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The Triple Effect of Carbon Taxation: Rhetoric Versus Reality in Climate Policy

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Abstract: This study examines the impact of carbon tax implementation across various sectors on carbon emissions and social welfare, moderated by subsidies and tax liability offsets. The sample consists of 28 countries that implemented a carbon tax in 2023. The analytical method is moderated regression analysis. The results show that the carbon tax significantly negatively affects carbon emissions, even without the interaction of subsidies and tax liability offsets. It is also found that the most effective sectors are transportation, electricity, and heat. Moreover, the carbon tax significantly positively affects social welfare, subsidies, and tax liability offsets interact, particularly in the building sector. These findings reveal that carbon taxes have three benefits for the environment, society, and the economy.
The keywords: Carbon Tax; Carbon Emissions; Social Welfare; Subsidies; and Tax Liability Offsets.

Abstrak: Penelitian ini bertujuan untuk mengetahui pengaruh penerapan pajak karbon di setiap sektor terhadap emisi karbon dan dampaknya terhadap kesejahteraan sosial, dengan moderasi subsidi dan penghapusan hutang pajak. Sampel yang digunakan adalah 28 negara yang telah menerapkan pajak karbon pada tahun 2023. Metode analisis yang digunakan adalah moderated regression analysis. Hasil penelitian menunjukkan bahwa pajak karbon berpengaruh negatif signifikan terhadap emisi karbon, tanpa adanya interaksi antara subsidi dan penghapusan hutang pajak. Ditemukan juga bahwa sektor yang paling efektif adalah transportasi dan listrik dan panas. Pajak karbon juga memiliki pengaruh positif yang signifikan terhadap kesejahteraan sosial, dengan interaksi subsidi dan penghapusan hutang pajak, terutama pada sektor bangunan. Hasil yang diperoleh menunjukkan bahwa pajak karbon memiliki tiga keuntungan, untuk lingkungan, sosial, dan ekonomi.
Kata Kunci: Pajak Karbon; Emisi Karbon; Kesejahteraan Masyarakat; Subsidi, dan Penghapusan Hutang Pajak.

INTRODUCTION

The environment, economy, and social health are interconnected forces that significantly impact one another. Global temperatures are rising unprecedentedly in recorded history (United Nations, 2025). This poses significant threats to humans and all living beings on earth. Rising temperatures are altering weather patterns that result in more frequent extreme natural disasters (Cappelli et al., 2021; Cvetković & Grbić, 2021; Khurana et al., 2022) and disrupting the natural balance of ecosystems (Conradi et al., 2024; Gilman & Wu, 2023; Rose et al., 2023; Salimi et al., 2021). The quality of social life is also hindered by various diseases stemming from inadequate environmental conditions (Schoierer et al., 2022; Valentová & Bostik, 2021), resulting in job losses and diminished labour productivity. This decline extends to the economy, where weakened production activities and industrial losses create a substantial financial burden on the government (Prasad, 2023). Addressing these environmental issues is crucial for public health, economic stability, and workforce productivity. To ensure the environment, the earth's temperature must not exceed 1.500°C above pre-industrial levels (United Nations, 2025).

The only way to prevent this catastrophic event is to immediately drop emissions of planet-warming greenhouse gases (Nar, 2021; Nong et al., 2021; Riyono & Widianingsih, 2024a). According to the Emissions Database for Global Atmospheric Research (2024), in 2023, carbon emissions comprised the majority of greenhouse gas emissions in the world, at 73.709 per cent of the total, while CH4 accounted for 18.921 per cent, N2O for 4.702 per cent, and F-gases for 2.668 per cent. These emissions primarily result from the combustion of fossil fuels. From 2020 to 2023, carbon emissions generated by fossil fuels consistently escalated yearly, with a total increase of 2869 Mt CO2eq or an average growth of 2.601 per cent per year. The power industry is the largest source of carbon emissions, contributing 38 per cent of the total, followed by the industrial sector, which accounts for 24 per cent of emissions. Transportation is responsible for 21 per cent of the total, buildings contribute 9 per cent, and the remaining emissions come from fuel exploitation, waste, and agriculture. The situation remains challenging despite numerous international agreements, including the Paris Agreement of 2015.

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United Nations (2025) calculated that to meet the 1.500°C temperature target, emissions need to be cut by 42 per cent in 2030, which must be done alongside climate adaptation. This can be done by adapting all sectors to incorporate climate resilience, especially in key sectors. By 2025, all countries must commit to new Nationally Determined Contributions (NDCs) that cover all emissions and sectors, aiming to reduce global GHG emissions to levels consistent with the 1.500°C pathway by 2035 (United Nations, 2025). So that all sectors are encouraged to reduce carbon emissions, according to the United Nations (2025) calculation, to meet the 1.500°C temperature goal by 2035, agriculture, forestry, and other land uses must reduce 13.630 Gt emissions, 12.600 Gt emissions in energy systems, 5.400 Gt in industry, 3.800 Gt in transportation, and 0.700 Gt in buildings. Through this, all countries are targeted toward a low-carbon and resilient future by ensuring the sectors can adapt to the expected climate impacts. According to the natural resource-based view theory, regulations are necessary for the country to serve as an environmental driving force, encouraging all stakeholders and companies to adopt greener practices (McDougall et al., 2019). Consequently, companies will be motivated to prioritise pollution prevention, product stewardship, and sustainable development. (Prasad, 2022) also finds that companies will not act if they feel no burden or responsibility. Therefore, a domestic environmental policy must engage all stakeholders to achieve the targeted goals. As state regulations, these policies place greater responsibilities on companies within the sector (Cheng et al., 2021; Muhammad, 2022).

Countries have begun implementing carbon pricing as an obligation for businesses to mitigate further emissions. This pricing strategy is applied in nine sectors: electricity, industry, mining and extraction, transportation, aviation, buildings, agriculture, forestry and fishing fuel use, waste, land use, land-use change and forestry (LULUCF). Carbon pricing is divided into emissions trading schemes (ETS) and carbon taxes. Both aim to reduce carbon emissions by assigning a cost to each ton of carbon emitted by companies within the designated sectors. It is also important to note that the operation of these two carbon pricing methods is different. The ETS is called "cap and trade," while the carbon tax follows the principle of "polluter pays." ETS generally requires a more complex infrastructure for carbon trading than a carbon tax (Verbruggen et al., 2019), and the prices set need to be constantly monitored; it also has the potential to fluctuate over time (Tsai, 2020; Xu et al., 2023).

Meanwhile, the carbon tax is simpler to implement, offering more stable and predictable pricing, unlike the ETS (Metcalf, 2021; Riyono & Widianingsih, 2025b; Timilsina, 2022). The number of sectors subject to carbon pricing and the carbon tax tends to be higher than the ETS. In 2025, among 28 countries that have adopted a carbon tax, 13 countries have implemented it in more than four sectors, exceeding the median number of applicable sectors. Among the 35 countries that have adopted ETS, only four have applied it to more sectors than the median threshold.

A carbon tax is a suitable solution to achieve Nationally Determined Contributions, as in the United Nations (2025), to reach more sectors. In alignment with the natural resource-based view theory, this carbon tax acts as the environmental driving force for all companies within these sectors to prevent pollution and mitigate carbon emissions. Carbon taxes are effective in reducing carbon emissions across various regions. A carbon tax significantly reduces energy consumption, carbon emissions, and other pollutants in China, proving more effective than resource taxes (Hu et al., 2021). In the G7 economies, environmental and carbon taxes reduce emissions and encourage a shift towards cleaner production methods (Doğan et al., 2022a). In Sub-Saharan Africa, carbon taxes significantly minimise carbon emissions, supporting the transition to a low-carbon future (Yeboah et al., 2024).

Although the results may be positive, determining which sectors qualify as key sectors in the carbon tax (King et al., 2019; Mintz-Woo, 2024; Riyono & Widianingsih, 2024b; Timilsina, 2022; Yang, 2024) and how the tax mechanism should be differentiated across sectors remains a subject of debate (Chen et al., 2020; Fang et al., 2024; Liu et al., 2023). Taxing inappropriate sectors has the potential to impact the country itself, mainly economically and socially negatively. Research by (Wei et al., 2022) and (Zhao et al., 2023) indicates that a significant carbon tax adversely affects China's economy and social welfare, potentially leading to price fluctuations. Aligning with carbon taxes can result in GDP losses, as demonstrated in studies from China and Finland, where GDP reductions varied from 0.500 per cent to 2.500 per cent based on the tax rate and sectoral coverage (Khastar et al., 2020; Xie et al., 2018). Carbon taxes can have regressive effects, disproportionately impacting lower-income households, as they allocate a larger portion of their income to energy-related expenses (Alonso & Kilpatrick, 2022; Zhang et al., 2023). This regressive nature is mainly indicated in developed economies, which lack revenue recycling mechanisms (Riyono & Widianingsih, 2024b; Steenkamp, 2021). The carbon tax will severely impact energy-intensive industries and cause them to lose competitiveness (Berry, 2019; Riyono & Widianingsih, 2025). Different sectors experience various impacts (Devulder & Lisack, 2020; Xie et al., 2018), potentially leading to job losses and economic contraction in these sectors. Without global coordination, carbon taxes can also lead to carbon leakage, where emissions are relocated to countries with less stringent policies, undermining global emission reduction efforts (Metcalf, 2019). These highlight the necessity for effective carbon tax policies that optimise environmental benefits while minimising economic impacts, considering the distortionary effects of other taxes. Successful implementation requires a thorough examination of these variables to ensure public acceptance and the overall success of the policy.

The carbon tax is widely recognised as an effective tool for reducing carbon emissions. However, in many regions, it remains more rhetoric than reality. The primary obstacles to its implementation include persistent public opposition, concerns about fairness and economic impact, and political challenges. Public resistance to carbon taxes is strong, mainly due to the belief that such taxes are regressive and disproportionately affect lower-income groups. Many individuals perceive carbon taxes as unfair unless the revenues are redistributed to benefit those most affected or promote climate justice. Policymakers also express concerns about the economic impacts of carbon taxes, including potential increases in costs for consumers and decreased competitiveness for carbon-intensive industries. Therefore, the design of the tax is crucial for gaining public and political support, particularly in terms of how revenues are utilised and how costs are allocated.

From the above statements, minimising the negative risks of a carbon tax involves a strategic approach that includes targeting specific sectors, recycling tax revenues, and global coordination. By identifying key sectors, the carbon tax can be more effectively implemented to minimise emissions by setting sector-specific tax levels. This ensures that less effective sectors are not overly impacted, thereby minimising the potential burden on society. Revenue recycling must also be implemented to mitigate regressive impacts and alleviate negative economic impacts. The effectiveness of carbon taxes and subsidies depends on their design and implementation. Excessive or insufficient tax or subsidy levels can lead to suboptimal outcomes (Zhang et al., 2023). Policies must be set at intermediate levels to balance economic performance, environmental efficiency, and social welfare. It will also enhance worldwide cooperation with the United Nations through nationally determined contributions to prevent carbon leakage. These strategies help balance the economic impacts and secure international competitiveness while achieving significant reductions in carbon emissions.

There are several novelties in this study. First, in its sectoral approach, unlike broad analyses of carbon taxation, this research provides sector-level granularity to identify which sector exerts the most significant influence on carbon emissions and social welfare. This also helps to understand whether the carbon tax should be differentiated across sectors. Second, a dual focus on emissions and social welfare helps to understand how to balance those across sectors—third, subsidies and offsets should be integrated as moderators and tailored revenue recycling mechanisms. The study introduces subsidies and tax liability offsets as interacting factors, a relatively underexplored area in carbon tax literature. Existing literature often discusses carbon tax revenues in general terms, whereas this research focuses on sector-specific recycling mechanisms. Fourth, the development of carbon tax measurement to enable cross-country comparison with intensity based on its price, thereby eliminating cross-country bias. Fifth, the author measures social welfare variables using theoretical and empirical considerations. This measure can better capture aspects of social welfare that are also related to environmental concerns. This research also adopts the perspective of the natural resource-based view theory, which has not been applied in previous studies. These contributions offer a more nuanced and policy-relevant perspective on designing effective and equitable carbon tax policies.

This study aims to determine how implementing the carbon tax in each sector affects carbon emissions and social welfare, interacting with subsidies and tax liability offsets.

This research offers valuable insights by providing answers to identify the key sectors influencing carbon emissions the most and examining how the carbon tax revenue recycling mechanism can be implemented to encourage its effectiveness. It also answers which sectors impose the highest economic burden on social welfare and how subsidies and tax liability offsets can be utilised to minimise it. The practical implication of this research can inform policymakers about the selection of sectors to implement a carbon tax and how the revenue recycling mechanism works. This enables more strategic and targeted taxation than a uniform tax across sectors. For the literature implication, this study enhances the literature on carbon taxation by providing a comprehensive answer for designing equitable environmental policies. While in society, this result provides insight to the public about the carbon tax to increase public perception and trust in the carbon tax compliance.

THEORETICAL REVIEW

The natural resource-based view theory extends the resource-based view of the firm by focusing on how a firm's relationship with the natural environment can be a source of competitive advantage (McDougall et al., 2019). It emphasises the importance of integrating environmental considerations into strategic management. There are three key components of the natural resources-based view. First, pollution prevention involves reducing waste and emissions, which can lead to cost savings and efficiency improvements (Gabler et al., 2023; Makhloufi et al., 2022; Riyono & Widianingsih, 2024b). Second is product stewardship, which minimises environmental impacts throughout a product's lifecycle (Alkaraan et al., 2024; Farrukh et al., 2022). It encourages innovation in product design and green technology. Third, sustainable development, aligning business practices with sustainable development goals, ensuring viability and competitiveness by addressing environmental and social challenges (Lau & Wong, 2024; Makhloufi et al., 2022). Firms can enhance their market position and ensure long-term sustainability by focusing on these components.

The natural resource-based view theory and carbon tax are closely correlated in the context of sustainable development and environmental policy. This enables understanding how the efficient management of natural resources and carbon taxes can drive green growth and reduce carbon emissions, thus enhancing social welfare. Therefore, the natural resource-based view theory is suitable for this research.

A carbon tax is a financial charge imposed on every carbon emitted by an individual or a company. This tax aims to reduce greenhouse gas emissions by making it more costly to emit carbon emissions (Planelles & Sanin, 2024; Timilsina, 2022). Carbon taxes are designed to incorporate the environmental costs of carbon emissions into the pricing of fossil fuels, thereby incentivising reductions in greenhouse gas emissions (Metcalf, 2021; Riyono & Widianingsih, 2024b). It is one of the environmental policies to tackle climate change and ensure long-term sustainability.

Subsidies and tax liability offsets are part of the carbon tax revenue recycling mechanism to alleviate the regressive impact of the tax. Both are used to manage the economic effects of carbon taxation on businesses and consumers (Carattini et al., 2018; Zhang et al., 2023). These tools aim to mitigate the financial burden of carbon taxes while encouraging environmentally friendly practices, making them more politically and socially acceptable (Carattini et al., 2018). Subsidies encourage manufacturers to adopt low-carbon production methods, which can be more effective than carbon taxes in promoting sustainable manufacturing (Naef, 2024; Riyono & Widianingsih, 2024b). Tax liability offsets allow for compliance with carbon tax obligations by using offsets from non-targeted emission sources, potentially resulting in actual emission reductions (Tsai, 2020).

Carbon tax sector on carbon emissions. According to the natural resources-based view, carbon taxation highlights the role of economic instruments in promoting sustainable resource use and reducing emissions. These taxes incentivise emission reductions and resource efficiency by putting a price on carbon. Carbon taxes drive companies toward pollution prevention, product stewardship, and sustainable development. In Sweden, introducing a carbon tax resulted in an 11 per cent decrease in CO2 emissions from transportation (Andersson, 2019). Carbon taxes have significantly reduced pollutants in China, including CO2, SO2, and NOx emissions (Hu et al., 2021).

Additionally, in several European countries, carbon taxes have demonstrated a positive and significant impact on lowering carbon emissions, underscoring their importance in enhancing environmental quality (Ghazouani et al., 2020). (Ahmad et al., 2023) conducted a comprehensive meta-analysis of 81 studies, revealing that carbon taxes are more effective than emissions trading systems in reducing carbon emissions. The effectiveness is particularly notable in carbon-intensive industries. Carbon taxes can encourage innovation and sharing low-carbon technologies among businesses, reducing emissions (Widianingsih & Riyono, 2024). This is essential to achieve long-term sustainability objectives. Consequently, a carbon tax effectively incentivises cleaner energy usage and technological advancement. However, (Nar, 2021) found that carbon taxes do not affect greenhouse gas emissions among the 36 OECD countries. (Pretis, 2022) also found that carbon taxes are likely too low to be effective in the time frame since their introduction in British Columbia. (Mardones & Flores, 2018) also state that excessively high carbon pricing can lead to stagnant development and does not reduce carbon emissions. This counterargument finding highlights the need for further evidence.

Studies show that sector-specific carbon taxes effectively reduce emissions. (Matsumura et al., 2024) found in Japan that while such taxes cut greenhouse gases, their impact varies by sector, stressing the need for strategic implementation. Targeting key sectors in the global production network can yield significant reductions (Planelles & Sanin, 2024). However, (Nar, 2021) found that the tax rates and the sectors they apply vary widely between countries. This leads to inconsistent effects and opportunities for carbon leakage, where emissions are shifted to other countries or sectors. (Yu, 2024) states that a sector-specific carbon tax can significantly reduce carbon emissions in the transportation sector, but its impact at the national level is not statistically significant. This highlights the need for coordinated sector-differentiated policies. Carbon taxes are effective, especially when aligned with regional and industrial contexts. From these previous statements, the hypothesis is:

H1: Every carbon tax sector hurts carbon emissions.

Subsidies and tax liability offset interaction in the carbon tax and emissions relations. From a natural resource-based perspective, environmental incentives, such as subsidies and tax liability offsets, should support carbon tax policies to foster green innovation and integrate sustainability into business strategies. These supports reduce the burden on companies, making the transition to sustainable practices more feasible. A combined tax-subsidy approach is more effective than standalone policies, as taxes discourage emissions while subsidies promote green investment. Subsidies can complement carbon taxes by encouraging the adoption of renewable energy and green innovations. For instance, subsidies can optimise the effectiveness of carbon taxes by increasing the penetration of renewable energy sources (Ahmad et al., 2023; Zhang et al., 2023), thus enhancing sustainability indices. Similarly, innovation subsidies and tax liability offset can motivate manufacturers to adopt radical green innovations aggressively (Metcalf, 2019; Tsai, 2020), which are crucial for significant carbon emission reductions, and widen the conditions for improving emissions reduction investments (Timilsina, 2022).

Significantly, the need for subsidies and their potential impact can vary widely across sectors. Different sectors may require tailored approaches and different environmental support because they are exposed to international competition, so it is also important to prevent carbon leakage (Fang et al., 2024; Kruse-Andersen & Sørensen, 2022; Liu et al., 2023). With that, subsidies can enhance the effectiveness of carbon taxes by creating a synergistic effect that promotes emissions reduction and green innovation. Environmental support is better focused on sectors estimated to require significant costs in the transition. This combination can lead to greater environmental and economic benefits than simply implementing carbon taxes while fostering sector-specific green technology. Despite its good intentions, (Nar, 2021), (Charlier et al., 2023), and (Wei et al., 2022) found that these exemptions reduce the effectiveness of the tax in reducing emissions. Most of the revenue from carbon taxes is not used for environmental purposes but rather to fund general government budgets or other non-environmental expenditures (Nar, 2021). This underscores the urgency to re-evaluate the current regulation on exemptions. Based on the previous statements, the hypothesis is:

H2: Subsidies and tax liability offset strengthen the relationship between every carbon tax sector and carbon emissions.

Carbon tax sector on social welfare. Based on the natural resources view, the carbon tax drives companies to adopt sustainability and environmental responsibility. However, green innovation is costly, and carbon taxes raise output prices, which can burden predominantly middle- to low-income individuals, reducing social welfare. The impact of carbon taxes on social welfare is a critical area of study, as it involves balancing environmental benefits with economic and social outcomes. In countries like Finland and China, carbon taxes have successfully reduced emissions but have negatively impacted social welfare (Khastar et al., 2020; Xie et al., 2018). So, an optimal carbon price is recommended to balance these effects. Carbon taxes can exacerbate inequality, as low-income households spend a larger share of their income on carbon-intensive goods (Riyono & Widianingsih, 2024b). Even so, optimal tax rates improve social welfare when carbon emissions per product unit are significant or carbon dioxide prices are high (Rustico & Dimitrov, 2022; Zhou, Hu, et al., 2018a). Environmental taxes effectively encourage businesses to shift production towards cleaner methods, which results in better social life quality (Doğan et al., 2022b; Riyono & Widianingsih, 2024b).

In sector-specific terms, the impact on social welfare depends on factors like the social cost of carbon and the ability of companies within sectors to absorb taxes

(Matsumura et al., 2024). Sectors with limited flexibility or lower profit margins may struggle to adapt, resulting in higher production costs, reduced competitiveness, and potential job losses. A carbon tax can be burdensome to society without mitigation efforts. Implementing a carbon tax is better to avoid sectors with the lowest carbon emission contribution, but it is difficult for the community. However, the carbon tax regime depends on product substitution and price elasticity of demand, which can achieve net-zero carbon emissions and promote social welfare (Chang, 2022). This highlights the importance of sector-specific testing to ensure carbon taxes do not unintentionally amplify social inequality or economic hardship. So, the hypothesis is:

H3: Every carbon tax sector hurts social welfare.

Subsidies and tax liability offset interaction in the carbon tax and social welfare relations. Under the natural resources-based view, an ineffective carbon tax can burden communities. To reduce regressivity, regulations should include support funded by carbon tax revenue. Environmental subsidies and tax offsets can ease the impact, promote fairness, and increase public acceptance. Carbon taxes can negatively impact social welfare without effective redistribution mechanisms, particularly in consumption and redistribution links (Metcalf, 2019; Riyono & Widianingsih, 2024b; Tsai, 2020). Strategies such as purposive transfer payments or compensation measures are recommended to mitigate the regressive effects. A combination of subsidies and tax liability offset can optimise social welfare than the policy alone (Timilsina, 2022). This approach can lead to a balanced responsibility-benefit scenario in supply chains. A well-designed carbon tax can provide a win-win solution by increasing welfare. However, governments often prefer green spending and fossil fuel subsidies over taxing carbon emissions, leading to lower welfare and increased costs (Ploeg, 2025).

Therefore, carbon taxes and subsidies should be tailored to specific sectors, and setting these tools at intermediate levels is crucial. Excessive values can either overburden industries or fail to incentivise low-carbon practices effectively (Matsumura et al., 2024). Such an approach acknowledges the uneven distribution of environmental responsibility and economic resilience across sectors and helps maintain a balanced responsibility-benefit equilibrium. Consequently, the balance between economic performance, environmental efficiency, and social equity must be managed holistically and contextually at the sectoral level. The balance between economic performance, environmental efficiency, and social welfare must be carefully managed. However, sectoral exemptions may reduce the overall cost of carbon tax policies and deadweight loss (Doğan et al., 2022a). They shrink the tax base, resulting in higher costs for the same emissions cuts and less revenue for redistribution. Investment cost subsidies are also not always advantageous and may not consistently benefit the most vulnerable groups (Wang et al., 2021). A balanced approach combining both tools can optimise environmental and economic outcomes. Hence, the hypothesis made is:

H4: Subsidies and tax liability offset weaken the relationship of every carbon tax sector toward social welfare.

METHODS

Sample, Variable, and Measurement. The population in this study is all countries in the world. This study uses purposive sampling with the criteria of countries implementing a carbon tax by 2023. With this, the number of data observations obtained is 28 countries. No countries were removed from the sample. To obtain accurate results regarding the sector-specific carbon tax, the sample only includes countries that have implemented it. The research year taken is at the end of 2023, because the availability of the latest carbon emissions variable data is limited to 2023, while reliable data for 2024 has not yet been published anywhere. Also, no countries implemented a carbon tax in 2024, and all countries implemented it before 2023, with an average effective year in 2010. With that, implementing the carbon tax has been effective and in place for at least five years, so its effects are already observable.

The dependent variables in this study are carbon emissions and social welfare. The carbon emissions variable is obtained from an index published by EDGAR, regarding the amount of carbon emissions in a country in 2023. EDGAR (2024) by the European Commission provides an independent estimate of emissions compared to what is reported by European Member States or by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), using consistent international statistics and IPCC methodology. Emissions Database for Global Atmospheric Research (EDGAR) is a widely used source for environmental data, particularly for greenhouse gas (GHG) and air pollutant emissions. It is generally considered reliable due to its comprehensive methodology and global coverage (Janssens-Maenhout et al., 2019; Lekaki et al., 2024).

This study employs social welfare as the dependent variable to assess the impact of carbon tax policy across countries in 2023. Given the limitations of conventional Gross Domestic Product (GDP) as a welfare metric, primarily due to its neglect of inequality, environmental degradation, and institutional factors, this research adopts a modified approach inspired by (Adler, 2019) through the construction of an adjusted GDP-based index known as the Cost-Benefit Adjusted GDP (CBAGDP). This method integrates economic output with relevant social, environmental, and governance dimensions to reflect comprehensive national welfare better. The social welfare indicator is derived using Principal Component Analysis (PCA), which incorporates GDP per capita, index of public expenditure on health and education, Gini coefficient to represent income inequality, environmental degradation proxied by CO_2 emissions per capita (t CO2e/capita), corruption perception index, and out-of-pocket expenditure as a percentage of total health expenditure. All variables are normalised using min-max scaling to ensure comparability, and the resulting SWF scores are standardised to allow cross-country comparison.

The inclusion of each variable is based on theoretical and empirical considerations by (Adler, 2019). GDP per capita is the core economic measure of welfare (Adler & Adler, 2019; Adrangi & Kerr, 2022). However, the Gini coefficient is included to capture the distributional aspect because higher income inequality diminishes overall societal well-being, even when aggregate output is high (Kaplaner & Steinebach, 2022; Stark, 2024). Environmental degradation is also considered since the loss of ecosystem services and poor air quality resulting from carbon-intensive growth negatively impact current and future quality of life (Riyono & Widianingsih, 2024b). Corruption is measured using the Corruption Perception Index, which reflects institutional inefficiencies and the erosion of public trust, ultimately hindering equitable development and access to services (Heide, 2022; Tsao & Hsueh, 2023). Out-of-pocket health expenditures represent public health burdens because higher private spending often indicates inadequate public provision, creating additional welfare costs, especially for vulnerable populations (Schoierer et al., 2022). Finally, public spending on education and health is viewed as enhancing welfare, reflecting investment in human capital and overall societal development (Heleta & Bagus, 2021). The composite indicator from these adjustments provides a more nuanced and multidimensional proxy for national welfare than GDP alone, aligning with Adler's systems-based and social choice theoretical foundation (2019). The data sources are from trusted and valid sources, including the World Bank, EDGAR, the World Health Organisation, and Transparency International.

The dependent variable in this study is the carbon tax, which is measured based on the price of carbon pricing applied to each sector. Data on countries implementing a carbon tax and its price are obtained from the World Bank Group (2024). The price per sector is gathered from the government websites of each country with a carbon tax. There are a total of nine sectors that can be subject to carbon taxation. However, not all of these sectors are commonly adopted across countries. Therefore, this study focuses only on the sectors with the highest implementation rates. The selected sectors, in order of most to least widely implemented, are: industry as CT1 (22 countries), mining and extractives as CT2 (19 countries), transport as CT3 (18 countries), buildings as CT4 (18 countries), electricity and heat as CT5 (16 countries), and agriculture, forestry, and fishing fuel use CT6 (14 countries). The remaining sectors, which are aviation (6 countries), waste (4 countries), and land use, land-use change and forestry (LULUCF) (4 countries), are excluded due to limited adoption.

It is important to note that each country has distinct regulatory, social, and economic conditions, which may introduce bias in cross-country analysis. To address this concern, based on (Penn et al., 2024), this study adopts a standardisation approach using a Likert-type scale, which translates raw carbon pricing data into a discrete categorical variable ranging from 1 to 4. To categorise the data into 1-4 Likert scales, the data is first sorted from the smallest to the largest value. Since there are 27 data points, the data is divided evenly into four groups. Based on the 7th, 14th, and 21st data positions, carbon pricing per sector in US$ is categorised as follows: a) less than 3.780 is classified as 1, b) more than 3.780 and less than or equal to 22.270 as 2, c) more than 22.270 and less than or equal to 48.500 as 3, and d) more than 48.500 as 4. If a country does not implement carbon pricing in a particular sector, a score of 0 is assigned. The carbon prices across countries range from US$0.071 to US$155.863. The Likert 4 scale was chosen to avoid having a neutral option. With an even number of options, data must lean in either direction (lower or higher) (Penn et al., 2024). In the context of cross-country carbon pricing, the use of a 4-scale forces classification into "low" or "high" intensity with no grey areas, supporting more rigorous comparative analysis and more precise policy interpretation. This scaling has three purposes: first, it reduces hypothetical bias by aligning countries with different contextual baselines onto a common evaluative framework. Secondly, it avoids oversimplification by capturing variation in the intensity of carbon tax implementation, rather than treating it as a binary, yes or no variable. Lastly, it improves cross-country comparability by representing carbon tax effort on a standardised ordinal scale. This methodological approach allows for a more nuanced analysis of the effects of carbon taxes. Although countries may all implement a carbon tax, these taxes' intensity and economic burden may vary. By categorising tax intensity in this manner, the model can better capture differences between countries while reducing structural biases often present in international policy comparisons.

Subsidies and tax liability offsets are measured with a dummy variable. A value of 0 is given to the variable if neither policy is present. If subsidies or tax liability offsets are applied, the value is 1. If both are present, then a value of 2 is given. The information was collected from the World Bank Group (2024) through the official government websites of each country that implements the carbon tax. The control variables used in this model are GDP and urbanisation. Both variables are incorporated into the statistical model to account for potential confounding factors. This helps to isolate the relationship between the primary variables of interest.

Analysis Method. This research model uses moderated regression analysis to examine the influence of independent variables on dependent variables with a moderator. Before that, the model must meet the classical assumptions test, which includes normality, heteroscedasticity, multicollinearity, and feasibility tests. This research is divided into two models: the first for the first dependent variable, carbon emission, and the second for the second dependent variable, social welfare.

The moderated regression analysis method uses the approach by (Sharma et al., 1981), dividing each model into three equations. For the first model, as follows:

$$CE = \alpha + \beta 1CT + \beta 2\log(GDP) + \beta 3\log(Urban) + \epsilon \ldots \quad (1)$$

$$CE = \alpha + \beta 1CT + \beta 2STO + \beta 3\log(GDP) + \beta 4\log(Urban) + \epsilon \ldots \quad (2)$$

$$CE = \alpha + \beta 1CT + \beta 2STO + \beta 3(CT * STO) + \beta 4\log(GDP) + \beta 5\log(Urban) + \epsilon \ldots \quad (3)$$

The second model is as follows:

$$SWF = \alpha + \beta 1CT + \beta 2\log(GDP) + \beta 3\log(Urban) + \epsilon \ldots \quad (4)$$

$$SWF = \alpha + \beta 1CT + \beta 2STO + \beta 3\log(GDP) + \beta 4\log(Urban) + \epsilon \ldots \quad (5)$$

$$SWF = \alpha + \beta 1CT + \beta 2STO + \beta 3(CT * STO) + \beta 4\log(GDP) + \beta 5\log(Urban) + \epsilon \ldots \quad (6)$$

Where CE is carbon emissions, SWF is social welfare, CT is carbon tax, STO is subsidies and tax liability offsets, GDP is gross domestic product, Urban is urbanisation, β is the coefficient, α is the constant, and ϵ is the error.

Based on (Sharma et al., 1981), four results can be obtained with moderated regression analyses. First, if β_2 in equation 2 is significant, while β_3 in equation 3 is not significant, the moderator variable is not a moderator, but an independent variable. Second, if β_2 in equation 2 is not significant, while β_3 in equation 3 is not, then the moderator variable is not interacting. Third, if β_2 in equation 2 is significant and β_3 in equation 3 is significant, then the moderator variable is a quasi-moderator. Fourth, if β_2 in equation 2 is not significant, while β_3 in equation 3 is significant, then the moderator variable is a pure moderator.

RESULTS

Descriptive Statistics Result. Table 1 presents the descriptive statistics results of 28 observational data from 28 countries in 2023. The carbon emissions, social welfare, idies, and tax liability offsets variables have standard deviation values higher than the mean value, indicating variation. Furthermore, the other variables have a minor variation because the standard deviation is less than the mean value. Most countries implementing carbon taxes are high-income countries, with 22 countries.

Meanwhile, there are only five upper-middle-income countries and one lower-middle-income country. The rise of industrial activities in developing and developed countries has resulted in most countries in this sample having high average carbon emissions. Most developed countries have high carbon pricing, averaging US$47.481. Meanwhile, upper-middle—and lower-middle-income countries tend to have very low carbon pricing, with an average of US$5,850.

Their GDP per capita is higher than the global average regarding social welfare, but this only reflects the financial aspect. These high-income countries have low overall social welfare when social and environmental dimensions are included.

It is also indicated that countries with higher carbon emissions tend to have higher carbon tax intensity. Most countries do not have subsidy and tax liability offset policies; only 10 out of 28 countries have adopted this form of revenue recycling. Most countries that implement it have high carbon tax rates, except for Singapore. Switzerland is the only country with a subsidy and a tax liability offset mechanism.

Table 1. Descriptive Statistics Result

Variable	Obs	Mean	Std. Dev.	Min	Max
CE	28	153543.612	220302.430	3086.232	944758.627
SWF	28	-2.26E-09	1	-1.882	1.569
CT	28	2.503	1.138	1	4
STO	28	0.392	0.566	0	2
GDP	28	26.594	1.438	23.882	29.067
Urban	28	15.984	1.581	12.821	18.557

First Model Results. The threshold p-value for the joint test in the normality test using the Skewness-Kurtosis method is set at 0.050 (DEMİR, 2022). **Table 2** presents the normality test results based on this method, where all p-values exceed 0.050. Therefore, it can be concluded that the model errors are normally distributed. In the heteroskedasticity test using the Breusch-Pagan method, data is considered free from heteroskedasticity if the p-value exceeds 0.050 (Guo et al., 2020). As in **Table 2**, all equations produced p-values greater than 0.050, indicating the absence of heteroskedasticity in the data. In the multicollinearity test using the Variance Inflation Factor (VIF), values typically range from a minimum of 1 to a maximum of 10. VIF values within this range indicate the absence of serious multicollinearity between variables (Shrestha, 2020). In **Table 2**, the multicollinearity test results for all models are within this acceptable range, suggesting that multicollinearity is not a concern. Thus, every equation has passed the classical assumption test so that it can be processed further.

Table 2. First Model Classical Assumption Test Result

Classical Assumption Test	Equation 1	Equation 2	Equation 3
Normality	0.113	0.065	0.059
Heteroscedasticity	0.144	0.113	0.108
Multicollinearity	3.604	3.037	2.692

The F-statistic tests whether the overall regression model fits the data well. A significant F-test (p value less than 0.050) indicates that the independent variables, as a group, have a statistically significant relationship with the dependent variable or at least one variable that significantly affects the dependent variable (Jenkins & Quintana-Ascencio, 2020). The F-test on all equations yields a p-value below 0.050, as in **Table 3**. Therefore, the null hypothesis is rejected, and all regressions are considered statistically significant overall. Thus, the results in the model can be used to explain the effect on the dependent variable.

Table 3 also shows the results when the carbon tax is tested jointly without being sector-specific. The results in **Equation 3** show that the carbon tax significantly negatively affects carbon emissions. This indicates that the higher the intensity of carbon tax implementation, the more it will mitigate carbon emissions; thus, the H1 is accepted. The results show that subsidies and tax liability offsets have no interaction with the effect of the carbon tax on carbon emissions, so H2 is not accepted. Because β_2 in **Equation 2** and β_3 in **Equation 3** have no significant effect. So, mitigating carbon emissions does not require subsidies and tax liability offsets. This model is the primary determinant of carbon emissions, with an adjusted R-squared value of 0.930. This indicates that 93.012 per cent of the variation in carbon emissions is explained by the variables included in the model. In comparison, the remaining 6.988 per cent is attributed to factors outside the scope of this model.

Table 3. First Model t-test Result

Variable	Equation 1 CE	Equation 2 CE	Equation 3 CE
CT	-0.219	-0.217	-0.217
	0.014*	0.016*	0.018*
STO		-0.067	-0.432
		0.661	0.795
CT*STO			-0.053
			0.671
GDP	0.450	0.454	0.453
	0.001*	0.001*	0.001*
Urban	0.555	0.561	0.556
	0.000*	0.000*	0.000*
Adj. R-square	0.934	0.932	0.930
Prob. F	0.000*	0.000*	0.000*

*p-value significance at the 5 per cent level

Table 4 shows the results of the classical assumption tests for the first model with a sector-specific carbon tax. The findings indicate that all classical assumptions are satisfied. Specifically, the normality test yields a p-value greater than 0.050, confirming that the errors are normally distributed. The heteroscedasticity test also shows a p-value above 0.050, indicating the absence of heteroscedasticity in the model. Additionally, all Variance Inflation Factor (VIF) values fall within the acceptable range of 1 to 10, suggesting no multicollinearity between the variables, except for **Equation 3**.

As shown in **Table 4**, **Equation 3** has a high output Variance Inflation Factor of 17, exceeding the upper limit of 10. This is due to the addition of moderator variables to the model. According to (Gujarati, 2003), the regression coefficients may become unstable if multicollinearity is high. However, Gujarati also emphasises that multicollinearity is normal in real-world data. Gujarati also mentioned that multicollinearity is a matter of degree, not presence or absence. This means that if the results still make sense, there is no need to correct a high VIF unless it is disturbing immediately. It is said that multicollinearity also makes it difficult for the regression coefficients to be statistically significant. However, in this model in **Equation 3**, independent variables become significant that were not previously in **Equations 1** and **2**, and the other variable remains consistent. Following Gujarati's argument, multicollinearity does not violate the regression model's classical assumptions and primarily affects estimators' precision, not the unbiasedness. This view is further supported by empirical findings from (Arici et al., 2023) and (Lavery et al., 2019), who demonstrate that multicollinearity does not significantly affect Type I error rates in regression analysis when the sample size approaches 30 observations. So, the model can still be used with caution.

Multicollinearity in **Equation 3** is partly attributable to the moderator variable, subsidies and tax liability offsets, where most observations are zero due to the limited adoption of such policies; only 10 out of 28 countries in the sample have implemented them. As a result, 18 data points take the value of zero after the interaction between the independent variable and the moderator, leading to a lack of variability and an increased risk of multicollinearity, since most observations share the same value.

Table 4. First Model in Sector-Specific Classical Assumption Test Result

Classical Assumption Test	Equation 1	Equation 2	Equation 3
Normality	0.951	0.889	0.683
Heteroscedasticity	0.720	0.525	0.149
Multicollinearity	3.690	3.673	17.972

In **Table 5**, all equations have an F-value below 0.050, so at least one independent variable affects the dependent variable. Therefore, the model can explain the influence of the variables.

Table 5 also presents the results of the sector-specific carbon tax regressions. Among all sectors examined, only the transportation, electricity and heat sectors exhibit a significant adverse effect on carbon emissions in equation 3, whereas other sectors show no significant impact. This suggests that carbon taxes are most effective in reducing emissions when applied to the transportation, electricity, and heat sectors. Additionally, the analysis finds that subsidies and tax liability offsets fail to interact with the relationship between sectoral carbon taxes and carbon emissions, because the β_2 of subsidies and tax liability offset in equation 2 and the β_3 of every moderated variable in equation 3 have no significant effect. The carbon taxes in the transportation and electricity sectors are strong enough to reduce emissions by themselves; they do not rely on extra government financial support to be effective. This model is also the main driver of carbon emissions, with a high adjusted R-squared of 0.948. It shows that 94.818 per cent of the data can be explained through this model, and variables outside the model explain the rest.

Table 5. First Model t-test in Sector-Specific Result

Variable	Equation 1 CE	Equation 2 CE	Equation 3 CE
CT1	-0.032	-0.019	-0.063
	0.761	0.852	0.824
CT2	0.050	0.050	0.136
	0.627	0.623	0.529
CT3	-0.180	-0.235	-0.303
	0.128	0.069	0.015*
CT4	0.007	0.065	0.084
	0.943	0.560	0.485
CT5	-0.097	-0.101	-0.195
	0.238	0.216	0.016*
CT6	0.103	0.103	0.118
	0.354	0.350	0.439
STO		-0.230	0.067
		0.256	0.730
CT1*STO			0.040
			0.957
CT2*STO			0.273
			0.632
CT3*STO			-0.175
			0.435
CT4*STO			-0.278
			0.072
CT5*STO			-0.356
			0.061
CT6*STO			0.358
			0.276
GDP	0.370	0.360	0.382
	0.017*	0.019*	0.034*
Urban	0.635	0.669	0.579
	0.000*	0.000*	0.003*
Adj. R-square	0.915	0.916	0.948
Prob. F	0.000*	0.000*	0.000*

*p-value significance at 5 percent level, CT1: Carbon tax (CT) in industry sector, C2: CT in mining and extractives sector, CT3: CT in transport sector, CT4: CT in buildings sector, CT5: CT in electricity and heat sector, and CT6: CT in agriculture, forestry, and fishing sector

Second Model Results. In the second model, social welfare is the dependent variable instead of carbon emissions. All equations for the overall carbon tax model have passed the classical assumption test, as in **Table 6**. With normality greater than 0.050, the errors are normally distributed, there is no heteroscedasticity with a p-value greater than 0.050, and there is no multicollinearity because it is within the range of 1 - 10. So, the model can be continued for further processing.

Table 6. Second Model Classical Assumption Test Result

Classical Assumption Test	Equation 1	Equation 2	Equation 3
Normality	0.213	0.198	0.803
Heteroscedasticity	0.955	0.963	0.264
Multicollinearity	3.601	3.030	2.693

The F test in this research model also passes in all equations. **Table 7** shows that at least one variable significantly affects the dependent variable. Thus, the model can be used to explain the effect of independent variables on the dependent variable.

Table 7, the t-test shows that the carbon tax variable significantly affects social welfare, so H3 is not accepted. The higher the intensity of the carbon tax, the higher the social welfare. Subsidies and tax liability offsets also strengthen the carbon tax and social welfare relationship, so H4 is not accepted. So that recycling revenue can successfully help reduce the burden on society. Since β_2 is insignificant, while β_3 is significant, subsidies and tax liability offsets are pure moderators. In other words, its influence is only seen in changing the connection between the other two variables, not in any direct outcome. This research model can explain 46.121 per cent, while other variables outside the model explain the rest.

Table 7. Second Model t-test Result

Variable	Equation 1 SWF	Equation 2 SWF	Equation 3 SWF
CT	0.349	0.344	0.346
	0.062	0.070	0.049*
STO		0.180	-0.072
		0.587	0.823
CT*STO			0.557
			0.030*
GDP	0.131	0.119	0.135
	0.597	0.638	0.563
Urban	0.204	0.188	0.237
	0.000*	0.000*	0.000*
Adj. R-square	0.236	0.2132	0.461
Prob. F	0.023*	0.048*	0.012*

*p-value significance at the 5 per cent level

Table 8 shows the classical assumption test results for the second model with a sector-specific carbon tax. All equations have passed the classical assumption tests. Normality tests indicate p-values above 0.050, the heteroskedasticity tests also show p-values above 0.050, and the variance inflation factor (VIF) values mostly fall within the acceptable range of 1 to 10, except for equation 3. Like the first model, multicollinearity consistently appears in sector-specific models involving the carbon tax variable, regardless of the model used. However, as previously mentioned and supported by Gujarati's view, multicollinearity is not a significant concern when the model is used solely for predictive purposes. Therefore, the model remains valid for explaining the influence of the variables.

Table 8. Second Model in Sector-Specific Classical Assumption Test Result

Classical Assumption Test	Equation 1	Equation 2	Equation 3
Normality	0.083	0.071	0.630
Heteroscedasticity	0.586	0.576	0.248
Multicollinearity	3.692	3.671	17.977

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As in **Table 9**, all F-tests have also been met for all equations with F-values below 0.050, so the model can be used to explain the influence of the dependent variable on the independent variable.

If the carbon tax is separated into sector-specific taxes, none significantly affects social welfare, as shown in **Table 9**. Subsidies and tax liability offsets in each sector also have no interaction, except for the interaction in the buildings sector, with positive and significant results. The moderation is a pure moderator because the β_2 is insignificant, and the β_3 is significant. So, social welfare will increase if subsidies and tax liability offsets are applied to the building sector. However, it has been seen previously that a carbon tax in the building sector, as an independent one, does not affect social welfare. According to (Busenbark et al., 2022), a non-significant independent variable does not affect the validity of a significant interaction. The presence of a significant interaction indicates that the effect of the independent variable depends on the moderator (Lorah, 2020). This means that the relationship between the carbon tax in the building sector and social welfare changes depending on the moderator. This model can explain 34.312 per cent, while variables outside the model explain the rest.

Table 9. Second Model t-test in Sector-Specific Result

Variable	Equation 1 SWF	Equation 2 SWF	Equation 3 SWF
CT1	0.158	0.154	0.481
	0.490	0.515	0.487
CT2	0.037	0.037	0.350
	0.862	0.866	0.500
CT3	-0.037	-0.020	-0.017
	0.877	0.940	0.947
CT4	0.281	0.262	0.380
	0.196	0.291	0.202
CT5	-0.031	-0.029	-0.088
	0.857	0.866	0.605
CT6	-0.207	-0.207	-0.686
	0.379	0.392	0.077
STO		0.073	-0.034
		0.867	0.941
CT1*STO			0.859
			0.632
CT2*STO			0.957
			0.486
CT3*STO			-0.108
			0.838
CT4*STO			0.817
			0.033*
CT5*STO			-0.073
			0.862
CT6*STO			-1.484
			0.072
GDP	0.142	0.145	0.179
	0.641	0.644	0.647
Urban	0.161	0.150	0.181
	0.000*	0.000*	0.000*
Adj. R-square	0.329	0.330	0.343

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Prob. F	0.000*	0.000*	0.000*

DISCUSSION

There are several concerns regarding the carbon tax, especially its effectiveness in mitigating carbon emissions and its regressivity effect on social welfare. Findings by (Pretis, 2022) show that the current carbon tax is too low to mitigate carbon emissions in British Columbia effectively. Also, findings by (Mardones & Flores, 2018) show that taxes between US$10 and $30/ton CO2 reduce emissions rapidly, while taxes higher than $30 stagnate. The way carbon tax revenues are used is crucial; options include reducing other taxes, funding climate programs, or direct compensation to households, each with different implications for equity and efficiency (Prasad, 2022; Riyono & Widianingsih, 2024b). Moreover, carbon taxes also have doubts regarding economic impacts, fairness, and public acceptance. Carbon taxes without revenue recycling tend to be regressive in developed economies, disproportionately affecting lower-income households who spend a larger share of their income on carbon-intensive goods (Khastar et al., 2020). In developing countries, evidence does not support the idea that carbon taxes are progressive (Timilsina, 2022). Energy-intensive sectors are more affected by uniform carbon taxes, and preferential treatment for these industries can create trade-offs between environmental goals and economic growth. However, the findings in this study are interesting, as they differ from previous studies. It turns out that subsidies and tax liability offsets do not help the effectiveness of carbon taxes, and it also turns out that carbon taxes can improve social welfare.

The first model results show that the higher the intensity of the carbon tax or its price, the more carbon emissions can be mitigated. However, subsidies and tax liability offsets have no interaction. As with the natural resources-based view, the carbon tax is the primary driver for all companies to transition to a more sustainable business, especially when integrated with broader natural resource management and fiscal policies. It effectively manages natural resources efficiently to achieve economic and environmental sustainability. So that companies can channel their financial resources into environmentally friendly investments. Overexploitation of natural resources without proper taxation or regulation accelerates emissions and environmental degradation. So, integrating carbon taxes with strategies to limit resource extraction and promote renewable energy is crucial for long-term sustainability. Carbon taxes have been shown to reduce emissions, especially when tax rates are sufficiently high and well-targeted. Higher carbon tax rates are associated with greater emission reductions, following an increasing marginal emission reduction pattern. Empirical evidence in some countries also consistently shows that carbon taxes significantly reduce carbon emissions. Sweden's carbon tax resulted in an 11 per cent decline in transport emissions, with the tax itself being the primary driver of this reduction (Andersson, 2019). In European countries, adopting carbon taxes has also positively and significantly lowered CO2 emissions (Ghazouani et al., 2020). Then, in British Columbia, the carbon tax reduced manufacturing emissions by 4 per cent while increasing output (Ahmadi et al., 2022). A previous study by (Mardones & Flores, 2018), (Nar, 2021), and (Pretis, 2022) found that carbon taxes in OECD countries are not effective in mitigating carbon emissions. This is likely because the tax rates are often much lower than needed to impact emissions significantly. This study is in line with (Doğan et al., 2022a), (Hu et al., 2021), and (Yang, 2024), which requires a high carbon price under the carbon tax to effectively mitigate carbon emissions.

The carbon tax in Finland also significantly reduces per capita CO2 emissions. However, in Denmark, Sweden, and the Netherlands, its effects are adverse but insignificant due to high tax exemption policies on energy-intensive industries (Charlier et al., 2023; Wei et al., 2022). This suggests that subsidies and tax liability offsets do not necessarily increase the effectiveness of carbon taxes. Poorly designed subsidies or offsets can reduce the effectiveness of enhancing carbon tax implementation in cutting emissions. If subsidies are financed using revenues from carbon taxes and directed toward low-emission sources, they can enhance overall welfare and contribute to reducing emissions. However, the benefits are typically minor compared to implementing a straightforward carbon tax.

In contrast, if these subsidies are funded through general tax revenues, without carbon tax collections, they can decline overall welfare and undermine the effectiveness of emission reduction policies (Tsai, 2020; Zhang et al., 2023). Implementing tax liability offsets, such as using emission reduction credits from outside the taxed sector, can sometimes lead to absolute emission reductions, but also carries risks. Low-quality offsets may undermine the environmental integrity of the carbon tax, reduce incentives for direct emission cuts in taxed sectors, and potentially lock in higher emissions over time (Wang-Helmreich & Kreibich, 2019). These show that a carbon tax can independently reduce carbon emissions without subsidies or tax liability offsets. This result is in line with (Charlier et al., 2023), (Nar, 2021), and (Wei et al., 2022), who found that these exemptions will not help the effectiveness of the tax, because most of the revenue generated is instead used to fund other non-environmental expenditures.

The carbon tax is effective in the transportation, electricity, and heating sectors due to the first model in the sector-specific approach. This effectiveness arises because these sectors are more prepared and capable of quickly transitioning to greener practices than others, supported by various renewable energy options, such as electric vehicles, solar panels, wind turbines, and hydropower plants. These sectors are also highly energy-intensive and rely heavily on fossil fuels. This makes their emissions more directly responsive to price signals from carbon taxes, leading to significant reductions in greenhouse gas emissions when such taxes are applied. In line with the study by (Chang, 2022), the carbon tax regime depends on product substitution and price elasticity of demand to mitigate carbon emissions. Previous studies also show that carbon taxes in the energy industry led to significant emission reductions, especially in electricity generation, even with modest tax rates, causing substantial declines in emissions (Gugler et al., 2021; Yang, 2024). Sectors with lower energy intensity or more complex supply chains, such as industry, buildings, and agriculture, are less directly affected by carbon taxes. Their emissions are less sensitive to carbon pricing, and they may have more limited options for reducing emissions in the short term. The effectiveness of the carbon tax is higher if fossil fuel use is direct and visible, as in power generation and transport, making it easier for these sectors to respond to price signals by reducing consumption or switching to cleaner alternatives.

However, while some argue for differentiated tax rates across sectors, research suggests that uniform carbon taxes are generally more efficient unless trade policies or other constraints require differentiation (Zhou et al., 2018). Sectors with higher energy intensity are more affected, and policy design must balance environmental effectiveness with economic and equity considerations. With this, the carbon tax is still better applied to all sectors; only the intensity needs to be differentiated by looking at how much the sector contributes to carbon emissions.

The results of the second model in this study indicate that a carbon tax can enhance social welfare, particularly through interactions with subsidies and tax liability offsets. Based on the natural resource-based view, a carbon tax encourages sustainable development, resource efficiency, and green innovation, aligning environmental objectives with long-term competitive advantages. Carbon taxes also yield social benefits by incentivising firms to internalise environmental costs and transition to low-carbon production. A well-designed carbon tax promotes resource efficiency, contributing to greater social welfare by reducing long-term ecological risks and improving public health. Furthermore, recycling carbon tax revenues into social investments, such as green infrastructure and subsidies for lower-income households, can further increase social welfare. Ultimately, this approach fosters long-term resilience and promotes sustainable social well-being.

Carbon taxes can increase social welfare under certain conditions, especially when set at optimal levels, targeted at production, and paired with effective revenue recycling. The design of the tax and how revenues are used are critical in determining whether social welfare rises or falls, and impacts can vary significantly across countries, sectors, and income groups. The optimal carbon tax policy in the model raises the welfare of all current and future generations on a consumption-equivalent basis (Kotlikoff et al., 2021). Optimal carbon tax rates can effectively improve social welfare when carbon emissions per product unit are significant or the price of carbon dioxide is high (Zhou et al., 2018). Also supported by (Ellalee & Alali, 2023), (Fu et al., 2023), (Guo & Huang, 2022), and (Wang & Wang, 2021), imposing a carbon-emission tax on products with higher production cost, higher product volume, or higher product density can increase the probability of improving social welfare. Thus, it reduces the carbon tax regressive effect by itself.

When carbon taxes are implemented alongside subsidies or tax offsets, the combined effect tends to enhance social welfare more than either policy alone, resulting from the second model in this study. Using subsidies and tax liability offsets to recycle carbon tax revenue can further reduce and reverse the potential regressive effect, making carbon pricing more equitable. Returning carbon tax revenue directly to households as lump-sum payments or cash transfers can offset the increased costs, especially for low-income households. These payments are especially effective at reducing inequalities and can substantially lower fuel poverty when targeted at low-income households (Berry, 2019; Bourgeois et al., 2021). Using carbon tax revenue to fund tax credits, such as an environmentally earned income tax credit, can make the policy distributionally neutral or even progressive.

Linking credits to earned income helps ensure that lower-income households are compensated for higher energy costs (Chen et al., 2020; Cheng et al., 2021). As noted by (Ploeg, 2025), improving social welfare also requires reducing subsidies for fossil fuels, thereby allowing a greater focus on incentives for renewable sources. Therefore, a carbon tax can also be used to improve social welfare. By recycling revenue through lump-sum payments, targeted subsidies, or tax credits, policymakers can ensure that climate action is effective and socially equitable.

Specifically, per sector, subsidies and tax liability offsets have no interaction, except for the buildings sector. The results show that most sectors do not show significant interaction. This suggests that the effectiveness of combining these policies depends on sector characteristics, such as technology, market structure, and consumer behaviour. As in the natural resource-based view, the buildings sector develops and accumulates eco-capabilities, such as green tech, design innovation, and energy efficiency. When carbon taxes push for sustainability and subsidies support capability acquisition, these align to create a competitive advantage and social benefits. At the same time, other sectors may lack the dynamic capability to translate that alignment into tangible welfare benefits. The positive interaction between carbon taxes and subsidies or tax liability offsets on social welfare is clear overall, but sector-specific factors determine whether this effect is present. The buildings sector stands out due to its greater responsiveness to combined policy incentives, highlighting the importance of tailored policy design for maximising social welfare benefits.

The carbon tax places a price on carbon emissions, requiring individuals and companies to pay for each carbon unit they release into the atmosphere. This mechanism not only serves as a deterrent to excessive emissions but also generates additional government revenue (Riyono & Widianingsih, 2024b; Timilsina, 2022; Tsai, 2020). Such revenue can be redirected to the public through subsidies, investment in green infrastructure, or developing renewable energy sources. In this way, the carbon tax functions as a fiscal tool that supports sustainable economic growth. While the short-term implementation costs may be high, the long-term benefits are substantial, including reduced environmental risks, increased energy efficiency, and decreased economic vulnerability to climate change. As a source of funding, the carbon tax can play a significant role in financing the transition toward a greener economy.

The natural resources-based view provides a valuable perspective on how a carbon tax can affect carbon emissions and social welfare. It is confirmed that a carbon tax can be a driver to incentivise all sectors to improve energy efficiency, green technology, and sustainable operation. Also, the existence of a carbon tax can improve social welfare with a revenue mechanism, benefiting the community. Thus, these findings empirically verify this theory.

This research differs from previous studies by addressing cross-country comparison biases, which are mitigated through adjustments to carbon tax measurements. In addition, prior assessments of social welfare were limited to financial aspects. Therefore, this study expands the measurement to include environmental and social aspects. Measured subsidies and tax liability offsets are introduced as moderating variables, a novel contribution. The analysis also adopts a sectoral approach rather than a broad examination of carbon tax implementation. These refinements are grounded in factual evidence and supported by statistical analysis to ensure robustness and relevance.

The literature implication of this study lies in its contribution to carbon tax research by offering a more equitable policy design and emphasising the effectiveness of sector-specific approaches. The social implication highlights the progressive nature of the carbon tax, benefiting the state, companies, and society, which can help improve public acceptance. The practical implication guides policymakers in selecting appropriate sectors and designing tailored mechanisms for revenue redistribution, ensuring both environmental impact and economic stability.

CONCLUSION

This research indicates that a carbon tax has a triple effect: it mitigates carbon emissions and enhances social welfare. As a result of this study, taxes also generate revenue from every single transaction, which means the contribution is not only to environmental and social but also to economic growth. The carbon tax price can be differentiated across sectors based on their contribution to carbon emissions and their ability to utilise renewable energy. Specifically, the transportation, electricity and heat sectors are significant contributors to carbon emissions due to their reliance on fossil fuels, but all also have options for renewable energy. As a result, a carbon tax is particularly effective in these sectors, making them a priority for implementation. The design of the carbon tax must be careful to avoid regressive impacts. This involves considering the selected sectors, the tax rate, and how the tax revenue is utilised. Implementing subsidies and offsets to tax liabilities can significantly benefit social welfare, mainly when revenue recycling is employed. This mechanism is particularly advantageous in sectors that can create synergistic effects between carbon taxes and subsidies, such as the building sector. A carbon tax is crucial for achieving the United Nations' net-zero target. While the carbon tax can potentially impact all sectors, currently only a few sectors are prepared for immediate transition; others will require a more gradual approach. Effective fiscal policy and management of national resources are also essential to support the success of the carbon tax.

These points help shift the perception of a carbon tax from mere rhetoric to a tangible and practical policy instrument. Contrary to the common negative connotation of "tax," the carbon tax has yielded positive societal outcomes. It is equitable, progressive, and capable of driving long-term economic benefits. As its advantages become more evident, public acceptance will likely grow, strengthening government efforts to implement and enforce the policy. Consequently, the carbon tax is strongly recommended as a vital step toward achieving a sustainable future. To ensure its success, consistent support from both the public and government institutions is essential.

This research was intended to categorise countries into lower-middle income, upper-middle income, and high income. Unfortunately, this is limited by the number of countries' characteristics, where the majority are high-income. So, the results for other income categories cannot be obtained due to the limited number of observations. A total of 20 countries are in the process of designing a carbon tax as of 2025. Therefore, it is possible to categorise by income group and strengthen the aspect of testing the carbon tax with time-series models. The price dynamics of carbon tax are also engaged in determining whether price increases can weaken the effect of carbon emissions because various studies found that prices that are too high may make them stagnant.

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