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Impact of carbon pricing policies on economic growth and green innovation: A global analysis

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ABSTRACT

This study conducts a systematic literature review to comprehensively analyze the impact of carbon pricing policies on economic growth and green innovation, with a focusing on selected countries. We tapped into Google Scholar and related sources to identify studies in this area on carbon pricing, economic growth, and green innovation among eight developing countries: Argentina, Brazil, China, India, Mexico, Indonesia, Colombia, and South Africa. The outlined survey aims to bridge existing knowledge gaps in emerging economies. Our analysis shows that some of the developing nations mentioned are implementing environmental fiscal reforms to reduce greenhouse gas emissions, while others maintain distorting subsidies. Notably, the safeguards of carbon prices can help businesses transition towards sustainability as well as encourage innovative activities that enchance competitiveness. Contrary to popular belief, carbon pricing in developing countries does not necessarily have a regressive effect at the household level, especially in rural areas with diverse energy use patterns. In addition, employment rate and GDP indicate different overall dynamics over time when undergoing structural change towards decarbonization processes by nation economies. In other words, a well-targeted set of socioeconomic-specific carbon price rules might result in many advantages, such as increased economic growth fairness and progress toward sustainable development goals. This study underscores the importance of designing complex carbon pricing strategies for transitioning to a low-carbon future in developing countries.

Keywords: Carbon price, economic development, green innovation, specific nations, sustainability

1. INTRODUCTION

The world needs to address carbon emissions and promote environmentally friendly innovation. As a result, the implementing of carbon pricing legislation has emerged as a significant solution under consideration by global communities (Frey, 2017). These policies aim to reflect the environmental costs associated with carbon emissions in the prices of goods and services by using mechanisms such as carbon taxes and cap-and-trade systems. The objective is to foster the adoption of cleaner and more sustainable technologies and practices. In recent years, the emission of carbon dioxide (CO_2) has significantly increased, and widely recognized as one of the primary drivers of global warming and climate change. Without changes to current climate policy, mainstream climate change scenarios project global temperatures increase by 3 degrees Celsius (°C) relative to pre-industrial levels by the end of this century (IPCC, 2014). Based on the most recent climate survey conducted by the European Investment Bank (EIB), a significant majority of Europeans (56%), view climate policy as a driving force for economic expansion.

Government expenditures, border controls, incentives, taxes, subsidies, and regulations collectively constitute climate action. Anticipated friction accompanies these changes, potentially resulting in heightened productivity and economic expansion (Nordhaus, 2019). Numerous scholars concur that the most economically efficient approach to curtailing greenhouse gas emissions is imposing a price on GHG emissions, commonly referred to as "carbon pricing", owing to CO_2 being the predominant GHG emission (Alton et al., 2014; Aldy, 2015; Edenhofer et al., 2015). Global net anthropogenic CO_2 emissions must decrease by approximately 45% from their 2010 level by 2030, reaching net zero by 2050, to align with emissions targets outlined in the Paris Agreement to limit global warming to 1.5°C above pre-industrial levels. By 2030, CO_2 emissions must decrease by roughly 25% from 2010 levels and achieve net zero by 2070 to constrain global warming to 2°C (United Nations, 2021).

However, forecasts from the United Nations for 2030 indicate a probable 16% increase in global greenhouse gas emissions over 2010 levels. Green innovation emphasizes on vibrant, low-carbon, resource-efficient, climate-resilient, clean, biodiverse, and sustainable economies. Carbon pricing schemes fall under the jurisdiction of individual regions. As of April 2020, there were 61 specific carbon initiatives globally, including 31 Emissions Trading Systems (ETS) and 30 carbon taxes, either already implemented or slated for implementation at regional, national, or subnational levels. These schemes encompass a carbon price per ton of carbon dioxide equivalent (/tCO_2 e) ranging from less than USD1 to over USD120, covering 12 gigatons of carbon dioxide equivalent (GtCO_2 e), or approximately 22% of global GHG emissions. Additionally, over 74 multilateral Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiatives were operational globally as reported (World Bank Group, 2020). Given the recent implementation of several of these programs, insufficient data is available to support extensive ex-post research.

Ex-ante studies regarding the potential socioeconomic impacts of carbon pricing may have been conducted in other emerging economies or developing nations. Hence, a critical aspect of this review entails understanding how policies related to carbon pricing influence economic growth. The evaluation will analyze the impact of policies related to carbon pricing on the incentives for green innovation alongside economic growth. Within this critical intersection, the review aims to comprehensively examine the effects of carbon pricing policies on two fundamental dimensions: Economic growth and green innovation. By scrutinizing empirical studies, theoretical models, and real-world instances, this research aims to elucidate the nuanced relationship between carbon pricing and various facets of economic development. This encompasses considerations of macroeconomic indicators, sectoral impacts, and the potential for sustainable and inclusive growth on a global scale within the context of these policies. The research questions become imperative:

What is the implication of carbon emissions on economic growth and green innovation?
What is the implication of gross national income (GNI) per capita (sdg8.5) (ppp $) on economic growth and green innovation?
What is the impact of carbon pricing on firms' competitiveness in selected countries?
What are the macroeconomic impacts of carbon pricing in selected countries?
What is the impact of carbon pricing on households in selected countries?

2. MATERIALS AND METHODS

China, India, Argentina, Brazil, Mexico, South Africa, Colombia, and Indonesia are selected for this study. The first two countries are the world's largest in population and GDP. Brazil and Mexico are also among the major emerging economies. South Africa and Indonesia represent regions with major environmental problems. All these countries are different economically and developmentally. The methodology integrates data from diverse sources, including peer-reviewed research papers, government policy papers, academic studies, the United Nations Statistics Division, and models to examine the impacts of carbon pricing policies.

Analytical techniques such as ex-post analysis, difference-in-differences analysis, Social Accounting Matrices (SAM), Computable General Equilibrium (CGE) models, microsimulation models, and input-output models are applied across various countries, including

China, India, Argentina, Brazil, Mexico, South Africa, Colombia, and Indonesia. Through a comprehensive review and synthesis of findings, the analysis assesses the effects on firms in terms of emission reductions, competitiveness, and patent filings, as well as on GDP, employment, greenhouse gas emissions, and households. It compares different carbon pricing scenarios, considering revenue recycling mechanisms and their implications for economic indicators and emissions reduction goals. Additionally, distributional impacts across income groups are evaluated using indicators such as the Gini coefficient and changes in poverty rates, shedding light on the equity implications of carbon pricing policies.

3. RESULTS

Distribution of selected countries to Carbon dioxide emissions per capita (production) (Tonnes)

Carbon emissions per capita reflect the average amount of greenhouse gases emitted by individuals within a country (Figure 1). Countries with higher emissions per capita typically have a more significant environmental impact and contribute more significantly to global climate change. In the dataset provided, countries such as China, South Africa, and Argentina have relatively higher carbon emissions per capita compared to others such as Colombia and India. This indicates varying levels of environmental impact and the potential for higher mitigation efforts. Countries with higher carbon emissions per capita, such as China and South Africa, face more significant pressure to mitigate their emissions to address environmental concerns and international commitments.

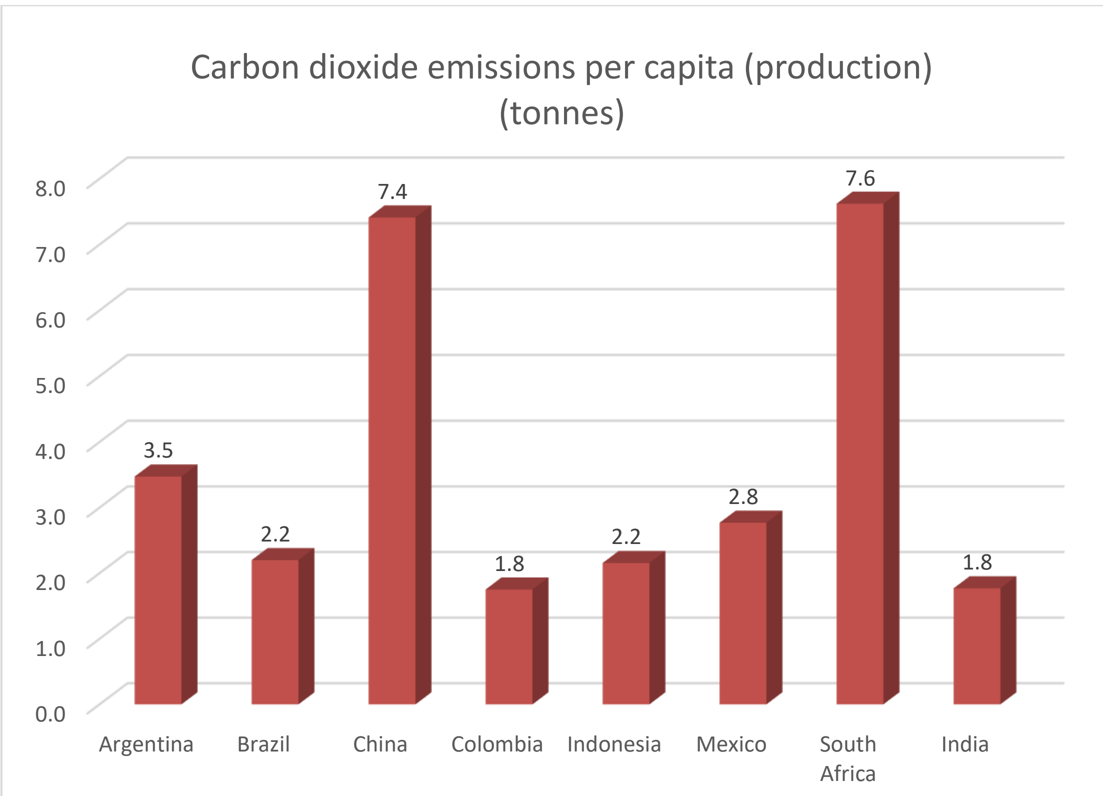

Figure 1 Distribution of selected countries with respect to Carbon dioxide emissions per capita (production) (Tonnes); Source: United Nations Statistics Division (2022).

Distribution of selected countries with for Gross National Income (GNI) per capita (SDG8.5) (PPP $)

The per capita Gross National Income (GNI) data in Figure 2 pertains to the mean income obtained by individuals in Argentina, China, Mexico, and Brazil. Economic growth, often assessed by the progression of Gross National Income (GNI) per capita, is pivotal role in enhancing quality of life, mitigating poverty, and promoting socioeconomic progress. Countries with higher Gross National Income (GNI) per capita, such as Argentina, China, Mexico, and Brazil, have a propensity for superior infrastructure, healthcare systems, and educational prospects, hence resulting in elevated levels of living standards. Carbon pricing is a policy tool aimed at reducing greenhouse gas emissions by assigning a monetary cost to carbon emissions.

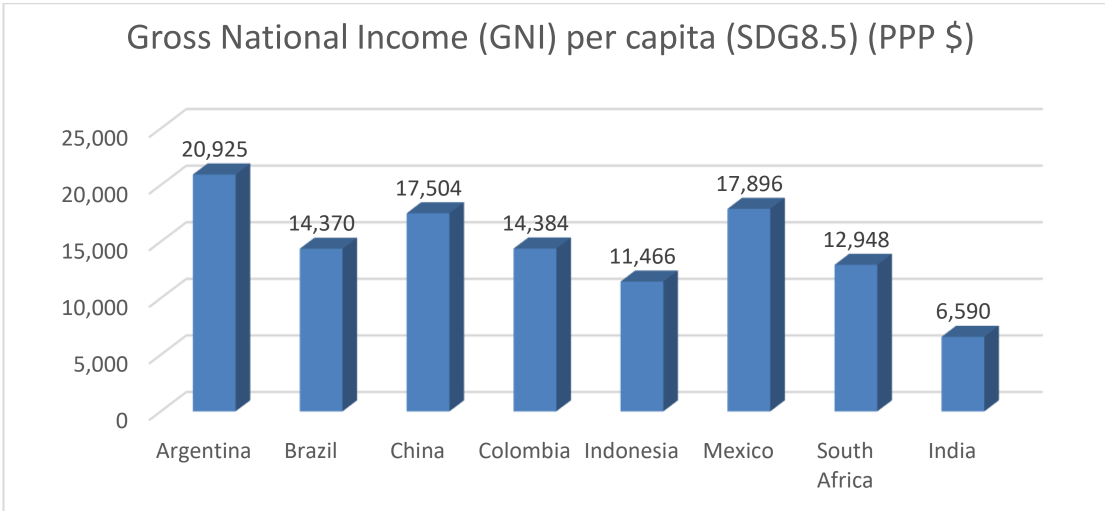

Figure 2 Gross National Income (GNI) per capita (SDG8.5) (PPP $); Source: United Nations Statistics Division (2022).

Impact of carbon pricing on the competitive position of firms in developing countries

To change business dynamics in many sectors of the economy, carbon pricing is an important policy instrument that influences decision-making on industrial activities such as production, consumption, and investment (Table 1). At least to combat climate change along with sustainability policies, this method, although part of broader policy frameworks, may increase expenses companies particularly when they are competing against locations with less stringent environmental regulations. This fosters integration that encourages innovation and technological advances, compelling firms to allocate funds towards R & D focused on reducing emissions and improving energy efficiency.

Although there may be initial challenges, the purpose of implementing carbon pricing is to align economic motives with environmental objectives thereby boosting competitiveness and promoting sustainable economic growth. While empirical evidence shows mixed results in some countries, enterprises can take proactive measures such as green innovation to reduce potential adverse effects and adopt sustainable practices for the long-term. For this reason, it establishes a link between carbon pricing, economic competitiveness, and worldwide sustainable development aspirations.

Table 1 Effects of carbon pricing on the competitiveness of companies in certain nations

Country	Research	Method and data	Carbon Price (USD/ tCO2 e)	Findings: Impacts on firms	Economic Implications
China	Zhang and Duan, (2020)	Various ex-post studies	Pilot ETS	The influence on the aggregated province or sectoral outcomes is shown to be insignificant. Still, the impact on listed businesses' firm-level results is negative.	The economic ramifications of observing a negligible effect on sectoral or provincial aggregate results and a detrimental effect on publicly traded companies indicate that although carbon pricing policies may not cause substantial alterations in broader economic indicators, specific firms operating in sectors or provinces may encounter difficulties. This circumstance may result in variations in the financial performance of different companies, which may impact their ability to compete and

					generate profits. Furthermore, this could underscore the necessity for personalized interventions or safety nets to facilitate the challenges faced by these particular enterprises thereby ensuring a more equitable and sustainable transition in the economy.
	-	Difference-in-difference	Pilot ETS (2013- 2015)	Emission reduction is achieved through capacity reduction rather than reducing the intensity of emission. It was observed that there was a loss of competitiveness, particularly among state-owned enterprises.	In terms of reducing emission, the economy may be influenced by prioritizing capacity reduction. This approach could potentially lead to issues such as inefficient production, which may have negative impacts on overall economic output. Prioritizing capacity decline above improvement in efficiency can result in the underuse of resources and hinder the prospect of economic development. The consequences of companies, especially state-owned enterprises, reducing competitiveness via using methods for reducing emissions are likely to harm the country's economy in terms of employment, gross product, and socioeconomic well-being generally. This statement emphasizes the importantce of crafting laws introduce carbon pricing and implement technologies aimed to reducing CO2 levels in ways that foster productive systems, innovation and sustainable environmental growth.
	Zhu et al., (2019)	Ex-post analysis 2001-2015 data.	Pilot ETS	Low-carbon patent filings increased 5-10% among the regulated companies due to The Pilot ETS initiative.	The increase in low-carbon patent applications that have been observed indicates a positive economic impact brought about by the introduction of the Pilot Emissions Trading Scheme (ETS), thus showing that carbon-pricing policies can be used as tools to drive innovation and sustainable economic development.
India	Goldar and Bhalla, (2015) Goldar et al., (2017)	ASI 2007-2008 data Ex-post firm-level 2009-2013 data	4 to 15	A mere 2-3% of manufacturing enterprises would see a decline in their export volumes. Inverse correlation between emission intensity and export volumes.	Carbon pricing can help reduce carbon emissions from manufacturers, thereby enhancing their global competitiveness. This is evident from the low number of manufacturing firms experiencing a drop in exports and the negative link between emission intensity and export quantity.

Table 2 illustrates the macroeconomic consequences of carbon pricing in selected countries. These analyses simulated emissions reductions through the application of different carbon price levels. To mitigate adverse effects, strategies for revenue recycling were employed to optimize the overall macroeconomic impact. Designing and implementing a carbon pricing policy package is complex, involving diverse input parameters and outcomes tailored to the socioeconomic context of each nation.

Table 2 Macroeconomic impacts of carbon pricing in selected countries

Country	Research	Method and data	Carbon Price (USD/ tCO2 e)	Findings: Impacts on GDP, employment, and GHG emissions	Economic Implications
Argentina	-	-	10	With revenue recycled to reduce corporate income tax and labor costs, expected +0.5% GDP	There is expected to be a 0.5% increase in GDP as a result of the shift of carbon pricing revenues towards reductions in corporate income tax and labor costs, suggesting good economic growth prospects. Businesses can potentially increase their competitiveness and profitability by reducing corporate taxes and labor expenses, thus leading to an expansion of investments, output, and employment.
Brazil	Grottera et al., (2017)	SAM 2002-2003 data	4.7 and 9.5	Without income recycling, GDP would fall -3.1% to -5.4%. Redistributing revenue to families reduces GDP by 1.5% to 2.5%. With income allocated to diverse sectors, GDP rose 0.3% while falling 2.1%.	Considering the impact of revenue recycling form carbon pricing, particular attention should be paid to presented cases. The absence of revenue recycling comes with a considerable fall in GDP: -3.1% and -5.4%. Therefore, it can be concluded that the failure of revenue recycling will lead to severe economic contraction.
China	Cao et al., (2016) and Timilsina et al., (2018)	CGE model (2010-2030)	0.3 rising to 3.7 1.4 rising to 22.6	With revenue recycled to reduce VAT and capital tax, −0.1% GDP, -3.3% emissions −0.7% GDP, -16% emissions	Reducing value-added tax (VAT) and capital tax to recycle revenue from carbon pricing has an economic implication that leads to a slight decrease of -0.1% of GDP thereby suggesting very slight adverse effects on the total economic output. Nevertheless, this method has been successful in acheieving environmental goals, resulting in a significant reduction in emissions by -3.3%.
Mexico	Landa et al., (2016)	Three-ME model (2014-2050)	100 in 2030, rising to 700 by 2050	With revenue fully recycled, positive impacts on GDP, consumption, and employment. Emissions from energy consumption: −40% by 2030, −75% by 2050 compared to BAU.	The economic implications of recycling all revenue from carbon pricing are that it shows positive effects on different indicators of the economy. GDP, consumption, and employment are positively affects by fully recycling revenue, indicating overall economic growth and stability. This implies that revenue recycling strategies effectively mitigate potential negative economic impacts of carbon pricing policies.
South Africa	Alton et al., (2014)	CGE (2010-2025)	3 rising to 30	GDP: −1.07% to −1.23% Employment: −0.5%	From these numbers, it can be inferred that implementing a carbon pricing policy would likely have mild adverse effects on GDP, employment, and

				to -0.6% Emissions: −36% to −41%	emissions hence the economic implication. If GDP were to decline form around -1.07% to -1.23%, there would probably be some reduction in economic growth. Similarly, employment is projected to fall between -0.5% and -0.6%.
India	Ojha et al., (2020)	CGE model (2021-2040)	0.9 to 6.7	With revenue recycled to households, 0.0% to −0.2% GDP. With revenue recycled to industries, slight gain in GDP	The economic implication of recycling revenue from carbon pricing to households suggests a negligible impact on GDP, ranging from 0.0% to -0.2%. This indicates that there may be a very slight decrease or no change in overall economic output when revenue is returned to households. On the other hand, recycling revenue to industries results in a slight gain in GDP, implying a small increase in economic output.

The composition of the environmental policy package influences both the trajectory of the consumer price index and the distribution of the burden of the carbon price. Revenue recycling strategies were developed through ex-ante simulations involving households with different income levels and residential locations. These strategies aimed to mitigate the effects of carbon pricing on domestic consumption while maintaining incentives for emission reduction. Additionally, employing revenue recycling techniques led to various socioeconomic advantages, such as enhanced equity and poverty reduction. A concise overview of these findings is provided in Table 3 of the comprehensive global studies compiled by Wang et al., (2016), encompassing recent and revised literature.

Table 3 Distributional impacts of carbon pricing on families in selected countries

Country	**Research**	**Method and data**	**Carbon Price (USD/ tCO2 e)**	**Findings: Impacts on households**	**Economic Implications**
Colombia	Romero et al., (2018)	Micro-simulation model	10 and 50	Higher-income households are most affected, and middle-class households are least affected.	Since higher-income households typically have greater consumption levels and may bear a larger share of the carbon pricing burden, they may experience more significant reductions in disposable income. On the other hand, middle-class households, with relatively lower consumption levels and potentially receiving compensation or subsidies through revenue recycling mechanisms, may experience fewer negative economic impacts.
Indonesia	Yusuf and Resosudarmo, (2015)	ORANI-G model	30	Urban households, progressive for rural households up to the eighth decile.	The potential economic consequences of urban families encountering a gradual influence in contrast to rural households, especially within the eighth decile, indicate a subtle dispersion of the policy's economic impacts across various geographic areas and income brackets. Urban areas,

					characterized by purchasing patterns and lifestyles that contribute to elevated carbon emissions, may see a more pronounced decrease in disposable income for families due of carbon pricing implementation. On the other hand, rural families, particularly those in lower-income categories up to the ninth decile, may have comparatively less economic effects, maybe because they consume less and rely less on activities that produce high amounts of carbon emissions. The unequal impact seen underscores the need to take into account geographical and income variations throughout the formulation and execution of carbon pricing policies, to guarantee impartiality and equality across various socioeconomic cohorts.
China	Jiang and Shao, (2014)	Input-output model	2.9	Metropolitan Shanghai's Suits Index = −0.078	Metropolitan Shanghai's Suits Index of -0.078 indicates a possible adverse effect on economic inequality in the region. The Suits Index is used to assess the impact of a tax or policy, indicating whether it is regressive or progressive. Negative values suggest that higher-income households bear a smaller burden than lower-income families.
Mexico	Renner, (2018)	Input-output model	3.5, 20, 50	Progressive in aggregate up to the sixth decile. Rural poverty increases more than urban poverty.	The fact that rural poverty increases more than urban poverty indicates that specific rural families, especially those in lower-income brackets, may bear a disproportionate burden or experience adverse economic consequences as a result of the policy.
South Africa	Alton et al., (2014)	CGE (2010-2025)	3 rising to 30	With revenue recycled to: Reduce corporate tax: Regressive Reduce sales tax: Proportional Transfer to households: Progressive	The economic implication of recycling revenue from carbon pricing to reduce corporate tax is regressive, indicating that the burden falls disproportionately on lower-income households. This approach may exacerbate income inequality as it benefits higher-income individuals and corporations more than lower-income households.
India	Ojha et al., (2020)	CGE model (2021- 2040)	0.9 to 6.7	With revenue recycled to households, −0.27%	The economic implication of recycling revenue from carbon pricing to households results in a decrease in the Gini coefficient

				Gini coefficient, With revenue recycled to industries, +0.01% to +0.02% Gini coefficient	by approximately -0.27%. This indicates a reduction in income inequality, as lower-income households receive a relatively more significant share of the redistributed revenue compared to higher-income households. This approach may than more significant economic equity by providing financial support to those with lower incomes people.

4. DISCUSSION

Implications of carbon emissions on economic growth and green innovation

Argentina's moderate carbon emissions per capita of 3.5 tonnes indicate room for improvement in emissions reduction. This suggests that implementing carbon pricing could incentivize industries to invest in cleaner technologies, potentially boosting economic growth and fostering green innovation (Gutman, 2019). With relatively low carbon emissions per capita at 2.2 tonnes, Brazil may not face immediate pressure for carbon reduction measures; however, implementing carbon pricing could still drive innovation and efficiency improvements in industries, contributing to economic growth and fostering green innovation (Grottera et al., 2017). China's high carbon emissions per capita of 7.4 tonnes highlight the urgency of carbon reduction measures, suggesting that implementing carbon pricing could help the country transition to a greener economy, driving significant investment in green innovation, particularly in renewable energy and clean technology sectors (Zhu et al., 2019).

Colombia's low carbon emissions per capita of 1.8 tonnes indicate lesser immediate pressure for carbon reduction measures. However, implementing carbon pricing could still contribute to economic growth by incentivizing emission reductions and innovation, fostering green innovation, particularly in agriculture and forestry sectors (Romero et al., 2018). Indonesia's moderate carbon emissions per capita of 2.2 tonnes suggest potential for emission reduction efforts. This indicates that implementing carbon pricing could encourage investment in cleaner technologies and contribute to eco-nomic growth while fostering green innovation, especially in crucial sectors like agriculture and forestry (Yusuf and Resosudarmo, 2015). Mexico's moderate carbon emissions per capita of 2.8 tonnes suggest a need for emission reduction measures, implying that implementing carbon pricing could drive economic growth by incentivizing emission reductions and investment in cleaner technologies, fostering green innovation, particularly in renewable energy and transportation sectors (Landa et al., 2016).

South Africa's high carbon emissions per capita of 7.6 tonnes underscore the urgency of carbon reduction measures. This indicates that implementing carbon pricing could facilitate a transition to a greener economy, driving investment in green innovation, particularly in renewable energy and energy-intensive industries (Ward and De-Battista, 2016). India's relatively low carbon emissions per capita of 1.8 tonnes, coupled with its large population, suggest significant total carbon emissions. This implies that implementing carbon pricing could drive economic growth by incentivizing emission reductions and fostering innovation, particularly in renewable energy and sustainable agriculture sectors (Ojha et al., 2020).

Implications of Gross National Income (GNI) per capita (SDG8.5) (PPP $) on economic growth and green innovation

Argentina’s higher GNI per capita compared to others in the list suggests greater levels of economic prosperity and development in the country. For example, a higher GNI could imply that Argentina may be well placed to increase its investments in green innovation and adapt better towards carbon pricing policies (Gutman, 2019). A robust economic situation can make implementing carbon pricing work in Argentina (Gutman, 2019). In this vein, if Brazil has a lower GNI compared to some of the other countries listed, it still possesses a relatively high GNI, indicating a certain level of economic capability that could be leveraged for green innovations and implementation of carbon pricing measures (Grottera et al., 2017; Karpavicius, 2020).

However, such factors as income inequality and other socioeconomic difficulties may affect the introduction and effectiveness of carbon pricing and green innovation policies in Brazil measures (Grottera et al., 2017; Karpavicius, 2020). China’s rapid economic expansion has led to significant growth in Gross National Income per person despite the challenges related to pollution and environmental degradation faced by the country faces (Cao et al., 2016; Timilsina et al., 2018). The Chinese government has made significant investments in renewable energy and green technology, in addition to implementing measures like carbon pricing to ensure that their economy is more environmentally sustainable (Cao et al., 2016; Timilsina et al., 2018). Colombia has a low Gross National Income per capita compared to other countries listed here, implying moderate economic status.

Nevertheless, the country boasts valuable natural resources and biodiversity that can be employed for green innovation (Romero et al., 2018). On the other hand, Columbia may experience challenges associated with implementing carbon pricing due to its business-oriented economy (Romero et al., 2018). Indonesia's lower Gross National Income per capita than most countries on the list implies financial constraints amidst peculiar barriers arising from her extensive archipelago nationhood relying on agriculture, forestry, and mining (Jiang and Shao, 2014; Yusuf and Resosudarmo, 2015). However, efforts aimed at environmental issues solutions within the Indonesian context are likely to promote sustainable economic development through green innovation while facing numerous hurdles related to both economics & politics, leading to implementation deficiencies regarding this approach (Jiang and Shao, 2014; Yusuf and Resosudarmo, 2015).

Impacts of carbon pricing on firms' competitiveness in selected countries

The impact of carbon pricing on firms' competitiveness varies depending on factors like cost structures and market dynamics. Companies subject to carbon pricing or abatement costs may face disadvantages compared to competitors. As these costs cascade down the value chain, affecting energy tariffs, material prices, and services, indirect impacts on other businesses in the economy may occur. To remain competitive, firms may adjust their operations to reduce energy use and emissions or optimize cost structures. In India, where explicit carbon pricing mechanisms are limited, the impact on competitiveness appears minimal. Simulations suggest only a small percentage of manufacturing firms would face reduced exports due to increased costs.

Additionally, a study spanning 2009 to 2012 showed no decline in competitiveness despite a decrease in CO2 emissions, indicating firms successfully managed emission-related costs (Goldar and Bhalla, 2015; Goldar et al., 2017). In China, introducing emissions trading schemes (ETS) in various provinces provided lessons for a nationwide ETS. Studies on the ETS's impact on competitiveness yield mixed results. While some found negligible effects at the provincial or sectoral level, others using firm-level data noted adverse effects, partly attributed to capacity reductions rather than emission intensity decreases. However, the ETS stimulated low-carbon innovation, as evidenced by increased patent filings among regulated firms. This suggests that carbon pricing can incentivize research and development, aligning with efforts to mitigate climate change and promote green growth (Cao et al., 2016; Zhang and Duan, 2020).

Macroeconomic impacts of carbon pricing in selected countries

According to IMF calculations, implementing a carbon price of USD35/tCO2 e could increase GDP by 1% to 2% (Paris Agreement, 2015). Investing revenue from carbon pricing into climate change projects could spur economic growth and job creation, particularly in sectors such as infrastructure and renewable energy. However, the effectiveness of recycling carbon revenue to lower labor costs may vary depending on a country's social development and organization. In Argentina, enacting a carbon tax of USD10/tCO2 e was expected to contribute to GDP growth by 0.5%, along with reductions in corporate income tax and social contribution requirements.

However, financial instability in 2018 hindered a clear assessment of the tax's impact (Gutman, 2019). Brazil aims to adopt carbon pricing tools to meet emission reduction targets, with simulations showing varying GDP impacts depending on income recycling strategies (Grottera et al., 2017; Karpavicius, 2020). China's ambitious emission reduction goals require modest carbon pricing increases, with negligible GDP effects under specific recycling scenarios (Cao et al., 2016; Timilsina et al., 2018). Mexico and South Africa have implemented carbon taxes, with simulations showing minor GDP impacts (Ward and De-Battista, 2016; Landa et al., 2016). However, concerns arise in India regarding the potential adverse impacts of heavy investment in clean energy on employment (Ojha, 2020). Evaluating the economic effects of carbon pricing is complex due to various factors influencing GDP. Nonetheless, studies suggest significant economic growth dividends can be achieved through carbon pricing initiatives (Freire-González, 2018).

Impact of carbon pricing on households in selected countries

Several studies suggest that carbon pricing mechanisms in developed nations tend to burden lower-income households more than higher-income ones, resulting in a negative Suits Index. This is because energy costs form a more significant proportion of discretionary income for poorer families, even though the wealthy spend more on energy overall. However, in underdeveloped nations, the situation is different. For instance, research analyzing low- and middle-income countries found that a USD30/tCO2 e carbon price model would be regressive for wealthier nations but progressive for lower-income governments (Dorband et al., 2019). In Colombia, carbon taxes modeled at USD10/tCO2 e and USD50/tCO2 e are projected to increase prices and reduce overall consumption, affecting middle-class households the least and higher-income households the most (Romero et al., 2018).

Without revenue recycling, a carbon tax at USD30/tCO2 e would lead to the reallocation of factors away from energy and capital-intensive sectors, making it progressive from an income perspective. Studies in Indonesia showed that urban households considered carbon taxes regressive, while rural households up to the eighth decile did not (Yusuf and Resosudarmo, 2015). Similarly, a case study in metropolitan Shanghai, China, found a regressive carbon tax at CNY20/tCO2 e (USD2.9/tCO2 e), with a Suits Index of -0.078 (Jiang and Shao, 2014). In Mexico, carbon tax scenarios were progressive in aggregate up to the sixth decile of family income, although rural poverty may increase more than urban poverty (Renner, 2018). In South Africa, revenue recycling options showed that lowering corporation tax would be regressive, reducing sales tax would be proportionate, and shifting revenue to households would be progressive (Aldy, 2015). Similarly, in India, carbon pricing would be progressive if recycled as food subsidies rather than regressive if recycled as a decrease in manufacturing taxes (Ghosh, 2016).

5. CONCLUSIONS

Carbon pricing, a versatile policy tool, has wide-ranging impacts on firms and households, permeating economic activity despite its focus on specific sectors. Increased energy and transportation costs, alongside general inflation, can strain household budgets, leading to reduced spending. Businesses, competing with regions that have lower environmental standards, may face increased cost. Carbon pricing is often included in comprehensive environmental policies since it is never implemented in isolation, owing to its potential to cause economic and social disturbances. The implementation process is carried out progressively to minimize negative consequences and ease economic shifts.

Although there are difficulties in measuring its impact, carbon pricing stimulate innovation, allowing firms to adjust to increased expenses and shift towards economies with reduced emissions. Research indicates that carbon pricing has a regressive effect on urban people while demonstrating a positive effect on rural residents. Income recycling programs have the potential to alleviate negative impacts on employment, gross domestic product (GDP), and green growth, while promoting economic fairness. Nevertheless, the attainment of sustainable development requires interventions beyond environmental legislation. It is essential to make enduring investments in technology and infrastructure to reduce dependence on ineffective systems.

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Author Contributions

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Not applicable.

Informed consent

Not applicable.

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The authors declare that there are no conflicts of interests.

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Data and materials availability
All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Aldy JE. Pricing climate risk mitigation. Nat Clim Change 2015; 5(5):396-398. doi: 10.1038/nclimate2540
2. Alton T, Arndt C, Davies R, Hartley F, Makrelov K, Thurlow J, Ubogu D. Introducing carbon taxes in South Africa. Appl Energy 2014; 116:344-354. doi: 10.1016/j.apenergy.2013.11.034
3. Cao J, Ho M, Timilsina GR. Impacts of Carbon Pricing in Reducing the Carbon Intensity of China's GDP. Policy Research Working Paper Series 7735, World Bank Group, 2016.
4. Dorband II, Jakob M, Kalkuhl M, Steckel JC. Poverty and distributional effects of carbon pricing in low- and middle-income countries a global comparative analysis. World Dev 2019; 115:246-257. doi: 10.1016/j.worlddev.2018.11.015
5. Edenhofer O, Jakob M, Creutzig F, Flachsland C, Fuss S, Kowarsch M, Lessmann K, Mattauch L, Siegmeier J, Steckel JC. Closing the emission price gap. Glob Environ Change 2015; 31:132-143.
6. Freire-González J. Environmental taxation and the double dividend hypothesis in CGE modelling literature: A critical review. J Policy Model 2018; 40(1):194-223. doi: 10.1016/j.jpolmod.2017.11.002
7. Frey M. Assessing the impact of a carbon tax in Ukraine. Clim Policy 2017; 17(3):378-396. doi: 10.1080/14693062.2015.1096230
8. Ghosh J. Analysis of India's Coal Cess Using an Economywide Framework. Korea: 4th Annual Conference on Transforming Development through Inclusive Green Growth, 2016.
9. Goldar B, Bhalla M. Scope for reducing CO2 emissions of Indian manufacturing: its likely impact on export competitiveness. J Int Commer Econ Policy 2015; 6(03):1550018. doi: 10.1142/S1793993315500180
10. Goldar B, Parida Y, Sehdev D. Reduction in carbon emissions intensity and impact on export competitiveness: Evidence from Indian manufacturing firms. J Int Commer Econ Policy 2017; 8(2):1750012. doi: 10.1142/S1793993317500120
11. Grottera C, Pereira AO, La-Rovere EL. Impacts of carbon pricing on income inequality in Brazil. Climate Dev 2017; 9(1): 80-93. doi: 10.1080/17565529.2015.1067183
12. Gutman V. Roadmap to Carbon Pricing: International Review and a Case Study of the Argentinean Carbon Tax. 7th Latin American Conference on Energy Economics, Buenos Aires, Argentina, 2019.
13. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2014: Synthesis Report, contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. R Pachauri and L Meyer (Eds). IPCC, Geneva, Switzerland, 2014; 151.
14. Jiang Z, Shao S. Distributional effects of a carbon tax on Chinese households: A case of Shanghai. Energy Policy 2014; 73:269-277. doi: 10.1016/j.enpol.2014.06.005
15. Karpavicius LM. Brazil Launches New Private and Public Policy Carbon Pricing Initiatives. Climate Scorecard 2020.
16. Landa RG, Reynès F, Cortes II, Bellocq FX, Grazi F. Towards a low carbon growth in Mexico: Is a double dividend possible? A dynamic general equilibrium assessment. Energy Policy 2016; 96:314-327. doi: 10.1016/j.enpol.2016.06.012
17. Nordhaus W. Climate change: The ultimate challenge for economics. Am Econ Rev 2019; 109(6):1991-2014. doi: 10.1257/aer.109.6.1991
18. Ojha VP, Pohit S, Ghosh J. Recycling carbon tax for inclusive green growth: A CGE analysis of India. Energy Policy 2020; 144:111708. doi: 10.1016/j.enpol.2020.111708
19. Paris Agreement. Paris Agreement. United Nations Climate Change (UNCC) 2015.
20. Renner S. Poverty and distributional effects of a carbon tax in Mexico. Energy Policy 2018; 112:98-110. doi: 10.1016/j.enpol.2017.10.011
21. Romero G, Álvarez-Espinosa A, Calderón S, Ordóñez A. Redistributive impacts of a carbon tax in Colombia: The link between models of microsimulations and general equilibrium. Lecturas de Economía, Universidad de Antioquia, Departamento de Economía 2018; 89:163-198. doi: 10.17533/udea.le.n89a06
22. Timilsina GR, Cao J, Ho M. Carbon tax for achieving China's NDC: Simulations of some design features using A CGE model. Clim Chang Econ 2018; 9:1850006. doi: 10.1142/S2010007818500069

23. United Nations. Nationally determined contributions under the Paris Agreement. Conference of the parties serving as the meeting of the parties to the Paris Agreement, third session, Glasgow, 31 October to 12 November, Synthesis report by the secretariat, advance version, 2021.
24. Wang Q, Hubacek K, Feng K, Wei YM, Liang QM. Distributional effects of carbon taxation. Appl Energy 2016; 18 4:1123-1131. doi: 10.1016/j.apenergy.2016.06.083
25. Ward J, De-Battista G. Modeling the Impact on South Africa's Economy of Introducing a Carbon Tax (Partnership for Market Readiness). Washington, DC: World Bank Group, 2016.
26. World Bank Group. State and Trends of Carbon Pricing 2020. Washington, DC, 2020.
27. Yusuf AA, Resosudarmo BP. On the distributional impact of a carbon tax in selected countries: The case of Indonesia. Environ Econ Policy Stud 2015; 17(1):131-156. doi: 10.1007/s10 018-014-0093-y
28. Zhang H, Duan M. China's pilot emissions trading schemes and competitiveness: An empirical analysis of the provincial industrial sub-sectors. J Environ Manage 2020; 258:109997. doi: 10.1016/j.jenvman.2019.10999
29. Zhu J, Fan Y, Deng X, Xue L. Low-carbon innovation induced by emissions trading in China. Nat Commun 2019; 10(1):4088.