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Does innovation drive emission cuts? Evidence from China and the UK under SDG 13

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ABSTRACT

The assumption that innovation inherently supports climate goals is central to policy and academic discourse, yet its actual impact on carbon dioxide (CO_2) emissions remains contested. This study investigates the relationship between national innovation levels and CO_2 emissions in China and the United Kingdom—two major emitters with differing developmental trajectories—to evaluate whether innovation supports climate action in line with Sustainable Development Goal 13 (SDG 13). Using annual data from 2007 to 2022, we employ a panel regression base model with fixed effects to assess the direct influence of the Global Innovation Index (GII) on per capita CO_2 emissions. To ensure robustness, an interaction model incorporating the Climate Policy Index (CPI), part of the Climate Change Performance Index (CCPI) is used to test for moderating effects of climate policy on the innovation-emissions nexus.

Findings reveal a positive correlation between innovation and emissions in China, indicating that innovation has not translated into sustainability gains. In contrast, the UK shows a decline in emissions despite stagnating innovation levels, suggesting alternative drivers of emission reductions. The robustness model finds no significant moderating role of climate policies in either case, exposing a gap between policy design and implementation.

Policy implications are clear: China must align its innovation strategy with green technology adoption, while the UK should bolster innovation to maintain long-term emission reductions. Both nations require more integrated, enforceable climate policies linked explicitly to innovation outputs.

Acronyms

CCPI	Climate Change Performance Index
CO_2	Carbon Dioxide
CPI	Climate Policy Index
CSR	Corporate Social Responsibility
EKC	Environmental Kuznets Curve
EMIS	Carbon Dioxide Emissions
GII	Global Innovation Index
INOV	Innovation
POLI	Policies
R&D	Research and Development
SDGs	Sustainable Development Goals
UK	United Kingdom
UN	United Nation

1. Introduction

In recent years, the term *climate change* has garnered significant attention from researchers, policymakers, businesses, and the public. It refers to long-term alterations in weather and temperature patterns, largely driven by human activities since the 19th century [1,2]. The year 2023 was particularly notable, recording the highest global temperatures since 1850, with carbon dioxide (CO_2) emissions playing a major role in this trend [3]. These emissions pose serious threats to ecosystems [4] and human well-being, while also creating operational and financial challenges for businesses across industries [5,6]. In response, the United Nations has established the Sustainable Development Goals (SDGs), with SDG 13 specifically targeting climate action. It calls for a 43 % reduction in CO_2 emissions by 2030 to mitigate the impacts of climate change [7,8]. Because of these growing challenges, the need for sustainable innovation is more relevant than ever, making this an important moment to focus on research and action on this topic.

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Research has shown that innovation is closely linked to CO_2 emissions [9–11]. Yang and Lin [12] and Chlebna et al. [13] support this idea, by arguing that transformative regional development is pertinent in driving sustainable economic growth amid complex challenges that the climate crisis poses for the present and future. Further, innovation is seen as a multifaceted concept that can be used as a critical lens to exploring climate challenges. Innovation, once narrowly associated with Research and Development (R&D), is now recognised as a complex, multifaceted phenomenon without one singular definition. It could include everything from revolutionary novelties to incremental improvements and effectiveness in application [12].

The level of innovation differs between countries, and so does the level of CO_2 emissions. In order to examine the relationship between innovation and CO_2 emissions, the current study has selected China and the United Kingdom (UK) as focal geographical points. While China and the UK differ in their global CO_2 emissions rankings: first and nineteenth, respectively; their selection is predicated on interesting commonalities and disparities that render their comparison academically valuable [14]. Factors such as regional prominence, population scales, and operational magnitudes offer a nuanced context for their comparative analysis [15,16]. Despite their rank difference, China's regional dominance in Asia and the UK's significant contribution to Europe's CO_2 emissions, underscore the rationale for the choice contrast [11,17,18]. Both nations are recognised for their innovation prowess, consistently securing top spots in the Global Innovation Index, which reflects the dynamic nature of their respective innovation ecosystems [19].

Similarities aside, there is a marked contrast between China's Confucianism influenced business ethos and that of the UK's more Westernised approach. This affects business operations and policy formation, particularly in the use of Corporate Social Responsibility (CSR) models [20]. For example, the integration of CSR within Chinese firms necessitates strategic policy frameworks, underscoring a critical facet of this study: the role of policies as a moderator between innovation and CO_2 emissions. Given the dichotomous business practices between the East and West, careful design and implementation of national policies, and use of potent tools in climate action is required [21,22].

The economic trajectories of China and the UK also differ. Despite its astounding economic growth, China still exhibits traits of a developing nation (e.g. Human Development Index) [23]. In contrast, the UK has consistently ranked among the UN's "major developed economies" [24]. Literature posits that economic conditions could mediate the innovation- CO_2 emissions nexus [25,26]. Therefore, the current research uses the theoretical framework of the Environmental Kuznets Curve (EKC) to further explore this relationship.

In such a context, the current study wishes to address the following research objectives:

1) Examine the link between innovation levels and CO2 emissions, and its contribution to national-level sustainable development.
2) Investigate the influence of policies on sustainable development by examining their effect on the innovation- CO2 nexus.
3) Assess whether China and the UK are on track to meet SDG 13 CO2 emission targets by 2030.

This study makes a significant theoretical contribution to the EKC literature by explicitly incorporating the moderating influence of national climate policy frameworks on the nexus between innovation and CO_2 emissions. While classical EKC research has predominantly examined the relationship between economic growth and environmental degradation [27,28], there remains a critical gap regarding how innovation, mediated by policy mechanisms, differentially impacts emissions trajectories across heterogeneous national contexts. By empirically analysing two contrasting economies, China and the UK, this research addresses this gap, thereby refining and extending the EKC theory to better account for the complex interplay of innovation, governance, and sustainable development pathways [29,30].

With the careful selection of countries, rooted in literature and theory, this research explores complex interplay between innovation, policy frameworks, and CO_2 emissions, highlighting the critical roles of China and the UK in addressing global climate challenges as outlined in SDG 13. In particular, this study answers the following research questions:

1) How does a country's overall innovation levels impact their sustainable development measured through CO_2 emissions?
2) How do policies influence national sustainable development by impacting the innovation- CO_2 emission nexus?
3) Are China and the UK likely to reach the SDG 13 goal by 2030, based on predictive analysis of existing data?

Key findings of this study reveal that innovation in China correlates with higher emissions, showing limited sustainability impact. The UK reduced emissions despite stagnant innovation, hinting at other influencing factors. Climate policies showed no significant moderating effect in either country, revealing a disconnect between policy design and actual environmental outcomes. The contributions of this paper consist of providing an updated, holistic view of the highly relevant innovation-CO_2 emissions nexus in two countries with vastly different economic development trajectories as well as climate crisis approaches through a 16-year time frame, while also considering the impact policies have on the relationship being investigated. The use of novel and comprehensive measures for the innovation and policies variables, namely Global Innovation Index (GII) and Climate Policy Index (CPI), allows this study to include different elements that make up national innovation and climate policy performance.

The article is organised into six sections. Section 1 contains a background to the study, the research questions, and the key findings of the study. Section 2 contains a literature review and hypotheses development pertaining to key concepts such as CO_2 emission, and innovation from a general perspective to the study context of China, and the UK. Section 3 comprises of the methodological design of the study. This includes information about data collection, sample selection, and data analysis methods used. Section 4 contains the results of the data analysis. Presented in Section 5 are the summaries of the main findings, policy suggestions, and limitations of the study. Finally, Section 6 identifies limitations and provide directions for future research.

2. Literature

2.1. Innovation

Innovation, which has gained considerable momentum over the past decade, is now understood as a multifaceted concept extending beyond its traditional association with research and development, as noted by O'Connor [31]. Recent studies by Granstrand and Holgersson [32] define innovation as the outcome of a complex interaction between novelty and utility, a perspective rooted in the work of early theorists like Schumpeter and further developed by Hasan and Tucci [33]. However, this evolving discourse reveals ongoing tensions among scholars regarding varying interpretations of innovation's "newness" and its practical application, ranging from radical breakthroughs to incremental improvements.

The discussion extends with Granstrand and Holgersson [32], and Ritala and Almpanopoulou [34], promoting a collaborative approach that moves away from the usual isolated innovation practices, aligning with Moore's [35] concept of open innovation. Yet, Erdogan [9] critiques this model for its limited focus on specific sectors or countries, advocating instead for a broader perspective. Moreover, the terminology of "innovation ecosystems" has faced scrutiny for its ecological implications, underscoring further debate over its conceptual clarity.

Additionally, the open approach discussion often overlooks the critical role of technological innovation, a gap that Schumpeter's analysis of potential downsides to innovation partly addresses. This oversight is significant in competitive environments, where the wide-ranging effects of innovation on market dominance are crucial, and where an open approach poses risks for firms.

Drawing on the insights of O'Connor [31] and Hasan and Tucci [33], who highlight the historical oversimplification of innovation and its implementation, and considering the wide range of scholarly perspectives on its definition, this paper adopts the Global Innovation Index as a comprehensive measure. The index captures a broad array of factors beyond patents and R&D, providing a more accurate reflection of the complex nature of innovation as a critical variable.

2.2. The innovation-CO_2 emissions nexus

Since the Industrial Revolution, rapid advancements in the global economy and living standards have resulted in substantial environmental degradation [36]. Among the most pressing issues is the rise in CO_2 emissions, which has become a major concern for organisations like the UN and national governments due to its severe environmental and public health consequences. Mongo, Belaïd and Ramdani [11] underscore the complexity of the factors driving CO_2 emissions, calling for further research to better understand these dynamics and assist policymakers in tackling the challenges of climate change mitigation.

Numerous scholars emphasise the necessity of innovation for a greener economy, with Chang et al. [37] highlighting the role of green technology innovations in enhancing environmental quality. Specifically, they note how China's government incentivises local firms to pursue green innovations, believing it will yield superior sustainability. Yet, Su and Moaniba [38] caution that, despite theoretical expectations linking increased climate-related innovations to climate change mitigation, empirical support remains sparse. However, such statements are contested in this paper, supported by an extensive array of studies identified and discussed in later sections.

Du et al. [36], in their analysis of 71 countries, found that innovation reduces CO_2 emissions in nations where per capita income exceeds $34, 694.08 (2011 USD), placing the UK in this category, but excluding China. This aligns with Grossman and Krueger's [28] argument that higher economic levels facilitate a shift toward less polluting service-based economies. Similarly, Mongo, Belaïd, and Ramdani [11] emphasise the link between a country's economic development and its environmental impact, identifying economic status as a key factor in adopting green innovations. In China, Wang et al. [39] noted that energy technology patents significantly reduce emissions only in the wealthier Northern regions. In contrast, Lin and Xu [40] found that energy efficiency measures effectively lower CO_2 emissions in central provinces, despite these areas not being among China's wealthiest. However, Yang and Lin [12] challenge these findings, showing that innovation levels and absorptive capacities are highest in coastal regions and lowest in central provinces. Conversely, Khattak et al. [41] suggest that innovation may actually contribute to higher CO_2 emissions at the national level in China, raising doubts about its positive environmental impact. These nuanced findings challenge the notion of innovation as a straightforward solution to environmental issues, supporting Erdogan's [9] argument that the effects of innovation should not be oversimplified, as they vary across different geographic regions and sectors.

While this study primarily focuses on innovation's impact on CO_2 emissions, the relevance of the income threshold is notably relevant. Such phenomenon could be justified by Erdogan [9], who posits that significant CO_2 reduction through innovation occurs once a nation achieves stages of invention, innovation, and diffusion: a process often hindered in emerging economies by resource constraints. This is echoed by Hasan and Tucci [33], who demonstrate a positive correlation between patenting and economic growth across 58 countries from 1980–2003, underscoring the vital role of innovation for development. Additional empirical evidence underscores the link between innovation and economic growth, noting that innovation often yields positive spillover effects. Challenging conventional wisdom, Sinha et al. [42] found that technological advancement tends to reduce air pollution in regions with low to moderate pollution levels, but paradoxically exacerbates it in areas with high pollution—findings that align with the air quality trends observed in the UK and China, respectively. Ganda [43] adds further complexity to the discussion by indicating that while R&D spending can reduce CO_2 emissions, an increase in patents might lead to the opposite effect, highlighting the nuanced relationship between different innovation metrics and environmental outcomes. Further, Odei et al. [44] found that R&D investments can positively moderate the relationship between economic growth and CO_2 emissions at early stages. Jaffe et al. [45] and Acemoglu et al. [46] emphasise the complex role of innovation in CO_2 emissions, particularly noting the distinction between short- and long-term effects due to the rebound effect. This occurs when the early benefits of energy-saving technologies are offset by increased resource consumption resulting from economic growth and behavioural shifts. Expanding on this, Mongo, Belaïd, and Ramdani [11] analysed data from 15 EU countries and found that while environmental innovations may initially lead to higher CO_2 emissions in the short term, they significantly reduce CO_2 emissions in the long term, highlighting the rebound effect's influence on innovation and environmental outcomes.

2.3. The environmental Kuznets curve (EKC)

The EKC serves as a foundational model in sustainability research, though its validity remains a topic of debate. Despite ongoing discussions, the EKC is widely applied to examine the relationship between economic growth and environmental degradation, a pressing issue given today's global environmental challenges. As Dinda [27] explains, the EKC suggests that environmental quality initially worsens as economies prioritise production with little regard for ecological costs. However, as economies mature, countries are expected to invest more in environmental conservation, leading to potential improvements in environmental quality, following a U-shaped curve. This framework highlights the delicate balance between promoting economic development and achieving environmental sustainability.

Since its development, inspired by Simon Kuznets and popularised by Grossman and Krueger [28], the EKC theory has led to varied interpretations in studies exploring the link between national development and environmental degradation. Despite its widespread use, the EKC's validity remains contentious. Erdogan [9] challenges its assumptions, reporting a direct link between financial growth and rising CO_2 emissions in China. Kinyar and Bothongo [47] found that the EKC is not valid for the UK. Similarly, Mongo, Belaïd and Ramdani [11] find no EKC pattern in 15 European countries. In contrast, studies by Grossman and Krueger [28] and Du et al. [36] support the EKC's U-shaped dynamic, where environmental degradation worsens initially but improves as economies grow. Ridzuan [48] highlights the lack of consensus in the literature, with results ranging from positive to negative or showing no correlation between economic growth and environmental indicators. Furthermore, Stern [49] critiques the EKC's econometric foundation, citing methodological flaws and a failure to meet rigorous statistical standards, suggesting the theory may not hold up under detailed scrutiny. Additionally, EKC studies have been criticised for neglecting other greenhouse gases, further limiting the theory's applicability.

Amid the complex discourse within existing literature, the relationship between innovation and CO_2 emissions emerges as an undeniable central theme, despite diverse findings and interpretations. The debate, enriched by studies both affirming and contesting the EKC, highlights the necessity of further exploration into this dynamic. Given the varied evidence on how innovation impacts environmental degradation, this paper proposes the following hypothesis:

***H1**: There is a significant relationship between innovation levels and CO_2 emissions.*

2.4. Climate policies as a moderator of the innovation-CO_2 emissions nexus

Dinda [27] argues that economic growth alone is insufficient to safeguard the environment; without deliberate government intervention and strategic resource allocation, its positive effects are unlikely to be sustainable in the long run. Chlebna et al. [13] further argue that innovation capacities are significantly shaped by the decisions of formal institutions. Similarly, Chang et al. [37] highlight that while green technology innovations are beneficial, their impact on CO_2 emissions remains uncertain without supportive policy frameworks to act as critical moderators. Porter (1991, cited in [37]) and Chang et al. [37] advocate for flexible regulatory measures to maximise innovation's environmental benefits, emphasising that the transition to a green economy requires both innovation and policy-driven incentives. These discussions underscore the essential role of policies in closing the gap between innovation and CO_2 emissions reduction. Chang et al. also note that businesses often adopt green technology innovations for competitive advantage rather than environmental altruism, highlighting the crucial role of government policies in compelling firms to invest in environmental sustainability and challenging the sector's cautious approach to green commitments.

Going further into this discussion, the Kuznets Curve theory, positing a U-shaped relationship between innovation levels and CO_2 emissions that emerges with economic stability, overlooks the capacity of developing nations to adopt green practices [28]. Stern [49] critiques this statement, questioning its practical validity. Despite criticism, China, a developing nation, has endeavoured to reconcile economic growth with environmental management, implementing policies like the Prevention and Control of Atmospheric Pollution Law [50] and increasing pollution treatment funding [37]. Studies have also found that environmental regulation in China has led to reduction in corporate carbon emissions significantly [51]. However, the country remains a leading emitter. Conversely, the UK has positioned itself as a climate leader, notably with the Climate Change Act of 2008 mandating a 90 % reduction in GHG emissions by 2050, showcasing the government's critical role in aligning policy with environmental goals [21].

The complexities and careful design required for effective policies are underscored by the cases of China and the UK. The Climate Change Act in the UK encountered significant challenges due to governmental miscoordination, raising alarms among global electricity firms about the UK's investment climate and sparking public calls for its repeal [21]. Patashnik [52] sees such policy development as the start of a political struggle, emphasising that the durability of policies aimed at public welfare, like environmental protection, depends on political dynamics. Lockwood [21] notes the risk of policy dilution post-implementation, influenced by shifting public and governmental focus, especially as environmental concerns tend to fade from immediate attention [21]. However, the increased visibility of climate change effects, highlighted by numerous natural disasters in recent years, contests the idea that environmental concerns are easily overlooked, necessitating a reassessment of strategies for policy engagement, and raising public awareness.

Although the UK has maintained its global climate leadership since the enactment of the Climate Change Act [53], persistent challenges remain. Meanwhile, despite China's implementation of stringent environmental policies, it continues to be the world's largest emitter of CO_2. This situation highlights the complexity of environmental policy effectiveness, which depends on more than enactment, calling for a holistic strategy that integrates public awareness, global cooperation, and flexibility in addressing changing environmental and economic conditions. Policymakers must craft laws with tangible objectives and establish strong enforcement mechanisms, ensuring adaptability to new challenges. Therefore, this study assesses the moderating impact of policies on the innovation-CO_2 nexus and proposes the following hypothesis:

***H2**: Policies act as a moderator of the relationship between innovation levels and CO_2 emissions.*

2.5. The SDG framework and SDG 13

The adoption of the SDGs by the United Nations General Assembly on September 25, 2015, represents a transformative moment in global development, fostering collaboration between both developed and developing nations [54]. This approach responds to critiques like those from Stern [49], which questioned the ability of less developed countries to pursue sustainability, by emphasising shared responsibility for environmental preservation. Building on the legacy of the Millennium Development Goals, the SDGs present a vision for sustainability that spans all levels of economic development. Kastrinos and Weber [55] and Belmonte-Ureña et al. [54] highlight the SDGs' influence in shaping future innovation and research policies, while Lockwood [21] points to their positive impact on the UK's energy sector, increasing investor confidence through renewable energy incentives and setting bold decarbonisation goals. As noted by Ul-Haq et al. [56], economic fitness is an influential factor in CO_2 emissions and can contribute to SDGs. Ultimately, the SDGs redefine global priorities, playing a key role in shaping environmental policy and economic investments, and driving international cooperation toward achieving the ambitious targets set for 2030.

This study focuses specifically on Sustainable Development Goal 13 (SDG 13), which addresses the urgent issue of climate change by promoting substantial reductions in air pollution. SDG 13 calls for immediate and decisive measures from global nations to mitigate climate change effects, emphasising the ambitious goal of reducing CO_2 emissions by 43 % within the next decade, aiming for net-zero emissions by 2050 (United [8]). This goal is not only a testament to the international community's commitment to environmental sustainability, but also underscores the urgency of adopting comprehensive strategies to curb the detrimental impacts of climate change. Through the lens of SDG 13, this study examines the integrative approaches nations, particularly China and the UK, are deploying to navigate towards these bold emission targets, reflecting on the broader implications of these efforts for sustainable development.

Within the period of study considered in this research, both China and the UK have demonstrated significant strides in innovation, as evidenced by their consistent performance in the Global Innovation Index [19]. Drawing on existing scholarship that establishes a strong connection between innovation and CO_2 emissions, the moderating effect of government policies, and considering the innovative achievements of UK and China, this study aim to test the following hypothesis to predict the onwards trajectory of the two countries in achieving SDG 13 by 2023:

***H3**: China and the UK are on track to achieve SDG 13 by 2030.*

With the above literature review and the hypotheses, this paper makes several contributions. Having argued in this section that 'Innovation' is a much broader concept than how it is being defined and discussed in current literature, this research has extended the current understanding of innovation beyond traditional metrics. This broader perspective not only expands the conceptual understanding of innovation but also sets a precedent for future studies to adopt more inclusive approaches. In addition, the above review breaks new ground by extending the discussion of the innovation-CO_2 emissions relationship to China and the UK. It offers a comparative analysis that is largely absent from current research, shedding light on the distinct national pathways both countries follow in tackling climate change. This comparative lens enriches the global conversation on sustainable development, providing valuable insights for cross-national learning and policy development. A key contribution of this paper lies in introducing policy as a moderating variable in the relationship between innovation and CO_2 emissions—an approach that represents a novel perspective within the existing literature. This integration allows for a comprehensive analysis of the complex interactions between innovation, CO_2 emissions, and policy frameworks, highlighting how different policy environments shape the innovation- CO_2 emissions dynamic. Lastly, by incorporating findings up to 2022, this research offers timely and relevant insights that address gaps in contemporary literature. The inclusion of recent data ensures that the analysis reflects current trends and developments, providing a strong foundation for policy recommendations and future research. The remainder of the paper reports on our methodological approach and empirical findings.

2.6. Overall literature evaluation

Although research on the link between innovation and CO_2 emissions is expanding, key gaps remain—particularly in understanding how national climate policy frameworks moderate this relationship. Much of the literature treats innovation and environmental degradation as separate issues or considers policy only marginally, overlooking the systemic interactions essential for sustainable development [11,37]. Innovation is often narrowly measured through proxies like R&D spending or patent counts, which fail to reflect its complex, context-specific nature [9,12].

Comparative, longitudinal studies across diverse national contexts are limited. The contrasting cases of China and the UK—economies with distinct institutional and developmental models—offer a valuable opportunity to explore how innovation and climate policy jointly shape CO_2 emissions. While disparities in innovation capacity and emissions between developed and developing nations are acknowledged [25,26], their implications for policy effectiveness remain underexplored.

The EKC framework, though widely used, often neglects the moderating roles of innovation and governance, limiting its relevance in today's climate-urgent context [29,30]. Therefore, this study addresses these gaps by:

- Using composite indices (GII and CPI) to capture the multidimensional nature of innovation and policy.
- Employing a 16-year comparative longitudinal design to track temporal and institutional shifts.
- Modelling national climate policy as a moderator in the innovation–CO_2 emissions nexus, extending EKC theory.
- Offering empirical insights from China and the UK to illuminate innovation-policy dynamics in sustainable development.

Through these contributions, this study refines EKC theory and delivers empirical evidence, underscoring the role of context-specific innovation in aligning economic growth with climate policy goals.

3. Methods

This study adopts a quantitative, positivist methodology that is widely employed in environmental economics and sustainability research. The methodological framework incorporates multiple complementary techniques: the Jarque-Bera (JB) test to assess data normality and robustness [57], linear regression to evaluate the innovation-emissions relationship, moderation analysis to test the influence of climate policies, and the time-series forecasting to project trajectories toward SDG 13 achievement. Such approaches are consistent with prior studies examining the Environmental Kuznets Curve (EKC) and the role of innovation in shaping environmental outcomes (e.g., [12,58]). Together, they enable robust testing of causal relationships, policy effects and projected outcomes, ensuring comparability with established research while extending insights to the specific contexts of China and the UK.

The data sources used in this study include the World Intellectual Property Organisation's (WIPO) GII [19], the CO_2 emissions data from Our World in Data [59,60], and the CPI [61]. All the data sources referenced are publicly available secondary datasets. A longitudinal approach was deemed essential for this research because the study aim to assess the progress made by China and the UK towards achieving SDG 13's target of reducing CO_2 emissions by 43 % by 2030. In addition to tracking CO_2 emissions trends, this approach also allows for the evaluation of the effectiveness of national climate policies in moderating the innovation-CO_2 emissions nexus over time, thus aiding future policy adjustments. The data analysed covers the period between 2007–2022. This period is significant due to substantial technological advancements and evolving environmental policies in response to climate challenges that occurred [12].

As summarised in Table 1 below, the two primary variables have been abbreviated and will be referred to hereafter as: a nation's innovation capacity (INOV) and CO_2 emissions (EMIS). The first was measured using GII. GII, as the INOV measure, reflects its encompassing assessment of a country's innovation ecosystem, considering both indigenous and domestic innovation, capturing dimensions from R&D to patent filings and underscoring innovation's complex nature [62]. For the second variable, EMIS, the study used data from Our World in Data. Here, CO_2 emissions are captured as a direct measure of environmental impact, offering a comprehensive view of the ecological footprints of China and the UK. In measuring the variable climate policies (abbreviated hereafter as 'POLI'), the CPI was used which provides a standardised metric for evaluating climate policy effectiveness.

The current research follows a positivist approach and uses deductive reasoning to explore the innovation-CO_2 emissions link [63]. This approach allows for quantitative analysis of causal relationships between variables which is required to rigorously test the hypotheses derived from literature in the previous section. Further, a quantitative approach facilitates empirical, data-driven examination of the relationship between innovation and CO_2 emissions. An explanatory and evaluative design was used to analyse the effects of innovation on CO_2 emissions and the mediating role of policies. Secondary, quantitative data from reputable sources was used in the analysis (with approval from the Brunel University of London Ethics Committee).

Statistical analysis was conducted using IBM's SPSS software and Python. Four types of analyses were conducted to test the hypotheses stated in the previous section. To assess the assumption of normality for the INOV, EMIS and POLI across the two nations, the Jarque-Bera (JB) test was applied (see Table 2). This test evaluates whether the skewness and kurtosis of the sample data deviate from those expected under a normal distribution [57]. Ensuring normality is particularly relevant as subsequent analyses rely on this assumption for the validity of inference. The JB test results indicated no significant deviation from normality for any of the variables, thereby justifying the use of parametric statistical methods.

Linear regression was used to examine the relationship between INOV and EMIS. By identifying the "best fit line", it was possible to assess if there is a significant relationship between the two variables and find the direction of this relationship. Then, using Andrew Hayes' PROCESS tool, a moderation analysis was conducted to examine how the interaction term of the CPI and GII impacts carbon emissions for each country [64]. This approach is key to unravelling how policies shape the interplay between the two main variables (INOV and EMIS) and for assessing the impact of policies on achieving SDG 13 targets. Finally, time series analysis was used to project CO_2 emissions trends for China and the UK up to 2030, evaluating their trajectory towards achieving the SDG 13 target of a 43 % CO_2 emissions reduction. Test results are presented in Section 4.

3.1. Methodological limitations

There are limitations inherent to secondary data sources. One such limitation is the temporal scope. Due to their availability, GII and CPI data are restricted to a 16-year timeframe. This, coupled with GII's scale modification in 2011, poses challenges in maintaining consistency and comparability across the dataset and constrains the predictive accuracy for 2030 CO_2 emissions checking for SDG 13 achievement. Further, a

Table 1
Variable details.

Variable	Abbreviation	Measurement	Units	Source
CO_2 Emissions	EMIS	National CO_2 Emissions (for China and the UK)	Billion tonnes (China) Million tonnes (UK)	Our World in Data [59,60]
Innovation	INOV	Global Innovation Index (GII)	No units	World Intellectual Property Organisation [19]
Climate Policies	POLI	Climate Policy Index (CPI)	No units	CCPI Climate Change Performance Index [61]

Table 2
Jarque-Bera test.

Country	Variable	JB-Statistic	p-value	Normality
China	CO_2 Emissions	2.5315	0.2820	Fail to reject null (normal)
China	Innovation	2.1738	0.3373	Fail to reject null (normal)
China	Climate Policies	0.7418	0.6901	Fail to reject null (normal)
UK	CO_2 Emissions	0.7140	0.6998	Fail to reject null (normal)
UK	Innovation	3.5460	0.1698	Fail to reject null (normal)
UK	Climate Policies	1.4802	0.4771	Fail to reject null (normal)

larger sample can enhance the reliability of the moderation analysis [65, 66]. Also, the quantitative approach used may not fully capture the complexities of the variables measured and their interactions. Despite the study's deductive nature, focusing specifically on China and the UK, may limit the generalisability of findings .

Nevertheless, the methodology used in this study advances the field of innovation and sustainability research significantly. For instance, use of GII ensures a broader measure of innovation than prior studies, which typically focused on single aspects like patents or R&D spending. Yang and Lin [12] particularly point out the flaws that arise by adopting patents as a measure of innovation, arguing that, while an intermediate output, they are not a direct and perfect measure of the concept. Additionally, this study explores the mediating effects of POLI on INOV-EMIS nexus, using the highly robust CPI; a strategy not found in the reviewed literature. Hence, despite the limitations, the research findings make valuable contributions to understanding sustainable development dynamics and policy development.

4. Results

In testing the first hypothesis (**H1:** There is a significant relationship between innovation levels and CO_2 emissions), it found that the data supports our hypothesis for both UK and China.

4.1. Innovation levels and CO_2 emissions

According to Table 3 above, the descriptive statistics for China show an average INOV score of 47.07, indicating a relatively high level of innovation with some variability, as evidenced by the standard deviation of 7.81. In contrast, the average CO_2 emissions are 9.73 billion tonnes, with limited fluctuation around this mean, as reflected by a low standard deviation of 1.32, suggesting a more stable emission pattern across the dataset.

Table 3
Descriptive statistics.

Variable	Country	Mean	Std. Deviation	N
	China			
EMIS		9.734	1.31818	15
INOV		47.073	7.81403	15
	UK			
EMIS		436.96	73.59862	14
INOV		58.516	5.51505	14

Table 4
Correlations.

			Emissions	Index
Pearson Correlation	China	EMIS	1.000	0.954
		INOV	0.954	1.000
Sig. (1-tailed)		EMIS		<0.001
		INOV	0.000	
N		EMIS	15	15
		INOV	15	15
Pearson Correlation	UK	EMIS	1.000	−0.632
		INOV	−0.632	1.000
		EMIS		0.008
		INOV	0.008	
		EMIS	14	14
		INOV	14	14

The descriptive statistics for the UK indicate a substantial mean value for EMIS at 436.9629, paired with a high standard deviation of 73.59862, suggesting significant variability in CO_2 emissions over the observed years. By comparison, INOV demonstrates a mean score of 58.5157 and a lower standard deviation of 5.51505, suggesting greater stability and consistently strong innovation performance in the country.

The correlation values for China (Table 4) reveals a significant positive relationship between EMIS and INOV (Pearson correlation coefficient of 0.954), meaning that as innovation levels rise, CO_2 emissions also increase. For the UK, the Pearson correlation coefficient stands at −0.632, reflecting a strong negative association, which suggests that an increase in INOV leads to a decrease in EMIS.

According to Table 5, the model's explanatory power is considerable for both China and UK, with an R-squared value of 0.910 and 0.399 respectively, indicating a solid model fit.

The overall significance of the model is supported by F-statistic (Table 6) with values of 131.892 (China), 7.965 (UK) and p-value of <0.001 (China), 0.015 (UK), confirming that the relationship between INOV and EMIS is statistically significant and not due to random chance.

4.2. Moderating effect of policies on innovation- CO_2 emissions nexus

The next hypothesis (**H2**: Policies act as a moderator of the relationship between innovation levels and CO_2 emissions) conducted through a moderation analysis failed to provide supporting evidence to accept H2 (for both China and the UK). The results of the analysis are as follows:

Table 7a show a statistically significant relationship between the combination of predictors: INOV, POLI, and the interaction variable between INOV and POLI (Int_1), and the dependent variable EMIS. This is demonstrated by the p-value of 0.00 (China) and 0.03 (UK).

Table 5
Model summary.

	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
China	1	.954[a]	.91	.903	.40975
UK	1	.632[a]	.399	.349	59.38902

[a] Predictors: (Constant), INOV.

Table 6
ANOVA.

	Model		Sum of Squares	df	Mean Square	F	Sig.
China	1	Regression	22.144	1	22.144	131.89	<0.001[a]
		Residual	2.183	13	0.168		
		Total	24.327	14			
UK	1	Regression	28,093.17	1	28,093.2	7.965	.015[a]
		Residual	42,324.67	12	3527.06		
		Total	70,417.84	13			

[a] Predictors: (Constant), INOV.

Table7a
Moderation analysis.

	R	R-sq	MSE	F	df1	df2	p
China	.94	.89	.18	27.27	3.00	10.00	.00
UK	.76	.58	2630.15	4.56	3.00	10.00	.03

However, different results can be observed when looking at the relationship of the predictors, separately, on EMIS (Table 7b). INOV's influence on EMIS for China is minor and statistically insignificant (coefficient = −.12; $p = .80$), implying that it does not effectively predict emission levels. For UK, INOV itself, though having a negative coefficient (−96.50), does not significantly predict EMIS, indicated by a non-significant p-value ($p = .24$).

Similarly, POLI's impact on EMIS is minor and not statistically significant for China (coefficient= −1.13; $p = .65$). Consistent with these findings, the interaction term between INOV and POLI (Int_1) shows an insignificant effect (coefficient = 0.03; $p = .58$), suggesting that the combined influence of these variables on EMIS is not evident in the Chinese context. In the UK, POLI's influence on EMIS, while negative (coefficient = −534.29), shows no statistical significance ($p = .17$), contradicting any assumptions that higher POLI scores directly translate into lower EMIS within the scope of this study's dataset. The interaction term Int_1, also shows an insignificant effect on EMIS (coefficient = 7.89; $p = 0.23$), indicating that the joint effect of INOV and POLI does not significantly alter EMIS outcomes in the context of this analysis.

4.3. Predictions for achieving SDG 13 by 2030

H3 tested whether China and the UK are on track to achieve SDG 13 by 2030. Using time series analysis, this study aimed to forecast CO_2 emissions for the two countries from 2022 until 2030. Results indicate that UK is on track to achieving SDG13 by 2030, but the same cannot be said for China.

Fig. 1 shows a consistent increase in China's EMIS from 2007, with a forecast of a further increase in EMIS figures by 2030. However, despite a strong model fit indicated by an R-squared value of 0.8267, increase in INOV is not associated with a decrease in EMIS, suggesting that, as of the current trajectory, China is not on track to meet the SDG 13 goal of reducing CO_2 emissions by 43 % by 2030.

Unlike China, the UK has shown a steady decline in CO_2 emissions since 2007, with projections indicating continued reductions through 2030 (Fig. 2). The study projections, supported by a strong model fit with an R-squared value of 0.9765, show a continued decline of EMIS by 2030. However, it is important to note that the analysis strictly illustrates trends and projections based on historical and current data.

4.4. Summary of results

Table 8 presents a summary of the key findings.

5. Discussion

The regression analysis, aimed at testing the first hypothesis, uncovers significant relationships for both countries, though in opposing directions, hence accepting H1. For China, the relationship between innovation and CO_2 emissions emerges as positively significant, suggesting that higher levels of innovation correlate with increased CO_2 emissions. This discovery presents a paradox, as theoretical expectations posited by SDG 13′s targets would anticipate innovation contributing to emission reductions. Yet, China's current innovation index exceeds the level presumed necessary for achieving SDG 13′s goals, contradicting the observed continuous rise in CO_2 emissions and its status as the world's foremost emitter. This incongruence signals a far more complex interaction between innovation and sustainability, underlined by the time series analysis that forecasts China's inability to meet 2030 emission targets, thus rejecting H3 for the nation.

In contrast, the UK's scenario delineates a requisite innovation index for SDG 13′s realisation that far surpasses its present score, emphasising the challenge ahead given the innovation stagnation observed since 2012. Nevertheless, a declining CO_2 emission trend persists in the UK, suggesting the influence of additional variables beyond innovation, in steering emission trajectories. This discrepancy is further explored through the time series analysis, which forecasts the UK's achievement of SDG 13 by 2030, thus accepting H3 for the country. Such contrasting findings between China and the UK illuminate the multifaceted nature of the innovation-CO_2 emissions nexus, stressing the need for a deeper exploration of all the potential elements shaping this relationship.

Relating these empirical findings to the literature discussed, the regression analysis for the UK is in line with Mongo, Belaïd and Ramdani [11], evidencing the cruciality of innovations for sustainability, while that of China validates Su and Moaniba [38] on their skepticism on the empirical evidence found, that supports that innovations combat climate change. Such discrepancy between the two countries could be due to the

Table7b
Moderation analysis.

		coeff	se	t	p	LLCI	ULCI
China	constant	13.57	22.88	.59	.57	−37.42	64.57
	INOV	-0.12	.47	-0.26	.80	−1.17	.93
	POLI	−1.13	2.42	-0.47	.65	−6.54	4.27
	Int_1	.03	.05	.57	.58	-0.08	.14
UK	constant	7020.43	4484.62	1.57	.15	−2974.65	17,015.51
	INOV	−96.50	76.46	−1.26	.24	−266.91	73.92
	POLI	−534.29	365.41	−1.46	.17	−1348.69	280.11
	Int_1	7.89	6.18	1.28	.23	−5.89	21.67

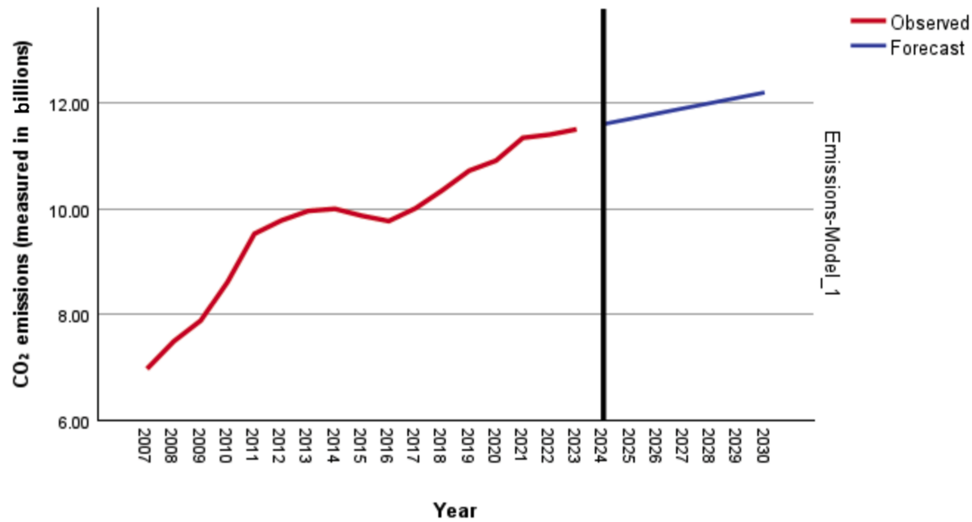

Fig. 1. Time series analysis to forecast China's CO_2 emissions by 2030.

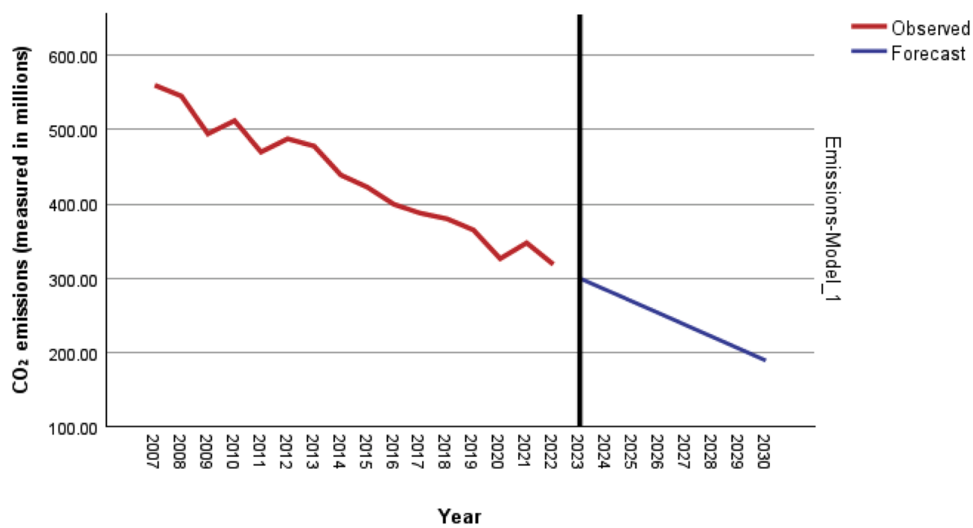

Fig. 2. Time series analysis to forecast UK's CO_2 emissions by 2030.

economic threshold effect in accordance with the EKC, as evidenced by numerous authors [28,36,39]. Interestingly, Sinha et al., 's [42] discussion could also explain the discrepancies between the two countries, as the authors find that technological process, a proxy for innovation, reduces air pollution in low and medium levels (the UK), and increases it in the case of high air pollution (China). Additionally, Acemoglu et al. [46] and Jaffe et al. [45] state that innovations lower CO_2 emissions in the long term, whereas in the short term the effect is opposite, which could be the case for China and the UK. This argument ties with that of the threshold effect, as the UK, having been a developed nation for far longer than China, has also had the resources needed to innovate and integrate said innovations into the nation's production processes for longer. Thus, it may be the case that the disparity between the two nations is because China is still experiencing the "short term" effects of innovations on CO_2 emissions, unlike the UK.

Table 8
Summary of results.

Aspect	China	United Kingdom
Normality (Skewness and Kurtosis)	Normal distribution	Normal distribution
Innovation → Emissions	**Positive** relationship	**Negative** relationship
Model Fit (R^2)	0.910	0.399
Policy Moderation	**Not significant**	**Not significant**
SDG 13 Projection by 2030	**Not on track**	**On track**

This study scrutinises the effect of policies on the innovation- CO_2 emissions nexus across China and the UK, employing a moderation analysis to explore the impact of the CPI alongside an interaction variable between innovation and CPI (Int_1). Despite identifying a statistically significant relationship when all four variables are considered collectively, the specific influence of the interaction variable on CO_2 emissions did not support the hypothesis that policies moderate the innovation- CO_2 emissions relationship for both nations. This outcome appears to diverge from the arguments of Porter (1991, as cited in [37]) and Chang et al. [37] who posited that flexible regulatory frameworks could amplify the environmental benefits of innovation. This discrepancy may find explanation in the literature review section, where Patashnik [52] and Lockwood [21] suggest policies might influence the innovation- CO_2 emissions dynamic, contingent upon precise policy development and execution. The case studies of China and the UK discussed previously, particularly their relatively unsuccessful initiatives like the Climate Change Act and sustainability efforts, reveal a lack of stringent governmental rigour, possibly elucidating the absence of significant policy moderation effects observed in this research.

Overall, this study critically delves into the nexus between innovation and CO_2 emissions, juxtaposing China's positive correlation against the UK's negative one. Utilising regression, moderation, and time series analyses, it challenges established perspectives, emphasising the nuanced interplay of innovation, policies, and CO_2 emissions across distinct national contexts. The unexpected finding that policy effectiveness does not significantly moderate this relationship in either country challenges existing assumptions and highlights a gap in policy design and effectiveness. By providing a refined understanding of how innovation impacts environmental outcomes, this research advocates for a reassessment of policy strategies, urging the development of more sophisticated, tailored and effective approaches to climate change mitigation.

5.1. Policy suggestions

This paper highlights the importance of continuous investment in innovation, closely coordinated with national sustainability targets, particularly those outlined in SDG 13, to tackle the growing issue of air pollution.

The inherently dynamic nature of innovation, combined with the lack of a universally accepted definition and recent global political and economic shifts that may have deprioritised CO_2 emissions, underscores the need for more rigorous monitoring of both variables. To ensure that CO_2 reduction goals remain central and innovation efforts continue uninterrupted, organisations such as WIPO and Germanwatch, which provide key data for this study, should consider increasing the frequency of their reporting to semi-annual or quarterly intervals. This more frequent reporting would allow for timely adjustments, enabling quicker responses to inefficiencies or the continuation of successful strategies within the same fiscal period, ensuring sustained focus on innovation and pollution control.

Despite suggestions from Chang et al. [37] on the potential moderating role of policies in enhancing the benefits of innovation on CO_2 emissions, this study found no evidence of such an effect in either China or the UK, challenging earlier assertions and suggesting a potential misalignment between national goals, innovation, and policies. The development and application of policies, particularly those aimed at the public interest and involving dynamic variables, demand careful crafting and ongoing revision to be effective. Given the critical nature of climate change, this research encourages national governments to leverage policy power to encourage sustainable innovation, aiming to make a more significant impact on CO_2 emissions in line with SDG 13′s goals.

China and the UK, despite exhibiting different dynamics between innovation and CO_2 emissions, both emphasise the crucial role of innovation in reducing air pollution on a national scale. China's positive correlation between innovation and CO_2 emissions may be attributed to its developmental stage, consistent with the Economic Threshold Effect. Rather than discouraging innovation, this highlights the need for greater resource investment in innovative efforts, which, though initially contributing to environmental degradation, is expected to eventually lower CO_2 emissions as suggested by the EKC theory. Similarly, while the UK is on track to meet SDG 13 targets despite a slowdown in innovation, the government is encouraged to further enhance its innovation efforts. Increased innovation could lead to even greater reductions in CO_2 emissions. However, it is important to acknowledge that other underlying factors, beyond the scope of this analysis, likely play a significant role and warrant further investigation.

6. Conclusion

This study offers fresh insights into the innovation–CO_2 emissions nexus by empirically comparing a developed economy (the UK) and a developing one (China). Using the Global Innovation Index, Climate Policy Index, and time-series forecasting within the Environmental Kuznets Curve (EKC) framework, the research moves beyond traditional approaches that focus narrowly on patents or R&D. It captures broader dimensions of innovation, integrates policy dynamics, and projects national trajectories toward achieving SDG 13 targets.

By revealing contrasting patterns between China and the UK, the study deepens understanding of how innovation interacts with policy and economic structures to influence emissions. In China, innovation correlates with rising CO_2 emissions, diverging from sustainability goals, while in the UK, emissions decline despite stagnating innovation. These findings challenge the assumption that innovation alone drives environmental progress, pointing to the influence of other factors such as energy sources and economic development.

The study also critically evaluates the role of policy, finding no evidence that current frameworks moderate the innovation–emissions relationship in either country. This suggests a disconnect between policy design and environmental objectives, despite theoretical claims that flexible regulations enhance innovation's environmental impact. The ineffectiveness of policies like the UK's Climate Change Act 2008 underscores the need for more targeted and adaptive strategies that align innovation with sustainability goals.

6.1. Limitations and future research

The selection of China and the UK, though theoretically justified, presents limitations due to their contrasting economic stages, policy frameworks, and socio-cultural contexts. These differences complicate direct comparison and may limit the generalisability of findings, given variations in innovation ecosystems and sustainability policy implementation [67,68]. National priorities and institutional dynamics may also shape the innovation–CO_2 emissions relationship in ways not fully captured. Nonetheless, the contextual contrast between the countries enrich the study, underscoring the need for tailored, country-specific approaches to sustainability and innovation, rather than relying on standardised, one-size-fits-all models.

While economic development and energy structures influence CO_2 emissions, this study prioritised innovation and national policy to isolate their specific effects within the EKC framework [58]. Variables such as clean technology adoption and sectoral energy use, though relevant, were excluded to maintain analytical clarity [69]. The focus was on assessing direct relationships across national contexts. Although innovation alone cannot fully explain emission trends, this study reveals how its impact varies between developed and developing economies, shaped by governance and policy. This contextualised approach advances the literature toward more nuanced, locally informed understandings of sustainable development dynamics.

While this study offers valuable contributions and policy insights, it acknowledges key limitations. Reliance on secondary data—specifically WIPO's GII and Germanwatch's CPI—restricted the analysis to 2007–2022, limiting predictive accuracy for 2030 CO_2 emissions and constraining EKC testing for China and the UK. The modest sample size of 16, may also reduce statistical power, as highlighted by Shieh [66] and Memon et al. [65], who emphasise the importance of larger samples for reliable moderation analysis. These limitations underscore the need for future research with broader datasets and extended timeframes to enhance robustness and generalisability in sustainability-focused innovation studies.

Recognising these gaps, future research should broaden its scope to include more countries and longer timeframes. Understanding the complex innovation–CO_2 emissions nexus is vital for effective policy. Exploring diverse economic contexts and policy environments will yield more generalisable insights, supporting tailored strategies for sustainable development across governments, industries, and environmental institutions.

To support sustainable development, ongoing empirical research is essential. Regularly tracking the innovation–CO_2 emissions relationship ensures insights remain timely and actionable. Such research informs balanced policies that promote economic growth through innovation while preserving the environment, guiding nuanced policymaking and advancing global strategies for a more sustainable future.

While digital technologies were not discussed as a stand-alone variable, but rather as a proxy for innovation within the scope of this study, they hold significant potential to shape sustainable innovations and emission trajectories. As such they represent an important avenue for future research.

Declaration of generative AI and AI-assisted technologies

During the preparation of this work the author(s) used Microsoft copilot in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Ethics approval was granted for this research by the Research Ethics Committee of the College of Business, Arts and Social Sciences, Brunel University London. The research uses secondary data published in the World Intellectual Property Organization, Germanwatch, and Our World in Data and therefore informed consent is not applicable to this manuscript.

Data availability

The datasets used in this manuscript are publicly available as follows:

- The World Intellectual Property Organization -https://www.wipo.int/publications/en/series/index.jsp?id=129
- Germatwatch -https://www.germanwatch.org/en/CCPI
- Our World in Data - https://ourworldindata.org/co2/country/china#citation and https://ourworldindata.org/co2/country/united-kingdom.

CRediT authorship contribution statement

Megi Bego: Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation, Conceptualization. **Hemamali Tennakoon:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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