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Research article

Catch-up growth with alpha and beta decoupling and their relationships between CO_2 emissions by GDP, population, energy production, and consumption

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ABSTRACT

This study explores the relationship between CO_2 emissions by GDP, population, energy production, and consumption in the United States, China, Romania, and Thailand economies from 1990 to 2019. It evaluates the phenomenon of catch-up growth, which transpires when an lagging economy goes through an expansionary phase after a period of below-average performance. We used the stochastic model to illustrate in terms of alpha and beta decoupling techniques. The outcomes validated by positive and negative decoupling attitudes play a crucial role in predicting a rise in CO_2 emissions owing to oil, gas, and coal use in comparison to Romania. Thailand and Romania have a more viable road to sustainability than the United States and China. The United States and China appear to have an antagonistic relationship, as suggested by decoupling attitudes. Thailand and Romania are considered to be highly environmentally sustainable countries on account of their minimal carbon emissions, efficient energy usage, and forward-thinking environmental policies. Accordingly, policy recommendations are offered based on CO_2 emissions and effective mitigation policies, since this allows for determining which countries with high emissions need technological advances, best practices, and intersectoral policies.

1. Introduction

A major contributor to climate change is the combustion of fossil fuels, which releases toxic carbon into the atmosphere. And at the same time, this phenomenon causes a huge spike in energy use. The computation of carbon dioxide (CO_2) emissions from the consumption of goods and services has received far less attention than the computation of total national CO_2 emissions [1]. To tackle the inherent challenge of carbon leakages in national emission inventories, we compute consumption-based CO_2 emissions by tracing various pathways of traded goods and services, thereby collecting emissions levels that occur either directly or indirectly [2,3]. As a result of the escalating climate emergency, the demand for measures to reduce CO emissions from the production and use of fossil fuel energy has increased dramatically [4,5]. In respect of examining the correlation between energy production and consumption during a phase of “catch-up” growth, this study employs alpha and beta decoupling techniques [6–8]. The catch-up growth effect between the countries is based on the hypothesis that impoverished economies expand quicker than wealthier ones [9]. This will lead to the ultimate convergence of economies concerning (per capita income). Weak economies will inexorably surpass more powerful ones in the absence of safeguards against global warming [10]. Typically, opposition to environmental concerns has increased globally. There is a

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reciprocal relationship between economic development, and energy production, and consumption [11]. When the maximum amount of energy that can be used from a source is reached, adding more elements to make energy always results in lower incremental returns per unit in the form of pollution [8,12,13]. This research provides empirical support for the catch-effect hypothesis by comparing developing (China, Romania, and Thailand) and developed (United States of America) countries across a variety of macroeconomic dimensions (GDP, population, energy production, and consumption [14].

There has been a lot of focus as of late on finding ways to reduce CO_2 emissions from power plants and other industrial processes [15]. Renewable energy and nuclear energy, both considered clean energy sources, are anticipated to significantly reduce CO_2 emissions and further contribute to the decarbonization of the world in the future [16]. As a consequence of climate change, the green economy and environmental sustainability have arisen as critical concerns for rapidly developing countries. Because, on the one hand, nations are expanding while, on the other, their energy use generates enormous CO_2 emissions [17]. It is evident that CO_2 emissions are a significant contributor to the aforementioned issue [18–21]. The current concern about climate change and global warming has drawn attention to the interconnections among energy use, ecological pollution, and economic indicators (e.g., oil, gas, and production growth). The primary goal is to reduce CO2 emissions in the atmosphere. This ensures that developed and developing countries achieve optimal utilization of natural resources in the domain of energy production [22]. Moreover, it is important to highlight that the magnitude of energy output increases significantly when compared to actual consumption levels that are considerably higher [23,24]. Through the "catch-up" effect, emerging countries can eventually achieve parity with more established nations through the adoption of cutting-edge advances in energy generation, technology expansion, and access to global markets [25–27].

The combustion of oil for energy purposes contributes significantly to CO2 emissions during petroleum production and consumption [28]. During the extraction, refining, and transportation of oil, emissions are generated. Reducing oil use and transitioning to cleaner energy sources is thus imperative in both developing and developed nations in order to mitigate climate change and decrease CO_2 emissions. Geographically separated developing countries, China, Romania, and Thailand are recognized for their rich diversity [29,30]. China is a major oil consumer and producer. GDP growth has boosted oil demand. High oil consumption has caused significant CO_2 emissions. China has reduced its carbon footprint by investing in renewable energy, energy efficiency, and electric vehicles [31]. Despite recent efforts, China's oil production and consumption still significantly impact global CO_2 emissions [32]. Endowed with a diversity of historical influences and awe-inspiring landscapes, Romania produces and consumes its oil for energy purposes [33]. The country's broad energy mix, which comprises nuclear and renewable sources, mitigates the influence on CO_2 emissions to some extent, offsetting the overall impact of oil consumption on emissions [34]. Thailand is dependent on imports to fulfill its energy requirements due to its limited oil production. Significant CO_2 emissions are a direct result of this reliance; as a consequence, the nation is developing energy efficiency and renewable energy initiatives to mitigate environmental concerns [35]. Comparing China to other developing nations like Romania and Thailand deepens and broadens the scope of China's progress [36]. China's economy is rapidly expanding and on track to become the largest in the world. Another consequence of China's rapid and sustained development is economic flow changes. As of 2019, the world's most populated nation has a growing economy that will soon peak energy demand and production. Chinese influence in the global energy industry has expanded as energy needs rise [37,38].

As a leading global user and producer of oil, the United States is a global leader in oil consumption and production [39]. Technical developments have led to a substantial rise in output, resulting in a reduction in oil imports [40]. The nation's economic activities and transportation sector continue to contribute significantly to its oil consumption [41]. As a consequence of its energy dependence on oil, the United States is among the greatest contributors of CO_2 to the planet. Energy efficiency improvements, investment in cleaner technology, and the promotion of renewable energy are all components of the effort to reduce emissions [42]. Furthermore, energy consumption and CO_2 emissions are being intentionally disentangled from economic growth by many countries [43]. Improving energy efficiency, increasing renewable energy production, and implementing strict restrictions are all ways the United States is working to promote economic growth while reducing emissions. Decoupling growth from fossil fuel dependency is a goal of China's energy policy, which includes investments in renewables, stringent energy efficiency standards, and the promotion of green buildings [44]. Lowering energy use and emissions while supporting development is achieved in Thailand through financial incentives, regulatory measures, and public awareness initiatives [45]. Romania adheres to European Union (EU) regulations, updates its infrastructure, and supports renewable energy in order to reduce CO_2 emissions and energy consumption while maintaining economic growth. These planned actions should lead to less pollution and longer-term economic growth [46]. Developing and sustaining a stable economy and ensuring security must consume their entire focus. Energy supplies (such as gas, oil, and coal) continue to be vital to the economies of emerging countries, despite their growing concern over climate change and the subsequent consequences of heightened CO_2 awareness [47–49]. As economic growth requires greater energy production and consumption, which contributes to increased CO_2 emissions, nations are hesitant to prioritize pollution mitigation above the former. This compromise thus receives an unfavorable reception [50]. Decoupling, the primary contribution of this study, would have a substantial influence on worldwide endeavors to reduce emissions [51]. However, it is noteworthy that the most developed country, which concurrently produces the most GHGs, is capable of carrying out this achievement [52].

Prior research has established that nations have achieved sustainable development when the relationship between economic growth and emissions is no longer directly proportional [53,54]. Furthermore, this inquiry pertains to the determinants that impact fluctuations in CO_2 emissions, as well as the decoupling analysis between economic expansion in various nations [48,55–57]. However, this remains mainly unexplored in the context of potential admission by the United States, China, Romania, and Thailand. In this study, we use the alpha (α) and beta (β) decoupling mechanisms implemented in a trading technique pair. In data analysis, the goal is to find and identify promising pairs. It has become the most valuable standard for studying the important data behind CO_2 emissions in relation to GDP, energy output, and consumption. The significant effects of domestic growth and CO_2 emissions in the United States, China, Thailand, and Romania are identified. According to studies done before [48], a decoupling occurs when economic growth revivals break away from the predicted or typical correlations between economic indicators. Studies on beta decoupling methods and their impact on CO_2 emissions provided early support for the decoupling idea [48,50]. The majority of the empirical findings are contradictory and show significant variation. The United States, China, Thailand, and Romania all use different approaches to separating economic growth from energy usage and CO_2 emissions. These approaches are significantly different from one another because of the nuanced considerations that are taken into account in each country's economic and environmental setting [58,59]. The United States and other developed nations have established energy policy frameworks that prioritize innovation, technological adoption, and market-driven incentives to increase energy efficiency and use renewable energy sources. On the other hand, rising economies like Romania and Thailand are achieving sustainable growth through a combination of infrastructure development and energy efficiency measures [60]. They are typically able to do this by utilizing international collaborations and regional commitments. China's strategy needs to balance economic progress with environmental stewardship is reflected in its centralized governance, which allows for ambitious national targets and investments in renewable energy [61]. In order to tackle the common problem of sustainable development, these varied perspectives show how crucial it is to adapt policies and investments to specific regions while also welcoming international cooperation [62].

This study added new insight into the relationship between CO2 emissions and GDP, population, energy output, and consumption when developing countries "catch up," by using alpha and beta decoupling techniques (A&BDT). In order to compete with a powerful economy like the United States, groundbreaking new technology is required [63]. It is conceivable that the existing technological systems of these nations may lack state-of-the-art advancements that are appropriate for the developing sectors. Among the top 25 countries in terms of CO_2 emissions, Thomas C. ranks China, the United States, and Thailand first, second, and twenty, respectively [64]. With respect to this expectation, we delineate a maximum of four developed and emerging nations, comprising one developed powerhouse such as the United States, and one developing powerhouse such as China. Additionally, we select a weekly emerging nation such as Thailand and Romania from the list of the top 25 countries by CO_2 emissions. Furthermore, new technology in emerging economies has contributed to climate change while also facilitating economic globalization. However, developing countries can use their relative returns to their advantage by adopting cutting-edge technology for energy production and consumption in the globalization process. The United Nations asserts that governments and corporations must establish suitable legislation, infrastructure, and incentives to encourage vital lifestyle changes [65]. One way to change consumption habits, particularly among the world's richest people, and perhaps cut greenhouse gas emissions by 40–70 percent by 2050 is to encourage plant-based diets and make it easier to use cleaner forms of transportation [66]. As a result, individuals evaluated the United States, China, Thailand, and Romania through the lens of numerous prior studies. In order to enhance comprehension of the correlation between escalating energy consumption and economic expansion, scholars have investigated decoupling across multiple domains and employing diverse methodologies, encompassing energy production and consumption [19,67–72]. In this study, the A&BD method is employed to investigate the Topia decomposition of energy generation and consumption. The countries demonstrated a range of decoupling strengths and weaknesses, as anticipated, with outcomes classified into categories A through F. This study focuses on the A&BD method among fluctuations in CO_2 emissions. In order to catch up, the catalysts for accelerated development, energy generation, and use. The report contrasts and analyzes the strong and weak decoupling attitudes and percentage (%) adjustments of the STIRPAT groups from a variety of perspectives.

Most empirical studies show inconsistent verification of directional causality, long-term vs. short-term, decoupling for energy policy, and vary widely. In the context of established causality, these findings may have far-reaching ramifications [67,73]. This finding provides further evidence in favor of the view that the relationship between energy use and economic growth may be broken down into separate but complementary dimensions, with both energy consumption and output contributing to overall economic expansion [69,74]. CO_2 emissions are broken down into traded and untraded components and compared to underproductive, consumption-based emissions. Through the use of structural decomposition analysis, they uncovered what exactly causes the intensity of emissions to shift [75,76]. Cultural economic indicators, which pertain to how different societies recorded their resource production and consumption, were used to illustrate the economy. (35) Strong evidence for the impact of energy efficiency in lowering pollution levels and boosting worker output. Policymakers were prompted by the aforementioned findings to investigate the potential contributions of energy consumption and production to the looming environmental problem. However, there has been no study that addresses the impacts of decoupling in terms of alpha and beta decoupling in percentage change [48,77]. The primary goal of this study is to verify the negative consequences of energy production and consumption on the environment in the United States, China, Romania, and Thailand. We use the decoupling mindset along with the alpha and beta techniques to assess the connections between economic expansion, energy output, and consumption, which adds considerable value to our research study. This inquiry was motivated by the need to meet strategies for long-term economic growth with high levels of governance.

In summary, the majority of research validated the decoupling of CO2 emissions from China, Thailand, Romania, and the United States by economic growth, population, energy production, and consumption, but remained aloof from remote results and inferences. This study's primary contribution is alpha decoupling, and we independently calculated beta decoupling with covariance and variance. In previous studies, the beta decoupling method was only used for the alpha effect, not alpha decoupling. (1) In general, extant literature attributes decoupling and disruptions in economic development to CO_2 emissions in Romania, China, the United States, and Thailand. It illustrated production and technological advancements. (2) For technical growth and efficiency, the logarithmic mean division index (LMDI) method is applied. To infer the large impact of CO_2 emissions from energy production and consumption on catch-up growth, it is important to employ a more robust and eloquent methodology. Decoupling, the study's primary finding, would affect international initiatives to reduce CO_2 emissions. Curiously, this is accomplished by the most industrialized nation, which simultaneously emits the largest levels of greenhouse gases. Studies show that countries achieve sustainable development when there is a balance between economic expansion and emissions. This study also incorporates decoupling analyses between economic growth in different countries and factors linked to CO_2 emissions. The trading strategy pair is subjected to alpha (α) and beta (β) decoupling techniques in this investigation. (3) The IPAT team widened the use of the A&BD method to include a stochastic model (STIRPAT) investigation of CO_2 emissions. From 1990 through 2019, we analyzed the A-to-F groups between these variables and CO_2 emissions, GDP, population, oil, gas, and coal production and consumption. This research lays forth a careful methodology for analyzing the A&BD method and its root causes in contemporary times in the United States of America, China, Thailand, and Romania.

This study's framework is: Section 1 introduces the topic; Section 2 reviews the literature on populace and CO_2 emissions, energy production, consumption, and CO_2 emissions. Finally, the report summarizes and identifies research gaps. Section 3 describes the techniques and data in accordance with the research objectives and conceptual and theoretical frameworks. Estimation results and discussion are in Section 4. Finally, the conclusion provides policy recommendations and a research summary.

2. Literature review

2.1. Populace and CO_2 emissions

The energy consumption and production patterns of the United States, China, Thailand, and Romania are different from one another, which is a reflection of their respective economic systems, resource assets, and regulatory frameworks [78,79]. The United States heavily depends on a combination of fossil fuels, nuclear power, and a growing proportion of renewables to support its advanced economy [80]. The country emphasizes enhancing energy efficiency and decreasing emissions through technological advancements and legislative measures. China, the world's biggest energy consumer, has greatly increased its renewable energy production, especially solar and wind, despite still heavily depending on coal due to its continuous industrial and urban growth [8,22]. In order to diversify its energy mix and improve energy security, Thailand is boosting its investments in renewable energy while simultaneously increasing its consumption of natural gas, which is a major contributor to the country's energy dependence [81]. As part of its energy strategy to wean itself off coal, Romania is putting an emphasis on renewable energy generation and energy efficiency within the context of the European Union [34,46]. Every nation is working to lessen its impact on the environment by reducing its carbon footprint through a mix of technological advancement, government regulation, and international collaboration, all while juggling the competing demands of economic growth and sustainable energy practices [82,83]. The United States, China, Thailand, and Romania all contribute to the calm atmosphere. Environmental difficulties for the committed rest of the civilized world through energy production and consumption are properly represented by the catch-up economic expansion of countries [84]. Nonetheless, higher CO_2 emissions are a side effect of the technological revolution occurring in emerging countries [85]. Increasing attention towards the most polluted countries is having a progressively detrimental impact on energy supply and demand in the worldwide market for natural resources [86]. Developing countries consider the reciprocal connection between CO_2 emissions and catch-up economic growth as tangible manifestations of proficiently managing sustainable development via energy production and consumption [87,88]. Indeed, the general populace delivered a compelling exhibition that shed light on the pressing environmental issues that confront the global community [80,89].

Simultaneously, a study [90] examined the impact of the pilot program for trading CO_2 emissions on the land supply for energy-intensive enterprises. By reducing the supply of energy-intensive industries by 25 % through the implementation of steps to reduce CO2 emissions, the results show that environmentally friendly growth can be promoted [91]. [92] indicated that the green investment market facilitates the mobilization of debt money for low CO_2 emission projects and investigated the impact of green investment on the short- and long-term performance of IPOs (IPOS) [93]. also illustrated that investor interest is higher and company performance is higher for those with green investments [7,76,94,95]. have analyzed the primary energy sources and renewable energy usage and discussed that the CO_2 emissions in China are the greatest in the world, according to the World Population Review. The projected value for 2019 is 11.535 gigatons, positioning it as the second largest emitter globally, trailing only the United States (5.243 gigatons). The International Energy Agency (2022) predicts that the combustion of fissile fuel will increase CO_2 emissions by less than 1 percent annually, a negligible portion of the 2018 increase due to the significant proliferation of renewable energy sources and electric vehicles [96]. New information suggests that by 2022, CO_2 emissions will have increased by close to 300 million tonnes, to 33.8 billion tonnes. The swift global recovery from the economic crisis induced by the pandemic led to a far larger increase of about 2 billion tonnes in 2021, therefore, this is a lot lesser increase. This year's increase may mostly be attributed to power generation and the aviation sector since air travel has rebounded from its lows brought on by the pandemic. In contrast, research has shown that economic expansion has the potential to increase CO_2 emissions, whilst the use of renewable energy sources has been connected to a substantial reduction in CO_2 emissions [48,97]. Moreover, this research unveiled a comprehensive causal relationship that is reciprocal in nature, affecting energy production and consumption, technological innovation, CO_2 emissions, and the general public [6,98]. Additionally, in the context of catch-up growth, economic diversification and the allocation of proceeds from natural resource exploitation towards the development of innovative technologies may serve as catalysts for the promotion of ecological development [99,100]. Although technological progress and ecological security are not the sole noteworthy indicators, the dual-edged impact on the decrease of CO_2 emissions receives insufficient consideration [48,101].

2.2. Energy production, consumption, and CO_2 emissions

There have been numerous studies conducted in countries like China, Romania, Thailand, and the United States on the topic of CO_2 emissions [48,73,98,102–106]. Four different foundations of study are tied to decoupling approaches that are often overlooked despite their significance. As a first step, we use a decomposition index (alpha and beta decoupling), a production decomposition model, and per-capita consumption data to establish which socioeconomic drivers are most important for determining CO_2 emissions [96,107, 108]. Second, the pertinent details reveal how the United States, China, Romania, and Thailand are all coordinating their catch-up growth with their CO_2 emission plans. The third metric depicts economic expansion and population increase, while the fourth metric displays CO_2 accounting literature across six-time intervals, 1990–2019.

As a developed nation, the United States contributes to global CO_2 emissions through its energy use and production [109]. Natural gas and renewable energy have been added to the energy mix, but coal and oil still emit CO_2. To cut emissions, use more renewable energy, improve energy efficiency, and use carbon capture and storage technology [110]. After diversifying its energy mix with natural gas and renewable sources, the US still relies on coal and oil, resulting in high CO_2 emissions [100,111]. The U.S. must accelerate renewable energy adoption, energy efficiency, and carbon capture and storage to reduce energy-related CO_2 emissions, according to the research [112]. As a developing nation, China is primarily the leader in energy consumption; but its economic growth and energy consumption have been supported by the pilferage of resources that were formerly global [72,113]. This accomplishment has a dual purpose: not only does it furnish China with a solid theoretical foundation, but it also sheds light on prospective policies regarding the development of energy on a worldwide scale [114,115]. Additionally [116,117], discussed due to its substantial reliance on these commodities, China, like the United States, can achieve resource security and speed up the transition to non-fossil energy sources [118, 119]. The energy sustainability metric can be used to track CO_2 output, energy use, and GDP expansion. They also give a solid practical foundation for considering the sustainability of China's economic growth over the long term [120,121]. In 2019, coal, natural gas, and oil were the three primary energy sources that supplied China with the most. (20 percent, 58 %, and 8 %, respectively). However, China has diversified its energy supply in recent years, substituting alternative sources for coal and oil. The increase in oil consumption, amounting to 14.5 million barrels per day (b/d), accounts for approximately two-thirds of the overall surge in global oil consumption [37,122,123].

Furthermore, the energy generation portfolio of Romania is multifaceted, encompassing coal, natural gas, hydroelectricity, and nuclear power. A combination of state and commercial energy businesses operates throughout the nation [124]. The primary determinants of energy demand in Romania are transportation, industrial activities, and household consumption [125]. In relation to the concern that energy production and consumption impact CO_2 emissions, the nation's energy composition comprises cleaner sources such as nuclear and hydroelectric power, but it continues to depend on coal and natural gas, both of which contribute to the emission of CO_2 [126]. Continual efforts are being invested in the development of renewable energy sources and the improvement of energy efficiency to address the CO_2 emissions linked to energy production and consumption in Romania. Such efforts are vital for ensuring that consumption demands are met sustainably [127,128]. Romania's energy consumption is predicted to decrease from 43.0 (Mtoe) in 2020 to 36.7 (Mtoe) in 2030, as outlined in the country's National Energy and Climate Plan (NECP) [129]. From 2021 to 2030, they estimated the Romanian energy strategy would cost EUR 127 billion (almost 6 % of current GDP). Romania, home to 19.4 million people, produced 112 kt of oil in 2019 but used 742 ktep less of the stuff in 2020 [76,130,131].

Thailand generates energy from gas, coal, renewable energy (solar and hydropower), natural gas, and foreign oil. Industry, households, and transportation utilize most of the nation's energy [132]. To promote sustainable consumption, energy efficiency and diversification are being improved [133]. Thailand's energy generation, which relies on fossil fuels like natural gas and coal, emits CO_2. Renewable energy integration has made progress, but prioritizing and accelerating these efforts to reduce CO_2 emissions is crucial [8,134]. Prioritized are energy efficiency and renewable energy in an effort to lessen the environmental impact of Thailand's energy production and consumption [81,135]. In last, industries under high stress release enormous amounts of CO_2 into the atmosphere in developing and developed countries. It shows how technical applications and well-planned strategies can reduce CO_2 emissions [136, 137]. Primary and tertiary sectors consumed less electricity and healing energies than secondary sectors. However, CO_2 emissions increased, and supply and demand cut back [76,138]. Thailand's overall energy consumption climbed by 2351 ktep in 2019 with a population of 69.4 million, despite a 256 kt drop in oil production. Nationally Determined Contribution (NDC) values predict that by 2030, Thailand will have reduced its CO_2 emissions by 20 percent, and by 25 percent if adequate funding and technology transfer are provided [116,139,140].

3. Methodology

3.1. Alpha and beta decoupling technique (A&BDT)

This paper provides a detailed explanation of the notion of decoupling, breaking it down into its parts, alpha and beta. When two different indicators increase/decrease or move in opposite directions, the decoupling approach is in effect. Alpha, and the beta decoupling method (A&BDT) display indicator pairs in which, as one variable rises, the other falls. As a result, it remains in a state between ± 1 and $\pm$ 2 until the alpha and beta decoupling. This study used a stochastic approach to analyze how the public produces and consumes oil, gas, and coal for energy. Assessing the possible action of specific indicators in countries and rethinking IPAT's uniqueness is the current hypothesis behind the IPAT method. By breaking down T into components like energy production and consumption (EP&C) and GDP (C) per impact (T). It's a self-identifier in the same vein as I=PACT. The CO_2 emissions were analyzed using the IPAT identification concept. Accordingly, the CO_2 emissions (consumption per person) in this analysis reflect (I), the total population (P), GDP per person (A), and CO_2 emissions per dollar of GDP (T). Inspired by IPAT, this stochastic model (STIRPAT) accounts for drivers of environmental change through CO_2 emissions.

The method presented in this research is based on the common decoupling concept, which is used to calculate the percentage of indicators with robots' analysis like once every five years in groups. This study modifies the strategy originally developed for Beta Decoupling Techniques (BDT) by adding the Alpha decoupling technique, hence the A&BDT. CO_2 emission estimation strategies based on GDP, population, energy output, and consumption for economic catch-up growth. A stochastic model was used to assess indicators

Table 1
Definition of variables and codes.

Variables		Code		IPAT	Description
CO_2 emissions		CO_2		**I**	Per capita- CO_2 emissions, consumption-based
Total populace		POP		**P**	Total populace (Gapminder-in 1 million)
Gross domestic product		GDP		**A**	GDP per capita using PPP (purchasing power of parity). The gross domestic output in international dollars is divided by the population.
Oi production (TWh)	Production and consumption of energy (oil, natural gas, and coal) are measured in twh (Terawatt Hour) and ej (Exajoules).	OPR	T1	**T**	It is the amount of energy released by a different burning process.
Oil consumption (E.J.)		OCS	T2		
Gas production (TWh)		GPR	T3		It is a change in gas output and consumption over time. It demonstrates the rate at which countries scale up manufacturing using a different method.
Gas consumption (E.J.)		GCS	T4		
Coal production (TWh)		CPR	T5		It is the most significant element utilized in the iron and steel industries and is typically employed to create power.
Coal consumption (EJ)		CCS	T6		

Source: https://ourworldindata.org/search?q=energy for the United States, China, Thailand, and Romania (IPAT). While IPAT shows four separate groups, this study analyses the effects of alpha and beta decoupling on indicators like changes in CO_2 emissions. However, the decoupling of different energy sources by the effects of GDP, energy production, and consumption, and their consequence on the population, has not received enough attention in the previous assessment of that research approach.

In this line of thinking, we choose variables that fall into IPAT categories: I (consumption-based CO_2 emissions), P (total population), A (GDP per capita), and T (total population growth rate) (OPR, OCS, GPR, GCS, CPR, and CCS). There is a close relationship and co-integration between these variables across industries and their role in catch-up growth. I (CO_2 emissions), P (population), A (GDP), and T (technology) are the categories that appear on the IPAT, and the entire population analyzes technology. To determine alpha (a) and beta (b) in A&BDT, this data is adjusted by covariance and variance. CO_2 emissions from the generation and use of energy are modified according to each person's unique decoupling value. Using catch-up growth for particular countries, it illustrates the effects of a 1 percent shift in population (P), economic output (A), and technological advancement (T). The alpha and beta decoupling model of choice for groups (IPAT) has emerged after meeting all of the groups' needs (Table 1).

3.2. STIRPAT model and data

In this study, we use a decoupling approach to computing the data. This graphic presents the interplay between decoupling strategies and catch-up growth in the United States, China, Thailand, and Romania in terms of CO_2 emissions, economic growth, population, energy production, and consumption. However, policymakers must face the unsettling reality that expanding the economy is ecologically unsustainable. The primary goal of this research was to use the STIRPAT model to analyze the decoupling of CO_2 emissions (α and β), as well as the IPAT disentangling component and the GDP-measured growth or decline. The analytical variables and their respective definitions are listed in Table 1. We examined the 1990–2019 statistics for the United States, China, Thailand, and Romania using panel data. These countries apply the idea of catch-up growth, and we compare their economic development at the technological frontier. Economies in various nations distant from the technological frontier can grow, and catch-up growth can be considerably more rapid than growth at the technological frontier (Appendix A). We chose four countries (the United States, China, Thailand, and Romania) among eight (the United States, Japan, South Korea, Poland, Romania, Thailand, Botswana, and China) based on the availability of data [141].

Prior research analyzed the relationship between CO_2 emissions, GDP growth, energy consumption, power generation, value-added sectors, and population using a stochastic approach, as stated in the preceding sentence [12,142–144]. In this research study, we use the alpha and beta decoupling method regarding the catch-up growth and it is critical to establish a strategy for simultaneous economic and environmental growth. Prior research has failed to consider energy consumption, value-added industries, electricity generation, and the economic impact of realization [145]. The stochastic (STIRPAT) approach was used to determine CO_2 emissions between 1990 and 2019. This study examines the decoupling process between (α) and beta (β) in data analysis. In the United States, China, Romania, and Thailand, A&BDT is utilized between CO_2 emissions, GDP, population, energy production and consumption. It compares and analyses catch-up growth with the decoupling (α and β) scenario and percent change from multiple STIRPAT cluster perspectives. Based on decoupling [22,48,50,146–149], this study uses the decoupling mechanism as a trading approach to uncover promising combinations of indicators in various countries based on catch-up growth. It's likely that the cutting-edge technologies that these expanding sectors need are not present in these countries' current technology.

A&BD converts percentage changes in CO_2 emissions into corresponding percentage changes in GDP. IPAT examines the covariance, variance, alpha, and beta of groups every five years and finds evidence that decoupling takes place in the elastic ranges' alpha and beta components. As a whole, there have been six distinct groups active between 1990 and 2019. By contrast, groups A and F allow for in-depth examination of explanatory factors such as POP, GDP, OPR, OCS, GPR, GCS, CPR, and CCS. There are descriptive statistics computed for each residual in the set. It shows that the Jarque-Bera statistics reject the normal distribution hypothesis for the experimental indicators of POP, GDP, OPR, OCS, GPR, GCS, CPR, and CCS. Furthermore, the experimental indicators that have been logarithmetic transformed simplify the comprehension of the exponents' regression coefficient. The following is the result of applying a log transformation to the data in order to normalize it. Further accuracy can be achieved due to the explanatory factors associated with CO_2, and the evolution of the CO_2 descriptive value can be observed. The CO_2 predictor bears the majority of the responsibility in calculating the worldwide average POP value. It is utilized by both developing and developed countries (Appendix B).

The A&BD calculation for this investigation involves two technical steps. Initially, beta is calculated every 5 years using covariance and the variance ratio (n-1). Furthermore, an alpha value is calculated every 5 years using the average change in the dependent variable as the beta. Two, decoupling, negative decoupling, and coupling are the categories used to categorize three-level decoupling distributions. Both the positive (+1 to +2) and negative (−1 to −2) decoupling characteristics serve as verifiers of the significance of decoupling. We calculate the decoupling stance over five years (average change in indicators) using beta (covariance/variance * 5/4) and alpha (average change in CO_2 emissions - beta). The primary contribution of this study is the alpha-decoupling of behaviors and attitudes, in contrast to the findings of the previous research. In terms of GDP, population, energy output, and consumption, it displays more accurate percentage changes in CO_2 emissions. According to the decoupling values in the A&BDT, zero and its subsets maintain their unique perspective on the concept. Different levels of support for and opposition to decoupling can be thought of as strong, weak, recessive, or expansive in unfavorable situations. In the meantime, value adjustments with spur catch-up growth. Since it is non-zero, the variable has a decoupling impact [48]. Strong decoupling, weak decoupling, expensive coupling, and negative decoupling are all present, as found in the previous research. Changes (%) in energy production and consumption expressed as a percentage concerning the highest and lowest decoupling levels imply corresponding changes in CO_2 emissions.

Both positive and negative perspectives on energy production (OPR, GPR, and CPR) and consumption (OCS, GCS, and CCS) in the

United States, China, Thailand, and Romania are considered. The real 1 % change in CO_2 emissions due to the catch-up growth of the countries was studied using A&BD's changes. The decoupling technique also improved every five years (groups) between 1990 and 2019. The A&BD method accounts for the range of +1 to −2, where production and consumption of oil, gas, and coal will cause increases and decreases in CO_2 emissions depending on per capita consumption. Even though the decoupling value between energy output and consumption is less than −1. We compress the CO_2 emissions caused by various technological competencies and fine-tune the new catch-up growth plans. The impact of GDP per capita on CO_2 emissions from primary sources of energy use was analyzed.

4. Results and discussion

We estimated decoupling for China, Romania, Thailand, and the United States using the A&BD link between CO2 emissions and GDP, population, energy output, and energy consumption. From 1990 to 2019, Our World in Data mined all relevant data.

4.1. GDP per capita

The A&BD calculation reveals divergent perspectives on the importance of a certain percentage change in CO_2 emissions based on the estimation results of individual countries (the United States, China, Thailand, and Romania). A one percent change in GDP in China should result in a −1.22603e-05 percent change in CO_2 emissions, according to the covariance of GDP, while the covariance of alpha and beta is 0.259 and −1.611 percent, respectively, according to the covariance of GDP computed over five years. The GDP shift has a value of 0.063 percent in terms of alpha and beta percentages. Thus, the distribution of CO_2 emissions in 2017 will change. GDP percentage change signifies the anticipated transition in CO_2 emissions throughout the subsequent three years. As a result, the A&BD projects a change in 2020 of −0.259 in CO_2 emissions and 1.612 in GDP. Additionally, estimated findings for 2017 show that the percentage change in GDP in the United States, Romania, and Thailand is 0.015 percent, 0.070 percent, and 0.036 percent, respectively. Fig. 2 displays the changes in CO_2 emissions due to alpha decoupling (−0.107 percent), beta decoupling (−0.013 percent), and zero decoupling (0.007 percent). Changes in CO_2 emissions of 1 % depending on catch-up growth (GDP) with a decoupling mindset. The alpha and beta decouplings were calculated by subtracting the results of a 1 % change in CO_2 emissions from the beta or alpha attitudes. According to the study's main contribution, each of the two hypotheses—alpha decoupling and beta decoupling—explained in greater detail one component of the relationship between economic development, population, energy output, consumption, and greenhouse gas emissions.

However, the decoupling values are revised annually, and we determined what each subset could reasonably expect to achieve (A, B, C, D, E, and F). The projected findings of alpha and beta decoupling in China in 2016 showed that the country produced a record volume of CO_2 emissions with a 1 % change, with values of 0.306 and 3.468, respectively. Similar results were seen in the United States (−0.029 and 1.175 in 2012), Romania (−0.186 and 1.268 in 2004), and Thailand (0.046 and 0.080 in 2015). As a result, it became clear that countries needed to slow their rapid expansion and revamp their strategic and sustainable policies in order to catch up. The nations of China, the United States, Thailand, and Romania exhibit the greatest decoupling values, which indicate a percentage change in CO_2 emissions that can be attributed to technological advancements. CO_2 emissions have gone up, but the decoupling attitude is greater than −2. The environmental impacts can't be managed without reforming sustainable policies. In this analysis, we have focused on the connections between CO_2 emissions, GDP, population growth, and the information technology revolution as driving forces in the world's need for, and supply of, energy. The oil industry, renewable-geothermal industry, nuclear industry, and the value-added sector are only a few of the others that use more energy [150].

[151] China has already implemented comprehensive decarbonization scenarios that are expected to save costs by between $12 and $35 billion by 2050 thanks to carbon capture and storage technologies or hydrogen-based technology [152]. They underlined the importance of energy-saving technology in the context of increasing economic growth and lowering CO_2 emissions [153,154]. showed that technical progress cut CO_2 emissions from the manufacturing sector by 78 % [154]. verified the need for Thailand to push for long-term solutions by validating the policy ramifications of CO_2 emissions reduction and energy efficiency [155,156]. implies that a developed country was the starting point for a significant decoupling of energy consumption (United States). The decoupling impacts of alpha on GDP and population in 2022 are displayed in Fig. 1. The United States, Thailand, and Romania have the largest documented differences between their GDP and population. In contrast, China is the world's largest country. There was growth in GDP

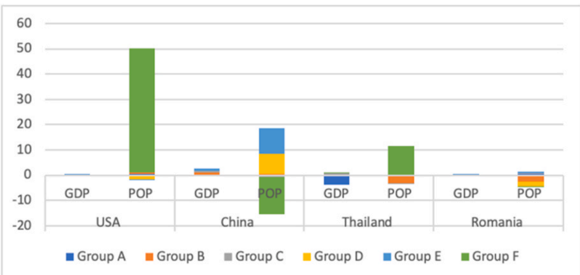

Fig. 1. Alpha decoupling of GDP and populace.

relative to population after 2009, and there was little change in GDP per person and total population. In addition, the growth of economies in countries that produce a disproportionate amount of global CO_2 emissions is no longer the single most important reason [157]. Due to advancements in infrastructure and technology, these regions' economies have flourished [158].

In beta decoupling, the United States has the most negative decoupling attitude of any country, whereas China and Thailand are examples of positively decoupling countries (2015–2019). Group F's alpha decoupling attitude, on the other hand, reveals a positive US decoupling attitude and a negative Chinese decoupling attitude in the same time frame. Thus, in order to catch up to the United States and China, Romania, and Thailand are investing heavily in rapid technological advancement (Fig. 2).

4.2. Energy production

Oil, gas, and coal output are broken down into their respective A-F categories in Fig. 2. The covariance of oil production (OPR) for 2017 energy output indicated that a 1 % shift in CO_2 emissions from the United States, China, Romania, and Thailand should each be 0.00031 %, 0.0058 %, −5.086e-05 %, and −0.0006 %, respectively. A decoupling attitude of 0.036 and −0.048 was also revealed by the United States alpha and beta covariance statistics. Similar shifts are occurring as a result of decoupling in CO_2 emissions, particularly in China, Romania, and Thailand. So, both the good and bad responses to the 1 % annual change in CO_2 emissions from oil production have gotten smaller over the past few years.

Changing CO_2 emissions by 1 % is used to determine the decoupling. As part of A&BD methods, it was deducted from the alpha and beta attitudes. We anticipated alpha and beta shifts by their attitudes because a 1 % change in oil, gas, and coal output immediately indicated a 1 % change in CO_2 emissions. On a five-year time, scale, we calculate the decoupling attitude. The decoupling mentality has grown increasingly resentful over the past three years. Similarly, in 2015, the A&BD attitude for US oil production (OPR) was between 0.050 and −0.165 (see Fig. 3). Here, a one percent swing in CO_2 emissions represents the impact in 2018. Thailand (0.036 and 1.977 in 2018), Romania (0.085 and 1.458 in 2014), and China (11.443 and 0.421 in 2009) all exhibit rather significant levels of decoupling.

According to the same formula, the United States has the most A&BD decoupling attitude in 2019 (0.218 and −4.896), followed by China (0.442 and −3.979) in 2016 (Fig. 4), Romania (0.061 and −0.266) in 2014, and Thailand (0.154 and −0.607) in 2007 (Fig. 4).

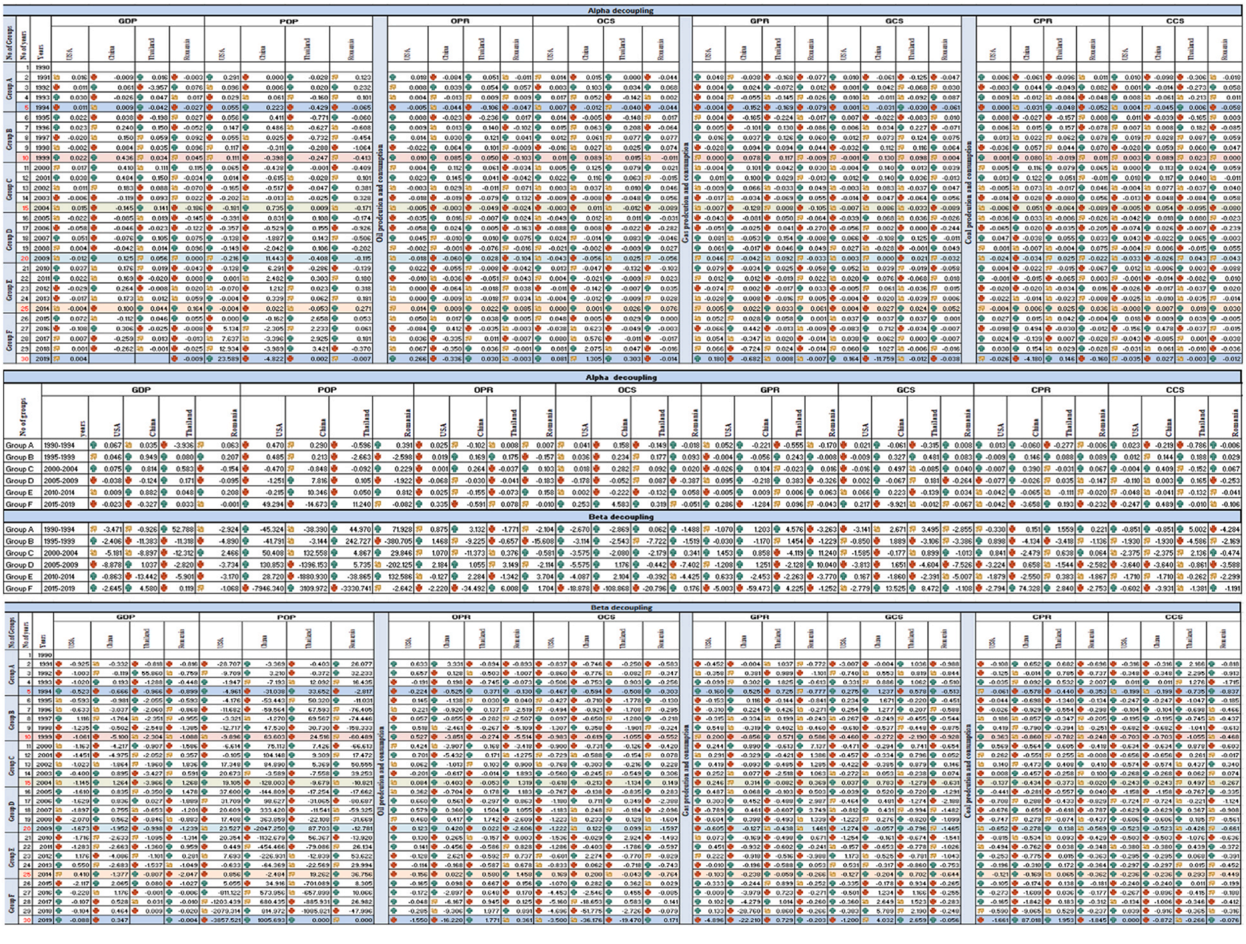

Fig. 2. Alpha and beta decoupling (individual and groups) Note: Variable's definition stated in Table 1.

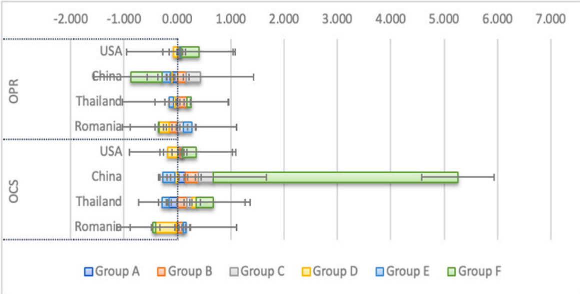

Fig. 3. Alpha decoupling of oil production (OPR) and consumption (OCS).

Thailand's 2019 CPR is predicted to be 0.146 and 1.953, the United States' CPR was −0.590 and 0.030 in 2018, China's CPR was 0.494 and −1.609 in 2016, Romania's CPR was −0.437 and 0.075 in 2008, and China's CPR was −1.609 and 0.075 in 2018. Greater numbers of GPR and CPR were recorded in China, the United States, Romania, and Thailand.

The A&BD decoupling method uses a five-year decoupling outlook to forecast the consequences of energy production in the next year (oil, gas, and coal). Let's pretend we calculated the Group F additive findings for the future 1 % decrease in CO_2 emissions. Five-year cumulative A&BD results reveal distinct decoupling impacts of oil, gas, and coal energy production and consumption. The United States (OPR of 0.335 and −2.220), China (OPR of −0.591 and −34.492), Romania (OPR of −0.010 and 1.704), and Thailand (OPR of 0.010 and 1.704) have the highest levels of OPR decoupling (0.078 and 6.008). In the United States, a GPR decoupling attitude of −0.286 and −0.042 is investigated; in China, −1.284 and −59.473; in Romania, −0.043 and −1.252; and in Thailand, 0.096 and 4.225. Attitudes about CPR decoupling are found to be −2.794 and −0.042 in the United States, −74.328 and −3.658 in China, −2.753 and −0.232 in Romania, and 0.193 and 2.840 in Thailand. This decoupling estimate details the factors that will lead to a one percent shift in CO_2 emissions in 2022 and how this will affect energy output.

Decoupling effects taken as a whole also showed that Thailand and Romania have a large impact on global CO_2 emissions [88]. Changes (1 %) in energy output in the United States and China are responsible for the predicted 1 percent increase in CO_2 emissions. As a result of the technological revolution, both China and the United States have begun to exert a modicum of control over oil production and the factors that contribute to the percentage change in CO_2 emissions. From what can be gleaned above, both the Thai and American public are generally supportive of GPR decoupling. Additionally, the CPR reveals a constructive decoupling attitude in China and Thailand. These projected findings span a period of five years, demonstrating a ± decoupling of attitudes. And if it's more negative than minus two, we can expect a rise in CO_2 output. China ranks fourth in annual oil output at 4.90 billion barrels, followed by Romania at 9.64 million and Thailand at 5.31 million barrels per day (bbl./day), respectively. With 14.837 billion (bbl./day), U.S. oil output is at an all-time high [159,160]. With a yearly output of 4.90 billion barrels of oil, China ranks 4th in the world, behind only Romania (9.64 million) and Thailand (5.31 million bbl./day), respectively. The 14.837 billion barrels per day (bbl./day) of oil produced in the United States is a record.

Finally, driving's intrinsic value as a source of both pleasure and inspiration is closely tied to its close association with oil and energy use. Furthermore, the use of renewable-geothermal energy has a significant impact on CO_2 emissions in industrial sectors, demonstrating how the adoption of new technologies can mitigate negative environmental impacts [161]. Furthermore, this report provides a comprehensive analysis of the issue, which is a big step up from earlier ones that mainly highlighted the issues affecting energy efficiency in Romania. Evidence suggests that urbanization, technological progress, industrialization, and international trade all have an impact on energy efficiency [162].

4.3. Energy consumption

Groups A through F analyze oil, gas, and coal (OCS, GCS, and CCS) using patterns. The decoupling's five-year impact was measured.

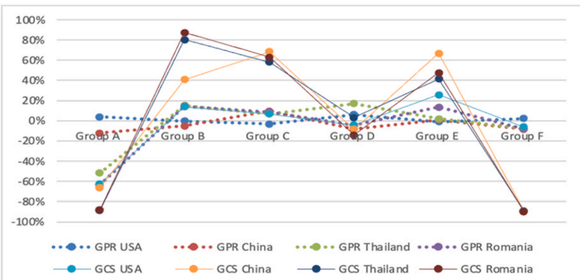

Fig. 4. Decoupling of the alpha of gas production (GPR) and consumption (GCS).

A 1 % change in CO_2 emissions is depicted in Fig. 2, along with the covariance and decoupling results of energy use. We expected a 1 % shift in alignment with the A&BD attitude based on covariance, alpha, and beta estimates for oil, gas, and coal usage. Covariance, alpha, and beta estimates for oil, gas, and coal usage indicated a 1 % shift in alignment with the A&BD attitude was to be expected. The covariance of OCS predicted that the percentage changes in CO_2 emissions from the United States, China, Romania, and Thailand would be 0.010 percent, 0.0431 percent, 0.0468 percent, and 0.0258 percent, respectively, in 2017. Furthermore, the United States had a decoupling attitude of 0.080 and −5.160 in terms of alpha and beta covariance. The above OPR calculation takes into account the grouping of China, Romania, and Thailand to determine the percentage change in CO_2 emissions counted by OCS with ± decoupling.

The A&BD five-year additive results for group F show individual decoupling effects and a comparison of oil, gas, and coal consumption with energy production. Similarly, the sum of the OPR and OCS for the United States as a result of alpha decoupling is 0.335. Thereby, the proportion is calculated to be 0.75. Even though China produces just −0.129 times as much OCS as it is assessed to be worth, the value of OCS is estimated to be substantially higher. The OPR output of Romania is more than adequate in light of its OCS ratio of 5.272. Comparing Thailand and Romania, the OCS ratio is substantially greater in Thailand, but the OPR volume is only 0.244. The beta decoupling estimate ratio of OPR and OCS in the United States, China, Romania, and Thailand is 8.504, 3.156, 0.104, and −0.257, respectively. Group F demonstrated the anticipated volumetric shift in CO_2 emissions in 2022 using A&BD methodologies, demonstrating the 1 percent shift in OPR and OCS. In particular, the percentage shift in CO_2 emissions is a major factor in shaping the A&BD perspective of OCS, which in this case stands for China and Thailand.

The largest A&BD decoupling attitude was also reflected by GCS in the United States in 2019 (−0.164 and −1.200), China in 2018 (−1.027 and 5.789), Romania in 2014 (−0.052 and −0.644), and Thailand in 2015 (−0.037 and 0.934). The sum of the alpha decoupling results for the United States is 0.286 for GPR and 0.217 for GCS, both expressed as a percentage of the total volume of the GCP. Given this, we can calculate that the ratio is 0.760. Moreover, in China, Romania, and Thailand, the estimated ratio values of GPR and GCS are 7.726, 1.560, and −0.122, respectively. Based on beta decoupling. In the United States, China, Romania, and Thailand, respectively, the estimated GPR and GCS are 1,800, −4.397, 1,130, and −0.499. Globally, China, the United States, Thailand, and Romania all produce less GCS than they use. There is a clear decoupling effect between GCS usage and the percentage change in CO_2 emissions, with GCS consumption being much lower in countries using OCS.

In addition, CCS is a representation of the A&BD attitude, with the highest decoupling in the United States (0.018 and −0.240 in 2015), China (0.478 and −11.658 in 2016), and Romania (0.030 and −0.449 in 2014). Lastly, Thailand, with a 2015 and 2014 total of 0.039. The cumulative effects of alpha decoupling in the United States reveal a CPR volume of −0.042 and a CCS volume of −0.247, respectively. That brings us to a ratio volume of 5.937. CPR/CCS estimates also come out to −7.474, 2.185, and −0.050, respectively, in China, Romania, and Thailand. The estimated relative volumes of CPR and CCS in the United States, China, Romania, and Thailand are 1.407, −1.032, 2.312, and −0.486, respectively, based on beta decoupling. Fig. 5. When compared to its production in the United States and Thailand, the volume of CCS is significantly lower. A new record for CCS decoupling effect in China. In the United States and Thailand, CCS in CO_2 emissions is less sensitive to percentage changes because of this decoupling effect.

[163] has reported that China's oil and gas consumption will likely peak at 705 (mote) in 2035 and that the country's reliance on oil imports will vary widely between 70 % in 2050 and 30 % in 2030. In addition, the anticipated outcomes highlight the consequences of energy use. The impacts of alpha and beta decoupling on a one percent change in indicators over the next three years are shown [164]. oil consumption in the United States is predicted to drop by around 13 % from 2018 to 2019 levels by 2020. This study's anticipated findings stressed the importance of coal and gas usage in determining the extent to which catch-up contributes to overall CO_2 emissions. The total amount of electricity used in Thailand has been revealed by the country's current energy status. That's equivalent to 97 percent of their domestic consumption, with the remaining 3 percent coming from imports. Key energy indicators, including crude oil, gas, and oil consumption, are used in energy production [165]. According to the decoupling attitude of Alpha, the energy consumption of Thailand (oil and gas) is relatively high compared to coal. The green, yellow, and red arrows represent the growing and decreasing effects of energy levels, while the A&BD results reveal the attitudes about decoupling 1 and 2. In addition, CO_2 emissions are on the rise [69]. Economic growth and openness in Thailand are anticipated to be high. Between 1990 and 2015, the percentage of energy that came from oil, gas, and coal jumped from 46 % to 80 %. CO_2 emissions are increased annually by 23 %, calculated on the basis of energy usage [69,166]. Group F's analysis of Thailand's oil and coal use found that the country's per capita CO_2 emissions have been rising in recent years.

Changes in the composition of the economy, the level of employment, and the style of living of the general populace are all factors

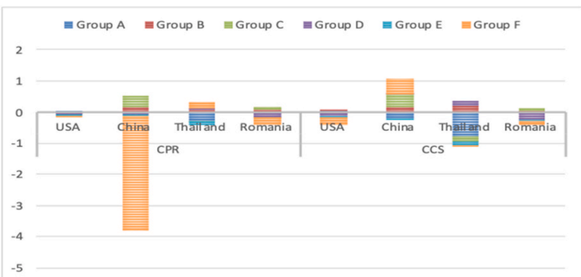

Fig. 5. Alpha decoupling of coal production (CPR) and consumption (CCS).

that are expected to raise energy demand by the year 2050 [167]. Consequently, an examination of the relations between the United States, China, Thailand, and Romania constitutes the primary objective of this study [168,169]. An EIA report claims that Romania has one of the major refining industries in Eastern Europe, with nine oil refineries and a combined capacity of 4.67 million barrels per day (bbl/d). The country is able to export excess oil products due to a consumption capacity that is substantially larger than the total energy output and domestic consumption. The Romani have also been ranked as the world's fifth-biggest source of natural gas. It was in 1983 when gas production peaked at 1,4 trillion cubic feet (Tcf). The numbers for coal output and use were 0.167 and 0.91 quadrillion Btu, respectively (50). Groups C and F's green arrows were found to be significantly impacted by energy use. Hence, separating the effects of changes in alpha and beta value on CO_2 emissions by 1 %. For the next three years, both positive and negative attitudes on decoupling point to productive outcomes. An increase in oil, gas, and coal use is to blame for Romania's rising CO_2 emissions under scenario F. After three years, it tracked how people felt about decoupling and how much importance they placed on it.

The United States, China, Thailand, and Romania all have a similar relationship between CO_2 emissions, energy consumption, output, economic growth, and population, which can only be measured primarily using BDT for groups A through F in Appendix C's figure. Previous research disregarded the effect that using separate decoupling methods like BDT and A&BDT would have on energy consumption and production. This chart indicates a significant change in the production and use of intellectual energy. China has the highest OPR decoupling attitude (3,334) and the lowest (0.124), whereas group F's OCS is only 0.299. In the same scenario, the second intellectual decoupling attitude is reported in Romania with 0.702 in the OPR and in the OCS with −1107. Thailand and the United States have the largest decoupling attitudes, with 0.466 and 1.173 in GPR and −0.219 and −0.44 in GCS, respectively.

Finally, the CPR scores of 0.466 and −0.036 for Thailand and the United States, respectively, are higher than the CCS scores of 0.188 and 0.038. Access to decoupling is provided by subtracting the beta value calculated from 1 percent CO_2 emission changes. We hypothesized that positive and negative attitudes would cause a shift in the beta value. For this strategy to work, the decoupling value must be greater than −2. Additionally, CO_2 emissions are rising, and we have calculated decoupling for the subsequent five years. A variety of approaches are being taken in the New Era by countries including the United States, China, Thailand, and Romania to curb CO_2 emissions and guarantee healthy populations, steady economic growth, and cost-effective energy use. Structured coal power generation with lower CO_2 emissions. Additionally, upgraded methods are derived from renewable (wind, water, solar, and nuclear) and less polluting (than traditional) sources of power. However, popular preconceptions and technological limitations make nuclear energy sources unsafe for everyday use. When used routinely, biomass energy is a clean source of power that can solve a variety of pressing energy issues without compromising the health of the environment.

4.4. Populace

POP was defined by the number of people in each country. Since the predicted covariance of beta in China is −0.0072, we can deduce that a 1 % change in POP should result in a 6.0670e-08 fluctuation in CO_2 emissions. Pollutants of primary importance (POP) emissions have decreased by 0.0054 %, whereas the beta fraction of CO_2 emissions has decreased by −0.0067 %. We estimate the value of decoupling to be −2.484 in 2014 with a negative outlook, based on the fact that a 1 percent change in CO_2 emissions was computed at 0.0054 percent. The beta attitude after decoupling from a one percent change in CO_2 emissions. So, we calculated that the beta decoupling attitude shift should be −0.0072. Decoupling happened (a −2.484-percentage point difference) and CO_2 emissions changed (by 0.0052 percentage points) only in group E, which is where this pessimistic outlook originates (2014). The decoupling grew by 34,916 % in year 2. As a result of decoupling, the sum of the two years' performance was −66.853. As a result, the estimated results demonstrate that the rise in CO_2 emissions is attributable to the shift in the POP in China, Romania, Thailand, and the United States. Similarly, POP estimated the percentage change in the covariance among Thailand, Romania, and the United States over the course of five years. A boost in CO_2 emissions from specific countries, however, can lead to population shifts. Group E consists entirely of countries where the living population has long since died, with the sole exception of Romania. CO_2 emissions in Group F members China and the United States rose as their populations grew faster than those in Romania and Thailand.

[48] The rate of urbanization in China was found to have risen by 20.61 percent between 2009 and 2019. More than 60 %.31 % of China's population visits urban areas annually. However, the high energy demand is expected to lead to massive increases in CO_2 emissions [170]. In 2020, the Romanian government has projected that green energy will account for 24 percent of the country's energy mix, more than double the amount. Green energy in Romania is expected to account for 24 percent of the country's energy mix in 2020, which is more than double the proportion the Romanian government had projected. Therefore, the European Commission (EC) recommends cutting net emissions of greenhouse gases by 55 % between 1990 and 2030. As a result, the whole population of Thailand has decreased at a similar rate in an effort to achieve net zero emissions by 2050. As a result, the report predicts that by 2028, the population will have risen to over 71 million, from a 2008 low of 63,4 million. Despite the varying rates of economic development and catch-up among countries, the volume of CO_2 emissions is on the rise [171]. Population growth in the United States in 2019 was also a major issue. The result was that 5.1 billion metric tons of CO_2 were released into the atmosphere as a result of energy use. This accounts for 15.4 % of total emissions worldwide [172].

In terms of global environmental health, CO_2 is by far the biggest concern. A major value of this research is its ability to aid policymakers in different countries in their analysis and decision-making about population, GDP, and technological advancements in energy use [173,174]. We built our stochastic model using dimensionality reduction and statistical analysis, focusing on the top four countries based on their influence [175,176]. Results also vary by region, with some studies highlighting the insignificant or even expanding effects of CO_2 emissions and their consequences, while others fail to find any link between the two. Due to the correlation of and with the decoupling (α and β) attitude, the decoupling is associated with a 1 percent shift in CO_2 emissions. The α decoupling value is less than the value because it represents the difference between the average change of CO_2 emissions with a 1 percent likelihood of indicator attitude and a β decoupling attitude. In the United States and China, the population α decoupling was expressed as 23,589 and −4,822, respectively. Nonetheless, the decoupling suggested respective values of −3857.52 and 1056.3 in 2019. We calculated the β decoupling attitude for each group using covariance and variance variation. In addition, the change of 1 percent in CO_2 emissions is valid for a third year. Therefore, the one percent change in the decoupling attitude for 2019 indicates a shift in 2022.

5. Conclusions and policy implications

We calculated CO_2 emissions for the years 1990–2019 for the United States, China, Romania, and Thailand by GDP, total population, energy production (OPR, GPR, and CPR), and energy consumption (OCS, GCS, and CCS) using the alpha and beta decoupling (A&BD) method.

An analysis was conducted on GDP, population, energy output, and energy consumption for each group A through F in order to ascertain the degree to which CO_2 emissions have decoupled from growth by ± and the rate at which each group has caught up to growth. Inferred from the above calculation are implications for energy production and consumption in the United States, China, Thailand, and Romania, all of which may be affected by future global decoupling consequences. To top it all off, we succeeded in adopting a decoupling mindset that places premium importance on energy efficiency and renewable. When compared to Thailand and Romania, China and the United States have much superior capabilities to guarantee environmental security using cutting-edge technology. This decoupling method is used to estimate future energy growth, with a focus on the volume rise of CO_2 emissions from the catch-up growth and use of oil, gas, and coal. As a result, we need to lessen the burden on the environment caused by technological advancements and recent policy changes. The data showed that the efficiency of collective energy production was diminished to a small extent due to CO_2 emissions.

There are policy ramifications that can be drawn from this study's findings. To realize the vision of creating carbon-free states, it is essential that the United States, China, Thailand, and Romania adhere to, and further reinforce, the basic principles of green energy, green production, green living, and green financing in all cooperative initiatives. Hydropower, solar power, and wind power are all examples of clean, renewable energy sources that the countries should prioritize in their cooperative initiatives to reduce their environmental impact. China is able to help other countries since it possesses the necessary technology and extensive experience in these fields. The implementation of these projects will have far-reaching effects on both the reduction of CO_2 emissions and the expansion of national economies. Third, the introduction of energy-saving and emission-reduction technologies from China, like electric cars and high-speed train technologies in the transportation industry, can have a positive environmental impact on some energy-intensive industries in countries, allowing those countries to make progress toward sustainable development. Fourth, in order to exploit China's technology and experience to cut CO_2 emissions during construction, the United States, Romania, and Thailand can improve their collaboration in various other sectors, such as building construction and urban regeneration. Fourth, in order to make better use of China's technology and experience in reducing CO_2 emissions throughout the construction process, the United States, Romania, and Thailand might improve collaboration in some other sectors, such as building construction and urban regeneration. Finally, in the manufacturing sector, trade with China and investment from China can be leveraged to stimulate industrial upgrading, enhance production efficiency, and decrease a country's CO_2 emission intensity.

Discovering new sources of renewable energy is the focus of this discussion. In order to phase out fossil fuel infrastructure, renewable energy like thermal, hydroelectric, and wind power facilities will be built. The environmental toll of oil drilling, coal mining, and other extraction methods is mitigated by switching to clean energy. Based on these findings, this research gives the most effective policy proposals. First, energy conservation allows for more control over overall usage, resulting in cheaper energy bills and less environmental damage due to CO_2 emissions. Powering our homes and businesses with renewable resources like biomass, geothermal, water, wind, etc. is an absolute necessity. Also, the updated HVAC system will help save money by using less energy. The paper traces the evolution of HVAC systems in buildings, which have significantly improved the living conditions of their occupants and the quality of their indoor air. Second, the implementation of carbon capture and storage (CCS) technology at various megawatt power stations could potentially eliminate enough CO_2 to offset the annual greenhouse gas emissions from millions of cars. The United States, Chinese, Thai, and Romanian oil and gas sectors have all introduced or modified (by means of Fuel Cell Energy and ExxonMobil) new CCS technology that has the potential to generate additional power while simultaneously reducing CO_2 emissions.

Third, monitor energy demand and take staid steps by strong government mandates, lower costs, and high demand for the vigor amassed usage of renewable energy. Also, regulate the climate change that can boost food insecurity, ecological changes, sea levels, and rise in extreme weather such as droughts, hurricanes, and flooding. Industrial pollution (direct and indirect emissions) can be regulated with new technologies and reduce industrial leaks and chemical reactions during manufacture. The industrial sector contributes to around 22 percent of greenhouse gas emissions in the United States. In addition, some are the major delights, requiring modifying standards in the manufacturing production process and facility management to minimize CO_2 emissions from industries. Last but not least, new studies need to prioritize decoupling energy consumption and population increase in order to better understand the relationship between energy and economic growth. We also suggest that the United States, China, Thailand, and Romania all improve their economic sustainability and development structures by revising strategic policies under the jurisdiction of environmental protection agencies. Finally, this article examined the influence of the growth in energy production and consumption in the United States, China, Thailand, and Romania, as far as the data allowed. It is clear that further investigation into how to correctly assess the impact of green money on energy efficiency is warranted.

CRediT authorship contribution statement

Rabnawaz Khan: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Rabnawaz Khan reports financial support was provided by Fujian University of Technology. Rabnawaz Khan reports a relationship with Fujian University of Technology that includes: employment. Rabnawaz Khan has patent Dr pending to Dr.Nawaz. N/A.

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Appendix A. All data are obtained from the Economic Growth

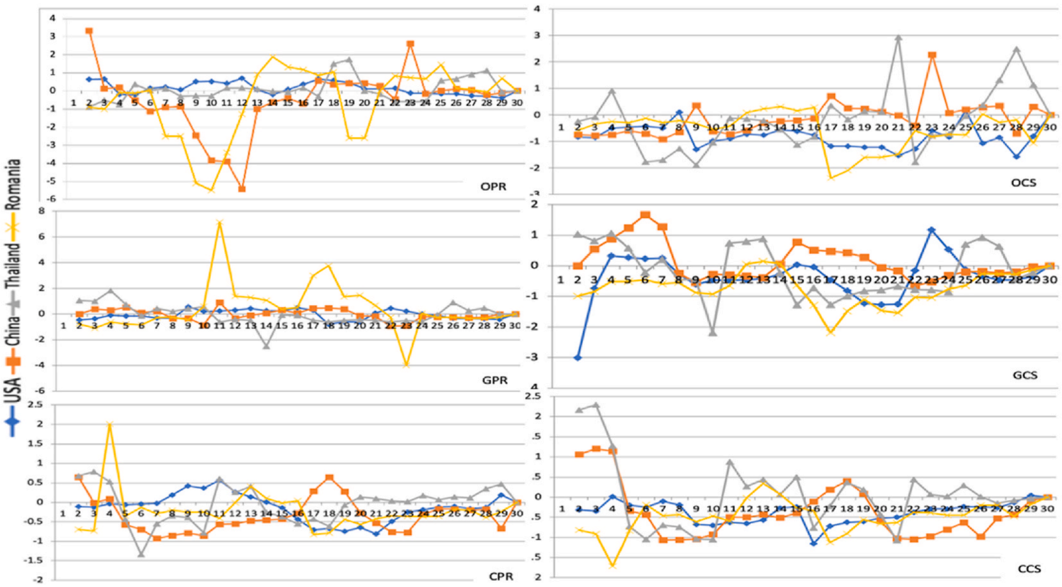
https://ourworldindata.org/economic-growth.

Appendix B. Summary of descriptive statistics

Des.stat	I(CO_2)	P(POP)	A(GDP)	T1(OPR)	T2(OCS)	T3(GPR)	T4(GCS)	T5(CPR)	T6(CCS)
Mean	7.926	19935.220	426.545	1724.764	3680.251	1683.348	1912.652	4963.160	5036.150
Median	4.201	12758.650	252.120	1605.934	1331.569	274.140	330.113	4083.578	3689.462
Maximum	22.398	55719.120	1427.648	7798.318	11213.710	8358.659	8199.426	22034.150	22900.340
Minimum	1.923	1526.409	19.506	28.325	97.088	67.499	60.653	41.606	45.351
Std. Dev.	7.245	16435.970	530.828	1950.281	4146.980	2397.755	2638.650	6345.643	6666.513
Skewness	1.111	0.985	1.032	0.940	0.718	1.247	1.114	1.362	1.491
Kurtosis	2.399	2.442	2.252	2.946	1.802	2.919	2.444	4.011	4.281
Jarque-Bera	25.365	20.107	23.106	16.942	16.756	29.839	25.248	40.456	50.489
Observations	115	115	115	115	115	115	115	115	115

Note: Table 1 shows the definition of the variables. Descriptive statistics (Des.stat). **Sources:** Author's estimates based on the dataset.

Appendix C. Beta decoupling of oil, gas, and coal consumption and production



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