Energy-Related Carbon Dioxide Emissions from Economic Growth

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Contributor: Zbigniew Gołaś

The study analyzed some energy, fossil fuel, economic, and environmental indicators, such as energy use, CO_2 emissions, driving factors, decoupling elasticity status, and decoupling effort status. It relied on the Kaya identity and Logarithmic Mean Divisia Index (LMDI) in determining the drivers of CO_2 emissions. As shown by the results, between 2004 and 2020, energy consumption in Poland grew at an average annual rate of 0.8%, while fossil fuel carbon emissions declined at 0.7% per year. Energy intensity was found to be the key force behind the reduction in CO_2 emissions, whereas rapid economic growth was the main driver of CO_2 emissions.

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1. Introduction

One of the major environmental challenges facing humanity today is the progressing global warming resulting from increased atmospheric emissions of greenhouse gases (GHGs), especially including carbon dioxide (CO_2), which contributes more than 60% to the greenhouse effect [1][2]. As confirmed by a number of publications, human economic activity is the key source of GHGs. In addition, CO_2 emissions are strongly related to the use of fossil fuels and economic growth [3][4][5].

The need to counteract climate change caused by excessive GHG emissions and to implement sustainable development principles is an increasingly urgent matter expressly addressed in Sustainable Development Goals (SDGs) and in the Paris climate agreement entered into in 2015 by 195 countries at the United Nations Framework Convention on Climate Change [6]. The key goal provided for therein is to limit global warming to 1.5–2.0 °C by the end of this century [7]. Meeting that objective requires a considerable reduction in GHG emissions, which, however, is not easy, because their growth is strictly related to economic development. Therefore, the core issue in today's debates within political and academic communities is the degree to which emissions can be decoupled from economic growth [8].

Decoupling emissions from economic growth is believed to be the key path of sustainable development that prevents environmental degradation with no adverse effects on economic development. However, it is extremely difficult to entirely decouple emissions from economic growth. It would be only possible in a situation where an increase in economic performance is accompanied by an absolute quantitative drop in emissions. The scenario of compatibility between economic growth and reduced emissions is possible both theoretically and practically, as illustrated by numerous examples. In order for this to happen, innovative technologies must be deployed together with an effective economic and fiscal policy, adequate legal regulations, education efforts, and a reorientation of lifestyle focused on implementing the principles of low-carbon living. However, it does not mean that decoupling emissions from growth—as one of the key paths to sustainable development—is not called into question. It is surrounded by different controversies, with negative economic growth being viewed as an enabler of environmental goals. In addition, these controversies gave rise to a broad debate on new terms such as “green growth”, “de-growth” and “agrowth” [8]. “Green growth”, a strategy promoted by the OECD, is designed to support economic growth and development while ensuring that natural assets continue to provide environmental resources and services upon which depends social well-being. Moreover, it is supposed to have a catalyzing effect on investments and innovations, which will provide a basis for sustainable growth and drive new economic opportunities [9][10][11]. In turn, “de-growth” calls into question the necessity of economic growth and proposes a shift toward a post-growth society that values social and environmental well-being over economic growth. Supporters of this concept argue that seeking continuous economic growth is an unsustainable process that contributes to environmental degradation, social disparities, and political instability. They propose alternative forms of economic organization and production that give priority to sustainable growth and to human equality and well-being. Generally, “de-growth” is defined as a fair reduction of production and economic consumption that ensures that the use of resources and waste remains within safe limits of the ecosystem [12][13][14][15]. The above makes “de-growth” clearly focused on a purposeful reduction of economic activity and material wealth [14]. Conversely, the objective of “agrowth” is to attain economic growth while reducing environmental impacts and increasing social well-being. It emphasizes the need to reduce the use of materials and to invest in renewable energies, sustainable infrastructure, and more equitable economic practices. Its supporters argue that economic growth and environmental sustainability can reinforce each other instead of being viewed as incompatible goals. “Agrowth” is a certain alternative to “green growth” and “de-growth”. As emphasized by van den Bergh [12], it is better to be agnostic about growth and implement a strategy that uses *GDP* only as an indicator (because *GDP* growth is neither the ultimate goal nor a means to achieve it). He also indicates that the “agrowth” strategy would allow the identification of more policy areas that may improve well-being and environmental conditions [12].

Generally, even though each of these three approaches supports the concern for environmental sustainability, they differ in how they view the role of economic growth in attaining that goal. “Green growth” supporters suggest that economic growth can be sustainable, whereas advocates of “de-growth” propose a fundamental shift away from seeking economic growth. On the other hand, supporters of “agrowth” seek both economic growth and environmental sustainability through a combination of political interventions and changes to economic practices [12][13][14].

Decoupling is at the core of the debate on sustainable growth, which is expressed by a considerable number of research projects launched to investigate the decoupling trends and to identify the factors that affect them. However, as Lundquist [8] emphasizes, the potential for a total decoupling of emissions remains unclear despite extensive research efforts. The results of empirical studies on emissions decoupling differ between the countries, periods, pollution types, and accounting methods. In addition, they depend on the views on each country’s potential for decoupling. However, generally, the key conclusion is that the current levels of decoupling indicators are below what is needed to enable sustainable growth [8].

In some emerging economies, the growth rate of CO_2 emissions between 1990 and 2020 was noticeably above the worldwide average [16]. For instance, it was 492.6, 435.8, 285.1, 219.4, and 317.9% in China, India, Turkey, Brazil, and Iran, respectively [16]. In turn, Poland saw a 35.7% decline in CO_2 emissions (without LULUCF), from 472.0 million tons in 1989 (base year) to 303.5 million tons in 2020, and a nearly 17% drop in emissions per capita, from 9.2 to 7.7 t [16][17]. Despite the considerable reduction in CO_2 emissions, the most recent per capita statistics for Poland continue to be above the European Union average level of 6.1 t. Poland remains one of the largest CO_2 emitters and is ranked second (2020) after Germany [18]. These emissions mostly come from the energy sector, an important and complex part of the national economy. In addition, Poland largely depends on coal in addressing its energy demand (coal-fired power stations account for most of the national production of electricity). In addition to coal, Poland owns large reserves of natural gas used in producing both electricity and heat. Despite the quite dynamically developing sector of renewables—in which wind and solar energy have an increasingly greater share in national production of electricity—fossil fuels continue to be the main source of energy and thus the main source of greenhouse gas emissions.

2. Studies on Decoupling Process in Country Groups

Chen et al. [2] used the Tapio model to examine the decoupling relationships between influencing factors and CO_2 emissions in OECD countries from 2001 to 2015. The results indicate that the decoupling states between fossil fuel CO_2 intensity, energy mix, energy intensity, *GDP* per capita, population size, and CO_2 emissions during that period are recessive decoupling, weak negative decoupling, and strong decoupling. In turn, Dai et al. [19] examined the occurrence of decoupling between economic growth and energy-related CO_2 emissions in BRICS countries from 1995 to 2014. It follows from their research that Brazil, Russia, and South Africa experienced five decoupling statuses during the study period. However, only three of them occurred in China and India. Moutinho et al. [20] used the Tapio model and the decoupling effort analysis in a study investigating the underlying driving forces behind energy-related per capita CO_2 emissions over the 1993–2017 period in a panel of 16 South American countries. Their study found that this group of countries shifted from the weak decoupling state to the strong decoupling state after the signing of the Kyoto Protocol. In addition, it demonstrated that “strong decoupling” was mainly achieved due to a group of economic drivers, with the negative changes in energy intensity and in domestic investment playing the strongest role in reducing CO_2 emissions per capita. In turn, Zhang et al. [21] analyzed the decoupling elasticity between carbon dioxide, *GDP*, and energy consumption in China and ASEAN countries over the period 1990–2014. As shown in their study, in light of the Tapio model, only three decoupling statuses occurred during the considered period, i.e., weak decoupling, expansive coupling, and expansive negative decoupling. Ozturk et al. [22] examined the decoupling of CO_2 emissions from economic growth for Pakistan, India, and China over the period 1990–2014. The results of the Tapio elasticity analysis showed that these countries experienced a decoupling of environmental impacts from economic growth. However, relatively speaking, it was a costly negative decoupling in Pakistan, mostly weak decoupling and costly coupling in India, and a weak decoupling in China over many years. In addition, the decoupling elasticity analysis showed that energy intensity was a key enabler of decoupling in these countries, while population, wealth, and energy mix undermined its progress. In turn, Li and Jiang [23] attempted to study the impact of R&D on reducing environmental pressures based on an empirical analysis of the world's six largest carbon emitters. The main results from the Tapio model and the LMDI technique showed that over the period 1996–2014, the developed countries enjoyed better and more stable decoupling statuses than developing ones. Another conclusion is that the effect of per capita R&D expenditure was the main inhibitor of decoupling CO_2 emissions from economic development. However, the energy intensity effect and R&D efficiency effect related to technological progress were the main driving forces for the decoupling process.

3. Studies on Decoupling Process in EU Countries

A number of studies have also been carried out in EU countries. Papież et al. [24] analyzed the impact of EU energy policy on decoupling GHG emissions from economic growth between 1996 and 2017. They relied on the Tapio model in carrying out two types of greenhouse gas measurements, i.e., production-based and consumption-based accounting. Although the results show a decoupling of emissions from economic growth in almost all countries, regardless of the type of GHG measurement, it occurs faster in the case of production-based emissions. As regards EU countries (EU-15), the decoupling processes were analyzed by Madaleno and Moutinho [25], who examined the decoupling states and decoupling effort in the context of changes in the evolution of carbon emissions over the period 1995–2014. The study showed that the most significant CO_2 reductions occurred in the years following the signing of Kyoto commitments due to a negative and significant impact of carbon intensity of petroleum products, energy intensity, and conversion efficiency. Furthermore, the authors found that the effects of flexibility and of the decoupling effort were not controlled for by internal CO_2 factors. In addition, the drivers of CO_2 emissions from electricity generation and decoupling processes in the EU were analyzed by Karmellos et al. [26]. According to their results, in the last five years of the study period (2000–2018), a significant number of EU countries moved into a state of strong decoupling, implying successful implementation of relevant energy and environmental policies. Further research among EU countries was carried out by Diakoulaki and Mandaraka [27]. They used the decomposition method to explain the changes in industrial CO_2 emissions and to comparatively assess the progress made in EU-14 countries in decoupling emissions from industrial growth between 1990 and 2003. The decomposition results they obtained were further used to assess the real efforts undertaken in each country and their effectiveness. On these grounds, the authors concluded that most EU countries made an important (although not always sufficient) decoupling effort, but no significant progression was observed in the post-Kyoto period.

4. Studies on Decoupling Process in Other Countries

Wang et al. [28] compared the decoupling efficiency between China and the U.S. They quantified the decoupling statuses using the Tapio index and decomposed the decoupling index to explore the driving factors behind the decoupling using the LMDI technique. They found that in most years between 2000 and 2014, China experienced expansive coupling and weak decoupling, whereas the U.S. mostly saw weak and strong decoupling. Moreover, the authors proved that income and population had a restrictive effect on decoupling, whereas energy intensity and energy mix effects promoted the decoupling process. In addition, the carbon intensity effect exerted negative and positive effects on decoupling in China and the U.S., respectively. Changes in decoupling processes and energy-related CO_2 emissions in the U.S. were also analyzed by Jiang and Li [29]. In light of the decoupling effort ratio, they found that the lack of decoupling prevailed in most of the surveyed years of the 1990–2014 period, whereas strong decoupling was the least frequent state. In turn, Wang and Wang [30] analyzed the decoupling states and the effectiveness of decoupling efforts in the U.S. from 1998 to 2015. Their study used the Tapio model and the decoupling effort model. The analysis of decoupling efforts revealed that energy intensity, R&D intensity and efficiency, and sectoral CO_2 intensity contributed to decoupling economic growth from carbon emission, whereas investment intensity, population size, and sectoral energy structure did not. Freitas and Kaneko [31] used the OECD method to investigate the incidence of decoupling between growth rates in economic activity and CO_2 emissions from energy consumption in Brazil between 2004 and 2009. In general, they identified various periods of relative decoupling in Brazil but also noted that the decoupling processes did not occur smoothly. Based on the Tapio model, Wang et al. [32] presented a new way to study the change in decoupling rates in China, making it possible to answer the question, why does the decoupling rate change over time? Their research found that only three states of CO_2–*GDP* decoupling (weak and expansive decoupling and negative expansive decoupling) occurred during the studied period. In addition, the researchers showed that the energy–*GDP* decoupling effect played a significant role in changing the CO_2–*GDP* decoupling rate, followed by the energy–fossil decoupling effect. In contrast, the CO_2–energy decoupling effect played a small role in changing the CO_2–*GDP* decoupling rate. Zhang and Da [33] implemented the Tapio index to examine the decoupling relationship between CO_2 emissions and growth in China between 1996 and 2010. The results indicate that a relative decoupling effect between CO_2 emissions and economic growth was recorded in most years during the study period. This suggests that the reduction effect of CO_2 emission inhibitors was less than the driving effect of economic growth, and the economy grew with increased carbon emissions. Xu et al. [34] used the Tapio model in decomposing the indicator of the decoupling of fossil energy CO_2 emissions from economic growth in China over the period 1995–2012. Their research showed that decoupling varied due to changes in economic growth and energy intensity between different sub-periods. The economic output effect significantly boosted the decoupling, whereas the energy intensity effect strongly decreased it. In turn, a comparative analysis across different sectors and sub-sectors revealed that industrial growth determined the status of decoupling CO_2 emissions from economic growth. In addition, energy-intensive sub-sectors strongly contributed to the decoupling of CO_2 emissions, whereas non-energy-intensive ones had a relatively slight impact on it. In turn, Engo [35] used the Tapio model to assess the decoupling and determinants that influenced the relationship between growth and CO_2 emissions in Cameroonian industrial and service sectors between 1990 and 2015. The findings showed that Cameroon experienced weak decoupling throughout the research period because weak negative decoupling, strong negative decoupling, and strong decoupling were witnessed in most years, whereas strong decoupling was recorded in only three periods. Roinioti and Koroneos [36] used the decomposition technique and the decoupling index in identifying the driving forces of energy-related CO_2 emissions in the Greek economy between 2003 and 2013. Their research shows that the effects of decoupling varied over time. Weak decoupling was experienced in most years, whereas strong decoupling was recorded in only three periods. Moreover, as a result of the recession, no decoupling was found in the last years of the considered period. Yasmeen and Tan [37] used the Tapio method in analyzing the decoupling relation between environmental degradation, energy use, and economic progress in Pakistan based on data from 1972–2017. Based on the decoupling analysis, they identified the decoupling linkage between energy use and CO_2 emissions (growth negative decoupling). Conversely, a weak decoupling relation was noticed between CO_2 emissions and economic development. Furthermore, a similar weak decoupling relationship was identified to exist between energy consumption and economic progress.

5. Studies on Decoupling Process in Transport Sector

Much research has also been undertaken on the transport sector. Tapio [38] presented a theoretical framework for decoupling and applied it in analyzing the relationships between *GDP*, traffic volumes, and CO_2 emissions from transport in EU countries from 1970 to 2001. Aggregate data showed a shift from expansive negative decoupling to expansive coupling in passenger transport and a shift from weak decoupling to expansive negative decoupling in freight transport. In addition, he discovered a weak decoupling of transport CO_2 emissions from *GDP*. Next, Engo [39] examined the decoupling relationship between energy-related CO_2 emissions and growth in the Cameroonian transportation sector between 1990 and 2016. The decoupling rates were decomposed into five factors with four fuels consumed in this sector. The results derived from the Tapio model showed that only four decoupling states emerged in the surveyed years, i.e., weak and strong decoupling, weak negative decoupling, and strong negative decoupling. However, scale effects, the energy mix effect, and the energy intensity effect precluded decoupling, while the economic structure effect played an important role in decoupling. In the transport sector, similar research was also conducted by Zhao et al. [40], who analyzed the main drivers of energy-related CO_2 emissions in Guangdong, China's richest and most populous province. The results showed that in general, the decoupling level between transport output and CO_2 emissions during the period 1995–2012 was relatively low. In addition, the optimization of the tertiary industry structure was the main inhibitor of CO_2 increase. However, the province experienced rapid growth of *GDP* per capita and population, which was more powerful at boosting CO_2 and resulted in the elasticity index rising directly. Moreover, the research shows that reducing energy intensity can be one of the most important ways to increase the decoupling effort. In turn, Li et al. [41] examined the relationship between the development of the transport sector and its CO_2 emissions from the perspective of 30 Chinese provinces. The results indicated that underdeveloped provinces were more likely to present a weak decoupling state than developed and coastal zones. The researchers also found that income was the major influential factor limiting the development of decoupling in the transport sector and that the population size played a very small negative role in the development of decoupling.

6. Studies on Decoupling Process in Agriculture

Decoupling processes have also been explored in the agricultural sector. Han et al. [42] studied the interactions between agricultural CO_2 emissions and growth in 30 Chinese provinces from 1997 to 2015. Based on these data, the coupling and decoupling effects of CO_2 emissions and the underlying driving factors were examined using the Tapio model. From these studies, it appears that at the regional basis, the degree of coupling between CO_2 emissions and growth was high in the central region of China and low in the western region. At the provincial scale, the coupling effects of CO_2 emissions exhibited four levels: minimal, low, moderate, and high coupling. In turn, in most other provinces, CO_2–growth relations indicated a weak decoupling state. Linkages between development and energy-driven agricultural CO_2 emissions was also studied by Hossain and Chen [43]. Their results showed that the agricultural sector of Bangladesh was strongly and weakly decoupled from agricultural growth in most years of the period 1990–2017. Research in agriculture was also carried out by Huang and Zhang [44] in Heilongjiang, China's largest grain-producing province. The study estimated its grain-production-induced CO_2 emissions and examined the nexus between this production and emissions between 2000 and 2018, using decoupling and decomposition methods. The decoupling analysis showed that weak decoupling occurred for half of the study period; however, the decoupling and coupling states occurred alternately, and there was no definite evolving path from coupling to decoupling. In turn, Liu and Feng [45] attempted to explain the mechanism behind the decoupling of economic growth and CO_2 emissions in the agricultural sector in mainland China from 2005 to 2016. The results obtained from the Tapio model showed that the decoupling efficiency was not perfect. Their study found that the most important factors affecting the decoupling status were investment and investment efficiency, and the major obstacle was investment in productivity growth being greater than investments in energy saving and carbon reduction. In addition, the decoupling status and investment orientation of decoupling activities varied across regions. At the national level, the dominant decoupling status changed from weak to expansive. Luo et al. [46] also studied the decoupling of carbon emissions from agricultural growth in China from 1997 to 2014. Their results indicate that decoupling in the agricultural sector generally followed a favorable trend. Strong negative decoupling prevailed in the early years of the studied period, while weak or strong decoupling was recorded in subsequent years.

7. Studies on Decoupling Process in Spatial Units

A significant number of studies on decoupling process have been carried out in Chinese provinces and counties. Based on the Tapio model and the LMDI method, Huang et al. [47] analyzed the evolution of energy-related CO_2 emissions as well as the decoupling relationship and its driving factors in the Qinghai province between 1997 and 2017. The results indicated that this relationship was represented by four types: weak and strong decoupling, expansion negative decoupling, and expansion coupling. Among them, strong decoupling was achieved in only five sub-periods. Qin et al. [48] used the Tapio index to decompose the driving forces of decoupling and measured the states of the sector's decoupling from CO_2 emissions in the Chinese province of Xinjiang between 2000 and 2017. These studies found the occurrence of four decoupling states in this period, i.e., weak decoupling, expansive coupling, expansive negative decoupling, and strong negative decoupling. Most industries in this province failed to reach the ideal decoupling state, with *GDP* per capita elasticity having the main inhibitory effect on the decoupling of CO_2 emissions. In turn, energy intensity elasticity was a major driver of decoupling. Based on the Tapio model, Shi et al. [49] analyzed the decoupling status of CO_2 emissions from economic growth in 16 districts of Beijing during the period of 2006–2017. Their decoupling states demonstrated some phased improvement characteristics. In 2017, over 93% of districts achieved a decoupling state (whether strong or weak); 37% of districts achieved strong decoupling, the most desirable state. The authors believe these favorable changes to be caused by urban functional zones and the transformation of the industrial structure, as well as by the direct impact of the national environmental policy. In turn, You et al. [50] analyzed the decoupling relationship between coal-related CO_2 emissions and economic growth in China from national and provincial perspectives between 1997 and 2016 through the Tapio index. The results reflect the inverted “U” shape of the decoupling curve and demonstrate that the vast majority of provinces achieved a strong decoupling of economic growth from coal-related carbon emissions by 2016. Furthermore, they prove that activity and energy intensity effects were the prevailing forces driving and curbing the increase in the decoupling rate, respectively. Wang et al. [51] used the decoupling effort indicator to examine the contribution of factors that influenced energy-related CO_2 emissions in the Chinese province of Jiangsu from 1995 until 2009. The findings show that during the period considered, strong decoupling was recorded only twice, and a weak decoupling effect prevailed in most of the remaining time intervals.

8. Studies on Decoupling Process in Other Sectors and Sub-Sectors

The decoupling analyses have also been frequently applied to a number of other sectors and sub-sectors of the Chinese economy. Li et al. [52] studied the decoupling relationship and its influencing factors between economic growth and CO_2 emissions in China in the manufacturing and household sectors between 1996 and 2012. The results showed that the decoupling status of the manufacturing sector remained mainly at the level of weak decoupling, while that of households generally indicated strong decoupling. Luo et al. [53] exploited the Tapio method to analyze the decoupling processes in 28 Chinese industries between 2002 and 2017. In these sectors, economic growth and CO_2 emissions were slowly decoupling. In addition, researchers proved that energy intensity promoted the decoupling, whereas economic growth had an opposite effect. Other factors showed little impact on the decoupling of CO_2 emissions. Wang et al. [54] constructed a decoupling effort index for the Chinese iron and steel industry. Based on the results, they found that the decoupling efforts of the industry gradually changed from weak to strong and that environmental regulations and technological developments particularly contributed to decoupling. In turn, Wan et al. [55] used the Tapio method in investigating the decoupling relationship between CO_2 emissions and growth of the equipment manufacturing industry in China from 2000 to 2014. Based on the results, the authors found this relationship to be weak, which means the industry grew faster than carbon emissions. The indicators of the industry’s decoupling effort were all below 1.0, suggesting that weak decoupling prevailed during the study period. Meanwhile, Wu et al. [56] used the Tapio model to investigate the decoupling relationship between economic output and CO_2 in the Chinese construction industry from 2005 to 2015. Their results indicate that there existed an expansive decoupling relationship between growth and construction-related CO_2 emissions in most Chinese provinces during these years. The researchers also found that economic output played the most significant role in inhibiting the decoupling at both the national and provincial levels, while indirect carbon intensity was the main driver for promoting nationwide decoupling. In turn, Wang et al. [57] explored the decoupling relationship between CO_2 emissions and power generation of the Chinese power sector and the driving factors of the decoupling index at provincial level between 2000 and 2019 using the Tapio and LMDI methods. The decoupling analysis showed that five provinces achieved decoupling, and most provinces were in expansive coupling states in this period. The decomposition analysis also indicated that per capita *GDP* and population size were responsible for inhibiting the decoupling process, whereas thermal power generation efficiency and electricity intensity promoted it. In turn, Yang et al. [58] used the LMDI method and the Tapio index to analyze the decoupling elasticity and effort index of industrial growth and CO_2 emissions in China from 1996 to 2015. They found that industry-related CO_2 emissions increased about 1.5 times during the study period, with the manufacturing sector contributing the most, followed by the transport sector. Furthermore, their research found that the manufacturing sector witnessed a reverse U of decoupling progression, moving from strong decoupling to weak decoupling and then turning back to strong decoupling. In addition, they noted that expansive decoupling and strong negative decoupling emerged in the construction, transport, and commercial sectors; provinces with high energy demand and heavy industry were able to achieve strong decoupling, while those with lower energy demand witnessed a clear trend toward decoupling.

References

1. Ozturk, I.; Acaravci, A. CO2 emissions, energy consumption and economic growth in Turkey. Renew. Sustain. Energy Rev. 2010, 14, 3220–3225.
2. Chen, J.; Wang, P.; Cui, L.; Huang, S.; Song, M. Decomposition and decoupling analysis of CO2 emissions in OECD. Appl. Energy 2018, 231, 937–950.
3. Jiang, Z.; Ding, Z.; Zhang, H.; Cai, W.; Liu, Y. Data-driven ecological performance evaluation for remanufacturing process. Energy Convers. Manag. 2019, 198, 111844.
4. Wang, X.; Yan, L. Driving factors and decoupling analysis of fossil fuel related-carbon dioxide emissions in China. Fuel 2022, 314, 122869.
5. Lv, J.; Gu, F.; Zhang, W.; Guo, J. Life cycle assessment and life cycle costing of sanitary ware manufacturing: A case study in China. J. Clean. Prod. 2019, 238, 117938.
6. COP21. Paris Agreement under the United Nations Framework on Climate Change, 2015. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 1 December 2022).
7. IPPC. Intergovernmental Panel on Climate Change. Global Warming of 1.5 °C. Special Report. 2018. Available online: https://www.ipcc.ch/sr15/ (accessed on 1 December 2021).
8. Lundquist, S. Explaining events of strong decoupling from CO2 and NOx emissions in the OECD 1994–2016. Sci. Total Environ. 2021, 793, 148390.
9. OECD. Sustainable Development: Indicators to Measure Decoupling of Environmental Pressure from Economic Growth. Paris, France, 2022. Available online: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=sg/sd (accessed on 1 December 2021).
10. OECD. Green Growth Indicators 2014. In OECD Green Growth Studies; OECD Publishing: Paris, France, 2014.

11. OECD. Green Growth Indicators 2017. In OECD Green Growth Studies; OECD Publishing: Paris, France, 2017.
12. Van den Bergh, J.C.J.M. Environment versus growth—A criticism of “degrowth” and a plea for “a-growth”. Ecol. Econ. 2011, 70, 881–890.
13. Kallis, G. In Defence of Degrowth. Ecol. Econ. 2011, 70, 873–880.
14. Van den Bergh, J.C.J.M.; Kallis, G. Growth, A-Growth or Degrowth to Stay within Planetary Boundaries? J. Econ. Issues 2012, 46, 909–920.
15. Schneider, F.; Kallis, G.; Martinez-Alier, J. Crisis or Opportunity? Economic Degrowth for Social Equity and Ecological Sustainability. J. Clean. Prod. 2010, 18, 511–518.
16. World Bank Data. World Bank National Accounts Data, and OECD National Accounts Data Files. 2023. Available online: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD (accessed on 1 December 2021).
17. UNFCCC. United Nations Framework Convention on Climate Change (2023) Greenhouse Gas Inventory Data 2023. Available online: https://di.unfccc.int/time_series (accessed on 1 December 2021).
18. EEA Greenhouse Gases. 2023. Available online: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (accessed on 1 December 2021).
19. Dai, S.; Zhang, M.; Huang, W. Decomposing the decoupling of CO2 emission from economic growth in BRICS countries. Nat. Hazards 2016, 84, 1055–1073.
20. Moutinho, V.; Santiago, R.; Fuinhas, J.A.; Marques, A.C. The driving forces of energy-related carbon dioxide emissions from South Latin American countries and their impacts on these countries’ process of decoupling. Environ. Sci. Pollut. Res. 2020, 27, 20685–20698.
21. Zhang, J.; Fan, Z.; Chen, Y.; Gao, J.; Liu, W. Decomposition and decoupling analysis of carbon dioxide emissions from economic growth in the context of China and the ASEAN countries. Sci. Total Environ. 2020, 714, 136649.
22. Ozturk, I.; Majeed, M.T.; Khan, S. Decoupling and decomposition analysis of environmental impact from economic growth: A comparative analysis of Pakistan, India, and China. Environ. Ecol. Stat. 2021, 28, 793–820.
23. Li, R.; Jiang, R. Investigating effect of R&D investment on decoupling environmental pressure from economic growth in the global top six carbon dioxide emitters. Sci. Total Environ. 2020, 740, 140053.
24. Papież, M.; Śmiech, S.; Frodyma, K. The role of energy policy on the decoupling processes in the European Union countries. J. Clean. Prod. 2021, 318, 128484.

25. Madaleno, M.; Moutinho, V. Effects decomposition: Separation of carbon emissions decoupling and decoupling effort in aggregated EU15. Environ. Dev. Sustain. 2018, 20, 181–198.
26. Karmellos, M.; Kosmadakis, V.; Dimas, P.; Tsakanikas, A.; Fylaktos, N.; Taliotis, C.; Zachariadis, T. A decomposition and decoupling analysis of carbon dioxide emissions from electricity generation: Evidence from the EU-27 and the UK. Energy 2021, 231, 120861.
27. Diakoulaki, D.; Mandaraka, M. Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector. Energy Econ. 2007, 29, 636–664.
28. Wang, Q.; Zhao, M.; Li, R.; Su, M. Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States. J. Clean. Prod. 2018, 197, 178–184.
29. Jiang, X.T.; Li, R. Decoupling and Decomposition Analysis of Carbon Emissions from Electric Output in the United States. Sustainability 2017, 9, 886.
30. Wang, Q.; Wang, S. Decoupling economic growth from carbon emissions growth in the United States: The role of research and development. J. Clean. Prod. 2019, 234, 702713.
31. Freitas, L.C.D.; Kaneko, S.J.E.E. Decomposing the Decoupling of CO2 Emissions and Economic Growth in Brazil. Ecol. Econ. 2011, 70, 1459–1469.
32. Wang, W.; Li, M.; Zhang, M. Study on the changes of the decoupling indicator between energy related CO2 emission and GDP in China. Energy 2017, 128, 11–18.
33. Zhang, Y.J.; Da, J.B. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. Renew. Sustain. Energy Rev. 2015, 41, 1255–1266.
34. Xu, S.C.; Zhang, W.W.; He, Z.X.; Han, H.; Long, R.Y.; Chen, H. Decomposition analysis of the decoupling indicator of carbon emissions due to fossil energy consumption from economic growth in China. Energy Effic. 2017, 10, 1365–1380.
35. Engo, J. Decomposing the decoupling of CO2 emissions from economic growth in Cameroon. Environ. Sci. Pollut. Res. 2018, 25, 35451–35463.
36. Roinioti, A.; Koroneos, C. The decomposition of CO2 emissions from energy use in Greece before and during the economic crisis and their decoupling from economic growth. Renew. Sustain. Energy Rev. 2017, 76, 448–459.
37. Yasmeen, H.; Tan, Q. Assessing Pakistan’s energy use, environmental degradation, and economic progress based on Tapio decoupling model. Environ. Sci. Pollut. Res. 2021, 28, 68364–68378.
38. Tapio, P. Towards a theory of decoupling: Degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. Transp. Policy 2005, 12, 137–151.

39. Engo, J. Decoupling analysis of CO2 emissions from transport sector in Cameroon. Sustain. Cities Soc. 2019, 51, 101732.
40. Zhao, Y.; Kuang, Y.; Huang, N. Decomposition Analysis in Decoupling Transport Output from Carbon Emissions in Guangdong Province, China. Energies 2016, 9, 295.
41. Li, Y.; Du, Q.; Lu, X.; Wu, J.; Han, X. Relationship between the development and CO2 emissions of transport sector in China. Transp. Res. Part D Transp. Environ. 2019, 74, 1–14.
42. Han, H.; Zhong, Z.; Guo, Y.; Xi, F.; Liu, S. Coupling and decoupling effects of agricultural carbon emissions in China and their driving factors. Environ. Sci. Pollut. Res. 2018, 25, 25280–25293.
43. Hossain, M.A.; Chen, S. Decoupling of energy-related CO2 emissions from economic growth: A case study of Bangladesh. Environ. Sci. Pollut. Res. 2020, 27, 20844–20860.
44. Huang, Q.; Zhang, Y. Decoupling and Decomposition Analysis of Agricultural Carbon Emissions: Evidence from Heilongjiang Province, China. Int. J. Environ. Res. Public Health 2022, 19, 198.
45. Liu, Y.; Feng, C. What drives the decoupling between economic growth and energy-related CO2 emissions in China's agricultural sector? Environ. Sci. Pollut. Res. 2021, 28, 44165–44182.
46. Luo, Y.; Long, X.; Wu, C.; Zhang, J. Decoupling CO2 emissions from economic growth in agricultural sector across 30 Chinese provinces from 1997 to 2014. J. Clean. Prod. 2017, 159, 220–228.
47. Huang, C.; Zhou, Y.J.; Cheng, J.H. Research on Energy-Related CO2 Emissions Characteristics, Decoupling Relationship and LMDI Factor Decomposition in Qinghai. Front. Energy Res. 2021, 9, 700385.
48. Qin, J.; Gao, L.; Tu, W.; He, J.; Tang, J.; Ma, S.; Zhao, X.; Zhu, X.; Brindha, K.; Tao, H. Decomposition and Decoupling Analysis of Carbon Emissions in Xinjiang Energy Base, China. Energies 2022, 15, 5526.
49. Shi, B.; Xiang, W.; Bai, X.; Wanga, Y.; Geng, G.; Zheng, J. District level decoupling analysis of energy-related carbon dioxide emissions from economic growth in Beijing, China. Energy Rep. 2022, 8, 2045–2051.
50. You, Z.; Zhao, T.; Song, C.; Wang, J. Analyzing China's coal-related carbon emissions from economic growth perspective: Through decoupling and decomposition model. Environ. Sci. Pollut. Res. 2021, 28, 3703–3718.
51. Wang, W.; Liu, R.; Zhang, M.; Li, H. Decomposing the decoupling of energy-related CO2 emissions and economic growth in Jiangsu Province. Energy Sustain. Dev. 2013, 17, 62–71.
52. Li, W.; Sun, S.; Li, H. Decomposing the decoupling relationship between energy-related CO2 emissions and economic growth in China. Nat. Hazards 2015, 79, 977–997.

53. Luo, G.; Baležentis, T.; Zeng, S.; Pan, J. Creating a decarbonized economy: Decoupling effects and driving factors of CO2 emission of 28 industries in China. Energy Environ. 2022, 1–19.
54. Wang, X.; Gao, X.; Shao, Q.; Wei, Y. Factor decomposition and decoupling analysis of air pollutant emissions in China's iron and steel industry. Environ. Sci. Pollut. Res. 2020, 27, 15267–15277.
55. Wan, L.; Wang, Z.L.; Ng, J.C.Y. Measurement research on the decoupling effect of industries' carbon emissions based on the equipment manufacturing industry in China. Energies 2016, 9, 921.
56. Wu, Y.; Chau, K.W.; Lu, W.; Shen, L.; Shuai, C.; Chen, J. Decoupling relationship between economic output and carbon emission in the Chinese construction industry. Environ. Impact Assess. Rev. 2018, 71, 60–69.
57. Wang, J.; Li, Z.; Wu, T.; Wu, S.; Yin, T. The decoupling analysis of CO2 emissions from power generation in Chinese provincial power sector. Energy 2022, 255, 124488.
58. Yang, L.; Yang, Y.; Zhang, X.; Tang, K. Whether China's industrial sectors make efforts to reduce CO2 emissions from production? a decomposed decoupling analysis. Energy 2018, 160, 796–809.