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Decoupling economic growth from energy consumption: Review of global trends and policy implications

Ali Abbas*

School of Management, Xiamen University, Xiamen, China

ABSTRACT

As the climate crisis worsens on a global scale, the need to reconcile economic growth with environmental sustainability has become a defining challenge of the 21st century. At the heart of this discourse is decoupling, which alleviates the negative impacts of economic activity on the environment without endangering development objectives. This review article provides a comprehensive synthesis of global experiences with both relative and absolute decoupling, focusing on the underlying theoretical foundations, empirical patterns, and policy mechanisms that characterize the pursuit of sustainable growth. Based on cross-country comparisons and detailed case studies, we examine how members of diverse income groups strike a balance between economic development and environmental responsibility. Developed countries are increasingly demonstrating absolute decoupling, supported by technological innovation, structural economic transformation, and robust policy frameworks. On the other hand, relative decoupling is evident in a middle-income economy, as it has recorded high growth while making modest gains in energy efficiency and emissions control. Low-income countries, on the other hand, tend to be tightly coupled, dogged by dependence on fossil fuels, weak institutions, and weak access to clean technologies. The review outlines the major drivers of climate action, including carbon pricing, investments in renewable energy, urbanization, and the quality of governance, along with persistent impediments, such as a shortage of infrastructure, policy inertia, and a lack of capital. In addition, the article defines new emerging research gaps and highlights the need for sector-specific analysis, behavioral insights, and equitable policy design with just transition in mind.

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Highlights

- Reconciling the growth of the economy and environmental sustainability has become a defining challenge
- Comprehensive synthesis of global experiences with both relative and absolute decoupling
- Major drivers of climate action, including carbon pricing, investments in renewable energy, urbanization, and quality of governance

*Email: mianali348@hotmail.com

1 Introduction

For many years, it has been widely believed that achieving economic development is incompatible with ensuring environmental health. Conventionally, the process of economic growth has been closely linked to increased energy consumption, primarily through the use of fossil fuels (Adom and Adams, 2020). This link is mainly due to the energy-mass-energy consumption associated with industrialization and infrastructure development, which have traditionally been drivers of GDP growth. Historically, the normative development path, first experienced in Western countries and then in numerous developing countries, suggests that energy consumption is inevitably linked to higher economic growth and income. However, this long-established belief is being scrutinized more intensely as global crises, such as climate change, become increasingly severe (Waheed et al., 2021).

Global environmental challenges, including the rapid increase in greenhouse gas emissions, depletion of natural resources, and destruction of biodiversity, have become more acute, and there is a need to rethink conventional economic development methods. “Decoupling” has been recognized as an essential mechanism for balancing the financial objectives with those for the environment (Luo et al., 2021). Decoupling is reducing or dismantling the links between economic growth and negative environmental implications: energy usage, carbon emissions. Practical evidence has emerged to support this paradigm shift. This concept is slowly becoming more apparent in regulatory policies, global agreements, such as the Paris conference, and observable patterns around the world (Wei et al., 2020).

Decoupling can exist in two forms: Relative decoupling is associated with greater economic growth rates versus energy or emissions growth. In contrast, absolute decoupling refers to economic growth alongside a reduction in the absolute numbers of energy used and emission levels. (Sanyé-Mengual et al., 2019). Attaining absolute decoupling is a key step forward in mitigating climate change, as it involves real reductions in environmental impact alongside economic improvement. The most obvious cases of decoupled energy consumption growth are found in wealthy economies, which possess fully developed industrial infrastructures, advanced technological capabilities, and prominent policy incentives for energy efficiency and renewable energy development.

Apart from being a purely technical and strictly economic problem, decoupling largely depends on the political and institutional context in which any country operates. A country’s ability to decouple emissions from economic growth is influenced by strong governance, funding for green infrastructure, the availability of clean technologies, and a public appetite for moving beyond fossil fuel dependency patterns. Moreover, massive changes in economic sectors, particularly the decline of manufacturing and the growth of services, directly lead to a decrease in energy intensity and emissions relative to output. However, differences in how these structural shifts manifest themselves from one country to another imply that a global decoupling movement is not the same in all places (Luo et al., 2021).

Moderately prosperous economies are increasingly demonstrating relative decoupling as they replace dirtier technologies and move towards industrial modernization. One is that while the economic growth is still in progress, countries like China and Brazil have significantly improved their energy efficiency. Nevertheless, the decoupling process is made difficult for these nations due to their dependence on fossil fuels and the need to meet the energy requirements of large populations and rapidly growing cities (Wang et al., 2020). During their early industrial stages, these countries face challenges such as a lack of funds, access to up-to-date technologies, and institutional support. In the short term, it may be challenging for such nations to achieve a relative decoupling of their economies from energy needs. However, they can circumvent conventional paths that require fossil fuels by adopting decentralized renewable systems first and making sustainable development central to their models.

The pursuit of global decoupling raises the central discussions on equity and justice. High-cost economies have the financial implications to support clean energy and energy efficiency projects; however, they are responsible for a large percentage of the currently recorded carbon emissions in the atmosphere. Therefore, cooperative international efforts, such as sharing climate finance and climate technology, are crucial for a just transition in less developed countries. Global discoordination may lead to the nullification of specific decoupling advantages elsewhere due to enhanced coupling (thus compromising joint climate objectives).

2 Conceptual framework

2.1 Definition of decoupling

Decoupling reduces the historically powerful link between growing economies and their rates of environmental degradation (Bergmann and Kalkuhl, 2025). In the context of energy economics, this idea envisions the possibility of an economy’s growth in terms of GDP without necessarily placing higher demands on energy use or polluting the environment, particularly in terms of carbon emissions. Recently, the decoupling idea has been aggravated by global efforts to balance harmonizing economic growth and environmental protection.

Applicant relative decoupling and absolute decoupling. Relative decoupling occurs when the economic output growth rate exceeds the growth rate in environmental

footprint, including energy consumption and carbon emissions. Economic growth and environmental impacts are also increasing, but the enhancement is becoming more modest in terms of ecological effects. Such an outcome can usually be observed at the early stages of development in countries that begin to introduce energy efficiency measures. Otherwise, absolute decoupling is a crucial change in which the economy continues to grow even when total energy use or emissions decline. This decoupling is more conducive to larger sustainability targets and critical to the success of international climate promises (Tian et al., 2025).

2.2 Theoretical underpinnings

Multiple theoretical glasses are helpful in clarifying the decoupling concept, revealing how this works and what it means. The Environmental Kuznets Curve (EKC), an inverted-U-shaped model explaining the relationship between income per capita to environmental destruction, is central to understanding the decoupling (Tian and Khan, 2025). Based on this theory, reactive industrial activity and increased energy consumption would lead to heightened ecological stresses at the onset of economic stress. People usually prefer cleaner technologies, implement strong environmental policy, and move into industries with lower pollution profiles after achieving this income milestone, and afterwards create environmental benefits. Inconsistency in the empirical support of the EKC between nations and environmental variables has resulted in several instances of empirical support being attributed to the model competitively, and for its overly simplistic model of economic and environmental factors (Danish et al., 2025).

Household energy transitions are typically discussed under the Energy Ladder Theory framework. According to this theory, as incomes increase, families tend to change from using traditional biomass fuels to superior and cleaner energy, such as electricity and LPG. Regular advancement upon the energy ladder often results in significant gains in energy efficiency, better health, and more advantageous environmental states. Despite that, the transition from biomass to modern fuels does not always take a predictable or guaranteed path. Cultural predispositions, market fluctuations, and the existence, or lack, of energy infrastructure can obstruct or slow the transition to greener energy sources (Hao and Khan, 2025).

Moreover, technological innovation and structural change are the main determinants that help explain decoupling. When economic re-configurations prefer services to manufacturing jobs, they usually lead to reduced energy intensity concerning measured output (Li and Khan, 2024). Emphasis on tech evolution in efficient energy consumption, introduction of smart networks, and expansion of renewable energy supply all reduce the ecological cost of economic operations. The shifts are made possible by policies that include carbon pricing, review of energy subsidies, and strong environmental governance, all aimed at promoting low-carbon development (Liza et al., 2024).

Fig. 1 explains the decoupling of emissions from the GDP: Germany identifies whether the country has successfully decoupled its growth (GDP) from the CO_2 emissions. Decoupling takes place when the GDP rises, and so does not increase, which shows the transition to a greener economy. This decoupling may be brought to light in the figure by policies that include the adoption of renewable energies or energy efficiency measures, among others.

3 Data and methodology

3.1 Data source

The analysis uses data from the World Development Indicators (WDI) database—a major global source for development tracking across countries—provided by the World Bank. The World Bank's World Development Indicators provide standardized data at the national level on economic activity, energy spend, environmental implications, and elements of population makeup. The dataset used for this study spans 1990 and 2022, a time of global integration and innovation and transformation in environmental policies. The indicated years are very important in studying decoupling patterns because they cover landmark initiatives like the Kyoto Protocol, improvements in renewable energy, and the Paris Agreement.

The selected countries represent a large variety of socioeconomic status, ranging from high income economies and significant emitters to industrialized states and rapidly developing states. The analysis is followed by important countries, i.e. United States, Germany, France, Japan, Canada, China, India, Brazil, South Africa, Indonesia, Russia, Mexico, Turkey, South Korea, and Saudi Arabia. This variety of countries represents a broad development paths, and facilitates a rigorous analysis of decoupling tendencies.

3.2 Selected variables

To evaluate the relationship between economic growth and environmental sustainability, the following key variables are utilized from the WDI database (See Table 1).

Fig. 2 is a correlation matrix scatter plot depicting relationships among variables like GDP per capita, energy use per capita, and CO_2 emissions. The objective is to track or detect any patterns or dependencies, whether a greater GDP corresponds to an increased amount of energy consumed or emissions. The visual aid is useful in determining the strength and direction of these relations, which is important to policy making and sustainability planning.

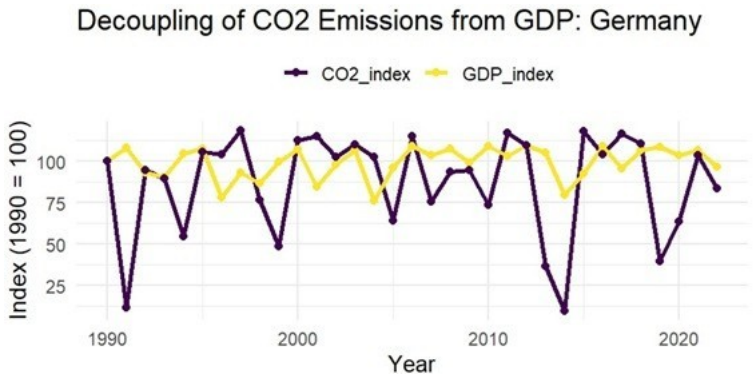

Fig. 1. Decoupling of CO_2 emissions from GDP: Germany.

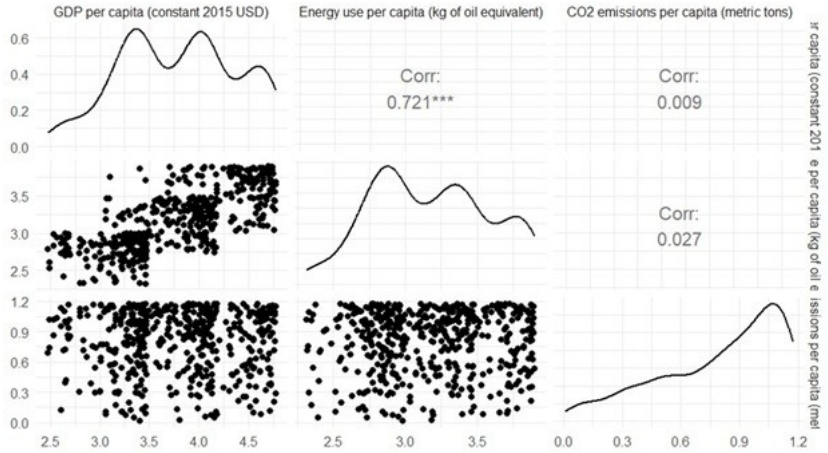

Fig. 2. Correlation Matrix.

Variable	Description
GDP per capita (constant 2015 USD)	Gross Domestic Product per capita adjusted for inflation (2015 constant USD).
Energy use per capita (kg of oil equivalent)	Total energy consumption per person, measured in kilograms of oil equivalent.
Energy intensity (MJ per USD of GDP)	Energy use per unit of GDP measures the efficiency of economic output.
CO_2 emissions per capita (metric tons)	Carbon dioxide emissions per person, measured in metric tons.
Renewable energy consumption (% of total final energy consumption)	Share of renewable energy in total final energy consumption.
Urban population (% of total population)	Proportion of population living in urban areas.
Industry value added (% of GDP)	Contribution of industry sector to total GDP, as a percentage.

Table 1. Description of the key variables used.

3.3 Methodological approach

This study uses a mixed-method approach: empirical evidence is used, individual countries' case studies are analyzed, and visual WDI data show cross-national patterns. The research examines the temporal change in relative and absolute decoupling and the key influences and constraints across countries. The methodology starts with the descriptive statistical analysis, which involves the calculation of the average and standard deviation of the variables identified in all 15 countries. This enables us to observe average trends and differences in performance between countries from one round to the next. Employing graphical visualization such as time series plots and decoupling trajectory charts, characteristics of correlations between GDP developments and the trends in energy or emissions are presented to map decoupling events as a function of time. Another element of it is synthesizing the empirical world's most recent findings from peer-reviewed studies and policy reports on decoupling. This chapter provides critical background to the data and situates the observed patterns within the broader context of established theories and policy discourse. Based on that, the review goes deep work of policy instruments and structures of institutions that make

the decoupling work successfully, and significant attention is paid to energy policy, technological change, and urban planning practices.

4 Global trends in energy use and economic growth

The altered character of how economic activity shapes demands for energy reveals unique, regionally shaped patterns that reflect stages of development, effective governance, energy frameworks, and rates of innovation. To explore these dynamics within a comparative framework between high-, middle-, and low-income countries, we estimate the world's overall success in decoupling.

4.1 High-income countries

The quintessential example of countries witnessing the greatest advances in achieving absolute decoupling is within high-income countries, particularly those that belong to the OECD. These economies of advanced countries have succeeded in expanding economically while reducing or maintaining both energy consumption and carbon emissions at very low levels. Germany and the United Kingdom are worthy examples, for instance. During the early 2000s, both countries have significantly lowered the energy intensity—i.e. the energy per variable unit of GDP—by adopting an energy efficiency policy, reforming policy, and commoditizing technology (Bilal et al., 2022).

The underlying cause of this success is the massive shifts on the organization of these economies. A change in the economy's direction, toward services and away from manufacturing, coupled with a reduction in manufacturing's contribution to GDP, has led to an overall plateauing in energy demand. In addition, programs such as trading emissions, carbon pricing, and financial incentives for renewables combined with strict energy efficiency regulation delivered on environmental promises while not incurring economic losses (World, 2019). Germany's Energiewende program has stimulated renewable energy growth and reduced coal use, whereas the UK has made advances in terms of decarbonization of its electricity both through market-funded changes and through pledges to phase out coal (IEA, 2020a). Persistent institutional endeavours aimed at promoting sustainability facilitate absolute decoupling in these cases. The success of these countries points to the fact that that policy consistency, innovation, and the transformation of the economy's structure can be used to advance to climate neutrality.

4.2 Middle-income countries

For middle coming economies—such as China, Brazil, Mexico and SA—there is a clear pattern of relative decoupling. With continued increase in energy demand and emissions, these countries are also achieving higher GDP expansion, which means reducing energy and emission intensity during their growth. In particular, China has shown much improvement in reducing its energy intensity. The Chinese government announced a series of ambitious energy conservation quotas into its Five-Year Plans and dramatically increased investment of renewable efforts such that today China is the world's largest producer of solar and wind energy (Tian et al., 2025). Strategies to restructure industrial processes especially through advanced manufacturing and services have added direction to conservation of energy resources (Cordesman, 2012).

Meanwhile, Brazil has a legacy of dependence upon hydropower that has been an effective constraint on the growth of its fossil fuel emissions. Brazilian investment in biofuels and recent projects in wind and solar power have improved its path to sustainability even amid the threat of burgeoning population and economic activity. However, middle-income countries continue to face obstacles in their efforts to reduce growth in levels of emissions. The problem of harmonizing the rapid development of the industry with the preservation of the environment can cause awkward decisions, especially in the context of politics of fossil fuel subsidies and the problems of accessibility of energy, high costs of the adoption of clean technologies. For middle-income countries the relative decoupling is more likely to be a preparatory stage of change instead of a final resolution.

4.3 Low-income countries

These economies are characterized by a high correlationship between the expansion of economic operations, associated increases in energy consumption and the emission of gases. In such economies as those in sub-Saharan Africa and some that of South Asia, energy use is also rising with GDP, often from a very small base. Fundamental factors include the expansion of infrastructure, the continuous urbanization, increased living standards, all of which lead to a higher demand for electricity, fuels used for transport and industrial energy inputs. One of the great challenges that low-income countries are experiencing, is the lack of clean energy infrastructure that can be trusted (Ahuja et al., 2008). A great number of these nations depend on conventional methods: biomass, diesel generators, and coal to produce power. The absence of financial resources, the improper frameworks for regulation, and insufficient technology infrastructure serve as barriers to the wider implementation of the renewable energy system (Nguyen and Su, 2021). Critically, clean energy investments around the world disproportionately advantage middle- and high- income economies, further widening the gap in energy opportunities worldwide.

Although these challenges do exist, they should not be allowed to overshadow the big opportunities for low-income countries to leapfrog. With aid aimed strategically beyond borders, the adoption of locally-dispersed renew-

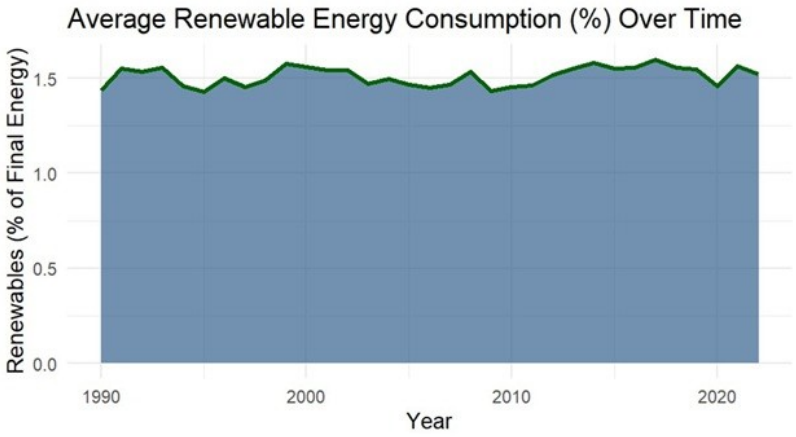

Fig. 3. Average Renewable Energy Consumption (%) over time.

able energy arrangements (off-grid solar systems for instance), and strong capacity-building schemes, these nations can avoid carbon-intensive development and switch straightaway to more sustainable forms of growth. However, the realization of such results is hugely dependent on high-international cooperation and climate financing arrangements that are also fair.

Fig. 3 presents the percentage of average renewable energy consumption over time, depicting the increase in the use of renewable energy in total energy consumption across the years. An upward trend would indicate worldwide efforts to shift away from fossil fuels to clean energy (such as wind, solar, and hydropower). This trend is crucial for reducing greenhouse gas emissions and fighting climate change.

5 Drivers and barriers to decoupling

The attainment of decoupling or the decoupling of economic growth from upward trends in energy use and environmental impact relies on the dynamic combination of enablers and impediments. For those blocks that are passively utilizing the system, it will

5.1 Drivers of decoupling

Various critical drivers have proved critical in facilitating relative as well as absolute decoupling, particularly, for the high- and middle-income countries. These factors can largely be distinguished on technological, structural and policy bases:

Technological Innovation: Thanks to advances in LED lighting, high-efficiency devices, smart meters, and industrial automation, energy consumption per output has been very considerably reduced. Smart grids and digital energy management technologies are centrally important in increasing demand-side efficiency and reducing transmission losses. The rise in the utilization of electric vehicles and the more efficient fuels have reduced transport related emissions (Chi et al., 2021).

Structural Economic Transformation: With economic growth, sometimes industries reorient themselves from energy consuming sectors that include manufacturing and heavy industries to the more efficient energy consuming sectors like finance, education and Information technology. Tertiaryization, the transition to greater service orientation, is one of the prime movers of decoupling in affluent countries. Even in manufacturing, the shift toward more valuable and digitally driven activities results in reduced energy demand (Akhtar et al., 2016).

Renewable Energy Investments: There is need to adopt more renewable energy sources, for example solar, wind, hydro, geothermal to decouple emissions growth from growth in GDP. Investment in cleaner energy technology and allows countries to limit their usage of fossil fuels thus allowing them to lower emissions while consumption of energy contributes to the economic development. Further grid diversification and storage technologies improvement are accelerating this transformation (IEA, 2020b).

Urbanization and Infrastructure Development: Sustainable urbanization directly helps decouple the growth from emission increase through the stimulation of economies of energy use due to scale and adoption the elements of sustainable transport and energy-efficient architecture, as well as compact city planning. Under the introduction of efficient infrastructure such as mass transit and district heating, it is possible to spur sharp reductions in per capita energy use and emissions in a growing urban population (Poumanyvong and Kaneko, 2010).

These drivers are not isolated; they often reinforce each other. Use urbanization as an example: it can cause progress in clean technologies, while economic reform often leads to the necessity to build low-emission infrastructure.

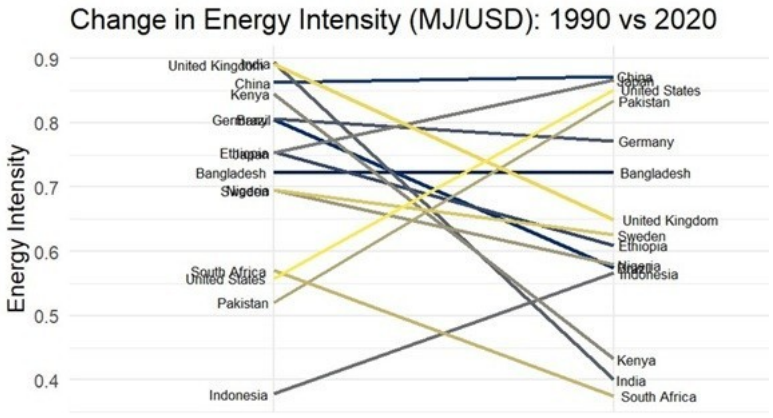

Fig. 4. Change in energy intensity.

5.2 Barriers to decoupling

Nevertheless, all these countries are still confronted with significant barriers, which prevent the complete decoupling of economic growth of economy and carbon emissions, implying excessive difficulty. Most of these barriers result from the old infrastructure, lack of money, and unproductive governance systems:

Fossil Fuel Dependency: Many areas rely on coal, oil and natural gas for power generation, transport and industrial activities. This tendency is often strengthened by policies favoring states, whereby fossil fuel costs are artificially repressed to make it more difficult to push for and fund renewable energy and energy efficiency efforts. In such circumstances, there will be no decoupling successes unless there is a blowover of economic policies (Speirs et al., 2015).

Inefficient Energy Systems: Power wastage and the limitation of energy use are complicated by poor infrastructure, great transmission inefficiencies, and neglected maintenance. In many underdeveloped areas, the lack of energy infrastructure leads to intensified demand for and production of energy, together with increased emissions (Lombardi and Gruenig, 2016).

The enormous cost of implementing renewable energy initiatives is one of the biggest barriers to adopting green technologies, coupled with scarce international commitment, among other reasons for the dearth of clean energy. Being the cornerstone of many national economies, small and medium enterprises usually have difficulties financing or receiving incentives to invest in energy-efficient tools or environmentally innovative solutions (Adams et al., 2018).

Weak Regulatory Frameworks: Successful decoupling also depends on a robust institutional framework consisting of clearly defined rules, strong regulatory oversight and lasting policy signals. Governance gaps, change of leadership on a regular basis and takes that is results-oriented in the guise of immediate gains can potentially erode the baseline for sustainable investments through uncertainties (Raza et al., 2025).

Furthermore, society and behavior-related aspects, such as consumers' behavior, public knowledge and societal attitudes, either promote or impede the direction of decoupling. By way of example, even if clean technologies and funding solutions are available, if people refuse to change their habits regarding living routines, energy conservation, or land-use practices, this can still reduce the speed of the decoupling process.

Fig. 4 presents energy intensity, looking at the amount of energy needed to generate one unit of GDP. This figure records a change in energy intensity throughout time and compares various countries or regions. A decreased trend would mean that energy was used more efficiently, that is, technological changes were made, or the country had moved towards less energy-consuming industries. Such trends are crucial for determining the advancements in this sustainable development.

Fig. 5 presents the distribution of CO_2 emissions per capita, revealing differences in emissions. Some areas have considerably higher per capita outputs than others. Knowing this distribution is crucial to climate justice and helping reduce the problem at the locations in focus.

Fig. 6 presents the frequency distribution in high-income countries (Absolute Decoupling) indicates the allocation of countries in the high-income category that have already achieved so-called absolute decoupling between economic development and environmental degradation, which is sometimes measured by carbon emissions or resource use. Absolute decoupling occurs when environmental impacts diminish, despite rising economic output (e.g., GDP). The frequency distribution in this case would indicate the number of high-income countries that belong to a specific range of decoupling intensity. A distribution

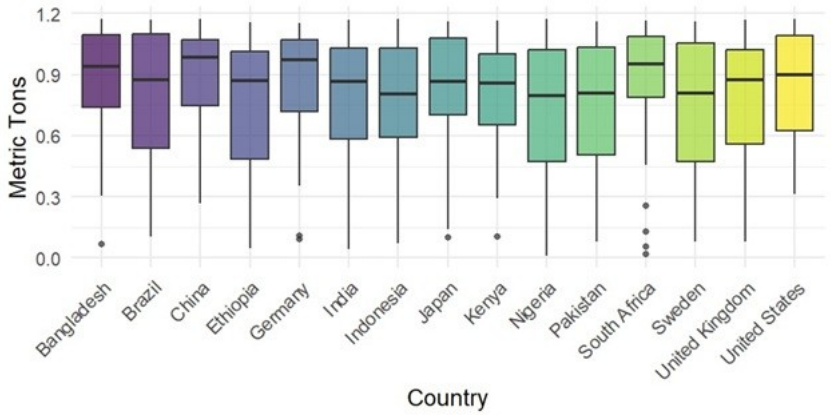

Fig. 5. Distribution of CO_2 emissions per capita.

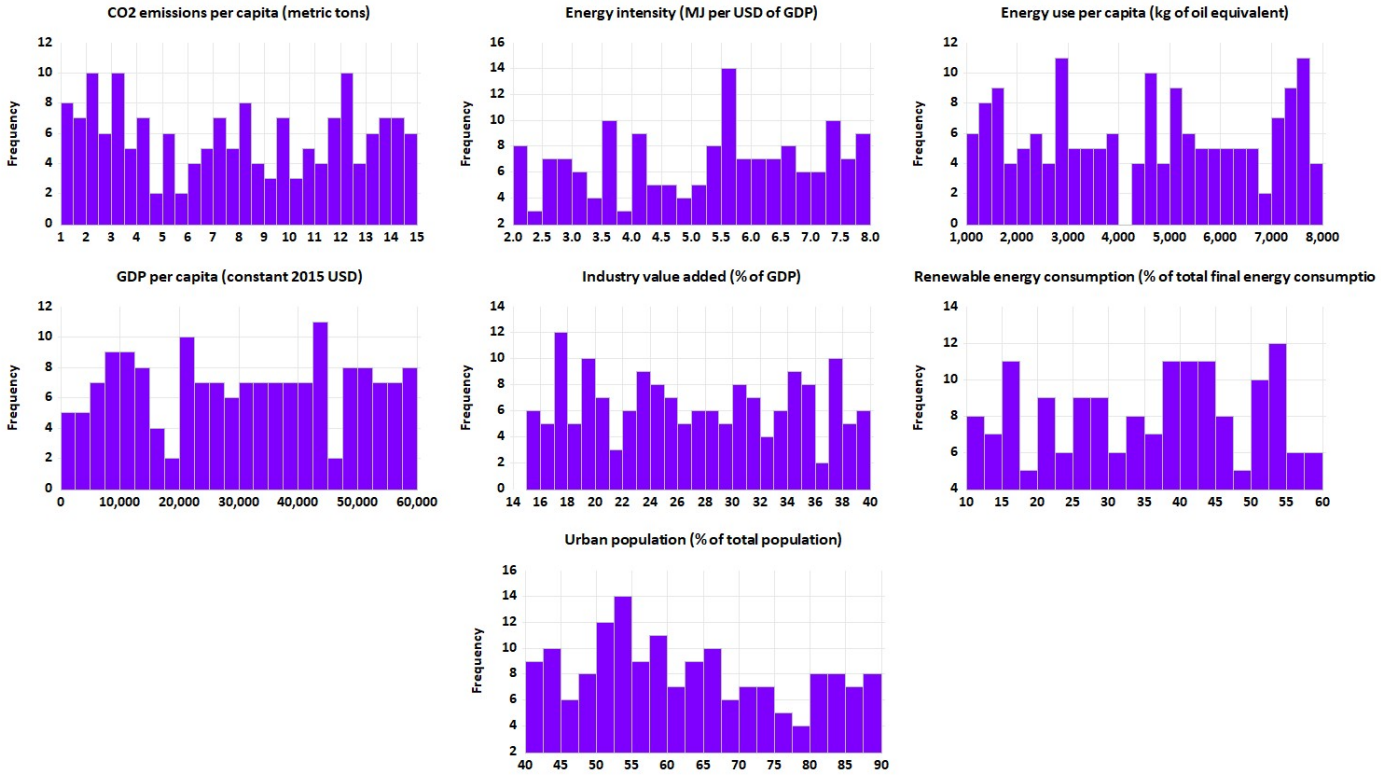

Fig. 6. Frequency Distribution in High-Income Countries (Absolute Decoupling).

biased towards high frequencies at the stronger decoupling levels would suggest that a high number of high-income countries are on track to reduce emissions as they strengthen their economies, likely due to the presence of efficient technologies, policy measures, and efficiency improvements.

Fig. 7 presents the frequency distribution of middle-income countries (Tight Coupling) reveals how often a phenomenon of tight coupling between economic growth and environmental degradation characterizes middle-income countries. Tight coupling refers to a situation in which the increase in GDP is directly proportional to the growth in emissions or resource consumption. The frequency here would be used to determine how often this pattern occurs in the middle-income countries. A cluster of data points in this region indicates that the economic growth in these countries still relies on carbon-intensive or resource-intensive processes. This number is likely indicative of structural

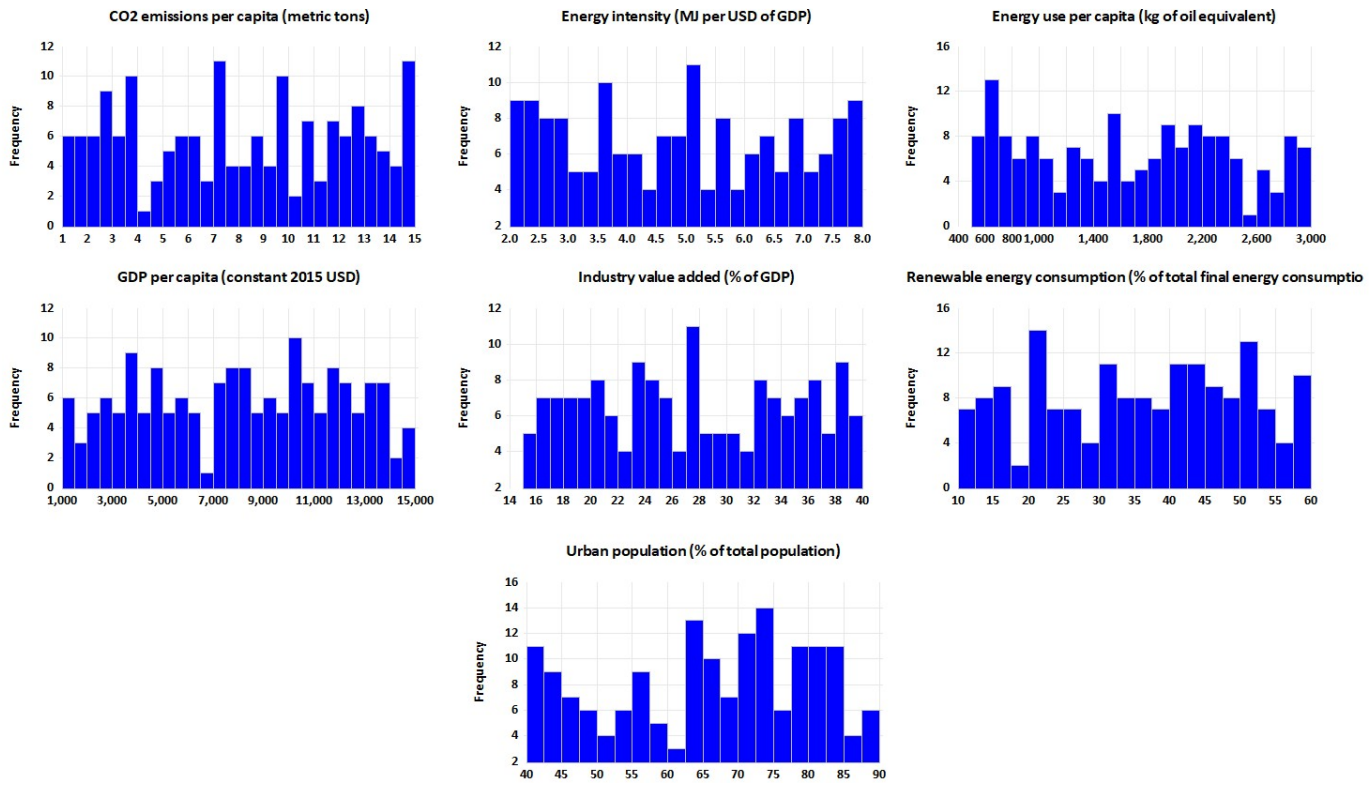

Fig. 7. Frequency Distribution in Middle-Income Countries (Tight Coupling).

bottlenecks, including the reliance of industries on fossil fuels, a lack of access to clean technology, and difficulties in implementing effective policies.

Fig. 8 shows the low-income countries: frequency distribution (Relative Decoupling), which describes the prevalence of low-income countries that managed to reach relative decoupling. Relative decoupling occurs when the rate of environmental degradation increases at a rate lower than that of economic production. The distribution can indicate that although GDP is growing, emissions or resource consumption is increasing at a decreasing rate. The pattern is typical of transitioning economies in the early stage of development, whereby certain gains in energy efficiency or technological achievements lower the environmental cost of growth. However, the overall environmental impact continues to rise. The figure can also be used to illustrate the heterogeneity of low-income countries in terms of their levels of development and access to sustainable technologies.

Fig. 9 presents the frequency distribution of high-middle-low-income countries (All Countries), which combines all income categories to provide an integrated picture of global tendencies toward or without decoupling economic development from environmental stress. The frequency distribution could be stratified or layered to make comparisons of the prevalence of absolute decoupling, relative decoupling, and tight coupling in high-, middle-, and low-income countries. This type of figure will provide a broader insight into the basis of development and sustainability regarding income levels. It can be seen that absolute decoupling is most prevalent in high-income states, relative decoupling is widespread in low-income states, and tight coupling prevails in middle-income countries, thereby underlining the differentiated responsibilities and capacities in global environmental governance.

6 Case studies

Through this chapter, it explains how it is possible to see a variety of strategies and policy landscapes that affect decoupling, and two economies that have distinct forms of economies are discussed; Sweden, which is a high-income country where forms of decoupling are completely achieved, and China which is a middle-income country that is industrializing rapidly with relative decoupling. From these cases, we observe the important influence of various policies, institutions, and growth phases on the extent and scale of decoupling efforts.

6.1 Sweden: A model of absolute decoupling

Since Sweden is a global exemplar, it has achieved absolute decoupling, keeping economic growth with a reduc-

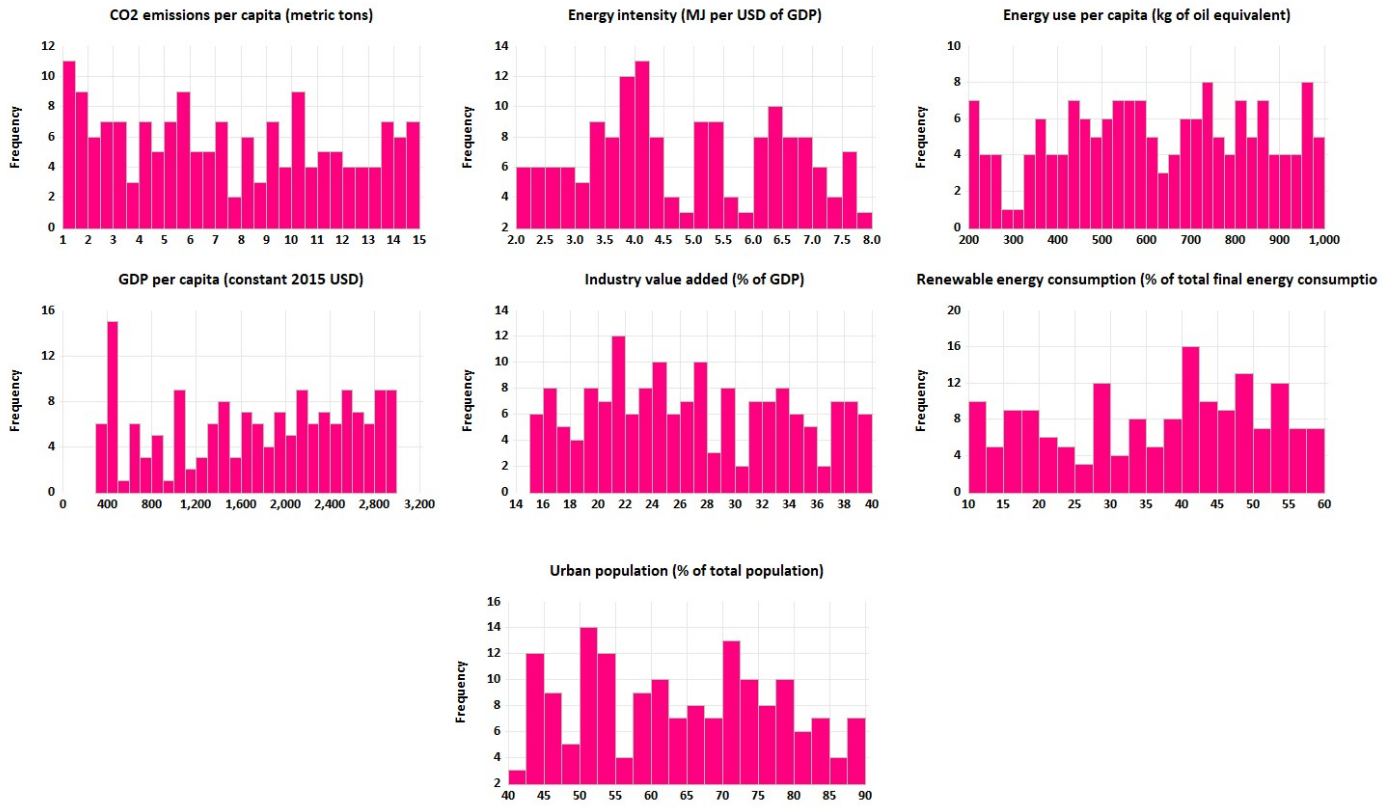

Fig. 8. Frequency Distribution in Low-Income Countries (Relative Decoupling).

tion of energy consumption and emissions of gases that cause the greenhouse effect. During 1990–2022, Sweden experienced increased GDP per capita, with significant decreases in CO_2 emissions per capita and continued decreases in energy intensity.

6.1.1 Key drivers

High Carbon Taxation: Sweden's carbon tax was instituted in 1991, and it is one of the most expensive carbon taxes in the world. This measure has successfully reduced the demand for fossil fuel while promoting increased energy efficiency and investment in renewable technologies. Subject to the industries not within the EU Emissions trading system, the carbon tax rate has increased over time.

High investments in district heating and renewable resources development: District heating has been identified as one of the country's priority areas; therefore, the networks are very efficient and based on biofuels and the calorific value of recovered waste heat. Furthermore, the country produces more than 50% of its total energy needs, and the leading renewable energy sources are hydropower and bioenergy.

Robust Governance and Regulatory Frameworks: Sweden's success is supported by transparent institutions and stable policy. Building energy performance regulations, introducing strict vehicle emission standards, and investing in green technology startups depict Sweden's coherent energy governance.

6.1.2 Lessons learned

The Swedish case provides an example of how to achieve absolute decoupling: fiscal incentives must be introduced, systemic energy strategies must be applied, and cooperation among institutions must be stimulated. It also demonstrates that early adoption of sustainable practices and continued solid public support for climate policies can facilitate the development of a resilient low-carbon economy while supporting economic advancement.

6.2 China: Rapid relative decoupling

As the world's second-largest economy and foremost CO_2 emitter, China shows impressive progress on the path of relative decoupling. Between the early 2000s and the present, China has been able to reduce its energy intensity by more than 40% to increase GDP per capita rapidly. Even though consumer demand and emission levels are continuously going up in general terms, the rate at which they are growing has slowed down tremendously compared to the growth in the economy.

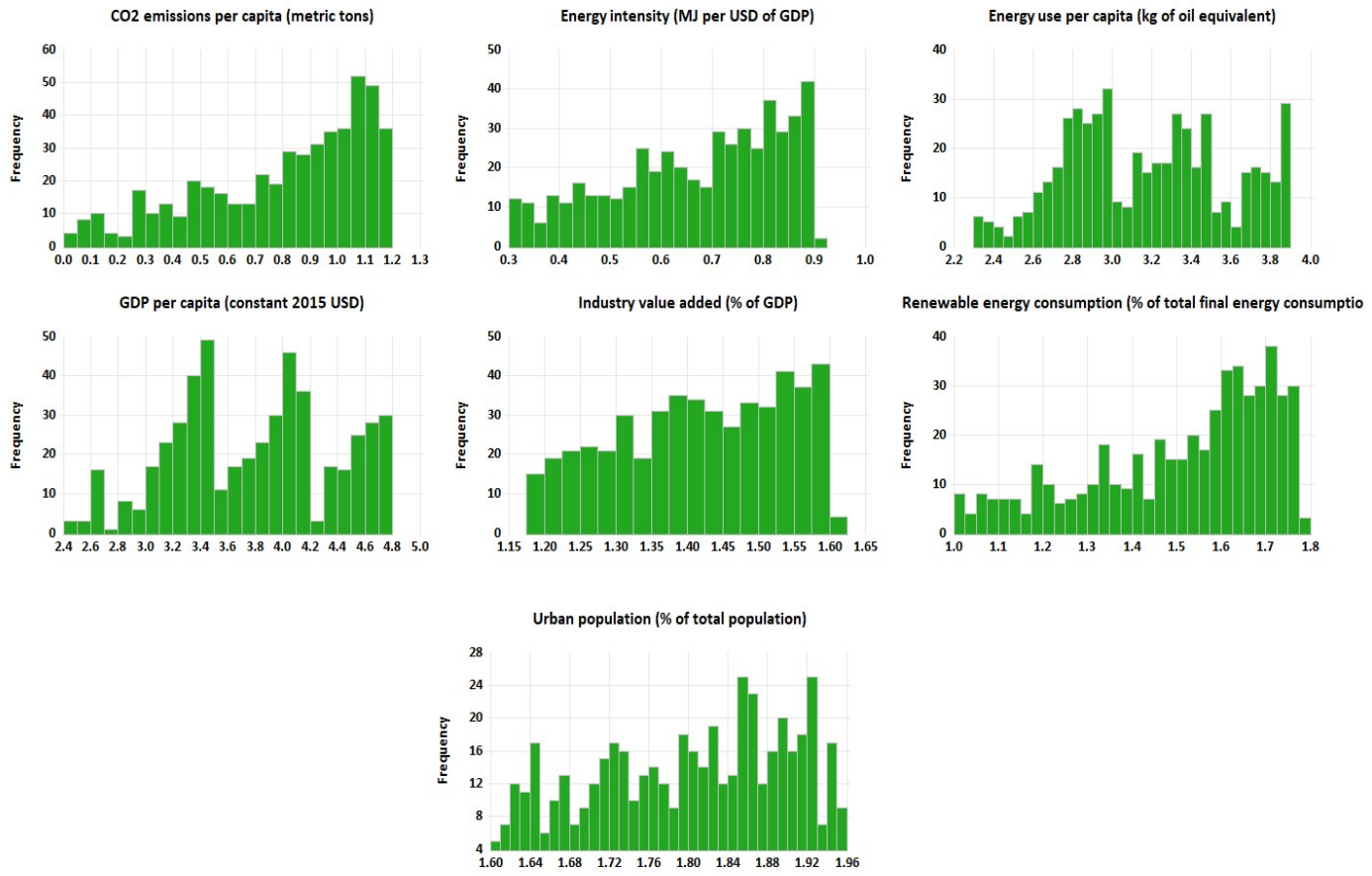

Fig. 9. Frequency Distribution High-Middle-Low-Income Countries (All Countries).

6.2.1 Key drivers

Industrial Energy Efficiency and Auditing: China's government-dominated Top-1000 Enterprises and Top-10,000 Programs have mandated energy audits and efficiency benchmarks for the country's top energy-consuming enterprises. Such programs encourage enterprises to invest in energy retrofits, install energy monitor systems and comply with demanding energy efficiency provisions.

Green Finance and Technology Policies: China has used green finance measures such as credit programs for projects providing clean energy and subsidies for electric vehicles to direct big money towards sustainable development goals. Put in place implementation of green bond markets and eco-industrial parks has enhanced efforts in shifting to more environmentally friendly industrial processes.

Massive Renewable Energy Deployment: China leads the world in renewable capacity, with its top accomplishments including solar photovoltaics and wind energy being particularly remarkable. State-led planning, targeted manufacturing, and reduced costs have facilitated viable, rapid growth in the renewable industry.

6.2.2 Challenges

Though having achieved so much, coal consumption, particularly in central and western provinces, continues to hold China's efforts towards decoupling. More information on the strategies and policies used in Sweden's transition can be gleaned from an upcoming publication by the East-West Centre, which will show off the driving mechanisms behind the successful decarbonization effort. Simultaneously, achieving energy security to meet decarbonization goals remains a significant challenge.

6.2.3 Lessons learned

The Chinese experience shows how state guidance, strategic industrial action, and financial innovation aid relative decoupling. On the other hand, it shows the difficulties encountered in achieving absolute decoupling in economies defined by an ongoing process of urbanization and industrialization that increases energy consumption.

These cases illustrate the reliance that is possible regarding the use of decoupling strategies and their moderators with regard to development levels. Sweden is a

perfect example of successful decoupling in a highly developed, institutionalized economy, whereas China shows how growing nations can achieve prosperity while pursuing sustainable objectives.

7 Policy strategies for promoting decoupling

Effectuating decoupling of economic growth from environmental deterioration requires a nation-specific policy reaction. The nation's achievements moving aggressively toward decoupling (relative or absolute) demonstrate the effectiveness of a strategy consisting of market-based reforms, regulatory standards, public funding, and development assistance aimed at technological innovation. These initiatives should be seamlessly incorporated into long-term development constructs that forgo consistency and dispositions for a successful outcome.

The deployment of carbon pricing instruments, including carbon taxes and emissions trading programs, stands out as a viable lever to accelerate decoupling activities. By assigning a price to carbon emissions, these policies thus quantify environmental costs in the market, and both industry and consumers are inclined to opt for cleaner alternatives. Sweden and Canada can prove that introducing carbon taxes can be used to reduce emissions while the economy increases. The cap-and-trade mechanism, as implemented in the form of the EU Emissions Trading System and China's national carbon market, provides a pragmatic strategy for minimizing greenhouse gas emissions by firms.

At the same time, support of renewable energy through subsidies plays a crucial role in the speedy transition to sustainable electricity generation. The subsidy of clean energy technologies makes them more affordable, reduces entrance barriers, and increases investment. Recent experiences have included the rise of feed-in tariffs, tax credits, and production incentives in countries such as Germany, the United States and China, which have propelled the increased capacity to use renewable energy. As soon as technologies prove commercially viable, governmental support for renewables might be reduced.

Another key decoupling aspect is the introduction of rigorous energy efficiency rules, particularly concerning buildings, transport and industry. Mandatory labelling for appliances, building insulation, and vehicle fuel economy standards are regulatory mechanisms that significantly cut energy use in the primary industries. Not only do these regulations reduce greenhouse gas emissions, but they also help households and even businesses save money on energy, both ecologically and financially.

Equally critical is the heavy investment in clean infrastructure by the public. There is a need for leadership in spending to establish energy-efficient transport networks, advance grid system placement, and promote green architectures. These investments are critical to future energy consumption and city development, especially in rapidly growing urban environments. In addition, with infrastructure development, there is a stimulus for private investment since it becomes less risky, and policy guidelines are clear.

In sum, it is critical to continue applying resources to research and innovation to guarantee innovations needed for deep decarbonization. Governments must invest their resources into research in clean energy, cutting-edge storage, carbon capture technologies, and ways of integrating energy systems. Inter-academy collaboration frameworks comprising academia, public research institutions, and the private business are essential for furthering technological breakthroughs and developing scientifically focused economic systems.

Eventually, decoupling is not linear, and an exclusive policy approach is imbecilic. The greatest opportunity for economic progress and environmental stewardship lies in combining resources such as carbon pricing, financial incentives, regulatory mechanisms, public investments, and innovation strategies, modified to specific national situations.

8 Research gaps and future directions

The decoupling literature in energy economics has improved greatly, but more significant gaps remain that need to be filled to promote a better understanding of decoupling and the formation of efficient policies. Overcoming these limitations is the essence of developing policies that ensure economic growth and environmental stewardship coexist effectively.

The consistency and comparability of data, especially concerning low-income and developing countries, is one of the most important research concerns. Since World Development Indicators (WDI) had sufficient data, the WDI database faces some missing, unreliable, or outdated data for many low-income countries. This limits both the scope and the precision of cross-country studies and precludes attempts at identifying global decoupling patterns with certainty. To fill these gaps, future studies should pay attention to harmonizing data, to establish temporal consistency, and to include additional data sources such as satellite imagery or real-time economic metrics.

Studies should therefore have more attention to sector-specific decoupling, even in such sectors as transportation and heavy industry, as they have huge environmental footprints. Close inspection of high-resolution sector-specific data shows that the overall national trends conceal significant differences in sector decoupling processes. By way of example, the rate of decoupling in residential energy consumption may differ greatly from the evidence of decoupling in aviation or the cement industry. Sector-specific analysis can reveal the most effective interventions and the

greatest gaps that may benefit from breakthroughs or tight regulation to effect decoupling processes.

It is necessary to move more research toward the role of behavioral economics and consumption habits in the decision maker's energy consumption and emissions levels. Societal norms, behavioral biases, and individual preferences, however, have a far greater influence on actual behavior, even though people traditionally model behavior as guided by rationality, economic incentives and regulations. To better understand the forces that drive energy decisions is also to understand the factors that influence strategic decisions—including nudges, social marketing and energy education programs—in line with what can also support decoupling.

It would also be important to pay sufficient attention to how decoupling measures are spread throughout society, particularly as a component of a just transition. It is possible that actions like carbon pricing, large energy sector reforms, and basic economic changes can increase the effects on low-income homes, workers in the carbon-based industries, and those in vulnerable zones. Future research should discuss equity and inclusiveness under the decoupling framework to understand how policy approaches can protect livelihoods, provide assistance for skills building, and advance the distributive assignments of cleaner growth benefits fairly. Proper policy assessment has to also include analysis of gender, regional discrepancies and indigenous perspectives for the sake of wholeness.

9 Conclusion

Countries' efforts to reduce the implications of climate change and save resources have made freeing up economic growth from environmental damage a major point of interest in energy economics research. With the help of data from the WDI, this review covers international patterns, theories, case studies of individual countries, and policy change strategies, leading to a comprehensive summary of the status quo in global sustainable development.

The current data clear demonstrates that high-income countries have not only developed a technical ability but also sustained the absolute decoupling. As the balance is met, these countries have reduced energy intensity and carbon footprints while the economy continues to grow, due to innovations, with a service orientation, and a strong regulatory authority. Relative decoupling is apparent in middle-income countries like China and Brazil as they move from industrial to increased investment in green energy projects. In contrast, low-income countries obtain less decoupling due to poor infrastructure, persistence of fossil fuels and lack of meaningful energy governance.

The primary lesson from the analysis is that decoupling needs a context-specific strategy, rather than a one-size-fits-all model. Due to major differences in the economy's structure, energy availability, institutional setting and nature of the social setting throughout regions, policy approaches should be tailored to suit the differences. Managed application of instruments like carbon pricing policies, renewable support, energy efficiency requirements and infrastructure projects may strengthen such instruments. It is equally important to focus on just transitions so as to avoid decoupling, bringing about enhanced inequality or disadvantage to marginalized groups in order to create social harmony and ensure policy acceptability in the long run.

Proceeding, the progress of sustainable energy systems requires increased inter-disciplinary cooperation in research. Research in the next few years should examine the specific impacts of decoupling on various sectors economically, the reasons behind individual behavior in energy use, and the distribution of changes to policy through society. Building up data collection efforts, especially in poorer countries, and promoting the cooperation between countries can provide a foundation for good, evidence-based policymaking.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Author statement

Ali Abbas: Conceptualization; Data curation; Formal analysis; Visualization; Writing—Original draft; Writing—Review & editing

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