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Article

Corporate carbon intensity and GDP contribution comparison across 4 countries

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Abstract: The paper analyzes the corporate carbon emissions and GDP contributions of the top ten companies by turnover for 2020–2023 in Germany, South Korea, China and the United Kingdom. Focusing on Scope 1, 2, and 3, the study explores the contribution of these companies to carbon intensity across different sectors and economies. The analysis shows that there are significant gaps in carbon efficiency, with the UK's and Germany's firms emitting the lowest emissions per unit of GDP contribution, followed by China and South Korea. Additionally, the study further examines the impact of Economic Policy Uncertainty on both firm carbon intensity and economic productivity. While EPU is positively associated with GDP contributions, its impact on emissions is nuanced. Firms apparently respond to policy uncertainty by increasing energy efficiency in direct (Scope 1) and energy-related (Scope 2) emissions but find it more difficult to manage supply chain emissions (Scope 3) in that case. The results point out the critical role of comprehensive ESG reporting frameworks in enhancing transparency and addressing Scope 3 emissions, which remain the largest and most volatile component of corporate carbon footprints. The paper then emphasizes the importance of standardized ESG reporting and bespoke policy intervention for promoting sustainability, especially in carbon-intensive industries. This research contributes to the understanding of how industrial and policy frameworks affect carbon efficiency and economic growth in different national contexts.

Keywords: corporate carbon emissions; GDP contribution; economic policy uncertainty; ESG reporting; sustainability
JEL Classification: M21

1. Introduction

The increasing urgency of climate change has intensified global scrutiny of corporate carbon emissions and their respective contributions to national economies. As governments and organizations strive to meet international sustainability goals, the measure of corporate carbon intensity is a key factor in gauging how industries contribute to either environmental degradation or economic growth. This paper examines the corporate carbon emissions-scope 1, 2, and 3-and the GDP contributions of the top 10 companies by turnover in Germany, South Korea, China and the United Kingdom from 2020 to 2023. This comparative study among countries looks at the different magnitudes of carbon efficiency and their consequences for environmental policy and economic strategy.

It is placed within the broader frame of Environmental, Social, and Governance (ESG) ratings, which have now cropped up as a vital measurement of corporate performance. However, the divergences in these ESG ratings, because of their inconsistent methodologies across rating agencies, raise questions over the reliability and comparability of such ratings or assessments. These inconsistencies have implications for corporate decisions, investor confidence, and audit costs, especially in markets where regulatory frameworks are still developing, as found in countries such as China (Jang et al., 2020; Zhang et al., 2023). Moreover, the impact of EPU on corporate performance also points to an added layer of intricacy. EPU often exacerbates risks for companies, leading to higher costs and reduced performance, though ESG disclosures may mitigate some of these negative effects by increasing transparency and reducing information asymmetry (Fatemi et al., 2018).

This paper seeks to address the existing research gaps by testing the relation between corporate carbon emissions, GDP contributions, and EPU in these four countries. Calculating the carbon intensity of economic output-through emissions per unit of GDP contribution-allows insight into how this might change across nations due to differing industrial compositions. Therefore, it shows the targeted policy interventions on emission reductions while sustaining economic growth, especially in high-emission sectors like China and South Korea. In addition, this analysis is expected to contribute to the ongoing discussion of ESG standardization and also underscore the role of sustainability as an increasingly important determinant of mitigating adverse impacts of policy uncertainty on corporate performance.

2. Review of literature

ESG ratings have turned critical in judging corporate performance beyond traditional measures of financial performance. They drive investment decisions and corporate strategy alike; they are a reflection of a company's performance with respect to sustainability and ethical impact. But with such wide variation in ESG ratings from the field of rating agencies, serious questions have arisen regarding the comparability and reliability of such ratings. Of course, this diverging trend in ESG ratings challenges the decision-making process among investors, companies, and auditors and influences the cost of operations (Liu, 2022). Divergence in ESG ratings is one of the most talked-about phenomena, which was attributed to its main cause: the lack of unified methodologies across rating agencies. Each agency, basically, uses its own set of criteria, weighting, and data sources, which results in extensive differences in ratings for the same company (Berg et al., 2022). The divergences will thus lead to multiple notions of a company's sustainability performance that could influence everything, from the decisions of an investor to those of policy regulators. The sensitive areas that the impact of ESG rating divergence spills over include audit fees. A number of studies have indicated that with increased divergence in ESG ratings, there will resultingly be increased audit fees. This would mainly be because divergent ratings can raise information asymmetry, increase operative risks, and increase the perceived cost of debt capital accordingly (Jang et al., 2020). Auditors are increasingly asked to undertake more uncertainty and difficulty in the process of verifying a company's ESG performance and therefore ask for higher compensation to compensate for these added risks and resources. This is, of course, even clearer in certain markets, such as China, where the relevant regulatory frameworks are at an earlier stage of development and contribute to considerable divergence in ratings outcomes (Zhang et al., 2023). Various threads of this in effect continuing debate relate to the growing chorus for standardization of methodologies of ratings. A lack of standards in these areas leads first to rating divergence and has as its general implication undermining of credibility in ESG evaluations (Berg et al., 2022). Other scholars again repeat the mantra of standardization of ESG ratings to relieve the confusion and thus yield more dependable ratings. For other scholars, divergence will also be inevitable given the nature of the ESG factors and subjective judgments upon varied priorities of different stakeholders (Christensen et al., 2021).

The nexus between Economic Policy Uncertainty and corporate performance is an academic controversy, particularly with regard to the assessment of the role of ESG factors. EPU reflects uncertainty in government policy and its subsequent effect on economic conditions. It has been observed to have a negative effect on firm performance since it leads the latter to be more uncertain for investors and managers; this leads to asymmetry of information and perceived risk (Al-Thaqeb and Algharabali, 2019). The significance of this relationship is that it may influence the decisions at the corporate level as well as in the long-run strategic selection. Various studies also support the fact that greater magnitudes of EPU are directly related to poorer firm performance because the firms have to incur higher capital costs and uncertainty associated with their investment decisions. For example, Ahsan and Qureshi (2020) find that EPU significantly impairs the accounting and market-based performance of firms in Europe. This reduced performance may largely be attributed to increased risk and information asymmetry that EPU introduces, which would drive investors away and hamper the capability of making good decisions by firms (Drobetz et al., 2017). The relationship between EPU and firm performance is further convoluted by the undertone provided by the disclosure of ESG. Factors of ESG have increasingly been considered crucial in mitigating adverse influences on EPU-firm performance. Literature in this aspect has indicated that strong ESG disclosures by companies have the ability to mitigate negative impacts brought about by EPU as a result of reduced information asymmetry hence increasing corporate transparency (Fatemi et al., 2018). Other scholars such as Buallay (2019) and Fatemi et al. (2018) also discuss that firms which disclose more on ESG issues can reduce negative consequences of EPU because such disclosure diminishes information asymmetry and enhances corporate transparency. Ahsan and Qureshi (2020) have evidence that ESG disclosures, mainly in environmental and social dimensions, facilitate the firms in reducing the devastating influence of EPU on performance through reputation building by gaining the trust of stakeholders (Ahsan and Qoureshi, 2020). Of particular note, environmental disclosure appeared to be the significant moderator in the nexus between EPU and performance. Firms with more developed environmental reporting can perform better in insulating levels of performance during high policy uncertainty since such disclosures have the potential to enhance the legitimacy of the firm and reduce market skepticism on its operations (Cormier and Magnan, 2015). Another important reason is that the social disclosures are important in developing close ties with customers, society, and workers, which would cushion a firm from uncertainties or unbalancing by changes in economic policies (Saini and Singhania, 2019). Another important mitigating factor, governance disclosure weakens adverse EPU effects that may be regarded as reflecting the level of effectiveness and efficiency of a firm’s corporate governance mechanism. This is because improved monitoring and strategic decisions, on account of strong corporate governance, may enable a firm to manage uncertain environments (Albitar et al., 2020). Al-Gamrh et al. (2020) also found in this line that governance disclosure significantly moderates the influence of EPU on performance by supporting the notion that well-governed firms are resilient to policy-induced uncertainty. These findings have been robust across many methodological approaches, such as dynamic panel data regression analysis and generalized method of moments systems that control for possible problems of endogeneity and firm-specific factors (Ferrero-Ferrero et al., 2016). These together hint at the fact that though EPU creates enormous hurdles for firms, ESG disclosures could act as a strong tool for firms in mitigating these risks and sustaining their performance (Pulino et al., 2022).

Few studies have directly tested the effect of EPU on carbon emissions, and their findings reflect quite a complex relationship. Sectoral data for the U.S., for instance, provide an overview of how EPU has been a critical determinant of carbon emission, especially during higher or lower growth periods across these sectors (bar commercial) established in the study by Jiang et al. (2019). While doing so, the narrow-focused studies on the top ten carbon-emitting countries note that the EPU, because of the time factor involved in this, may reduce or deteriorate carbon emissions (Anser et al., 2021). Because of this fact, its relation to EPU seems to be multidimensional, while most studies indicate that firms improve ESG activities in cases where uncertainty is at higher levels. For example, Vural-Yavaş (2020) reports the case where European companies improve their ESG performance-in particular, governance and environmental performance-by decreasing corporate risks and capturing value-enhancing opportunities in times of uncertainty. EPU also significantly impacts corporate sustainability strategy. For instance, a study was carried out to identify how the carbon emissions trading policy has taken effect on the ESG performance of Chinese firms; it reported that they have improved their sustainability performance and hence acted as an indicator that the market-oriented environmental regulation enhances companies' resilience to EPU (Zhang et al., 2023). Additionally, reputation capital gained by firms through ESG investments can dampen the potentially negative influence of EPU on market performance. These are but common examples of sheltering effects that sustainability practice have under regimes of economic uncertainty (Zhang and Liu, 2022). Literature thus suggests that EPU significantly influences the levels of corporate carbon emissions, ESG performance, and sustainability behavior of firms. One might observe that the strategic response of EPU, especially in those cases where perceived risks from political and economic standpoints are higher, acts to improve ESG activities and further sustainability efforts (Alandeani and Al-Shaer, 2023). It therefore supports the belief that integration of ESG strategies should hedge against adverse effects of EPU for improving both corporate resilience as well as environmental sustainability.

3. Research questions

- How do corporate carbon emissions (Scope 1, 2, and 3) vary across industries in Germany, South Korea, China and the United Kingdom from 2020 to 2023?

- What are the key factors influencing the divergence in corporate carbon intensity among the top 10 companies by turnover in Germany, South Korea, China and the United Kingdom?
- What are the differences in GDP contribution per unit of carbon emissions between the top 10 companies in Germany, South Korea, China and the United Kingdom?
- How does the carbon emission per GDP contribution metric ($kgCO_2$/$) compare among the top 10 companies by turnover in Germany, South Korea, China and the United Kingdom?

4. Methodology

The methodology analyses the top 10 companies by turnover in Germany, South Korea, China and the United Kingdom. For the analysis, Scope 1, Scope 2 and Scope 3 emissions data for the period 2020–2023 were extracted from the companies' sustainability reports. Furthermore, for the calculation of the GDP contribution of the companies, the annual accounting reports were analysed.

The GDP contribution was calculated using the following methodology:

1) Employee benefits + Depreciation, amortization + Net profit = GDP contribution

Table 1. Research sample.

	Germany	South Korea	China	UK
Number of companies	10	10	10	10
Number of years	4	4	4	4
Number of GDP contribution data	40	40	40	40
Number of Scope 1 emission data	40	40	40	40
Number of Scope 2 emission data	40	40	40	40
Number of Scope 3 emission data	40	40	40	40

The data collected was used to calculate the emissions of companies and their contribution to GDP. This was done using the following formula:

2) Scope (1, 2, 3) / GDP contribution = Scope (1, 2, 3) emission for 1 dollar GDP contribution

After calculating the values, the Economic Policy Uncertainty Indices of Germany, South Korea, China and the United Kingdom (Baker et al., 2016) for the period 2020–2023 were collected. These indices were used to perform composite statistical analyses of emission values and composite emission and GDP contribution metrics.

5. Results

Table 2 shows the descriptive statistics for Scope 1, Scope 2, and Scope 3 carbon emissions across South Korea, Germany, and China from 2020 to 2023. The data in this table has shown dispersed trends of emission across these countries in terms of both their averages and standard deviations. For example, the consistent high level of Chinese data, especially for Scope 1 and Scope 3 categories, has averaged values that are much greater compared to South Korea and Germany. This indicates China's higher industrial output or heavier reliance on carbon-intensive processes.

Table 2. Descriptive statistics of Scope 1, 2, 3 emissions.

South Korea					**Germany**				**China**				**United Kingdom**			
(1000 tCO_2)	**Avg.**	**Mdn.**	**Std. Dev.**	**N**	**Avg.**	**Mdn.**	**Std. Dev.**	**N**	**Avg.**	**Mdn.**	**Std. Dev.**	**N**	**Avg.**	**Mdn.**	**Std. Dev.**	**N**
2023					2023				2023				2023			
Scope 1	9969	1056	22,895	9	5019	1362	6895	10	26,781	96	56,383	10	5206	106	15,742	10
Scope 2	2756	1579	2895	9	1360	738	1476	10	8132	1644	15,683	10	1000	65	2204	10
Scope 3	42,607	11,472	54,712	9	138,709	81,150	169,045	10	1109	740	1405	4	210,523	4460	637,732	10
2022					2022				2022				2022			
Scope 1	9992	3394	20,794	10	8900	1787	17,154	10	28,657	112	56,898	9	5347	214	16,044	10
Scope 2	2988	1843	2672	10	1451	878	1525	10	7997	1613	14,530	9	1000	85	2195	10
Scope 3	33,884	9319	47,297	10	138,846	92,000	158,076	10	739	19	1,453	4	216,233	4060	656,452	10
2021					2021				2021				2021			
Scope 1	11,131	3765	23,466	10	8639	2205	15,809	10	30,014	74	59,838	9	6247	136	18,890	10
Scope 2	3068	1780	2895	10	1583	862	1676	10	7650	1516	13,810	9	1128	102	2497	10
Scope 3	24,352	12,873	35,889	9	142,704	102,290	153,187	10	863	36	1679	4	239,306	5300	727,402	10
2020					2020				2020				2020			
Scope 1	10,782	3786	22,867	10	7701	2294	13,356	10	36,606	4	62,486	7	6531	133	19,844	10
Scope 2	2784	17,178	2707	10	1994	1101	2160	10	12,156	927	19,801	7	1150	107	2501	10
Scope 3	23,191	13,202	34,516	9	141,537	97,600	175,075	10	25	25	35	2	243,680	524	743,125	10

Among all years, the lowest Scope 1 and Scope 2 emissions were recorded for Germany, which could be an indication that industries here tend to employ cleaner or more energy-efficient technologies compared to South Korea and China. The standard deviations also present evidence that there is a greater variation of emissions within Chinese companies, therefore indicating a discrepancy in emissions control among industries. This table indicates that a differentiated set of policy measures should be necessary to suit the industrial composition and energy practices of each country. For China, the majority coming from Scope 1 and Scope 3 indicates that direct and indirect emissions are seriously relevant. Where South Korea has moderately high emissions with large variance, it may focus more on normalizing its carbon output; whereas for Germany, with relatively low emissions, it can highlight its leadership in the best practices of carbon intensity reduction.

Table 3 presents the descriptive statistics for the GDP contribution of companies in South Korea, Germany, China and the United Kingdom from 2020 to 2023. The data highlights noticeable differences in economic output among the countries, with Germany consistently reporting the highest median GDP contribution across 2023–2021. For instance, in 2023, Germany's companies contributed an average of $38.7 billion, significantly higher than South Korea's $12.6 billion and China's $37.4 billion. This suggests that German companies, on average, have a larger economic footprint compared to their counterparts in South Korea, the UK and China. Interestingly, China's GDP contribution remains close to that of Germany, indicating the significant economic power of its top companies. However, the large standard deviations across all countries, especially in Germany, the UK and China, point to substantial variation among firms. This means that a few very large companies could be skewing the average GDP contribution figures. South Korea, while showing smaller GDP contributions compared to Germany and China, demonstrates relatively less variability (lower standard deviations), implying a more consistent contribution across its top firms. This may suggest a more evenly distributed corporate sector in terms of economic impact.

Table 3. Descriptive statistics of GDP contribution.

	South Korea				Germany				China				United Kingdom			
(million USD)	Avg.	Mdn.	Std. Dev.	N	Avg.	Mdn.	Std. Dev.	N	Avg.	Mdn.	Std. Dev.	N	Avg.	Mdn.	Std. Dev.	N
2023	12,584	5611	18,753	10	38,782	34,359	29,486	10	37,446	29,728	21,100	10	26,390	23,210	20,046	10
2022	15,638	4595	28,017	10	34,466	32,525	32,804	10	38,657	36,463	22,811	10	23,251	19,188	21,403	10
2021	10,483	7499	10,821	10	33,797	30,088	28,653	10	36,810	29,362	22,624	10	22,919	16,607	17,748	10
2020	7191	5583	8016	10	28,609	24,492	23,951	10	35,886	35,738	17,273	10	12,521	13,073	8758	10

Table 4. Descriptive statistics of calculated emission per GDP contribution metric.

South Korea				Germany			China			United Kingdom		
($kgCO_2/\$$)	Scope 1	Scope 2	Scope 3	Scope 1	Scope 2	Scope 3	Scope 1	Scope 2	Scope 3	Scope 1	Scope 2	Scope 3
Average				Average			Average			Average		
2023	1.90	0.64	15.15	0.31	0.06	5.10	0.69	0.18	0.04	0.09	0.02	1.13
2022	1.40	0.52	11.86	0.47	0.06	5.68	0.55	0.16	0.02	0.08	0.04	5.66
2021	1.38	0.44	9.08	0.26	0.22	14.38	0.76	0.18	0.05	0.12	0.03	4.75
2020	9.64	2.18	8.22	1.81	0.31	10.37	0.85	0.28	0.00	0.78	0.12	28.95
Median				Median			Median			Median		
2023	0.28	0.24	1.91	0.03	0.02	3.62	0.00	0.05	0.04	0.01	0.01	0.32
2022	0.37	0.27	0.76	0.03	0.02	3.33	0.00	0.02	0.00	0.01	0.01	0.41
2021	0.31	0.31	0.79	0.02	0.02	3.87	0.00	0.02	0.00	0.01	0.01	0.46
2020	0.42	0.35	0.55	0.04	0.04	4.98	0.00	0.02	0.00	0.01	0.01	0.06
Standard deviation				Standard deviation			Standard deviation			Standard deviation		
2023	3.18	0.64	38.14	0.58	0.09	6.81	1.73	0.33	0.05	0.24	0.04	1.42
2022	2.49	0.48	32.54	0.99	0.09	8.65	1.18	0.24	0.03	0.21	0.05	10.39
2021	2.39	0.34	21.86	0.49	0.48	21.18	1.77	0.30	0.10	0.31	0.05	11.99
2020	23.83	5.29	18.20	4.80	0.75	15.17	1.54	0.50	0.00	2.39	0.29	89.65
N				N			N			N		
2023	9	9	9	10	10	10	10	10	4	10	10	10
2022	10	10	10	10	10	10	9	9	4	10	10	10
2021	10	10	9	10	10	10	9	9	4	10	10	10
2020	9	9	9	10	10	10	7	7	2	10	10	10

Table 4 presents the calculated emission per GDP contribution metric, in $kgCO_2$ per dollar of GDP contribution, for South Korea, Germany, China and the UK over Scopes 1, 2, and 3 for the years 2020 through 2023. This metric helps evaluate the

carbon intensity of each country's economic output, or the environmental cost to produce one dollar of GDP. Throughout the years, South Korea is always at the top in Scope 1 and Scope 2 per dollar of GDP, which suggests that South Korean industries are relatively more carbon-intensive compared to those of Germany and China. In 2023, for instance, the average Scope 1 emissions per GDP contribution of South Korea were 1.90 $kgCO_2$/$, while those of Germany were 0.31 $kgCO_2$/$, China's was 0.69 $kgCO_2$/$ and the UK's was 0.09 $kgCO_2$/$. This would mean that United Kingdom relies more on highly carbon-intensive industries. The United Kingdom has the lowest intensity of emission in all scopes and for all years because of its more energy-efficient industries and probably stronger environmental regulations. For instance, in 2023, Scope 2 emissions per GDP in the UK were only 0,02 $kgCO_2$/$, while in South Korea and China, respectively, they were 0.64 and 0.18 $kgCO_2$/$. Although the United Kingdom has shown a high stake in emission reduction compared to both South Korea and China, Germany has also shown an enviable trajectory toward low emission sustainment. For example, in 2023, Germany's Scope 2 emissions reached 0.06 $kgCO_2$/$, an indicator that really justifies its commitment to being greener. China, while having larger absolute emissions, shows relatively lower emissions intensity per GDP contribution, especially in Scope 3, reflecting its ability to generate higher economic output relative to its carbon emissions. This could indicate that China is starting to adopt less carbon-intensive processes or is benefiting from its large economy of scale. Generally, from **Table 4** it can be observed that the carbon efficiencies are different among these four countries, with the UK being more carbon-efficient and China in the middle, while Germany and South Korea bears a higher carbon intensity. The implication of this finding is that South Korea needs to focus on appropriate policy intervention for carbon reduction against economic output.

Table 5 shows the results of a chi-squared test comparing the carbon emission intensity ($kgCO_2$/$) of Germany, South Korea, China and the UK, using the average over four years. The chi-square values for Scope 1 and Scope 2 are 5.27 and 1.46, respectively, with no significant *p*-values. However, the chi-square for Scope 3 emissions is 10.28 at a significant *p*-value of 0.05, showing a significant statistical difference in the carbon intensities with regard to supply chain emissions across the four countries. The implication here is that China, with its high industrial output and heavy reliance on carbon-intensive processes, makes substantial contribution to the variation in Scope 3 emissions. The results highlight the importance of paying attention to supply chain-related emissions, Scope 3, when designing the carbon intensity reduction strategy, especially for countries like China with higher indirect emissions.

Table 5. Chi-squared of $kgCO_2$/$ (4 years average).

		df	**$\varkappa^2$**	***p*-value**
Germany, South Korea, China, United Kingdom	Scope 1 ($kgCO_2$/$)	3	5.27	-
	Scope 2 ($kgCO_2$/$)	3	1.46	-
	Scope 3 ($kgCO_2$/$)	3	10.28	<0.05

Table 6 presents chi-squared test results for the four countries' Scope 1, Scope 2, and Scope 3 emissions in Germany, South Korea, China and the UK over a four-year average show striking dissimilarities in the countries' carbon emissions. That is, Scope 1 that accounts for direct emissions and Scope 2, indirect emissions as a result of energy consumption, show great variations, as the chi-square values of 28,882.50 and 10,966.03, respectively, with *p*-values of 0.01 indicate critical fluctuations in how these nations account for emissions from industrial processes and energy consumption. However, the most striking result is in Scope 3 emissions, which are related to supply chain-related emissions; it shows the highest chi-square value: 325,337.60, also at a *p*-value of 0.001. That would indicate that the largest differences between these countries come from their supply chain activities and that China's high industrial output may be one of the causes for its higher emissions. These results underline the need for countries to apply targeted policies concerning carbon emissions, especially pertaining to value chains sustainability, given that Scope 3 emissions are the most significant contributor to the difference between countries.

Table 6. Chi-squared of Scope 1,2,3 emissions (4 years average).

		df	**χ^2**	***p*-value**
Germany, South Korea, China, United Kingdom	Scope 1	3	28,882.50	<0.01
	Scope 2	3	10,966.03	<0.01
	Scope 3	3	325,337.60	<0.01

Table 7 presents the chi-squared test results for the GDP contributions of companies in Germany, South Korea, China and the UK averaged over four years, highlighting significant differences in economic output among these countries. The chi-squared value of 16,230.98 with a *p*-value of 0.01 indicates a statistically significant variation in the GDP contributions across the four nations. China consistently shows the highest average GDP contribution, suggesting that its top companies have a more substantial economic footprint compared to those in South Korea, Germany and the United Kingdom. South Korea exhibits lower GDP contributions but with less variation, suggesting a more balanced economic output in contrast to the rest of the analysed countries across its top companies.

Table 7. Chi-squared of GDP contribution (4 years average).

		df	**χ^2**	***p*-value**
Germany, South Korea, China, United Kingdom	GDP contribution	3	16,230.98	<0.01

In **Table 8**, Pearson's correlation test between GDP contribution and Economic Policy Uncertainty (EPU) index in Germany, South Korea, China and the UK. The value of the Pearson's correlation test is 0.741, and the p-value is less than 0.001. This means that an increase in EPU goes with a high increased GDP contribution by companies. This would, therefore, imply that firms may respond to economic policy uncertainty by altering their strategies, maybe even increasing their economic activities in order to diversify risks linked with uncertain policy environments. The positive correlation also shows that companies in such countries may be resilient to any policy fluctuations and continue to contribute significantly to the GDP despite the uncertainty. This relationship captures the complex dynamics between economic policy uncertainty and corporate performance, indicating the ability of firms to adapt to uncertainty and, in that way, to sustain or even improve their economic contributions.

Table 8. Pearson's correlation test of GDP contribution and EPU index.

	GDP contribution	EPU index
GDP contribution	1.000	
EPU index	0.741**	1.000

p value ≤ 0.001**.

Table 9 provides regression analysis showing the relationship between the contribution of GDP and EPU index. The regression is strongly positive, with an *R* value of 0.770 and an R square of 0.593, thus meaning that changes in the EPU index account for about 59.3% of the variation in GDP contribution. This is further supported by a high *F*-value of 20.4 and a statistically significant *p*-value of below 0.001, hence strength in the significance of this relationship. These results have shown that with increased economic policy uncertainty, companies tend to increase their GDP contributions, perhaps as a way of cushioning themselves against the risks associated with uncertain policy environments (Tajaddini and Gholipour, 2020). Considering such uncertainty, it would be great that firms could still contribute positively to economic output, which would point to the ability of companies across Germany, South Korea, China and the UK to maintain economic performance in difficult and unpredictable policy climates.

Table 9. Regression of GDP contribution and EPU index.

	Values
R	0.770
R^2	0.593
Corrected R^2	0.564
Standard error	97.65
F value	20.4
F significance	0.001***

p value ≤ 0.001***.

Table 10 shows Pearson's correlation test results examining the relationship between the Economic Policy Uncertainty (EPU) index and the carbon emission intensity (kgCO_2/$) for Scope 1, Scope 2, and Scope 3 emissions across Germany, South Korea, China and the UK. The results reveal a slightly positive and insignificant correlation between the EPU index and both Scope 1 (0.179) and Scope 2 (0.191) emissions. Interestingly, there is no significant correlation between the EPU index and Scope 3 emissions (−0.438). Scope 1 and scope 2 have strong and statistically significant relationship (<0.001***) implies that Scope 1 and Scope 2 very often move together. Companies that have high Scope 1 emissions probably consume a lot of energy, which could then be translated into high Scope 2 emissions. Overall, the findings suggest that firms are likely to adopt more energy-efficient practices and reduce direct emissions in response to policy uncertainty, potentially as a way to manage risks and costs, but may struggle to address supply chain emissions as effectively.

Table 10. Pearson's correlation test of (Scope 1,2,3) $kgCO_2$/$ and EPU index.

	EPU index	**Scope 1 $kgCO_2$/$**	**Scope 2 $kgCO_2$/$**	**Scope 3 $kgCO_2$/$**
EPU index	1.000			
Scope 1 $kgCO_2$/$	0.179	1.000		
Scope 2 $kgCO_2$/$	0.191	0.899***	1.000	
Scope 3 $kgCO_2$/$	−0.438	0.350	0.381	1.000

p value ≤ 0.001***.

Table 11 presents the regression analysis examining the relationship between the Economic Policy Uncertainty (EPU) index and carbon emission intensity ($kgCO_2$/$) for Scope 1, Scope 2, and Scope 3 emissions. The overall model shows a moderate relationship with an *R*-value of 0.522 and an R-squared value of 0.273, indicating that around 27.3% of the variation in carbon emission intensity is explained by changes in the EPU index. However, the regression results show differing effects across the emission scopes. Scope 1 emissions have a positive coefficient of 27.7, suggesting that as policy uncertainty increases, direct carbon emissions slightly increase, though this result is not statistically significant (*p*-value = 0.848). Scope 2 emissions show a negative coefficient (−190.9), indicating that companies tend to reduce energy-related emissions under higher policy uncertainty, though this result is also not statistically significant (*p*-value = 0.764). Scope 3 emissions, related to supply chains, have an insignificant (*p*-value = 0.085) coefficient (14.0) showing little relationship with policy uncertainty. The analysis suggests that while there is some responsiveness in supply chain emissions (Scope 3) to policy uncertainty, the effects are not strong enough to draw definitive conclusions. Additionally, Scope 1–2 emissions seem unaffected by policy uncertainty.

Table 11. Regression of (Scope 1,2,3) $kgCO_2$/$ and EPU index.

		Values	
R		0.522	
R^2		0.273	
Corrected R^2		0.091	
F value		1.500	
F significance		0.264	
	Estimate	**Standard error**	***p* value**
Intercept	506	84.72	<0.001
Scope 1 $kgCO_2$/$	27.7	141.48	0.848
Scope 2 $kgCO_2$/$	−190.9	620.36	0.764
Scope 3 $kgCO_2$/$	−14.0	7.43	0.085

6. Discussions

These findings depict wide discrepancies that closely match the industrial composition, economic policies, and corporate sustainability practices of each country, which is consistent with prior literature in environmental economics and corporate governance. The data hence indicate that companies from China are consistently showing higher Scope 1 and Scope 3 emissions, especially in industries with heavy industrial output. This points to the fact, as observed by Zhang et al. (2022), that China relies on carbon-intensive manufacturing processes in order to achieve rapid industrialization and economic growth objectives. On the other hand, the United Kingdom and German companies, have lower emissions across all scopes, reflecting the country's more advanced adoption of cleaner technologies and the stringent environmental regulations in place. For China and South Korea, the regulatory frameworks around sectoral targets, further tightening control over direct Scope 1 emissions, and technology incentives may help speed up the transition toward more sustainable industry practices.

Based on the results, the Scope 3 emissions, arising from supply chains, remain the largest and most inconsistent contributor to carbon intensity across all four countries. Such high variability in these emissions indicates difficulties in controlling and reporting indirect emissions in generally fragmented supply chains with low oversight mechanisms. With increased political uncertainty, stakeholders may prioritise short-term economic performance over long-term sustainability, exacerbating potential supply chain inefficiencies. Addressing these issues requires targeted policy incentives, practical carbon neutral supply chain policies and close cooperation and flexibility with suppliers on the part of companies and policy makers.

Moreover, this research finds radical differences in carbon intensity per unit of contribution to GDP ($kgCO_2/\$$), whereby the German companies are leading in carbon efficiency. Low emissions per dollar value of GDP, noticeably in Scope 2 emissions, emphasize Germany's and the UK's effective integration of sustainable business models and energy-efficient technologies into the way of doing business (Porter and Van der Linde, 1995). This efficiency is in line with the Porter Hypothesis, which says that strict environmental regulations may increase competitiveness by way of innovation. The companies based in South Korea and China, while producing a substantial share of GDP, have lower carbon efficiency, especially in Scope 1 and Scope 3 emissions. These results agree with the findings of Anser et al. (2021), who note that economies with strong manufacturing and fossil fuel sectors tend to have higher carbon intensities. This might be explained by cost-saving approaches and risk aversion, as the firms want to gain effectiveness in times of uncertainty. In alignment with the above argument, Vural-Yavaş (2021) mentions that firms increase their governance and environmental performance in order to reduce the risk of unpredictable policies.

Robust ESG reporting may increase transparency, decrease information asymmetry, and increase stakeholder trust, which could help mitigate any negative effects stemming from policy uncertainty. Fatemi et al. (2018) believe that comprehensive ESG disclosures allow companies to better manage environmental risks and integrate sustainability into the corporate strategy. However, the continued difficulty in Scope 3 emissions puts into focus the gap within current ESG reporting frameworks. Christensen et al. (2021) highlighted the importance of standardized and comprehensive ESG metrics that should envelop the whole value chain. This would enhance the quality and scope of ESG disclosures, which would empower firms to manage their supply chain emissions more effectively and to align with global sustainability goals.

7. Conclusions

A detailed comparative analysis of corporate carbon emissions and their respective GDP contributions is carried out among the top 10 companies with the highest turnover in Germany, South Korea, China and the UK between the period of 2020 to 2023. The results show large differences in carbon intensity and economic impact across these countries, which could trace back to differences in industrial composition, regulatory frameworks, and corporate responses to economic policy uncertainty. The United Kingdom and Germany showed the lowest carbon intensity among all the emission scopes, in regard to especially Scope 1 (direct emissions) and Scope 2 (indirect emissions from the consumption of energy). This underlines the effectiveness of the UK's and Germany's leading-edge environmental policy and also reinforces wide adoption of energy-efficient technologies. By contrast, companies in China contribute more to total emissions, but tend to have relatively lower emissions per unit of contribution to GDP, especially in Scope 3 (other indirect emissions, for example, those related to supply chains). The latter may indicate an ability to produce significant economic output despite dependence on carbon-intensive processes.

The latter finding also underscores the potential role that ESG disclosures can play in mitigating the adverse effects of EPU through transparency and reduced information asymmetry. These findings show the importance of tailored policy approaches in order to reduce carbon emissions and increase sustainability within the different industrial contexts. For South Korea and China, adoption of policies that encourage continued efforts in carbon reduction across industries is greatly necessary. With its vast industrial base, China should therefore prioritize a comprehensive strategy that brings down overall carbon output while guaranteeing economic growth. Its experience offers lessons for other countries looking to upgrade their sustainability practices related to strong economic performance with low carbon intensity.

Future studies could focus on the role of emergent technologies, such as blockchain and AI-driven monitoring systems, in enhancing the accuracy and traceability of Scope 3 emissions reporting. Cross-country comparative studies could also explore how policy harmonization and international ESG regulations affect the firms' capacity to mitigate supply chain emissions while balancing economic policy uncertainty. Finally, empirical research should assess the long-term benefits of standardized ESG disclosures on corporate resilience, investor confidence, and global carbon reduction efforts. Advancing best ESG practices and policy interventions could thus let firms around the world more fittingly contribute to mitigating climate change while preserving economic resilience.

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