, when the distribution of economic resources of the whole society tends to favour environmentally friendly industries, at this time, the financial development through the structure of the industry to show inhibition.

4.2 Economic development affects carbon emissions through foreign trade dependence

In the context of economic globalisation, the upgrading of a country or region's economic level and the improvement of its domestic economic situation will, on the one hand, be conducive to the development of its own externally oriented economy, which will have an effect on the expansion of the total volume of international trade and foreign direct investment. On the other hand, their impact on carbon emissions may be positive or negative due to differences in the host country's own situation. The following analyses the impact of foreign trade on carbon emissions through the scale effect, structural effect and technological effect.

(1) Scale effects

Participation in international trade, based on the international division of specialisation, reduces carbon emissions in capital-intensive countries and increases carbon emissions in resource-intensive countries due to the fact that services and low energy consumption dominate the industrial structure of capital-intensive countries. Resource-intensive countries, on the other hand, are dominated by industry and manufacturing in their industries, which are the main sectors of energy consumption. That sustained economic growth in a country or region attracts large amounts of foreign direct investment, which can have both a positive and a negative impact on carbon emissions. On the one hand, the inflow of foreign capital expands domestic production and increases the energy consumption of the production sector, and energy is burned to emit large quantities of industrial emissions, which directly raises the level of carbon emissions in the country of inflow of foreign capital. But on the other hand, FDI inflows will also raise the host country's per capita income level and help it cross the carbon emission peak quickly.

(2) Structural effects

The structural effect of foreign trade on carbon emissions refers to the fact that foreign trade affects a country's economic structure through changes in the structure of trade, which in turn impacts a country's environmental system. If foreign trade leads to adjustments in the industrial structure, resulting in the central pillar industries of the region being energy-consuming and high-emission industries, carbon emissions will increase. Typically, during the initial period of development of a country's international trade, foreign trade can have a negative impact on the environment due to structural effects that predispose a country to the development of pollution-intensive industries. The structural effects of foreign trade are conducive to easing the pressure on carbon emissions as a country's level of economic development continues to rise, and its trade structure continues to be optimised.

(3) Technological effects

The technological effects of foreign trade, which accelerate the flow of advanced technology, improve the efficiency of factor use and reduce carbon emissions per unit of output, can be seen as a kind of knowledge spillover. Foreign trade can improve the efficiency of energy use and reduce the burden on the environment through the introduction of better energy-saving and emission-reduction technologies and related experience. If there can be exchanges and penetration between countries in the field of technology, and advanced clean technology and equipment can be spread from technologically advanced countries to backward countries, this is of great significance to the environmental protection of technologically backward countries.

4.3 Economic development affects carbon emissions through GDP growth

In the environmental Kuznets curve, in the early stage of social development, economic development is relatively backward. In the early stages of development, rising GDP per capita means rapid industrial growth using fossil fuels, which will increase the pressure on the environment. Conversely, when a country reaches a certain level of economic development, steady and sustained economic growth will reduce the pressure on the environment. When the state of environmental pollution in the environmental Kuznets theory is measured in terms of carbon dioxide emissions, it reveals the dynamic process of economic growth on carbon emissions.

The expansion of a country's or region's economy directly reflects its economic growth, which necessitates a substantial quantity of energy as a source of power. The predominant form of energy consumption is fossil fuels, which directly contributes to an increase in carbon emissions. In addition, the expansion of the economic scale requires a large amount of investment in physical capital. Investing in physical capital, such as plants and infrastructure, directly increases the demand for raw materials and energy, directly increasing carbon dioxide emissions. However, the EKC curve reveals that when the economic growth exceeds the critical point, the economic growth will instead reduce carbon emissions, which is due to the fact that the scale expansion provides a material guarantee for the development of a low-carbon economy, which focuses on protecting the environment while expanding the economic scale.

4.4 Hypothesis of this Project

Based on the content of the previous sections, the following thesis hypotheses can be summarized:

- Economic growth suppresses carbon emissions through industrial structure.
- Economic growth dampens carbon emissions through foreign trade dependence.
- Economic growth contributes to carbon emissions in the early stages through an increase in GDP per capita, and after reaching a specific economic size, an increase in GDP per capita suppresses carbon emissions.

5. Current status of economic growth and carbon emissions in the Czech Republic

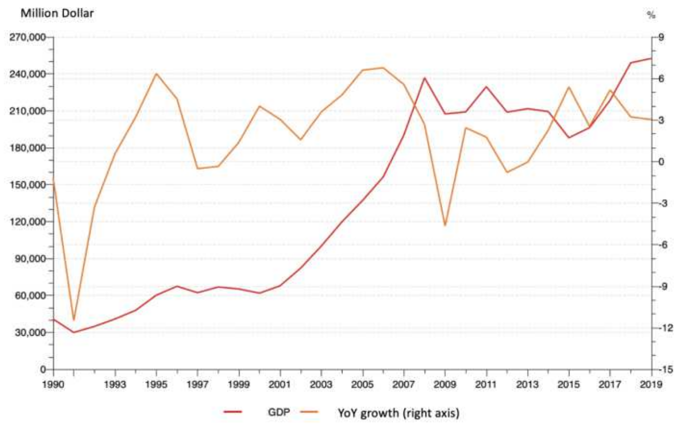
5.1 Analysis of the status of economic development in the Czech Republic

From 1990 to 2004, the GDP of the Czech Republic increased from 40,728.95 million US dollars to 119,814.67 million US dollars, a total increase of 194%; the per capita GDP increased from 3,941.50 US dollars in 1990 to 11,749.88 US dollars in 2004, and the per capita GDP became 2.98 times from 1990.

In 2004, the Czech Republic officially joined the European Union, and the macroeconomic environment improved further, with the economy generally on an upward trend. The old member States have resource-intensive products and the new member States, such as the Czech Republic, have advantages in terms of labour and resources. The old and new member states have complementary production, combining production energy to reduce costs and increase product competitiveness, which is conducive to the rapid development of Czech productivity and economy.

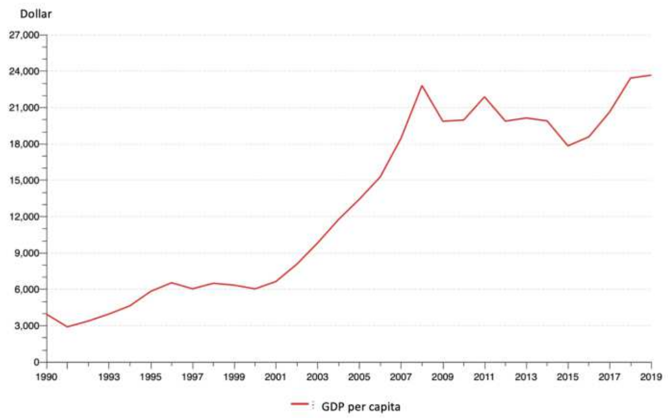
After the world financial crisis, the Czech economy recovered in 2010 with a 2.3 per cent increase in gross domestic product (GDP); in 2011, the Czech economy slowed down as a result of the European debt crisis, with a 1.7 per cent increase in GDP; in 2012, the GDP decreased by 1.2 per cent; in 2013, the GDP decreased by 0.9 per cent; and since 2014, the Czech economy has maintained its growth for the last six consecutive years. Since the Czech Republic has been a member of the European Union , the total GDP of Czech Republic has grown gradually from $137,143.38 million in 2005 to $252,548.18 million in 2019, a GDP change of 1.84 times; Per capita GDP has also continued to increase, from US$13,430.66 in 2005 to US$23,664.85 in 2018, an increase of 76.2%.

Figure 2. 1990-2019 Czech GDP and year-on-year growth rate of GDP (constant price in 2010)



Data source: World Bank/IMF
Note:
GDP in the article is the 2010 constant price dollar after excluding price factors.
GDP at purchasers' prices is the sum of value added by all resident producers in an economy plus any taxes on products and less subsidies not included in the value of products. The calculation does not take into account the depreciation of assets or the depletion and degradation of natural resources.

Figure 3. 1990-2019 Czech per capita GDP change map (constant price in 2010)

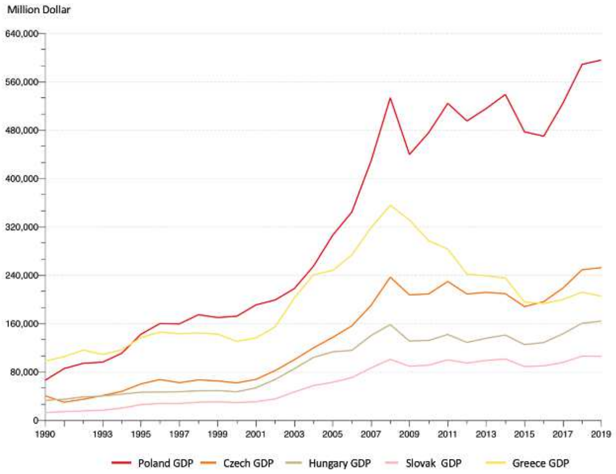


Data source: World Bank/IMF

Note: GDP in the article is the 2010 constant price dollar after excluding price factors

The Czech Republic is an integral component of Central and Eastern Europe and the European Union. When examining the economic development of the Czech Republic, it is feasible to examine the relationship between the Czech Republic's GDP and the GDP of the principal economies in Central and Eastern Europe. The chart below shows the Czech Republic's GDP change and some significant economies in Central and Eastern Europe from 1990-2019. Poland, Slovakia, Greece, and Hungary are selected as essential economies in Central and Eastern Europe because the above four countries are among the more advanced countries in terms of comprehensive development in Central and Eastern Europe. As can be seen from the figure, the GDP of the five countries is generally upward during these 30 years, with Poland's upward trend being the most obvious, followed (in descending order) by Greece, the Czech Republic, Hungary, and Slovakia. In 1990, Greece had the largest GDP of $97,891.09 million, followed by Poland ($65,077.75 million) and the Czech Republic ($40,728.95 million). In 1995 Poland's GDP overtook Greece to become first place. During 1900-1995, the Czech Republic and Hungary were similar. In 2016, the Czech Republic overtook Greece to second place in the GDP of significant Central and Eastern European economies.

Figure 4. Changes in GDP in the Czech Republic and Selected Significant Economies in Central and Eastern Europe, 1990-2019 (Constant 2010 Prices)



Data source: World Bank

Foreign trade accounts for a large proportion of Czech economic growth. The dependence on foreign trade has gradually increased from 38% in 1990 to 150% in 2019. The global financial crisis in 2008 had severely impacted the EU's total foreign trade volume. In 2009, the EU's import and export of goods and services had a relatively large proportion of import and export trade in GDP decreased by 17% compared with 2008.

Table 1. Status of Czech foreign trade (import and export of goods and services) from 1990 to 2019

Year	Imports (millions of United States dollars)	Exports (millions of United States dollars)
1990	19768.83	20502.19
1991	13276.07	19261.91
1992	17216.84	21101.38
1993	21305.92	24440.29
1994	24492.14	25366.69
1995	30250.48	31318.30
1996	33811.23	32100.17
1997	35790.07	34537.12
1998	37784.07	37870.75
1999	39744.30	39838.73

2000	45450.89	45727.32
2001	50608.43	50038.80
2002	53130.55	50500.33
2003	58160.76	54956.21
2004	73041.56	71266.91
2005	82156.82	84207.90
2006	91589.78	96240.54
2007	103385.29	106857.18
2008	106670.62	111359.97
2009	94854.78	100415.59
2010	108905.05	115138.13
2011	116220.38	125688.83
2012	119282.48	131067.55
2013	119356.02	131407.94
2014	131312.32	142859.37
2015	140304.41	151477.13
2016	144274.81	158055.10
2017	153292.79	169432.23
2018	162158.48	175712.87
2019	164664.10	178311.78

Data source: World Bank

Note: The import and export indicators in the article are: import of goods and services (constant price).

Table 2. 1990-2019 Changes in the Czech Republic's Dependence on Foreign Trade

Year	FTD	Year	FTD
1990	0.38	2006	1.20
1991	0.65	2007	1.27
1992	0.67	2008	1.22
1993	0.71	2009	1.05
1994	0.69	2010	1.24
1995	0.77	2011	1.37
1996	0.74	2012	1.43
1997	0.80	2013	1.45
1998	0.81	2014	1.57
1999	0.84	2015	1.59
2000	0.99	2016	1.56
2001	1.03	2017	1.58
2002	0.96	2018	1.55
2003	1.00	2019	1.50
2004	1.16		
2005	1.13		

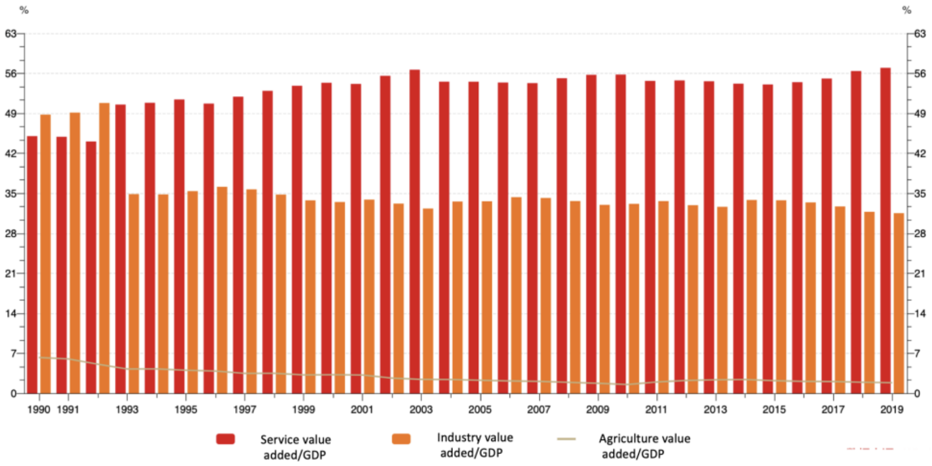
Data source: Czech Statistical Office
Note: The degree of dependence on foreign trade is expressed by the ratio of the current import and export of goods and services to the current GDP.

The proportion of agriculture in the Czech economic structure is very small, and the proportion has been in a state of continuous decline from 1990 to 2009, from about 6% to 1.8%. The Czech economic structure is mainly dominated by industry and service industries. The ratio was almost half and half in 1990, about 45% and 48%, but the changes in the added value of the industry and the service industry were different. The added value of the service industry increased from 45.02% in 1990 to 56.96% in 2019. However, the proportion of industrial-added value decreased from 48.78% in 1990 to 31.53% in 2019. This is because, after 1990, the upsurge of deindustrialization and the development of the knowledge economy swept the world. Most EU member states believed that the development of industrialization was an outdated concept and began to shift the centre of their economic development from industry to service industry and R&D activities.

The 2008 financial crisis had a particular impact on the financial industry, aviation industry and other fields in the special service industry of the EU industry, which made the EU realize the importance of developing industry and the real economy. The industrial sector has the characteristics of innovation and export-oriented. Therefore, the development of the industry is an essential means to promote the rapid recovery and growth of the EU economy. Since the 'Barroso Committee', the EU's industrial policy has once again emphasized the development of industry and the improvement of industrial competition. In 2012, the EU proposed the 're-industrialization' strategy[30], which will return the focus of economic growth to the industrial sector and revitalize European industry. The Czech Republic has been economically integrated with the EU since joining the EU in 2004 and therefore has the same impact. However, judging from the data on the proportion of industrial added value, although there was a slight increase in 2009-2010, the overall situation continued to decrease.

[30] European Commission.(2012).A Stronger European Industry for Growth and Economic Recovery.

Figure 5. 1990-2019 Czech Republic's industrial added value as a percentage of GDP (%)



Data source: World Bank

The table below shows the structure of demand for GDP in the Czech Republic, which is analysed from three perspectives: capital formation as a share of GDP, consumption as a share of GDP, and net exports as a share of GDP. The trend of the three analysed latitudes from 1990 to 2019 has been slightly fluctuating and almost constant. The share of capital formation in GDP increased between 1993 and 2009 before returning to a value of around 24 in 2009. At the same time, net exports as a share of GDP had a downward fluctuation. This indicates that the Czech economy is still developing smoothly in general.

Table 3. Demand structure of Czech GDP

	Capital formation as a share of GDP	Consumption as a percentage of GDP	Consumption as a percentage of GDP
1990	24.55	71.20	2.35
1991	22.48	68.96	5.58
1992	25.62	71.82	1.21
1993	26.71	70.83	1.13
1994	30.06	70.40	-1.14
1995	34.17	68.90	-3.07
1996	36.11	68.73	-4.83
1997	32.98	71.16	-4.14
1998	30.94	69.37	-0.31
1999	29.83	70.65	-0.48
2000	31.95	69.92	-1.86
2001	32.12	69.18	-1.30
2002	30.62	70.71	-1.33
2003	29.69	71.82	-1.52
2004	30.03	69.35	0.63
2005	29.55	68.12	2.33
2006	30.38	66.89	2.72
2007	32.39	65.18	2.42
2008	31.33	66.51	2.16

2009	26.80	69.31	3.89
2010	27.36	69.58	3.06
2011	27.19	69.03	3.78
2012	26.36	68.88	4.76
2013	25.01	69.29	5.69
2014	26.01	67.66	6.33
2015	27.98	66.07	5.94
2016	26.02	66.35	7.63
2017	26.37	66.11	7.52
2018	27.20	66.86	5.94
2019	27.61	66.40	5.99

Data source: World Bank

5.2 Analysis of the status of carbon emission development in the Czech Republic

The Czech Republic is a central European landlocked nation. It has a land area of 78,900 square kilometers and borders Slovakia to the east, Austria to the south, Germany to the west, and Poland to the north. The Czech Republic has a high plateau in the northwest, the Carpathian Mountains in the east, and the river valleys in the center, rich in natural resources. The Czech Republic is rich in lignite, hard coal, and uranium, with lignite and hard coal reserves totaling approximately 13,4 billion tonnes and ranking third and fifth in the globe and Europe, respectively. Oil, natural gas, and iron ore reserves are negligible and are primarily imported. Manganese, aluminum, zinc, fluorspar, graphite, and kaolin are some of the additional mineral resources.

The Czech Republic supports the European Green Deal and endeavours to achieve the EU's stated green development goals. The Czech government approved the Energy and Climate Action Plan (NECP) at the beginning of 2020 and set the share of renewable energy sources in the overall energy mix of the Czech Republic at 22 per cent by 2030. The Czech digital economy is at the lower end of the medium range of EU countries. According to the Digital Economy and Society Index 2021 (DESI) report published by the EC, the Czech Republic scored 47.4, below the EU average (50.7) and ranked 18th.2021 The Czech government approved the National Recovery Plan (NRP) in May 2021, which invests CZK 200bn (USD 9.3bn) in six areas, including infrastructure and green transformation, education and labour market, digitalization, and energy efficiency. Transformation, education and labour market, digital transformation, healthcare, research and development, and business regulation and support. The most significant investments are in infrastructure development and green transformation, with environmental projects and digital transformation accounting for 41 per cent and 23 per cent of the total, respectively.20 In January 2022, the new Czech government launched a 'programme of governance' focusing on developing key areas such as clean and renewable energy, the circular economy, and infrastructure.

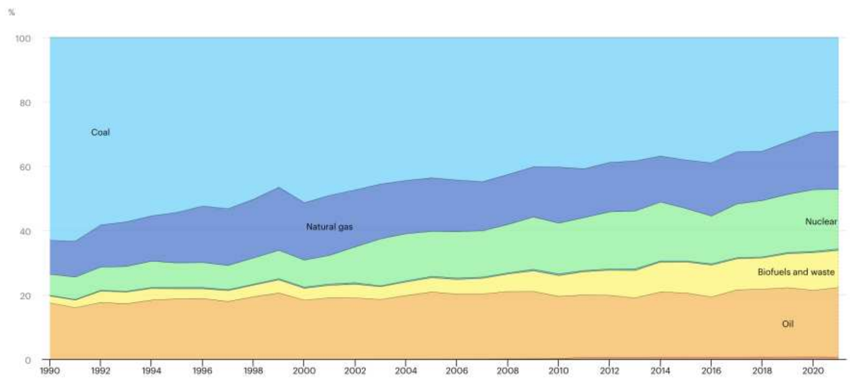
The Czech Republic has a long history of industry, especially the automotive industry. The automotive industry has been a pillar of the Czech national economy for more than 100 years and accounts for 21 per cent of Czech industrial production and exports, generating 7.5 per cent of GDP with 3.1 per cent of the employed population. It, therefore, has a specific impact on carbon emissions.

The Czech energy mix has undergone a significant restructuring, with increased reliance on renewable energy sources such as natural gas, nuclear, hydropower, wind and solar. The energy intensity of the household and industrial sectors has decreased without a significant adjustment in the demand for energy consumption. In addition, the legal regime for a low-carbon economy and sustainable development has been gradually improved.

The total energy consumption of the Czech Republic fluctuated from 1990 to 2008, from 1,380,791 TJ to 1,152,632 TJ, a decrease of 16.5%. Export trade has also been greatly affected, reflected in the total energy consumption reduction. In 2009, total energy consumption decreased to 1,103,100 TJ, a decrease of 4.30%. Since then, the EU has undergone energy transformation and upgrading, and the total energy consumption has gradually decreased, from 1,123,698 TJ in 2010 to 1,073,151 TJ in 2013, a decrease of 4.50% compared to the consumption in 2010.

The energy consumption of the Czech Republic also accounts for a large proportion of the energy consumption of Central and Eastern European countries. It mainly relies on coal to promote the development of its industry and maintains industrial competitiveness with its large production volume and low cost. Although it has the national task of undertaking the EU's energy conservation and emission reduction goals, and the Czech Republic is also actively developing shale gas, nuclear energy, wind energy and other energy sources, it still cannot replace coal's important position in achieving economic growth and ensuring domestic energy security.

Figure 6. 1990-2019 Czech Energy Consumption Structure Proportion (%)



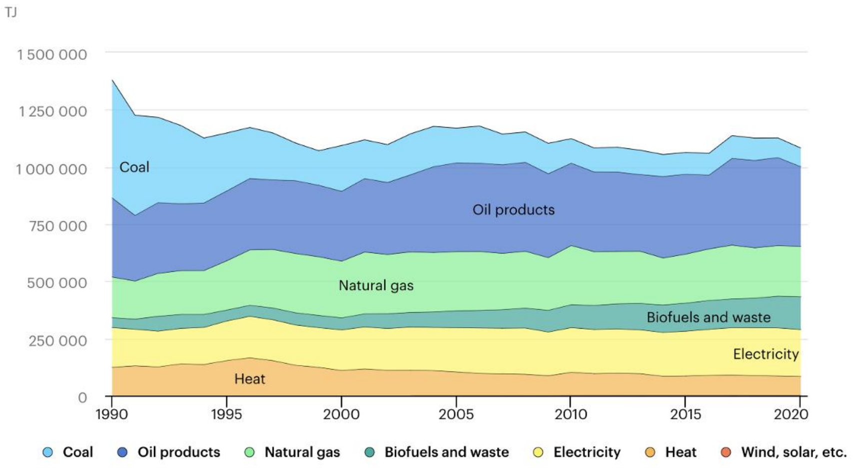
Data source: IEA (https://www.iea.org/countries/czech-republic)

From the EU energy consumption structure perspective, energy types are divided into six categories: Coal, Natural gas, Electricity, Heat, Biofuels and waste, Oil products, wind and Solar. The proportion of consumption of main energy types in total consumption demonstrates: Initially, coal was the primary source of energy consumption in the Czech Republic, with solid fossil fuels, including coal, oil, and natural gas, accounting for more than 70% of total energy consumption. In the later stage, petroleum products were the largest amount of energy consumption in the Czech Republic.

From the perspective of changing trends, the proportion of Czech oil consumption increased from 1990 to 2019, decreasing from 25.08% to 34.14%. The proportion of Czech coal consumption decreased from 37.36% to 7.62% in the past 30 years. At the same time, the proportion of natural gas consumption has continued to rise, from 12.87% in 1990 to 23.02% in 2010. Although it has declined since then, it is still higher than the level in 1990. By 2019, the proportion of natural gas consumption was 19.63%.

The curve of renewable energy and biomass energy shows an upward trend. Its proportion in energy consumption increased from 3.16% in 1990 to 12.34% in 2019. The proportion of renewable energy is expected to increase to 14% by 2020, indicating that The Czech Republic's 'open source' policies and measures have made great achievements, making the Czech Republic a world leader in the development and utilization of renewable energy. This will help the Czech Republic realize its commitment to reduce emissions and alleviate the country's passive position in energy diplomacy due to its over-reliance on energy imports.

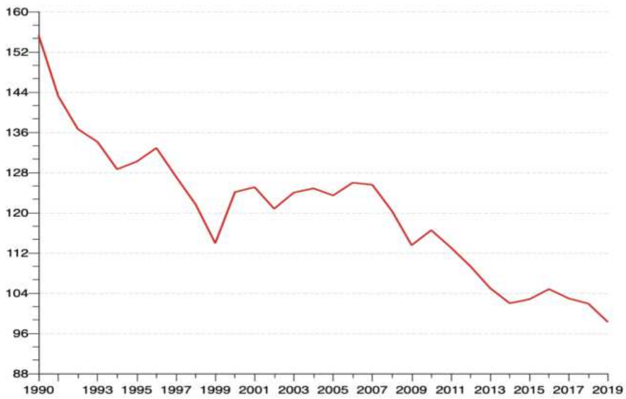
Figure 7. Total Energy Consumption and Consumption Structure of the Czech Republic from 1990 to 2019



Data source: IEA (https://www.iea.org/countries/czech-republic)

From 1990 to 2019, Czech carbon dioxide emissions showed a downward trend year by year, from 155.33 million tons in 1990 to 98.22 million tons in 2019, a reduction of 36.77%. The Czech Republic has a low emission reduction effect due to its high dependence on coal.

Figure 8. 1990-2019 Czech CO2 emissions (million tons)

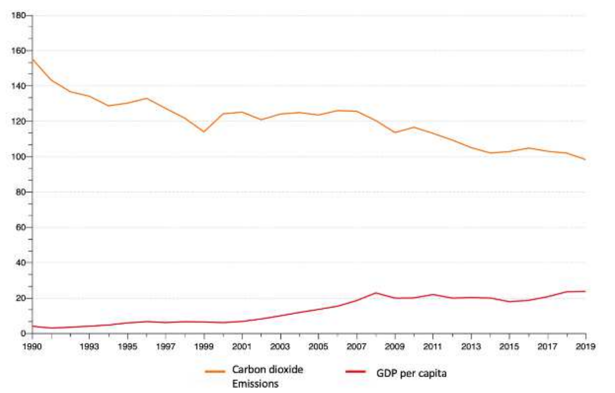


Data source: Eurostat

5.3 Analysis of the current situation in the Czech Republic about the impact of economic development on CO2 emissions

As can be seen from the graph, the Czech GDP per capita has been steadily increasing. The overall CO2 emissions have steadily decreased in the last 20 years, which shows that GDP per capita has had a significant effect in suppressing CO2 emissions. According to the environmental Kuznets curve, environmental pollutants increase in the early and middle phases of economic development until the inflexion point is reached from the curve and economic growth begins to suppress pollutant emissions. In the context of the Czech Republic, the Czech Republic has already gone through the early stages of economic development, and, as a developed country, the Czech economy is in the declining part of the environmental Kuznets curve. Although, according to current data, Czech economic development has served to curb carbon dioxide emissions, there is still room for upward movement in the Czech industrial structure and technological innovation. Lagging in these areas will increase carbon emissions, and more than economic growth is needed to curb CO2 emissions.

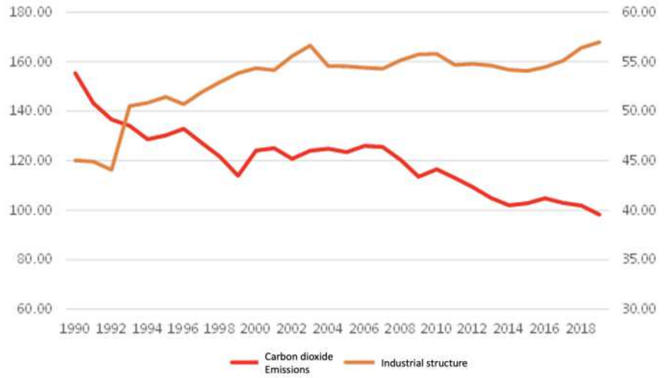
Figure 9. Trends in the relationship between GDP per capita and CO2 emissions, 1990-2019 (million tone/thousand dollar)



Data source: Eurostat/World Bank

From the perspective of the Czech Republic, the current energy structure of the Czech Republic is still dominated by coal, and economic growth increases energy consumption all the time. In the short term, it still increases the emission of pollutants. Although relevant departments require businesses to prioritise energy conservation and emission reduction, attaining this objective must be preceded by industrial structure improvement; therefore, this paper examines the relationship between industrial structure and carbon emissions.

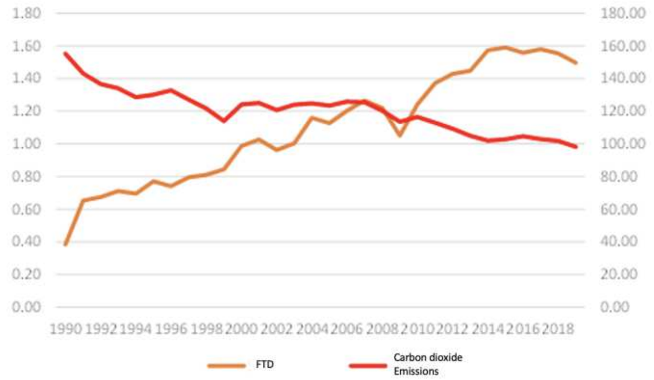
Figure 10. Trends in the relationship between industrial structure and CO2 emissions, 1990-2019



Data source：World bank/Eurostat

As can be seen from the graph, the industrial structure of the Czech Republic has continued to increase from 1990-2019, with more minor changes after 2004. The trend graph of industrial structure and carbon emissions shows that the Czech Republic's vigorous development of the service sector has led to a decline in the value-added of coal-based industries, which, together with growing GDP, has slowed down the industrial structure. At the same time, the growth of carbon emissions has slowed down. The effect of the industrial structure in curbing carbon emissions has begun to be seen.

Figure 11. Figure: Trends in the relationship between External trade dependence and CO2 emissions, 1990-2019



Data source：World bank/Czech Statistical Office

As can be seen from the graph, the Czech foreign trade dependence shows a wave-like upward trend, with a slight decline in 2008 due to the subprime crisis and a steady increase after 2012. The Czech Republic's foreign trade dependence has been developing steadily since 1990. At the same time, carbon dioxide emissions have been on a downward trend. High foreign trade dependence brings advanced technology to the Czech Republic, so energy-intensive enterprises in some developing countries help the Czech Republic reduce the demand for energy-intensive enterprises and therefore reduce carbon dioxide emissions. Therefore, foreign trade dependence shows a dampening effect on carbon emissions.

6. Empirical analysis of the impact of economic growth on carbon emissions

6.1 Research design

6.1.1 Model selection

The theoretical analysis of the impact of economic growth on carbon dioxide emissions has been carried out above. This paper establishes a VAR model through the collected data, considers all the factors affecting carbon dioxide as endogenous variables, and conducts an empirical analysis of the impact of economic growth on carbon dioxide emissions.

6.1.2 Selection and description of variables

Based on the mechanism of economic growth affecting carbon emissions, this paper selects the three factors of GDP per capita, foreign trade dependence and industrial structure as variables when measuring the scale of economic growth. The two variables, GDP per capita and foreign trade dependence can reflect to a considerable extent the size of a country or region's economy in quantitative terms. Industrial structure, on the other hand, is a measure of the main sectors driving economic growth from the perspective of output, an indicator that explains to some extent the 'qualitative' improvement of the economy, i.e., whether there has been a shift in the pattern of growth towards higher output. The above variables are combined to study the extent to which each variable affects carbon emissions in the development of a complex process of economic growth.

(1) GDP per capita: According to the environmental Kuznets curve, carbon dioxide emissions vary at different stages of economic development; in the early and middle stages of economic development, economic growth promotes carbon emissions, and continued economic development suppresses carbon emissions, so in this paper, GDP per capita is used as an explanatory variable in the study of the impact of economic development on carbon emissions.

(2) Industrial structure: the characteristics of the production structure describing the composition of different industries and the share of value added of each of them, which is measured in this paper using the ratio of value added of the service sector to GDP.

(3) External trade dependence: External trade dependence reflects the scale and extent of a country's international trade activities and is expressed as a ratio of total trade to GDP. A higher ratio indicates that a higher proportion of a country's GDP is derived from the proceeds of international trade, that it is more dependent on foreign trade to achieve economic growth, and that it is a typical open economy.

6.1.3 Data sources and processing

Due to the EU's 2030 emission reduction target set in 2014 - a 40 per cent reduction in greenhouse gas emissions by 2030, based on 1990 greenhouse gas emissions - and the start of the COVID-19 in 2019 and the events in Ukraine, there is an impact of external factors on Czech energy. In order to ensure the continuity and completeness of the research data, the relevant Czech data for the period 1990-2019 have been chosen to constitute time-series data for this report to delve deeper into the influencing relationships.GDP, GDP per capita, and services value added to GDP ratios are based on the World Bank[31]. Carbon emissions were obtained from Eurostat[32]. Foreign trade dependence was obtained from the Czech Statistical Office. [33]The following table shows the explanatory notes for the selected variables.

Table 4. Explanation of indicators

Variable type	Variable	Symbol	Unit	Meaning of the indicator
Dependent Variable	Carbon emission	C	million tonnes	Total CO2 emissions from energy consumption
Independent Variable	GDP nominal per capita	$PGDP$	dollar	GDP/total population
	Foreign trade degree of dependence	FTD	%	Import/export trade volume to GDP ratio
	Industrial structure	IS	%	Ratio of services value added to GDP

In order to eliminate the phenomenon of heteroskedasticity, the data of carbon emissions and GDP per capita were logarithmically transformed into $\ln C$ and $\ln PGDP$.

This paper used Stata software to analyse the collected data empirically. The reason for choosing Stata is that, firstly, the empirical analysis required for this paper is statistical analysis, so choosing software mainly used for statistical analysis is essential. Stata is

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31 https://databank.worldbank.org/.

32 https://ec.europa.eu/eurostat/

33 https ://www.czso.cz/csu/czso/population-statistics#demographic-statistics.

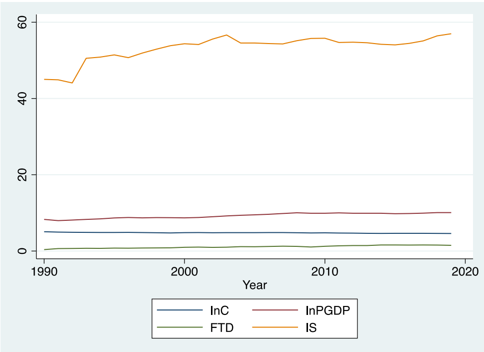
the more popular statistical econometric analysis software today. Secondly, Stata is an open software system. Compared with other statistical software, the most significant advantage of Stata is that it can continuously receive the latest research results in statistics and econometrics to ensure that it can keep abreast of the times. Thirdly, Stata has powerful data analysis functions; Stata software can realise all statistical and econometric analysis functions. For example, in terms of statistics, it can achieve the descriptive analysis of data, analysis of variance and other statistics required in this paper; in terms of econometric analysis, it can achieve a variety of econometric models, and it can achieve the regression analysis of the VAR model required in this paper. Fourth, Stata has powerful graphic production capabilities. Graphical analysis is still an essential part of various analyses. Stata software can complete the production of scatter plots, histograms, line graphs, bar graphs, function charts and other graphics, in addition to their own needs to modify the graphics. In summary, this paper chooses stata software for empirical analysis.

Table 5. Escriptive statistics results for each variable

Variable	Obs	Mean	Std. dev.	Min	Max
InC	30	4.783668	.1112185	4.58721	5.045552
InPGDP	30	9.267725	.6843968	7.971296	10.07175
FTD	30	1.097839	.341581	.3841985	1.591432
IS	30	53.21995	3.342087	44.08	56.96359

As shown in the table above, during the period 1990-2019, the lnC, lnPGDP, FTD, and IS have a mean of 4.78, 9.27, 1.10, and 53.22, respectively. The standard deviations of lnC, lnPGDP, FTD, and IS are 0.11, 0.68, 0.34, and 3.34, respectively, which indicates that the first three variables, lnC, ln PGDP, and FTD have smaller standard deviations, indicating that these three variables have a lower degree of dispersion and smaller fluctuations, while the standard deviation of IS is 3.34, which has a more significant standard deviation, indicating that this variable has a more considerable degree of dispersion and more significant fluctuations.

Figure 12. Timing diagram for each variable



Doing a trend chart for each of the above variables for 1990-2019, as shown in the figure above. Czech carbon dioxide emissions, GDP per capita, foreign trade dependence and industrial structure generally have roughly the same path. The change trend is relatively similar, and the trend of all four shows a slow increase. There is a certain degree of correlation between the variables.

6.1.4 Modelling and theoretical foundations

The vector autoregressive model, also known as the VAR model proposed by Christopher Sims, focuses on forecasting interrelated time series variables and analysing the dynamic shocks of stochastic perturbations on a system of variables. Meanwhile, VAR models can analyse the short-term and long-term dynamics between two or more time-series variables with interconnections and are widely used in many fields.
The general representation of the P-order vector autoregressive model VAR(P) is

$$y_t = A_t y_{t-1} + \ldots + A_p y_{t-p} + Bx_t + \varepsilon_t$$

As shown in the above VAR equation, where y_t means a k -dimensional vector from endogenous variables, and x_t is a d -dimensional vector of exogenous variables. In addition, the subscript p in the equation is the lag order, and T represents the sample number. And $k * k$ refers to -dimensional matrices of A_1 to A_p, $k * d$ refers to -dimensional matrix $\boldsymbol{B}$ (the coefficient matrices to be estimated).
And, ε_t is the k -dimensional perturbation vectors that can be contemporaneously correlated with other vectors, but not with their own lagged values & the variables on the right-hand side of the equation. Assuming that $\sum$ is the covariance matrix of ε_t , then we can have a $k * k$ positive definite matrix. After this , the above equation can be expressed in terms of a matrix as show below:

$$\begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{kt} \end{pmatrix} = A_1 \begin{pmatrix} y_{1t-1} \\ y_{2t-2} \\ \vdots \\ y_{kt-1} \end{pmatrix} + A_2 \begin{pmatrix} y_{1t-2} \\ y_{2t-2} \\ \vdots \\ y_{kt-2} \end{pmatrix} + \cdots + B \begin{pmatrix} x_{1t} \\ x_{2t} \\ \vdots \\ x_{dt} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \vdots \\ \varepsilon_{kt} \end{pmatrix}$$

The above matrix indicates that the VAR model consisting of k data variables is made up of k equations. The equation can also be expressed as:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t$$

where y_t is the residual of the regression of y_t on the exogenous variable x_t. The VAR model used in this paper does not contain exogenous variables and belongs to the unrestricted vector autoregressive model, which is expressed in the form of

$$y_t = A_t y_{t-1} + \ldots + A_p y_{t-p} + \varepsilon_t$$

Compared with traditional econometric methods, the advantage of the vector autoregressive model is that it is not based on any economic theories. The initial assumptions of endogenous and exogenous variables are unnecessary in building the model. However, the dynamic relationship between endogenous variables is estimated by constructing the joint equations. That is to say, the VAR model pays more attention to the dynamics of the variables, which is coincident with the theme of this paper, which explores the dynamic impacts of economic growth and carbon dioxide emissions, and the vector autoregressive model is also very widely used in empirical analysis, the core of the model is to study the mutual impacts of the variables through further forecasts and impulse response analyses.

Based on the aforementioned theoretical analyses and real-world examples, we can conclude that there exists an interactive relationship between carbon dioxide emissions, per capita GDP, foreign trade dependence, and industrial structure. This relationship is a dynamic one, so this paper chooses the vector autoregressive model to study this relationship between them. This paper aims to study the impact of economic growth on carbon dioxide emissions without imposing the constraints in the traditional model and to estimate the dynamic relationship of all endogenous variables through the multi-equation linkage, in which all the explanatory variables are used as their lagged terms.

6.2 Empirical Analysis

This part of the study aims to examine the dynamic relationship between economic growth and carbon emissions in the Czech Republic from 1990-2019 by building an applicable VAR model to validate endogeneity analyses of variables related to Czech economic growth and carbon emissions data.

Moreover, the first step in building the model in this report is the need to perform a smoothness test on the selected raw data. This step serves to avoid pseudo-regression results in the model. The smoothing test is performed because the validation of the model needs to be carried out only if the data is smooth. Moreover, only when the data are smoothed the optimal lag order of the model is determined, which ensures that the developed model can be used to study the interplay between economic growth and carbon emissions in the Czech Republic. The model results are then tested for unit root result values to ensure the accuracy of the results. Once the test is passed, the impulse response and variance decomposition can be made, mainly to see how much each variable affects and contributes to the explanatory variables. The essential steps of empirical testing will be briefly described below.

6.2.1 ADF unit root test

A smoothness test is performed first when building a VAR model on the data. The main reason:

（1） Time series analysis requires certain assumptions, e.g., that the numerical characteristics of the time series do not vary over time or are somehow stable, because if the statistical characteristics of the time series vary over time (the mean or the variance varies), the stochastic situation of the time series will change and its progress will not be captured.

（2） The primary purpose of the stability test is: firstly, the model constructed from the smooth time series is straightforward to meet the stability requirement, and if the model is not stable, an attempt can be made to differentiate the unsteady series to achieve a smooth state. The second is to prevent pseudo-regression.

Therefore, to ensure that the study results are meaningful, testing whether the variable data are smooth is essential. In this paper, the ADF unit root test is used to test the data for smoothness. It mainly checks whether there is a unit root in the series, i.e., if there is a unit root, it is a non-stationary time series. For non-stationary series, differentiation can be performed until the series becomes stationary. Below are the results of the ADF test on the data.

Table 6. ADF test results table

Variable	ADF	1%	5%	10%	P-Value	Result
$\ln C$	-1.709	-3.723	-2.989	-2.625	0.4263	non-stationary
$d\ln C$	-5.24	-3.73	-2.992	-2.626	0.0000	stationary
$\ln PGDP$	-0.865	-3.723	-2.989	-2.625	0.7993	non-stationary
$d\ln PGDP$	-5.107	-3.73	-2.992	-2.626	0.0000	stationary
FTD	-1.920	-3.723	-2.989	-2.625	0.3225	non-stationary
$d\,FTD$	-6.199	-3.73	-2.992	-2.626	0.0000	stationary

IS	-2.418	-3.723	-2.989	-2.625	0.1368	non-stationary
$d\ IS$	-5.647	-3.73	-2.992	-2.626	0.0000	stationary

Note: d **indicates first-order differencing of the corresponding data**

The significance level chosen here is 5%. When the p-value is less than 0.05, it means that it is significant at the 5% level, the original hypothesis is rejected, and the series is smooth. The smaller the p-value, the more unlikely a unit root exists. The results of the ADF test show that the variables are of the same order as the single-integrated series, which meets the requirements of the VAR modelling.

As can be seen from the table, subjecting the raw data to the ADF test, the test results were: The p-value of all the data is more significant than 0.05 at a 5% confidence level. None of the raw data is smooth, indicating that the original series does not reject the original hypothesis and the series is not smooth at a 5% confidence level. Next, the first-order differencing is performed on the series where the original data are not smooth. The differenced data continue to do the ADF test, which results in： The p-values of $\ln C/\ln PGDP/FTD/IS$ are less than 0.05 at a 5% confidence level, indicating that the series rejects the original hypothesis and the series is smooth at 5% level of significance. In summary, the sequences $d\ln C$、$d\ln PGDP$、$d\ FTD$、$d\ IS$ are smooth at the 5% confidence level.

6.2.2 Determining the lag order of a VAR model

The VAR model's lag order can present the whole model's complete dynamic characteristics. However, the choice of the lag order should be neither too broad nor too small if the lag order is too large. However, the established VAR model can capture more information, with the increase in the lag order will reduce the degree of freedom of the system of equations, reducing the accuracy of the estimation of the multi-establishment model. Therefore, the optimal lag order should be balanced between capturing more information and reducing the degree of freedom.

In this paper, a variety of principles are used to determine the optimal lag order, including the likelihood ratio test (LR), the final prediction error criterion (FPE), the Akaike Information Criterion (AIC), the Schwartz Criterion (SC), the Hannan-Quinn

Criterion (HQ)[34], etc., and the one that satisfies the most is chosen to determine the optimal lag order, and the following table shows the results run through the Stata software, which is analysed as follows:

Table 7. Selection of lag order of VAR model

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	74.4609				4.2e-08	-5.63687	-5.58278	-5.44185*
1	86.2581	23.594	16	0.099	6.0e-08	-5.30064	-5.03019	-4.32554
2	102.897	33.277	16	0.007	6.4e-08	-5.35172	-4.86491	-3.59654
3	123.305	40.818	16	0.001	6.1e-08	-5.70442	-5.00125	-3.16916
4	153.401	60.192*	16	0.000	4.2e-08*	-6.83211*	-5.91258*	-3.51677

Note: Data with * in the table indicate the optimal order.

The results of the test show that the optimal lag order of the model is 4, given the combination of the five criteria.

6.2.3 Cointegration tests

The Johansen cointegration test is based on the VAR method, which is more accurate for cointegration estimation with a small sample size. The test is continuous; whether it is the cointegration test, characteristic root trace test or the maximum eigenvalue test, the corresponding original hypothesis test statistic is greater than the critical value at the 5% significance level, indicating that the hypothesis of no cointegration can be rejected at the 95% confidence level, indicating that there is a cointegration relationship between the variables. The primary purpose of the Johansen cointegration analysis is to verify a long-run equilibrium relationship between certain variables. The primary purpose of Johansen's cointegration analysis is to verify the existence of a long-run equilibrium relationship between certain variables. Cointegration is only possible when the order of the variables is the same. From the results of the ADF unit root test, it can be seen that all the variables are smooth series after differencing, so this paper uses the Johansen method to judge whether there is a cointegration relationship between them. The test results are shown in the table below:

[34] Bloom, & Williamson, J. G. (1998). Demographic Transitions and Economic Miracles in Emerging Asia. The World Bank Economic Review, 12(3), 419–455.

Table 8. Johansen cointegration test results

H0: Random walk without drift, a = 0, d = 0

	Test statistic	Dickey-Fuller critical value 1%	5%	10%
Z(t)	-5.128	-2.655	-1.950	-1.601

The test shows that the original hypothesis is rejected at the 5% level for all variables, indicating that there is a long-term stable influence relationship between the variables.

6.2.4 VAR model regression

Table 9. VAR model regression results

Sample: 1995 thru 2019			Number of obs	=	25
Log likelihood =	153.4014		AIC	=	-6.832112
FPE =	4.18e-08		HQIC	=	-5.912577
Det(Sigma_ml) =	5.50e-11		SBIC	=	-3.516769

Equation	Parms	RMSE	R-sq	chi2	P>chi2
d1碳排放量ln	17	.040384	0.5404	29.39107	0.0214
d1人均GDPln	17	.088169	0.7819	89.60501	0.0000
d1外贸依存度	17	.095203	0.5391	29.2439	0.0223
d1产业结构	17	.768835	0.6980	57.7855	0.0000

	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
d1碳排放量ln						
d1碳排放量ln						
L1.	.3121235	.2410015	1.30	0.195	-.1602307	.7844778
L2.	-.244329	.2056272	-1.19	0.235	-.647351	.158693
L3.	.0439996	.3276086	0.13	0.893	-.5981014	.6861007
L4.	.0580226	.1946965	0.30	0.766	-.3235756	.4396208
d1人均GDPln						
L1.	-.1119252	.08679	-1.29	0.197	-.2820304	.05818
L2.	.1402924	.0670258	2.09	0.036	.0089244	.2716605
L3.	-.1817767	.0591782	-3.07	0.002	-.2977637	-.0657896
L4.	.0776207	.0681871	1.14	0.255	-.0560235	.2112649
d1外贸依存度						
L1.	-.1061751	.0995726	-1.07	0.286	-.3013338	.0889837
L2.	.0022348	.1037385	0.02	0.983	-.2010889	.2055585
L3.	.1572484	.0851502	1.85	0.065	-.0096429	.3241397
L4.	.046767	.0869845	0.54	0.591	-.1237194	.2172534
d1产业结构						
L1.	-.0075834	.0107261	-0.71	0.480	-.0286061	.0134392
L2.	.0097532	.0085014	1.15	0.251	-.0069093	.0264156
L3.	.0092419	.0053436	1.73	0.084	-.0012313	.0197152
L4.	-.005244	.0042869	-1.22	0.221	-.0136462	.0031581
_cons	-.0106044	.0167348	-0.63	0.526	-.0434041	.0221952
d1人均GDPln						
d1碳排放量ln						
L1.	2.404309	.5261746	4.57	0.000	1.373025	3.435592
L2.	2.266684	.4489426	5.05	0.000	1.386773	3.146596
L3.	2.447953	.7152625	3.42	0.001	1.046064	3.849842
L4.	.3980323	.4250778	0.94	0.349	-.4351048	1.231169
d1人均GDPln						
L1.	-.4041486	.1894871	-2.13	0.033	-.7755366	-.0327607
L2.	-.0978697	.1463362	-0.67	0.504	-.3846835	.1889441
L3.	.1333523	.1292027	1.03	0.302	-.1198804	.386585
L4.	.1200412	.1488717	0.81	0.420	-.171742	.4118244
d1外贸依存度						
L1.	.1081826	.2173953	0.50	0.619	-.3179044	.5342696
L2.	.2497365	.2264905	1.10	0.270	-.1941768	.6936498
L3.	.4791839	.1859071	2.58	0.010	.1148128	.8435551
L4.	.2995532	.1899118	1.58	0.115	-.072667	.6717735
d1产业结构						
L1.	-.0144146	.023418	-0.62	0.538	-.060313	.0314839
L2.	.0605418	.018561	3.26	0.001	.0241629	.0969207
L3.	.0240815	.0116666	2.06	0.039	.0012154	.0469476
L4.	-.0272534	.0093595	-2.91	0.004	-.0455977	-.0089091
_cons	.106026	.0365369	2.90	0.004	.034415	.177637
d1外贸依存度						
d1碳排放量ln						
L1.	-.1138754	.5681573	-0.20	0.841	-1.227443	.9996925
L2.	-.389845	.4847631	-0.80	0.421	-1.339963	.5602732
L3.	.7734057	.7723322	1.00	0.317	-.7403376	2.287149
L4.	.8361406	.4589941	1.82	0.069	-.0634713	1.735752
d1人均GDPln						
L1.	-.3929828	.204606	-1.92	0.055	-.7940032	.0080377
L2.	-.0742878	.1580122	-0.47	0.638	-.383986	.2354104
L3.	-.1241252	.1395116	-0.89	0.374	-.3975629	.1493125
L4.	.1515412	.16075	0.94	0.346	-.163523	.4666053
d1外贸依存度						
L1.	-.0566597	.234741	-0.24	0.809	-.5167435	.4034241
L2.	-.0916752	.2445619	-0.37	0.708	-.5710077	.3876573
L3.	.1840153	.2007403	0.92	0.359	-.2094285	.5774591
L4.	.1624328	.2050646	0.79	0.428	-.2394864	.5643519
d1产业结构						
L1.	-.0279535	.0252865	-1.11	0.269	-.0775142	.0216071
L2.	.0288001	.020042	1.44	0.151	-.0104814	.0680816
L3.	.0138561	.0125974	1.10	0.271	-.0108344	.0385467
L4.	.0177036	.0101063	1.75	0.080	-.0021044	.0375115
_cons	.0562494	.0394521	1.43	0.154	-.0210753	.1335741
d1产业结构						
d1碳排放量ln						
L1.	.3168413	4.588267	0.07	0.945	-8.675996	9.309679
L2.	12.71974	3.9148	3.25	0.001	5.046874	20.39261
L3.	2.786909	6.237121	0.45	0.655	-9.437624	15.01144
L4.	-8.450506	3.706697	-2.28	0.023	-15.7155	-1.185513
d1人均GDPln						
L1.	-2.00616	1.652336	-1.21	0.225	-5.24468	1.232359
L2.	-.0115088	1.276059	-0.01	0.993	-2.512538	2.48952
L3.	-1.115587	1.126653	-0.99	0.322	-3.323787	1.092613
L4.	2.196058	1.298168	1.69	0.091	-.3483042	4.740421
d1外贸依存度						
L1.	-2.009856	1.895697	-1.06	0.289	-5.725354	1.705641
L2.	1.05167	1.975008	0.53	0.594	-2.819274	4.922614
L3.	-.7375744	1.621118	-0.45	0.649	-3.914907	2.439759
L4.	1.042158	1.656039	0.63	0.529	-2.203619	4.287936
d1产业结构						
L1.	.2275598	.2042061	1.11	0.265	-.1726769	.6277964
L2.	.1466025	.1618528	0.91	0.365	-.170623	.4638281
L3.	-.0720222	.1017332	-0.71	0.479	-.2714156	.1273711
L4.	.0240252	.0816153	0.29	0.768	-.1359379	.1839882
_cons	.2878763	.3186033	0.90	0.366	-.3365747	.9123273

As can be seen from the above figure, when examining the effect of the relevant variables on carbon emissions, the first group of d lnC on its own P-value is more significant than 0.05, which is insignificant, indicating that there is no effect. The p-value of the effect of the second set of d lnPGDP on carbon emissions is significant in the second and third orders, 0.036 and 0.002, respectively, corresponding to coefficients of 0.14 and -0.18, and thus has a homogeneous effect on carbon emissions in the second order and an inverse effect in the third order. The p-value of the effect of the third group d FTD on carbon emissions is significant at the second order, 0.02.

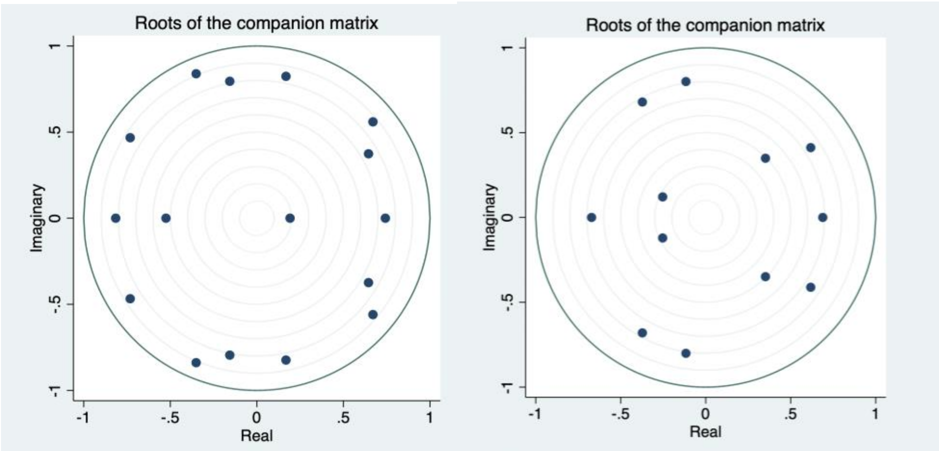
The corresponding coefficient is 0.002, so the effect on carbon emissions is homoscedastic in the second order. The p-value of the effect of the fourth group d IS on carbon emissions is significant at the third order, 0.084, and the corresponding coefficient is 0.009, so the effect on carbon emissions is homoscedastic at the third order.

6.2.5 Stability Tests for VAR Models

Before proceeding to the impulse response and variance decomposition analyses below, the model developed needs to be tested for stability. This is because a stable VAR model allows whichever variable in the model is affected by an external shock to reduce the effect of that external shock over time and, in the end, can bring the system to a new equilibrium state. If a VAR model is built, that is non-stationary or poorly stabilised. Any variable in the model is affected by an external shock. That shock becomes more and more influential on a variable and often invalidates the model.

In this paper, we use the method of unit circle test to test the stability of the established vector autoregressive model. The principle of the unit circle test is to test whether all the characteristic roots of the endogenous variables in the model fall within the unit circle so as to prove whether the mode of the characteristic roots of the system of equations is less than 1. The results of the test are shown in the figure below:

Figure 13. Unit circle test results



The VAR model built in this paper has four variables, and the optimal lag order is fourth order. The left figure is the number of roots, including the d lnC, the number of roots of the characteristic polynomial is 4*4=16 characteristic roots. The right figure is the number of roots of the characteristic polynomial excluding d lnC is 4*3=12 characteristic roots. Hence, the test results show that all the dots are located in the unit circle, i.e., the inverse is less than 1, which indicates that the model is stable. The smoothness test is passed, and we can Impulse response analysis is performed on the model.

6.2.6 Granger causality test

Granger causality test is a method to test the relationship between X and Y. It can be used to determine whether the pre-existing changes in X can effectively explain the changes in Y. If Y is affected by the changes in X. X is said to be the Granger cause of Y. Then there is said to be a Granger causality between these two variables. Usually, the Granger causality test requires a smooth series. However, this test only analyses the sequential relationship of the time series, not the actual causal relationship between the two variables. Whether a causal relationship between the variables still needs to be judged according to the theory, experience, and model.

In order to ascertain if there is Granger causality between economic growth and carbon dioxide emissions, this paper verifies that the results of the Granger causality test are displayed in the Table below. According to the relevant statistical results show that when the test results corresponding to the P value is less than 0.05, the original hypothesis of 'not Granger cause' is rejected so as to determine the Granger causality between the two variables, the test results are shown in the table below, and the specific analyses are as follows:

Table 10. Results of Granger causality test

Equation	Excluded	P-Value	Lag Order
$d\ln C$	$d\ln PGDP$	0.202	4
$d\ln C$	$d\,FTD$	0.171	4
$d\ln C$	$d\,IS$	0.227	4

As can be seen from the table, at the optimal lag order of 4, the significance level P-value is less than 0.05, and all of them reject the original hypothesis. That is to say, at the lag order of 4, d lnC, d lnPGDP, d FTD, and d IS are each other's Granger causes. Meanwhile, it can be found through the previous theoretical analyses that GDP per capita, foreign trade dependence and industrial institutions can affect carbon dioxide emissions. Therefore the study can be continued below.

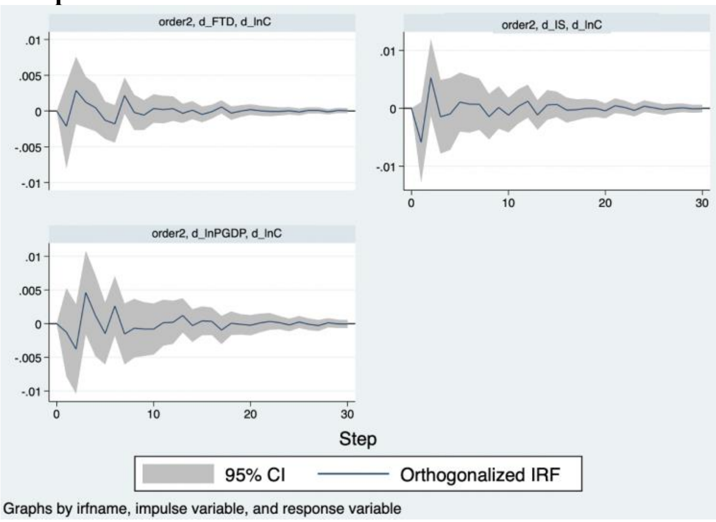
According to a review of the pertinent literature, a majority of studies did not conduct the Granger test prior to impulse response and variance decomposition, and the Granger causality test result is only a statistically significant causal correlation. It is not a test of the actual causality between the two variables, so there is no way to judge the correlation between the variables based on the test results. However, Granger has a particular significance at the level of statistics and has a specific significance in economics for economic prediction.

6.2.7 Impulse response function analysis

Impulse response analysis is mainly to analyse the interactions between endogenous variables in the model by observing the impact of this shock on other endogenous variables in the model given a shock to one of the endogenous variables in the model, which is a more intuitive and effective way to study the dynamic relationship between endogenous variables than the parameter estimation of the model. In this paper, the established VAR model is used to conduct impulse response analysis on d lnC and d lnPGDP, d FTD, and d IS, respectively, to illustrate the dynamic relationship between endogenous variables and to study how the variables of economic growth affect carbon emission after being subjected to specific shocks so that the empirical results are more convincing.

As shown in the figure below, the solid line indicates the impact on carbon emissions when each variable is subjected to a shock. The upper and lower grey areas represent the range of the shock response (95% confidence interval), the X-axis indicates the number of response periods of the impulse response, and the maximum number of response periods in this paper is set to 30. The Y-axis indicates the degree of response of an endogenous variable in the model after it is subjected to a shock.

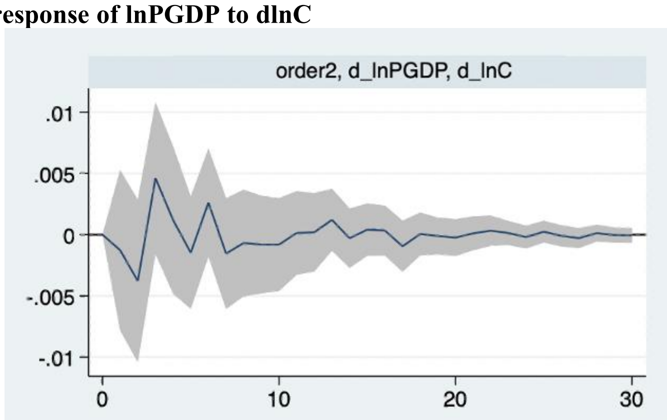
Figure 14. Impulse Response Function Plot



The impulse response results are analysed from the above figure as follows:

（1）Variable $\ln PGDP$

Figure 15. Impulse response of lnPGDP to dlnC



The figure above shows the response of carbon dioxide emissions when hit by a shock to one unit of GDP per capita. After a positive GDP per capita shock in the first period, carbon emissions show a rapid negative swing from zero, reaching a maximum negative impact in the second period. After that, the negative impact gradually decreases, and the impact returns to zero in the third period, followed by a positive impact that reaches the maximum positive impact in the fourth period. This shows that GDP per capita has both positive and negative effects on CO2 emissions. The positive effect then decreases again and reaches zero in the fifth period, maintaining this pattern of change until the eighth period. Starting from the eighth period, it begins to fluctuate in a wave-like manner. It gradually tends to zero as the number of lagged periods increases, which indicates that the initial shock to GDP per capita has a smaller and smaller impact on carbon dioxide emissions as the number of response periods increases. Such a result aligns with our expectations and proves that the VAR model established in this paper is stable.

The economic significance of this is that when GDP per capita rises rapidly, it first has a dampening effect on carbon dioxide emissions, and then the dampening effect decreases and turns into a facilitating effect; GDP per capita has a facilitating effect on carbon dioxide emissions, and in the subsequent lag periods, there will be a facilitating and dampening effect of GDP per capita, which will eventually converge to 0.

（2）Variable FTD

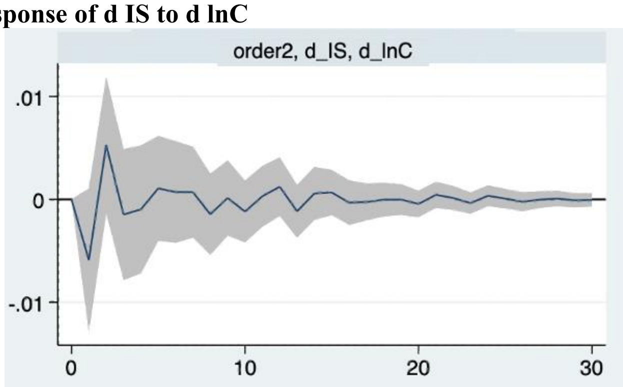
Figure 16. Impulse response of d FTD to d lnC

The figure above shows the response of CO2 emissions when shocked by one unit of foreign trade dependence. After a positive shock to foreign trade dependence in the first period, carbon emissions fluctuate negatively from zero. Moreover, it reaches the maximum value of negative impact in the second period. The negative impact weakens and gradually turns to positive impact, reaches the maximum value of positive impact in the third period, then the positive impact continues to weaken and reaches zero in the fifth period, then the negative impact becomes larger and larger, reaches the second high value of negative impact in the seventh period. The negative impact weakens, produces a positive impact, and reaches zero in the tenth period. Around zero, after which it begins to fluctuate wave-like and gradually tends to zero, so it can also be shown that the established VAR model is stable.

The economic significance of his performance is that foreign trade dependence is a short-lived inhibition of carbon dioxide emissions in the initial period. Due to the increase in import and export trade volume, the effect of foreign trade dependence on carbon dioxide emissions changes to a facilitating effect from the third period onwards and eventually tends to zero.

（3）Variable IS

Figure 17. Impulse response of d IS to d lnC



As can be seen from the figure, after the positive shock to the industrial structure in the first period, the carbon emissions first started to fluctuate negatively from zero. The negative impact effect is the largest in the second period. Then the adverse effect is weakened and starts to change to the maximum positive impact in the third period. Then the positive impact gradually decreases, and there is a slight negative impact from the fourth and the fifth period. It then starts to fluctuate in a wave-like manner. It gradually tends to zero as the number of lagged periods increases, so it can also be shown that the established VAR model is stable.

The economic significance it exhibits is that the industrial structure initially had an inhibitory effect on carbon emissions. The inhibitory effect gradually diminishes with the continuous improvement of the industrial structure, followed by a facilitating effect, which is short-lived, after which changes in the industrial structure no longer have a significant impact on carbon emissions.

6.2.8 Analysis of Variance Decomposition

The impulse response analyses above are primarily designed to examine the persistent dynamic effects of shocks to each endogenous variable in the overall system on the dependent variable in the model developed over different periods. Therefore, after the impulse analysis, the characteristics of the model can be further investigated using variance decomposition. The importance of each factor is objectively evaluated by comparing the contribution of all endogenous variables in the model to a given variable. In order to more accurately evaluate the impact of each disturbance term on the endogenous variables in the system, this paper uses Stata software to implement the variance decomposition. The results and specific analyses are shown below:

Table 11. Variance decomposition of factors on carbon emissions

Step	$d\ln C$	$d\ln PGDP$	$d\,FTD$	$d\,IS$
0	0	0	0	0
1	1	0	0	0
2	0.927502	0.061612	0.00286	0.008026
3	0.853678	0.100366	0.02551	0.020445
4	0.820777	0.099858	0.057399	0.021967
5	0.817806	0.100753	0.059256	0.022185
6	0.812841	0.101054	0.061697	0.024408
7	0.809906	0.095258	0.067436	0.0274
8	0.801655	0.094809	0.069951	0.033585
9	0.79912	0.097211	0.070213	0.033457
10	0.798764	0.09674	0.070753	0.033743
11	0.79892	0.097149	0.070545	0.033385
12	0.798937	0.097168	0.070496	0.033399
13	0.797147	0.098995	0.070386	0.033471
14	0.794124	0.100354	0.072061	0.033462
15	0.793811	0.100673	0.072079	0.033436
16	0.792987	0.101119	0.072194	0.0337
17	0.792932	0.101134	0.072262	0.033672
18	0.791703	0.100974	0.073296	0.034027
19	0.791648	0.100942	0.073277	0.034133
20	0.791763	0.100878	0.073247	0.034112
21	0.791459	0.101099	0.073293	0.034149
22	0.79129	0.101307	0.073271	0.034132
23	0.791163	0.101311	0.073396	0.03413
24	0.791034	0.101448	0.073395	0.034124
25	0.790878	0.101585	0.073423	0.034114
26	0.790788	0.101581	0.073495	0.034137
27	0.790716	0.101639	0.0735	0.034145
28	0.790637	0.101623	0.073593	0.034147
29	0.7906	0.101626	0.07361	0.034164
30	0.790593	0.101631	0.073607	0.034169

Note:

(1) irfname = Variance decomposition, impulse = $d\ln C$**, and response =** $d\ln C$.

(2) irfname = Variance decomposition, impulse = $d\ln PGDP$**, and response =** $d\ln C$.

(3) irfname = Variance decomposition, impulse = $d\,FTD$**, and response =** $d\ln C$.

(4) irfname = Variance decomposition, impulse = $d\,IS$**, and response =** $d\ln C$.

As shown in the table above, there are different degrees of the contribution of each variable to influence the change of carbon emissions within 30 periods. According to the average contribution of the variables to the changes in carbon emissions, in descending order, they are carbon emissions themselves (80.33 per cent), foreign trade dependence (6.69 per cent), national income per capita (9.87 per cent) and industrial structure (3.12 per cent).

When carbon emissions are subjected to their own perturbation term, it is evident that carbon emissions are decreasing, from 1 to 0.6475. In general, the contribution of industrial structure and foreign trade dependence to carbon emissions shows an upward trend. In contrast, the contribution of GDP per capita to carbon emissions shows a short-term fluctuation but an overall upward trend.

As can be seen from the table, the magnitude of the impact on CO2 emissions at a one-period lag is, in descending order, $\ln C > \ln PGDP > FTD > IS$. The contribution of GDP per capita to the impact of CO2 emissions is the largest with increasing lags, and the impact stabilizes after the 14th period, remaining at 10 per cent at the 15th period; The second significant influence on CO2 emissions is foreign trade dependence, and the contribution of the influence is increasing with lag order, stabilizing after 18 periods and remaining at 7.3 per cent with a lag of 19 periods; Finally, the impact of industrial structure on CO2 emissions is increasing with lag order, and the contribution stabilizes after 18 periods. At lag 19, the contribution is still 3.4 per cent.

6.2.9 Analysis of Results

This chapter uses time-series data on carbon emissions, GDP per capita, foreign trade dependence and industrial structure from 1990-2019 to construct a VAR model. It analyses the trend of carbon emissions when they are subjected to shocks from variables related to economic growth using the impulse response function and variance decomposition method.

(1) From the results of the impulse response, after giving a positive shock to the per capita GDP, it is inhibitory to the carbon emissions. With the continuous change of the per capita GDP, its effect on carbon emissions is persistent, and the per capita GDP is also the most intuitive response to the economic growth of an indicator; after giving a positive shock to the dependence on foreign trade and the industrial structure, the carbon emission intensity has an inhibitory effect from zero and becomes promotional after a few periods. After a few periods, it becomes a

promotion effect. To sum up, it can be concluded that economic growth has a suppression and then promotion effect on carbon emissions.

(2) From the results of variance decomposition, per capita GDP has always had the most significant impact on carbon emissions. The influence of foreign trade dependence on carbon emissions is also gradually increasing, which shows that national income per capita, foreign trade dependence and industrial structure can all have an impact on carbon emissions.

In summary, the relationship between per capita GDP and carbon emissions is in line with the environmental Kuznets theory; industrial structure and foreign trade dependence significantly inhibit carbon emissions. Overall, economic growth suppresses carbon emissions.

7. Conclusion

Environmental problems related to global warming have become a significant challenge in economic and social development, and the development of a low-carbon economy is an effective way to combat global warming. As an important country in Central and Eastern Europe, the task of controlling Czech carbon emissions is essential. Therefore, it is crucial to determine the factors affecting Czech carbon emissions and their relative contribution in order to develop policies and instruments to reduce them more effectively.

The concepts of carbon emission and economic growth are explained in the theoretical part of the above paper. The variables that can represent economic growth and affect carbon dioxide emissions, such as industrial structure, foreign trade dependence and per capita GDP, are analysed through the theory of sustainable development, environmental Kuznets curve, low carbon economy, decoupling theory, energy-economy-environment theory and externality theory. Then, analysing the mechanism of economic growth affecting carbon emissions, it is found that the above three variables are indeed closely related to carbon dioxide emissions.

In analysing the current situation of economic growth and carbon emissions in the Czech Republic, this paper finds that the Czech GDP grew from 40728.95 million USD to 252548.18 million USD between 1990 and 2019, an increase of 520%; the GDP per capita increased from 3941.50 USD to 23664.85 USD in 2019, an increase of more than 500%; the dependence on foreign trade has realised significant growth, from 0.38 in 1990 to 1.5 in 2019, an increase of more than 295 per cent; the value added of the services sector in the industrial structure is relatively large, remaining at around 40-56 per cent.

This paper starts from the actual situation of the Czech Republic, based on the data of the Czech Republic from 1990-2019, analyses the current situation of carbon emissions from the current economic and social development of the Czech Republic, constructs a VAR model to analyse the role and contribution of GDP per capita, industrial structure and foreign trade dependence to the growth of carbon emissions in the Czech Republic, and draws the following conclusions: GDP per capita is the leading cause of the increase in CO2 emissions. In line with the environmental Kuznets theory, an increase in GDP per capita in the early stage of economic development will lead to increased carbon dioxide emissions. When the economy reaches a specific size, an increase in GDP per capita will decrease carbon dioxide volume. On the contrary, the industrial structure and foreign trade dependence on carbon emissions is inhibitory. The higher the proportion of the value added by the service industry in the GDP, the more favourable to reduce carbon emissions. The influence of the above three variables on carbon dioxide emissions are, in descending order, GDP per capita, foreign trade dependence and industrial structure. In conclusion, economic growth is an essential factor influencing CO2 emissions in the Czech Republic, and, in the current economic situation in the Czech Republic, economic growth inhibits CO2 emissions.

7.1.1 Relevant recommendations

By analysing the impact of Czech economic growth on carbon emissions, it was found that economic growth raises CO2 emissions to a certain extent, so it is essential to start with other influencing factors to alleviate the pressure of increasing carbon emissions while pursuing economic growth.

(1) The higher the share of the added value of the service sector in the industrial structure, the more favourable it is to reducing carbon emissions. The Czech Republic needs to develop the modern service sector and high-tech industries vigorously, encourage the integration of electronics and information and communication technologies with other fields, promote the intelligent development of other industries, improve the efficiency of industrial production, and promote energy conservation and emission reductions in other industries, as well as promoting the integration of clean technologies with traditional technologies in traditional energy-intensive industries such as iron and steel, cement, and electrical engineering, to improve the energy structure of these energy-consuming industries.

(2) Trade restructuring to promote energy conservation and emission reduction. On the export side, the development goal of foreign trade should be to increase the added value of products, increase scientific and technological investment in export products in order to promote the optimisation of the Czech export trade structure and achieve the effective use of resources, i.e., to encourage the export of products that have a high value-added rate and low energy intensity, such as

communication equipment and computers. At the same time, the export of products with high energy intensity, such as chemical, metal, and mineral products, is appropriately restricted. On the import side, to achieve effective resource conservation and carbon emission control, import-intensive products should be actively encouraged to reduce domestic production of carbon-intensive products.

(3) Developing a circular economy helps reduce carbon emissions. A circular economy is based on the circular and effective use of resources. Low consumption, low emissions and high efficiency characterise it. The development of a circular economy will help to improve the efficiency of energy use and reduce carbon emissions and resource consumption.

(4) Changing the public mindset will help reduce carbon emissions. Energy consumption in daily life is one of the critical factors causing the growth of carbon emissions, and only by fundamentally changing the mindset and raising environmental awareness can energy consumption be effectively reduced. Therefore, knowledge of emission reduction and awareness of energy conservation should be promoted through different channels. People should be aware of the importance of energy conservation and emission reduction through different forms so that citizens and enterprises can consciously participate in energy conservation and emission reduction measures. Guiding society to use and distribute energy rationally, transforming low-carbon lifestyles and consumption habits into people's conscious actions, and working together to improve the ecological environment are very important for the Czech Republic to achieve the goal of energy conservation and emission reduction.

7.1.2 Research gaps and prospects

By referring to many domestic and international literature, this study analyses the factors influencing carbon emissions in the Czech Republic. It provides a basis and direction for the Czech Republic to achieve further emission reduction. However, due to the limitations of knowledge, the availability of data, and the uncertainty and complexity of the factors influencing carbon emissions, the thesis still needs to be improved and will be further improved in future research.

This paper mainly has the following limitations:

(1) The data limit this paper. Only the data from 1990-2019 are selected for the study. Suppose the data are available in the future. In that case, more years of variables will be added as the object of the study, enriching the study and enriching the study's conclusions.

(2) This paper is based on model assumptions to carry out research, only theoretical assumptions. However, in reality, the process of carbon emissions is very complex, there are many factors affecting carbon emissions, and there may be some differences between the assumptions and the reality. The model also has specific requirements for the number of variables. Carbon emissions are the result of a combination of many factors, this paper focuses on the impact of economic growth on carbon emissions, so there may be other vital variables omitted in the establishment of the model, which may lead to an incomplete analysis.

(3) Due to my limited knowledge and space constraints, I cannot study the various models individually, and the research on carbon emissions needs to be further expanded.

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