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Environmental Tax and Vulnerable Employment: A Global Empirical Evidence

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Abstract

The role of government policies in creating employment has remained topical. However, focusing on the relationship between environmental taxes and vulnerable employment is a relatively rare line of academic inquiry in the literature. This study examines the asymmetric relationship between environmental taxes and employment vulnerability. This study provides empirical evidence using the new method of moments quantile regression on a global panel of data from 92 countries from 1994 to 2020. The findings show that restrictive environmental tax policies reduce employment vulnerability across the globe. The findings further show that in low-income and lower-middle-income countries, the impact of environmental taxes has been largely and significantly progressive, which is the case for the American continent. However, in high-income countries, the impact has been emphatically regressive, which is similar to the context of Asia and Europe. These findings, therefore, present ramifications for Sustainable Development Goals and Goal 8 in particular.

Keywords: Carbon emissions, environmental tax, global, method of moments, quantile regression, vulnerable employment

1. Introduction

Globally, several countries face two major challenges, intensified by the global pandemic and Russian-Ukrainian war crisis (Bin-Nashwan et al. 2022; Chaaya et al. 2022, Martinho 2022, Patwary et al. 2022; Pereira et al. 2022; Quinn et al. 2021). The first challenge involves the detrimental impact

of climate change and environmental degradation, which significantly affect health, lives, and livelihoods worldwide (Barnes et. al., 2023; Ison et. al., 2023; Yamazaki, 2022; Liu et al., 2022; Hamill, 2013; North, 2013; Foster et al., 2016; Siya et al., 2020; Yaro et al., 2015; Malyshev, 2009). The second issue is the rise in vulnerable employment, driven by significant changes in the labour market, leading to job insecurity, low pay, low job autonomy, and non-standard work arrangements (Lo Bue et al. 2022; Chen, 2022; Zuber & Sanders, 2013; Burrone and Giannelli, 2020; Heltzer and Shelton, 2015; Wei and McGee, 2015; Singer, 2013; Ren and Xiao, 2014, Adams, 2014; Rostan, 2014).

Moreover, recent UNEP (2021) statistics indicate that the world does not meet the global emission target of maintaining temperatures below 2 °C, as set in the Paris Agreement, raising serious concerns (Lo Bue et al. 2022; Gills and Morgan, 2020; Kirchner et al. 2019; Alvarez 2013; Masino, 2014). This is compounded by an alarming ILO (2018) report showing that in 2017, approximately 1.4 billion workers globally were in vulnerable employment. Environmental taxes have gained popularity in the fiscal policy literature and among global and regional policymakers (Bashir et al. 2022; Delgado et al. 202; Hänsel et al. 2022; Hua et al. 2022; Rustico 2020; Xian et. al., 2014), because they are theoretically posited to yield double dividends. The first dividend involves imposing taxes on pollutant products, increasing their prices, discouraging production and consumption, reducing greenhouse gas emissions, and improving environmental quality. The second dividend enhances employment, economic growth, and welfare through the redistribution of tax revenues to reduce other distortionary taxes, lower labour taxes, or provide lump-sum payments to vulnerable populations (Lo Bue et al. 2022; Castro et al. 2019; Hassan et al. 2020; Lancker et al. 2019; Denton 2010; Zhou and Richetts, 2014). However, some studies raise concerns about the burden on poor and vulnerable populations, who spend a significant portion of their income on pollutant products and services (Klenert et al. 2018; Patriarca and Vona 2012). Additionally, economic theory suggests ambiguous effects: while environmental taxes might decrease firms' profits and labour demand, recycled tax revenues through other tax reductions could potentially increase firms' profits and labour demand. This ambiguity leaves economists with the empirical question of how environmental taxes affect employment vulnerability.

Despite the admirable efforts in the literature to untie the nexus between environmental tax policy and employment empirically (Klein and van den Bergh 2021), much focus has been tilted towards employment and unemployment to the neglect of vulnerable employment; indeed, studying the impact of environmental taxes on vulnerable employment is essential to ensure that environmental policies are equitable and considerate of the socio-

economic well-being of these workers and communities (Yang et al. 2020; Li et al. 2020; Brown et al. 2020; Rahman et al. 2019; Kilimani et al. 2015; Chateau and Saint-Martin, 2013; Fæhn et al. 2009; Landry, 2013; Carraro et al. 1996). The impact of environmental taxes on various employment dimensions remains under-researched, particularly regarding volume, estimation methods, and the neglect of vulnerable employment. Environmental tax policies are closely tied to vulnerable employment, potentially disproportionately affecting low-income households reliant on pollutant products targeted by these taxes (Bosquet, 2000). However, Bosquet suggests that tax revenues could fund compensatory measures for vulnerable groups. We propose redirecting these revenues towards tax cuts and support for the vulnerable employment sectors. Existing studies focus on a few advanced and emerging nations and local levels, overlooking the global impact, which is essential for evaluating collective efforts against environmental issues. This oversight contributes to the lack of consensus on how to redistribute environmental tax revenues efficiently, as these studies do not consider the heterogeneous, distributional, and asymmetric effects of such policies.

The asymmetric behaviour of environmental tax policy, akin to many macroeconomic variables, is well-documented (Saubert et. al., 2011; Holmlund and Kolm, 2000; Preobragenskaya and McGee, 2016; McGee et al., 2019). Thus, the connection between environmental taxes and vulnerable employment is well-established. Given the objectives and preferences for redistributing revenues from environmental taxes, the heterogeneous nature of workers, imperfect labour markets, varying pollution consumption externalities, and responses to environmental tax policy in vulnerable employment may be diverse or non-homothetic, with extreme tail dynamics. Additionally, it remains unknown whether the environmental tax-vulnerable employment nexus varies across countries according to income level and continent. This study aims to fill these gaps by examining the asymmetric impact of environmental tax on vulnerable employment globally, by continent, and income level groupings.

This study is motivated by a lack of existing research, which restricts policymakers from formulating environmentally beneficial employment policies. This gap conflicts with the assertion of Heine et al. (2020) that the economic costs of climate change disproportionately affect developing nations. Additionally, environmental taxes are crucial for generating state revenue and improving environmental quality by promoting renewable energy and technologies to reduce greenhouse gas emissions and enhance global welfare. Furthermore, vulnerable employment significantly impacts socioeconomic growth, especially in developing and low-income countries, where limited employment opportunities make vulnerable employment a

viable alternative to unemployment (Yerrabati, 2022; Belvis et al., 2022; Jin et al., 2022; Lamontagne et al., 2022; Pfaff and Elgar, 2022; Masino, 2011).

This study extends the literature in several ways. First, it extends, in particular, the employment double dividend literature on environmental tax (see, in particular, Klein and van den Bergh 2021; Neifar, 2018) that has been a subject of scholarly enquiry by being among the first to discuss the link between environmental tax and vulnerable employment. In particular, this study demonstrates how restrictive environmental tax policies reduce vulnerable employment worldwide. Second, this study advances the vulnerable employment literature by identifying environmental tax as a determinant of vulnerable employment, an important but overlooked subject that extends insights into the vulnerable employment domain. Although Domguia et al. (2022) examined the effects of environmental taxes on employment in OECD and non-OECD countries, their study does not address the issue of vulnerable employment, the domain where the risk and hazards associated with environmental degradation are the hardest hit. Empirically, this study demonstrates that the relationship between environmental tax and vulnerable employment is asymmetric, underscoring the significance of environmental tax for vulnerable workers and laying the groundwork for further improvement in their lives. Third, this study provides new methodological insights that diverge from the existing literature by applying the novel Method of Moments Quantile Regression (Machado and Santos Silva, 2019). This model identifies specific quantiles where environmental tax significantly impacts vulnerable employment, either positively or negatively, aiding policymakers in crafting suitable environmental and labour market-enhancing policies. This contribution is particularly relevant and timely in the context of developing countries where environmental tax laws are in their nascent stages of development.

The main findings suggest that environmental taxes significantly reduce vulnerable employment, indicating their potential as a tool for policymakers to mitigate the adverse effects of global vulnerable employment.

The remainder of this paper is organised as follows. Section 2 reviews the theoretical and empirical literature on the environmental tax-vulnerable employment nexus in detail. The methods used in this study are described in Section 3. Section 4 presents the empirical results of the study, while Section 5 presents the conclusions, policy implications, and future research agenda.

2. Summary of prior literature

The interplay of climate change, the Russian-Ukraine war, and the COVID-19 pandemic has drastically altered the labour market, leading to

unemployment and new employment norms, some of which result in "bad jobs" characterised by job insecurity, low wages, limited job autonomy, and non-standard work arrangements (Churski et al., 2021; Clapp and Moseley, 2020; Energy and Justice, 2022; Marsden, 2014; Prohorovs, 2022). Recently, researchers have seen a surge in both the theoretical and empirical literature on vulnerable employment (Tsambou et. al. 2024; Boboc and Ghita 2024; Gunashekhar et. al. 2024; Sakamoto, 2024; Menk and Huber, 2016; Jin et al. 2022; Lo Bue et al. 2022; Sarfraz et al. 2022; Uwajumogu et al. 2022; Yerrabati, 2022, 2021; Gammage et al. 2020a; Ngozi et al. 2019; ILO, 2018b; Joseph, 2016; Davey et. al 2025; Alakent and Goktan, 2025 Asquith and Scott, 2007). These studies explore the connections between vulnerable employment and gender, economic growth, and the COVID-19 pandemic as well as the impact and trends across different countries and sectors. Lo Bue et al. (2022), in a World Bank working paper, analyzed the effect of gender inequality on vulnerable employment, revealing that women are seven times more likely to be in vulnerable employment than men. Gokhool and Tandrayen-raoobur (2017) studied the socioeconomic characteristics of workers in vulnerable employment in Mauritius and found that youth and women were less likely to be in vulnerable employment, with education level, age, and marital status as key determinants. Yerrabati (2021) examined the potential non-linear relationship between vulnerable employment and economic growth, discovering a U-shaped nexus where higher levels of vulnerable employment correlate positively, while lower levels show a negative relationship. Erkul and Külünk (2022) identified the primary factors driving vulnerable employment in 43 sub-Saharan African countries, attributing it largely to urbanisation and non-industrial employment. Yerrabati (2022) reveal the potential of vulnerable employment to reduce poverty in developing countries after a quantitative analysis of panel data of 25 years in 65 countries. Specifically, the study shows an asymmetric relationship, where vulnerable employment marginally decreases the poverty of people living on daily incomes of $1.9 but when the poverty levels reach a higher threshold of $3.20 a day, the effect is non-existent. Chen et. al. (2023) employed 28-year panel data of 163 countries to examine the effect of urbanisation on vulnerable employment within the period under review. Research shows that urbanisation has a significant negative effect on vulnerable employment, especially in high-income countries, where the level of significance is more intense. These findings highlight the concerns of vulnerable employment in cities, particularly in the post-COVID period.

Furthermore, recent literature underscores the ever-concerning issue of vulnerable employment across many countries and sectors of the global economy. For instance, Rahman and Sitorus (2024) provide supporting evidence from the East Java Province of Indonesia, a community identified

with the highest level of vulnerable employment in 2022, to show that several factors account for vulnerable employment, including demographic factors (such as age, gender, marital status, and disability status), economic factors (work experience in the formal sector, and contributions from sectors such as manufacturing and agriculture. Baskak (2024) explored the impact of vulnerable employment on economic growth in various sectors of the N11 countries (Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Nigeria, Pakistan, Philippines, Turkey, and Vietnam), particularly in the service, industry, and agricultural sectors. The study reveals a nuanced effect where, on the one hand, vulnerability reduces economic growth in the service and industry sectors, but increases economic growth in the agricultural sector.

Similarly, Yerrabati (2025) investigated the effect of remittances in reducing vulnerable employment, given that many developing countries are bedevilled to achieve their targets under Sustainable Development Goal 8. Using instrumental variable two-stage least squares and the dynamic panel regression approach on panel data consisting of 73 countries, the study finds that an increase in remittances can moderately reduce vulnerable employment, particularly for males. Another recent study examined the nuanced relationship between financial inclusion and vulnerable employment in 25 countries in sub-Saharan Africa. The study further examines the effect of four decomposed financial inclusion measures in terms of availability, accessibility, usability, and concentration on vulnerable employment (Dianda, 2025). The findings show that both the composite and all four decomposed types of financial inclusion are associated with decreasing vulnerable employment. Indeed, these recent findings underscore the issues of vulnerable employment as hydra-headed, and the need to identify the various levers of policy prescriptions required to address this issue.

Prior research has primarily examined environmental tax in terms of its effects on unemployment and employment. Kuralbayeva (2018) uses a general equilibrium model to show that environmental taxes can reduce unemployment by shifting the tax burden from urban to rural workers through rural-urban migration. Moosavian et al. (2022) find that implementing carbon taxes and redistributing the revenue to lower labour taxes improves both environmental quality and employment, based on data from the Iranian economy. Environmental taxes can directly affect industries that significantly contribute to pollution, such as manufacturing or transportation, leading to higher costs and potential job losses or reduced employment opportunities in these sectors. Vulnerable workers in these industries may be affected disproportionately. Indirectly, environmental taxes can drive companies to adopt cleaner technologies, invest in renewable energy, or reduce their environmental footprint, resulting in the creation of

new "green jobs" and shifts in employment patterns away from polluting industries.

Other research related to environmental taxes in the recent period has churned out very insightful findings, although it has been predominantly in China and a handful of Europe. In a larger sense, Köppl and Schratzenstaller (2023), in pursuit of an answer to the raging empirical question and the mounting pressure for practical policy instruments in addressing the climate change menace, conducted a literature review to synthesise the major dimensions of the effect of environmental tax examined thus far. This study finds employment as one of the dimensions that has attracted the attention of scholars, practitioners, and policymakers. The findings also showed that a number of studies empirically show revenues from environmental taxes have been used to reduce labour taxes. Sun and Zhang (2023) examined how the government's environmental policy direction is impacting the labour market in China, using 16-year panel data gathered from several provinces, and found that environmental policies significantly and heterogeneously affect employment, especially in Western Chinese provinces.

Within the same context, Gao and Guan (2025) modelled comprehensive panel data of listed firms in China for the period 2007 to 2022 to investigate the association between carbon policies and labour demand. The results provide evidence that carbon policies, either market instruments or regulations, increase labour demand. This study also underscores the heterogeneous nature of the effect of carbon policies on market-based policies, propelling labour demand in low-polluting areas and the regulations are more suitable for increasing labour demand in high-polluting sectors.

In response to the introduction of an environmental protection tax law in 2018 in China, several studies have been conducted to test the efficacy of the law. Wei et. al. (2023) similarly set out to test the efficacy of the same environmental protection tax law in China, and their study utilised data on Chinese listed companies spanning 2013-2020, applying a difference-in-difference model to analyse the labour share effects of environmental taxes. The findings show that environmental taxes significantly reduce labour share by creating technologically innovative green jobs to the detriment of low-skilled jobs. Similarly, Zhao et al. (2024) assessed the effect of the Chinese environmental protection tax on employment, paying little attention to the social effects of environmental taxes. An 18-year analysis using differences-in-differences-in-differences econometric analysis shows that environmental taxes significantly reduce corporate employment through a double channel, that is, factor substitution and output effects. Additional findings were that the rate of employment reduction as a result of the tax effect was more pronounced for mining institutions, large-scale enterprises, and private

enterprises. Lu and Yang, (2024) also empirically examined how depending on the size of the companies, the strategies employed to deal with the employment consequences of the environmental protection tax law in China using the triple difference framework, the study shows smaller companies down size in response to the tax laws but bigger companies rather invest in technologically innovative ventures. The evidence further shows that low-skilled workers are affected more than high-skilled workers.

From the European perspective, Nelson et al. (2025), on the back of their study, underscore the critical role environmental taxes can play in ensuring not only ecological sustainability but also social sustainability. Their study assessed whether consumption-related environmental taxes resulted in poverty risk for households in 26 European countries. The findings confirm that many countries insulate households from the ravaging effects of consumption-related taxes. Fuinhas et. al. (2025) assessed the response of skill-based employment to stringent environmental regulations in European countries, given the rising urge of governments across the globe. They find stringent environmental policies to have an asymmetric effect on the labour market, where skilled employees such as professionals and managers tend to benefit because of the surge in green jobs. However, low-skilled workers suffer because of the squeezed opportunities for unskilled jobs.

Other studies, such as Iida and Mukherjee (2025), relating to other jurisdictions have also examined how a monopolist's final good producer's motivation to offshore a crucial intermediate good is impacted by pollution levels and domestic environmental harm. They discovered that higher domestic environmental damage, which results in a higher domestic environmental tax, may reduce the incentive for offshore operations, which is contrary to the conventional pollution haven hypothesis. The increased pollutant intensity of the final product manufacturing contributes to this tendency. Therefore, offshoring and pollution leakage may increase if the production of the final good has a lower pollution intensity. Given that offshoring has implications for employment, this study posits that offshoring may be excessive or insufficient from the perspective of the home nation.

The role of environmental taxes in vulnerable employment has been largely overlooked. Consequently, the research discourse is shifting from focusing solely on the environmental tax impacts on employment or unemployment to exploring other employment dimensions. This study adopts the OECD definition of an environmental tax: "A tax whose base is a physical unit (or a proxy of it) of something that has a proven, specific negative impact on the environment." Environmental taxes affect the pricing of goods or the costs of activities that harm the environment and internalise

negative externalities. There are four categories of environmental tax: energy, transportation, pollution, and resources.

This research examines the validity of the second dividend, predicted to enhance employment (reduce vulnerable employment) and economic growth, based on the Double Dividend Hypothesis. Pearce (1991) expanded Pigouvian tax theory, asserting that environmental taxes yield two dividends. The first, or green dividend, enhances environmental quality by taxing polluting behaviour, thus discouraging it. The second dividend involves using tax revenues to shift the tax burden from capital (corporate taxes) and labour (income taxes) to environmentally harmful activities, potentially increasing employment and economic growth. This is referred to as a blue dividend.

Some studies have suggested that environmental taxes can be linked to employment benefits by creating green jobs and implementing transition programs. Environmental taxes can encourage businesses to invest in cleaner technologies (Jensen and Kristensen, 2017; Johnson, 2023; Killian and Doyle, 2023), creating job opportunities for renewable energy, energy efficiency, and environmental remediation, thus benefiting the unemployed or underemployed (Hepburn et al., 2020; Bruce-Twum, 2023; Friedman et. al., 2023; Fellows et al,. al. 2023). Revenue from these taxes can fund "just transition" programs, supporting workers in moving from high-carbon to green jobs (OECD, 2020). These programs offer retraining, income support, and relocation assistance to reduce job losses in vulnerable sectors (van der Ploeg & Rezai, 2020; Alvarez, 2023). However, these studies do not account for the impact of taxes on vulnerable employment. Other recent studies highlight challenges such as potential job losses in carbon-intensive sectors. Environmental taxes, which increase production costs for fossil-fuel-dependent industries, may lead to job losses, especially among low-skilled workers with limited retraining opportunities (Wolford, 2021; Krupka, 2023; Landry et. al., 2023). Furthermore, these taxes disproportionately affect low-income communities and vulnerable workers reliant on fossil fuels for essential needs such as energy and transportation (Reyes, 2020; McGee and Liu, 2023; Abdulraqeb et. al., 2025). Rising energy costs can strain household budgets and exacerbate inequalities (Amlie & Ozawa-Meida, 2019; Al-Asfour, 2024; Amlie, 2024; Amlie & Gibney, 2023). However, empirical examination of the impact of environmental taxes on vulnerable employment is lacking.

The literature emphasises the need for careful policy design to mitigate negative employment impacts. Aldy et al. (2019) argue that sector-specific environmental tax policies can minimize job losses in high-risk industries while fostering innovation and green job creation. Golub et al. (2019) suggest that revenue from environmental taxes should support just

transition programs and social safety nets to alleviate the burden on vulnerable workers and communities. Educating the public on the long-term benefits of environmental taxes and ensuring a just transition can also garner support for these policies (Baker et al., 2017; Heltzer & Mindak, 2023; Bruce-Twum & Appiah, 2024).

While these studies advance the literature by varying in nature and importance, they do not directly address how environmental taxes affect vulnerable employment, despite their theoretical and political relevance.

Based on the limitations established in the literature, as discussed above, this study adds more insight into the literature by examining the environmental tax-vulnerable employment nexus.

3. Materials and Methods

3.1. Data and Variables

The data for this study consists of panel data on 92 countries across the globe to examine the effects of environmental taxes on vulnerable employment at the global, continental, and income levels. The data cover the years 1994 to 2020. The concentration on the number of nations and the time frame of the analysis was solely made possible by the accessibility of data for all variables, particularly environmental tax. According to earlier research, the OECD database contains data on environmental tax (Bashir et al. 2021; Wolde-Rufael and Mulat-Weldemeskel 2022b; Zahid et al. 2022). Data on vulnerable employment were acquired from the World Bank. According to numerous studies, the remaining variables, gross domestic product (GDP), energy use, and urbanisation, represent the control variables and were all taken from the World Bank's global development indicators (see Khoso et al. 2021; Liya et al. 2021), data on globalization which was sourced from the KOF Swiss Economic Institute's economic database.

3.2. Variable description and measurements

Variable description

Vulnerable employment is the main dependent variable in this study, in line with the extant literature (Álvarez-verdejo et al., 21; Candeira and Winter, 2; Hardardottir and Erik, 2021). The environmental tax variable is the main independent variable. GDP, urbanisation, energy use, and globalisation were employed as control variables after a cursory scan of the literature (Khoso et al. 2021; Zhou,2012; Wolf, 2012; Wan et al. 2022; Abdullah and Morley, 2014; Liya et al. 2021; Banham, 2012; Johnsson, 2013). **Environmental taxes**, or eco-taxes, target activities with adverse environmental effects, internalise damage costs, and encourage sustainable practices. They incentivise individuals, companies, and sectors to minimise their environmental impact by raising the costs of harmful activities such as

pollution and resource depletion. Revenues generated support for environmental protection and conservation. Taxable activities include pollutant emissions, nonrenewable resource use, waste generation, and energy consumption. Examples include carbon taxes on fossil fuels, taxes on greenhouse gas emissions, plastic bag levies, hazardous waste disposal fees, and charges on fuel usage and vehicle emissions. "**Vulnerable employment**" encompasses jobs with inadequate working conditions, minimal job security, low pay, insufficient social support, and poor conditions. It subjects workers to risks such as exploitation, economic insecurity, and denial of basic labour rights. Such employment often involves irregular schedules, temporary or part-time contracts, and informal arrangements with little job security. Workers typically earn modest wages, lack income security, and miss out on formal job benefits, such as paid leave, health coverage, or retirement programs, making them prone to financial difficulties. They have limited access to social safety programs, such as maternity leave, disability benefits, or unemployment compensation, which increases their vulnerability to financial shocks and health risks. Poor working conditions, including long hours, health hazards, and lack of safety standards, are common because of limited opportunities for skill development and career advancement. These employees often lack access to labour rights and protections, including collective bargaining and the right to join or form trade unions, leading to a lack of representation in negotiations. The gross domestic product (GDP) per capita measures the average economic output per person in a nation or area. It is calculated by dividing a nation's total GDP by its population, and indicates the standard of living or economic well-being per person. The GDP per capita is vital for comparing the relative prosperity or economic performance of different nations or regions, providing insights into the typical income and economic output generated by individuals in a specific population. Urbanisation concentrates populations in cities, transforming rural land into residential, commercial, and industrial zones, and necessitates infrastructure development, such as roads, transit systems, utilities, and educational and medical facilities. Cities have become economic hubs and offer diverse job opportunities across various industries. Globalisation**,** the increasing interconnection and interdependence of national economies, occurs through cross-border trade of goods, services, capital, technology, and information. This process, which is driven by advancements in communication, transportation, and technology, involves economic, political, social, and cultural factors. Energy usage is a term used to describe the consumption of primary energy prior to its transformation into other end-use fuels. It is equal to domestic production plus imports and stock adjustments minus exports and fuel used by ships and planes engaged in international

travel. See Table 1 for details on the variables in terms of measurements, sources, and expected signs.

Table 1: Variable Measurement

Variable	Abreviation	Unit of measurement	Source	Sign
Vulnerable employment	lvulemp	Vulnerable employment, total (% of total employment)	World Bank	Not applicable
Environmental Tax	let	Environmental tax revenues (% of GDP)	OECD	+(-)
Gross Domestic Product	lgdp	GDP per Capita	World Bank	+(-)
Urbanization	lurb	Urban population (as a % of total population)	World Bank	+(-)
Globalization	lglobal	Globalization index	KOF Swiss Economic Institute	+(-)
Energy use	energy use	People per sq. km of land area	World Bank	+(-)

Table 1 provides a description of the study variables. **Vulnerable employment** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP, **Gross per capita is used as a proxy for economic growth**. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation.

3.3. Estimation Strategy

This section describes the statistical steps employed to obtain the empirical results for the model discussed above. The process starts with diagnostic checks, followed by unit root and cointegration tests, before applying the Method of Moments Quantile Regression, which is the primary model of interest. Then, a hierarchical regression was run to test the robustness of the results. The detailed steps are as follows:

3.4. Preliminary checks

Before estimating the relationships between the study variables, initial checks were conducted to ascertain their characteristics. First, descriptive statistics and data correlations were examined. Diagnostic checks began by testing the normality of the series using Jarque and Bera's (1987) test. Slope homogeneity was assessed using the Pesaran and Yamagata (2008) test, presenting both Δ- and Δ-adjusted statistics. Considering the potential interdependence between countries due to trade and GDP, Pesaran's (2008) test was employed to check for cross-sectional dependence. These checks aim to identify estimation issues and guide appropriate steps for assessing stationarity, unit root, cointegration, and long-run relationships, thereby preventing biased or spurious results.

3.5. Unit root and Cointegration test

This study utilised Pesaran's (2014) CIPS method to test series stationarity, favouring its ability to handle cross-sectional dependence and heterogeneous slope coefficients. Additionally, the Fisher augmented Dickey-Fuller test assessed the unit root. For cointegration, this study employed Westerlund's (2007) due of its efficiency with heterogeneous slope coefficients and cross-sectional dependence. This test includes four statistics: two mean group statistics and two panel statistics. For validation, the Kao (1999) cointegration test was conducted.

3.6. Method of moments quantile regression

This study employs the Method of Moments Quantile Regression (MMQR) technique developed by Machado and Santos Silva (2019) to explore the heterogeneous and distributional relationship between environmental tax and inequality. The model captures the tail dynamics of the impact of environmental tax on inequalities within a global sample, including both affluent and disadvantaged groups, with the aim of addressing the research question and proposing welfare-maximising policy recommendations. Analysing 2,470 observations, we divide data on vulnerable employment across the 10th to 90th quantiles to thoroughly capture the heterogeneity in the environmental tax-vulnerable employment nexus and identify any tail dynamics in this relationship.

The MMQR model addresses several limitations of traditional regression models (Ma, 2022; Sun & Razzaq, 2022; Wolde-Rufael & Mulat-Weldemeskel, 2022a). It yields accurate and robust results for skewed datasets, outliers, low correlations, and non-normal data. It effectively handles uneven distributions by determining the distributional and unique properties of various quantile values. MMQR accommodates individual fixed effects across a conditional distribution, allowing predictors to adjust for location and scale functions (Alhassan et al. 2020). It is robust in discerning the conditional heterogeneous covariance effects of GDP, trade, population density, urbanisation, and environmental tax on income inequality as well as GDP, energy use, globalisation, urbanisation, and environmental tax on vulnerable employment, thus addressing unobserved heterogeneity. MMQR permits location-based asymmetry, as parameters may depend on the position of the predicted variable, income inequality, and provides good estimates, even in nonlinear conditions. Described as a practice-based approach, MMQR simultaneously handles heterogeneity and endogeneity via moment restrictions, appealing to both asymmetric and non-linear estimations. It is intuitive to handle noncrossing estimates without producing invalid responses. In line with Machado and Santos Silva (2019), for the conditional quantile of the random variable in the panel data for the location

and scale $Qy\ (\tau|X)$ is specified in equation (3.1) as follows:

$$y_{it} = \alpha_i + x'_{it}\beta + (\partial_i + N'_{it}\theta)v_{it} \quad \textbf{(3.1)}$$

where y_{it} the dependent variable, x'_{it} is an i.i.d endogenous variable (α, β, ∂, θ) are parameters to be assessed. The probability, $P\ \{\partial_i + N'_{it} > 0\} = 1$. v_{it} is an i.i.d unobserved random variable distributed across individuals and is orthogonal to x'_{it} satisfying the moment conditions (see Ma, 2022; Sun, 2022). i = 1 … n, denotes the individual i fixed effects and N is a k-vector of known components of X (Adebola et al. 2022; Adeleye et al. 2021; Anser et al. 2021; Firpo et al. 2021; Ma, 2022; Mdaghri and Oubdi, 2022; Sun and Razzaq 2022; Wolde-Rufael and Mulat-Weldemeskel, 2022b; Xie and Jamaani 2022; Xin and Xie 2022).

Again, x'_{it} is orthogonal to cross-sections (i) and time (t) in the expression as captured in Machado and Santos Silva (2019). Thus, reserves and external variables stabilise. Hence, Equation (3.1) might be rewritten as follows:

$$Q_{y_{it}(\delta|x_{it})} = \left(\alpha_i + \partial_i r(\delta)\right) + x'_{it}\beta + X_{it}\theta r(\delta) \quad \textbf{(3.2)}$$

Where $Q_{y_{it}(\delta|x_{it})}$ is the quantile distribution of the dependent variable, yit. $\alpha_i(\delta) \equiv \alpha i + \partial_i r(\delta)$ is the scalar coefficient (Ike et al. 2020) and δth is the sample quantile (Sun and Razzaq, 2022; Mdaghri and Oubdi, 2022). Z denotes a k-vector of known components x'_{it} which is normalised to satisfy the Machado and Santos Silva (2019) moment conditions E(U) = 0 and E(|U|) = 1 (see Xie and Jamaani, 2022).

4. Empirical results and discussions

In this section, the descriptive statistics are initially presented, followed by the outcome of the diagnostic tests, that is, normality checks, correlation, and variance inflation factor unit root tests. Then, the results of the Method of Moments Quantile Regression are presented before the hierarchical regression is presented for robustness checks.

4.1. Descriptive statistics

Table 2: Descriptive statistics for the six variables provide valuable information. Every variable has a constant sample size of 2,484 observations, which improves reliability. With a mean of 34.47 and a high standard deviation (27.16), Vulnerable Employment shows considerable variability; Environmental Tax, with a mean of 7.34, displays unusually high skewness (4.07) and kurtosis (39.93), suggesting extreme outliers or data entry errors, as reflected in its negative minimum value (-12.14). Reflecting significant economic variances, GDP has the largest range (102.60 to 180,367.00) and a

high standard deviation (22,541.46). Energy Use, with a mean of 28,275.85 and a wide range (98.17 to 189,841.00), also shows considerable variation. Urbanization (mean = 62.47) and Globalization (mean = 65.09) have moderate variability, with slightly negative skewness (-0.47 and -0.26, respectively), indicating that more countries have moderate to high levels of these characteristics. However, GDP and Environmental Tax stand out for their highly skewed and peaked distributions, which could impact regression analysis unless properly handled.

Table 2: Descriptive statistics for the variables

Stats	Vulnerable employment	Environmental tax	GDP	Energy use	Urbanisation	Globalisation
N	2,484.00	2,484.00	2,484.00	2,484.00	2,484.00	2,484.00
Mean	34.47	7.34	14,971.33	28,275.85	62.47	65.09
SD	27.16	5.70	22,541.46	30,019.92	20.80	15.24
Min		- 12.14	102.60	98.17	8.49	26.00
Max	95.07	85.48	180,367.00	189,841.00	100.00	91.00
Skewness	0.80	4.07	2.93	1.92	- 0.47	- 0.26
Kurtosis	2.32	39.93	15.13	7.87	2.59	2.13

Table 2 displays the descriptive statistics for all the variables captured above, it shows the number of observations. Shown as N, the mean, Standard deviation (SD), minimum and maximum values for each variable as well as the skewness and kurtosis.

Table 3 depicts the results of the normality test, which shows that the variables follow a non-normal or non-parametric distribution; hence, a non-parametric econometric model is required. This is one of the main reasons for selecting MMQR as the main estimation model in this study. Second, the results of the slope coefficient heterogeneity test indicate that the slope coefficients are heterogeneous, largely due to the diversity in structures relative to tax, income, and consumption patterns. Third, the results of cross-sectional dependence indicate the existence of cross-sectional dependence, which is expected through trade and globalisation, making the economies of the world a small global village entwined. All results are significant at the traditional levels of 1%, 5%, and 10%.

Table 4 also shows the results of the correlation analysis, and the essence is to understand whether the variables are highly correlated, which can result in multicollinearity. The correlation matrix shows that none of the correlation coefficients exceed 0.8, clearly indicating the absence of a serious multicollinearity problem. Again, the results of the Variance Inflation Factor (VIF) are also very low, all below the value of 2 and certainly not up to the level that can cause multicollinearity. This is consistent with prior studies that employed VIF, such as Poursoleyman et al. (2022).

Table 3: Normality, slope heterogeneity test, and cross-sectional dependence

Shapiro-Wilk test for normality						
Variable	Vulnerable Employment	Environmental Tax	Renewable Energy	GDP	Urbanisation	Globalisation
Shapiro-Wilk	10.974***	13.689***	12.129***	8.531***	13.579***	11.234***
Pesaran (2015) CD test for weak cross-sectional dependence						
CD	75.297	18.395	14.464	249.736	149.9499	252.849
Prob Value	0.000	0.778	0.000	0.000	0.000	0.000
Slope heterogeneity test						
Statistic	Δ	(p-value)		Δ adjuste	(p value)	
	46.162***	0.000		53.689***	0.000	

***Significance level at 1%. **Significance level at 5%. *Significance level at 10%

Table 4: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	VIF
(1) Vulnerable employment	1						N/A
(2) Environmental tax	-0.1572	1					1.04
(3) GDP	-0.1213	-0.0578	1				1.09
(4) Urbanization	-0.2735	-0.0616	0.1355	1			1.32
(5) Globalization	-0.8144	0.1461	0.2627	0. 2321	1		1.32
(6) Energy use	-0.4191	0.0294	0.1505	0.4754	0.4198	1	1.50

Table 4 shows the correlation matrix for all variables listed above. It also captures the variance inflation factor for each independent variable.

Table 5 outlines the results of the unit root test, which was carried out using the Pesaran Panel Unit Root Test with cross-sectional and first difference means included in the estimates. For comparison purposes, the Fisher-augmented Dickey–Fuller type was also run to observe if any variation existed in the outcomes of the unit root test. The combined and net results from both tests indicate that many of the variables are stationary at the first difference, except urbanisation, which is rather significant at the level but insignificant at the first difference. Therefore, the results confirm that there is evidence of stationarity of all the variables used in the study at either the level or first difference.

Table 5: Panel unit root

Test	**Pesaran CIPS**		**Fisher**	
Variable	I(0)	I(1)	I(0)	I(1)
Vulnerable employment	7.255	-21.523***	5.357	-47.971***
Environmental tax	0.383	-22.925***	-4.256***	-57.822***
Energy use	7.477	-11.264***	6.253	-34.198 ***
GDP	1.349	-19.674***	1.755	-36.568 ***
Urbanization	-	-	-55.810***	1.634
Globalization	-9.072***	-24.714***	-16.607***	-58.651***

***Significance level at 1%. **Significance level at 5%. *Significance level at 10%

In Table 6, we proceeded to check for long-term cointegration among variables using three cointegration tests: the Kao (1999), Pedroni (1999), and Westerlund (2007) tests. The essence of employing multiple tests is to compare and arrive at a reliable conclusion. The overall reported outcomes reject the null hypothesis of the absence of cointegration in favour of the alternative of the presence of long-term cointegration relationships, both in group and panel statistics. The overall results demonstrate that long-term relationships are validated for vulnerable employment, environmental tax, gross domestic product, globalisation, energy use, and urbanisation in the study models.

Table 6: Cointegration test

Westerlund	**Value**	**P-value**
Statistics	-2.9350	0.0017
Pedroni		
Statistic	Value	P-value
Modified Phillips-Perron t	6.2152	0
Phillips-Perron t	-3.7344	0.0001
Augmented Dickey-Fuller t	-3.7784	0.0001
Kao Test		
Parameter	Statistics	P-Value
Modified Dickey-Fuller	2.2997	0.0107
Dickey-Fuller	0.2083	0.4175
Augmented Dickey-Fuller	0.2638	0.396
Unadjusted modified Dickey-Fuller	1.8924	0.0292
Unadjusted Dickey-Fuller	-0.1508	0.4401

***Significance level at 1%. **Significance level at 5%. *Significance level

Table 7 and Figure 1 show the global-level results of the impact of the environmental tax on vulnerable employment. The results clearly show that environmental taxes have a negative and statistically significant effect on vulnerable employment, particularly for countries with low to medium vulnerability, but only become insignificant in countries with extreme levels of vulnerable employment. The implication of the significant negative effect of environmental tax on vulnerable employment is that environmental tax is a good fiscal policy instrument to progressively dampen vulnerable employment, provide even more decent employment, which is consistent with the Sustainable Development Goal 8, a push for full and productive employment by 2030. This clearly confirms the achievement of the second dividend, as posited by the double-dividend hypothesis. This finding is consistent with those reported in the literature (Sha, McKnight2023; Soku et al. 2023; McKnight, et al. 2022; Oxner, 2022; Jens, 2020). For instance, Streimikiene et al. (2018) in their study posited that greening tax schemes have affected the growth of sustainable energy in the Baltic States. They conclude that converting labour taxes to green taxes hastens economic

expansion and boosts employment. The location parameter shows that aside from economic growth, all the other variables can averagely, reduce vulnerable employment, and the scale parameter also shows that, except globalisation and urbanisation, all other variables will increase the dispersions in vulnerable employment. Globalisation, urbanisation, and energy use can all be spiralled in the hope of complementing a good environmental tax regime to collectively reduce vulnerable employment. Figure 1 depicts a decreasing trend in the negative effect of environmental taxes on employment vulnerability. Energy use also shows a decrease, but is stable in vulnerable employment. GDP, urbanisation, and globalisation have exhibited an increasing trend in vulnerable employment.

Table 7: Global level results of the effect of environmental tax on vulnerable employment

VARIABLES	-1 location	-2 scale	-3 qtile_1	-4 qtile_2	-5 qtile_3	-6 qtile_4	-7 qtile_5	-8 qtile_6	-9 qtile_7	-10 qtile_8	-11 qtile_9
Environmental Tax	-0.0364***	0.0210***	-0.0710***	-0.0583***	-0.0486***	-0.0404***	-0.0345***	-0.0278***	-0.0210**	-0.0128	-0.00515
	-0.011	-0.00686	-0.0182	-0.015	-0.0129	-0.0115	-0.0108	-0.0104	-0.0105	-0.0112	-0.0123
GDP	0.0570***	0.0167***	0.0294***	0.0395***	0.0473***	0.0538***	0.0586***	0.0639***	0.0693***	0.0758***	0.0819***
	-0.00634	-0.00395	-0.0105	-0.00864	-0.00744	-0.00664	-0.00623	-0.00602	-0.00605	-0.00643	-0.00707
Energy use	-0.0379***	0.000353	-0.0385***	-0.0383***	-0.0382***	-0.0380***	-0.0379***	-0.0378***	-0.0377***	-0.0376***	-0.0374***
	-0.00787	-0.00491	-0.013	-0.0107	-0.00922	-0.00823	-0.00773	-0.00745	-0.0075	-0.00798	-0.00879
Urbanization	-0.149***	-0.0254	-0.108**	-0.123***	-0.135***	-0.145***	-0.152***	-0.160***	-0.168***	-0.178***	-0.187***
	-0.0287	-0.0179	-0.0474	-0.039	-0.0336	-0.03	-0.0282	-0.0271	-0.0273	-0.0291	-0.032
Globalization	-2.722***	-0.148***	-2.478***	-2.567***	-2.636***	-2.694***	-2.736***	-2.783***	-2.831***	-2.888***	-2.942***
	-0.0475	-0.0296	-0.0788	-0.0647	-0.0558	-0.0498	-0.0467	-0.0452	-0.0454	-0.0482	-0.053
Constant	15.01***	0.925***	13.49***	14.05***	14.47***	14.83***	15.10***	15.39***	15.69***	16.05***	16.39***
	-0.189	-0.118	-0.314	-0.257	-0.222	-0.198	-0.186	-0.18	-0.181	-0.191	-0.21
Observations	2,470	2,470	2,470	2,470	2,470	2,470	2,470	2,470	2,470	2,470	2,470

Table.7 presents the results of the nexus, as described above at the global level. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

The results of the control variables show that increased energy use drives economic growth, creating job opportunities even for vulnerable populations, while globalisation expands markets and requires diverse skill sets, benefiting marginalised communities. Additionally, globalisation fosters technological advancements, enabling workers to acquire new skills and compete in the job market. However, alongside increased GDP, globalisation may intensify competition, lower wages, and promote labour exploitation, especially in developing countries with lax labour standards (Ayres, 1996).

Figure 1: Graphical effect of environmental tax on vulnerable employment

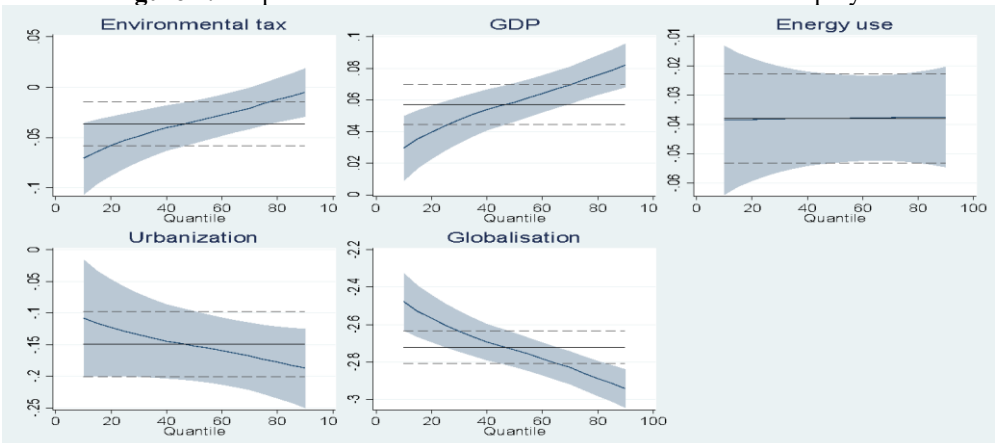

Figure 1 presents a graphical view of the method of moments results of the impact of all covariates in the study, that is, environmental tax, GDP, population density, trade, urbanisation, and renewable energy on climate change vulnerability, across the 10th to 90th quantiles.

Table 8 presents the output of Africa's dimension of the effect of the environmental tax on vulnerable employment. The results show an insignificant mixed outcome, where environmental tax positively impacts countries within the low quantiles (1-2 quantiles) of vulnerable employment and gradually turns to insignificantly and negatively impact countries with vulnerable employment within the higher quantile brackets. The results imply that in Africa, environmental taxes only have the tendency to dampen vulnerable employment relative to countries with appreciable levels of vulnerability in employment; a more restrictive tax rate will be a strategy to gradually and subtly reduce vulnerable employment in Africa, especially for countries with high levels of employment. This finding also confirms the peculiar circumstances of Africa when it comes to environmental taxation and vulnerable employment. Africa has its own set of difficulties, including a significant proportion of unofficial work, a lack of institutional capacity, insufficient social safety nets, and a disproportionate reliance on natural resources for subsistence. The findings

contradict those of Degirmenci and Aydin (2021), who investigated the effects of environmental taxes on environmental pollution and unemployment in selected African countries and revealed that the double dividend hypothesis, which posits that environmental taxes can reduce environmental pollution and increase employment, was not valid for African countries. Indeed, in their study, environmental taxes increased environmental degradation and unemployment in some countries. On average, all variables except economic growth can reduce vulnerable employment, as the location parameter shows, and aside from energy use and globalisation, all other variables can reduce the dispersion in vulnerable employment.

Table 8: Africa's results of the effect of environmental tax on vulnerable employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	Location	scale	qtile__1	qtile__2	qtile__3	qtile__4	qtile__5	qtile__6	qtile__7	qtile__8	qtile__9
Environmental tax	-0.00673	-0.00699	0.00432	0.00109	-0.00240	-0.00507	-0.00885	-0.0110	-0.0128	-0.0143	-0.0162
	(0.0158)	(0.0124)	(0.0331)	(0.0278)	(0.0222)	(0.0181)	(0.0133)	(0.0114)	(0.0106)	(0.0107)	(0.0117)
GDP	0.0981***	-0.0678***	0.205***	0.174***	0.140***	0.114***	0.0775***	0.0567***	0.0395***	0.0242***	0.00596
	(0.0141)	(0.0110)	(0.0282)	(0.0235)	(0.0191)	(0.0165)	(0.0129)	(0.0105)	(0.00954)	(0.00920)	(0.00993)
Energy use	-0.0433***	0.0295**	-0.0900***	-0.0764***	-0.0616***	-0.0504***	-0.0344**	-0.0253**	-0.0178	-0.0111	-0.00322
	(0.0162)	(0.0127)	(0.0336)	(0.0281)	(0.0225)	(0.0186)	(0.0138)	(0.0117)	(0.0109)	(0.0109)	(0.0119)
Urbanization	-0.0992**	-0.00113	-0.0974	-0.0979	-0.0985	-0.0989*	-0.0995***	-0.0999***	-0.100***	-0.100***	-0.101***
	(0.0455)	(0.0357)	(0.0953)	(0.0799)	(0.0637)	(0.0522)	(0.0381)	(0.0327)	(0.0305)	(0.0308)	(0.0337)
Globalization	-1.990***	0.357***	-2.556***	-2.391***	-2.212***	-2.076***	-1.882***	-1.772***	-1.682***	-1.601***	-1.505***
	(0.110)	(0.0863)	(0.226)	(0.189)	(0.152)	(0.128)	(0.0961)	(0.0804)	(0.0742)	(0.0733)	(0.0797)
Constant	11.73***	-0.728*	12.88***	12.54***	12.18***	11.90***	11.51***	11.28***	11.10***	10.94***	10.74***
	(0.486)	(0.381)	(1.011)	(0.847)	(0.677)	(0.558)	(0.412)	(0.351)	(0.326)	(0.327)	(0.357)
Observations	646	646	646	646	646	646	646	646	646	646	646

Table 8 presents the results of the nexus in Africa, as described above. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as

urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Table 9 explains the American perspective, which is similar to the African results, containing both positive effects from the early to medium quantiles, which are insignificant, and gradually turn to adverse effects from the medium to the higher quantiles, moving from insignificant to significant, especially at the highest echelons. The results obtained typify an asymmetric nexus between the variables under investigation. In America, the results imply that a more restrictive environmental tax policy applied to countries with medium-to-high levels of vulnerability will incrementally diminish vulnerable employment. The asymmetric nature of the relationship confirms the exact prediction of the expected behaviour of many economic policies, such as the environmental tax policy, which might depict varied impacts as the policy matures. The outcome for this continent is consistent with that reported by Sun et al. (2019).

Table 9: America's results of the effect of environmental tax on vulnerable employment

A	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11
VARIABLES	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
Environmental Tax	0.000513	-0.046	0.0949	0.0484	0.0276	0.00741	-0.00754	-0.0221	-0.0345	-0.0446*	-0.0622**
	-0.0395	-0.0345	-0.105	-0.0714	-0.0569	-0.0436	-0.0347	-0.0277	-0.0239	-0.0233	-0.0279
GDP	0.0236	0.00183	0.0198	0.0217	0.0225	0.0233	0.0239	0.0245**	0.0250**	0.0254**	0.0261**
	-0.0174	-0.0152	-0.0465	-0.0316	-0.0252	-0.0193	-0.0153	-0.0122	-0.0105	-0.0103	-0.0122
Energy use	-0.0868***	0.0357**	-0.160***	-0.124***	-0.108***	-0.0921***	-0.0805***	-0.0692***	-0.0596***	-0.0517***	-0.0380***
	-0.0196	-0.0171	-0.0515	-0.0351	-0.028	-0.0215	-0.0172	-0.0137	-0.0119	-0.0115	-0.0139
Urbanization	0.176***	-0.026	0.229	0.203*	0.191**	0.179**	0.171***	0.163***	0.156***	0.150***	0.140***
	-0.0631	-0.0551	-0.168	-0.115	-0.0913	-0.0699	-0.0556	-0.0442	-0.0382	-0.0372	-0.0443
Globalization	-2.928***	0.400***	-3.750***	-3.345***	-3.164***	-2.988***	-2.858***	-2.731***	-2.623***	-2.535***	-2.382***
	-0.172	-0.151	-0.449	-0.306	-0.245	-0.189	-0.151	-0.121	-0.104	-0.102	-0.124
Constant	15.35***	-1.494**	18.42***	16.90***	16.23***	15.57***	15.09***	14.61***	14.21***	13.88***	13.31***
	-0.744	-0.65	-1.944	-1.326	-1.059	-0.815	-0.65	-0.521	-0.45	-0.438	-0.531
Observations	503	503	503	503	503	503	503	503	503	503	503

Table 9 presents the results of the nexus in America, as described above. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Table 10 shows the effect of the relationship in Asia, where, on the contrary, environmental tax positively impacts vulnerable employment insignificantly in countries with low to medium employment vulnerability, but significantly positively in Asian countries with higher vulnerability. The results from the Asian experience indicate that environmental tax is a regressive fiscal policy for curbing vulnerable employment. A more restrictive environmental tax gradually and significantly increases the level of vulnerable employment, particularly in Asian countries with high levels of vulnerable employment. This is particularly interesting because the Asian continent is the second-worst affected by vulnerable employment because of the high levels of unbalanced development, which is reflected in the levels of vulnerable employment. Even so, Asia is the second lowest-charged continent regarding environmental taxes, born out of high rates of unsustainable growth, which not only suggests a general inability to raise the needed tax revenues but also an inability to factor the economic, environmental, and social costs of pollution externalities, which suffices to justify why the region remains the most vulnerable to climate change as a result of a loud market failure resulting in the drift of capital to fossil-fuel-based energy industries at the expense of the heavy investments needed in renewable energy. This finding contradicts a study by Sulisnaningrum et al. (2023), which discussed the equalisation of diesel tax with gasoline and its potential to provide additional income for the state. According to the study, this additional income can be used to compensate vulnerable groups and promote equitable and socially beneficial environmental reforms. The location parameter indicates that, apart from environmental tax, all other variables, on average, reduce vulnerable employment. The scale-bound shows that apart from energy use and urbanization, all the other variables can increase the dispersion of vulnerable employment.

Table 10: Asia's results of the effect of environmental tax on vulnerable employment

VARIABLES	-1 location	-2 scale	-3 qtile_1	-4 qtile_2	-5 qtile_3	-6 qtile_4	-7 qtile_5	-8 qtile_6	-9 qtile_7	-10 qtile_8	-11 qtile_9
Environmental Taxes	0.0678*	0.0269	0.0228	0.0404	0.0494	0.0564	0.0735*	0.0805**	0.0929**	0.0976***	0.106***
	-0.0392	-0.0208	-0.0612	-0.0511	-0.0464	-0.0434	-0.038	-0.0368	-0.0368	-0.0373	-0.0393
GDP	-0.00064	0.0486***	-0.0819**	-0.0501*	-0.0339	-0.0213	0.00958	0.0223	0.0446**	0.0531***	0.0686***
	-0.0216	-0.0114	-0.0331	-0.0285	-0.0255	-0.0243	-0.0218	-0.0208	-0.0205	-0.0204	-0.0214
Energy use	-0.0229	-0.0116	-0.00351	-0.0111	-0.015	-0.018	-0.0253	-0.0284	-0.0337	-0.0357	-0.0394
	-0.046	-0.0244	-0.0719	-0.0598	-0.0545	-0.0508	-0.0444	-0.0431	-0.0431	-0.0438	-0.0462
Urbanization	-0.0679	-0.00162	-0.0651	-0.0662	-0.0667	-0.0672	-0.0682	-0.0686	-0.0694	-0.0697	-0.0702
	-0.0668	-0.0354	-0.104	-0.0869	-0.0791	-0.0737	-0.0644	-0.0625	-0.0625	-0.0636	-0.0671
Globalization	-2.493***	0.057	-2.588***	-2.551***	-2.532***	-2.517***	-2.481***	-2.466***	-2.439***	-2.429***	-2.411***
	-0.166	-0.0882	-0.26	-0.216	-0.197	-0.184	-0.161	-0.156	-0.156	-0.158	-0.167
Constant	14.10***	-0.173	14.38***	14.27***	14.21***	14.17***	14.06***	14.01***	13.93***	13.90***	13.85***
	-0.648	-0.343	-1.012	-0.843	-0.767	-0.715	-0.625	-0.607	-0.606	-0.617	-0.65
Observations	295	295	295	295	295	295	295	295	295	295	295

Table 10 presents the results of the nexus as titled above in Asia. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Table 11 reveals that in Europe, environmental tax increases vulnerable employment across all quantiles except the first. The more stringent the environmental taxes, the greater the impact on countries with higher vulnerable employment. This suggests that environmental taxes are regressive with regard to vulnerable employment in Europe. Europe, which has some of the highest environmental taxes and the lowest vulnerable employment, indicates an overemphasis on environmental tax policy, leading to significant revenue redistribution to address the issue, thus making

further taxes regressive. Urbanisation and globalisation in European countries can reduce vulnerable employment, while the scale parameter shows that, apart from energy use and globalisation, other variables increase dispersion in vulnerable employment within the region.

Table 11: Europe's results of the effect of environmental tax on vulnerable employment

VARIABLES	-1 location	-2 scale	-3 qtile_1	-4 qtile_2	-5 qtile_3	-6 qtile_4	-7 qtile_5	-8 qtile_6	-9 qtile_7	-10 qtile_8	-11 qtile_9
Environmental tax	0.248***	0.105***	0.0803	0.143***	0.179***	0.209***	0.254***	0.282***	0.338***	0.365***	0.397***
	-0.0357	-0.021	-0.053	-0.0448	-0.0403	-0.0381	-0.0357	-0.0356	-0.0376	-0.0391	-0.0422
GDP	0.0585***	0.0232***	0.0214*	0.0353***	0.0434***	0.0500***	0.0600***	0.0661***	0.0785***	0.0847***	0.0916***
	-0.00865	-0.0051	-0.0129	-0.0108	-0.00977	-0.00921	-0.00865	-0.00862	-0.00908	-0.00948	-0.0102
Energy use	0.0468***	-0.0393***	0.110***	0.0861***	0.0723***	0.0612***	0.0443***	0.0339**	0.0129	0.00254	-0.00924
	-0.0169	-0.00995	-0.0251	-0.0211	-0.0191	-0.018	-0.0169	-0.0168	-0.0177	-0.0185	-0.02
Urbanization	-0.398***	0.0149	-0.421***	-0.412***	-0.407***	-0.403***	-0.397***	-0.393***	-0.385***	-0.381***	-0.376***
	-0.0583	-0.0343	-0.0866	-0.0726	-0.0659	-0.0617	-0.0579	-0.0574	-0.0606	-0.0641	-0.0693
Globalization	-2.120***	-0.263***	-1.701***	-1.858***	-1.950***	-2.024***	-2.137***	-2.206***	-2.347***	-2.416***	-2.494***
	-0.111	-0.0655	-0.165	-0.139	-0.126	-0.118	-0.111	-0.111	-0.117	-0.122	-0.132
Constant	11.85***	1.417***	9.584***	10.43***	10.93***	11.33***	11.93***	12.31***	13.07***	13.44***	13.86***
	-0.44	-0.259	-0.654	-0.553	-0.496	-0.47	-0.441	-0.441	-0.464	-0.481	-0.519
Observations	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026

Table 11 presents the results of the nexus in Europe, as described above. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Regarding countries with high income levels, the results in Table 12 show that, across all quantiles, environmental taxes increase vulnerable employment, and the coefficients indicate that countries with higher vulnerable employment are most likely to worsen as a result of more restrictive environmental taxes. In terms of the results within the context of high-income countries, the regressive nature of environmental tax is potentially borne out of the alarmingly low rates of vulnerable employment in these countries. This could mean that the fiscal policy tool has been very effective in reducing vulnerable employment beyond optimal levels, leading to an increase in vulnerable employment. This finding contradicts the outcome of a study by Radulescu et al. (2017), who examined the impact of environmental tax policies in Romania and the EU. They found that environmental taxes can increase employment in European countries, although the effect on output is weak or negative. The effects are more significant in Northern European countries than in Mediterranean countries. All variables other than environmental taxes can reduce employment vulnerability according to the location parameter.

Table 12: High-income countries results of the effect of environmental tax on vulnerable employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	location	scale	qtile 1	qtile 2	qtile 3	qtile 4	qtile 5	qtile 6	qtile 7	qtile 8	qtile 9
Environmental tax	0.237***	0.0393*	0.166***	0.189***	0.209***	0.226***	0.242***	0.254***	0.264***	0.279***	0.295***
	(0.0361)	(0.0203)	(0.0572)	(0.0486)	(0.0420)	(0.0378)	(0.0355)	(0.0349)	(0.0353)	(0.0372)	(0.0406)
GDP	-0.00130	0.0301***	-	-	-	-0.00922	0.00288	0.0117	0.0191**	0.0312***	0.0428***
			0.0551***	0.0379***	0.0223**						
	(0.00792)	(0.00446)	(0.0125)	(0.0109)	(0.00936)	(0.00851)	(0.00793)	(0.00768)	(0.00783)	(0.00825)	(0.00891)
Energy use	-0.0108	-	0.0339	0.0196	0.00670	-0.00420	-0.0143	-0.0216	-	-	-
		0.0250***							0.0277**	0.0378***	0.0474***
	(0.0137)	(0.00771)	(0.0217)	(0.0185)	(0.0160)	(0.0144)	(0.0135)	(0.0133)	(0.0134)	(0.0142)	(0.0154)
Urbanization	-	0.0293	-0.298***	-0.281***	-	-	-	-	-	-0.214***	-0.202***
	0.245***				0.266***	0.253***	0.241***	0.233***	0.225***		
	(0.0620)	(0.0349)	(0.0985)	(0.0836)	(0.0722)	(0.0650)	(0.0610)	(0.0600)	(0.0606)	(0.0640)	(0.0698)
Globalization	-	-0.569***	-0.313	-0.638***	-	-	-	-	-	-1.945***	-2.164***
	1.330***				0.932***	1.180***	1.409***	1.576***	1.716***		
	(0.158)	(0.0888)	(0.248)	(0.216)	(0.186)	(0.169)	(0.158)	(0.153)	(0.156)	(0.164)	(0.177)
Constant	8.871***	2.618***	4.189***	5.685***	7.039***	8.181***	9.235***	10.00***	10.65***	11.70***	12.71***

	(0.687)	(0.387)	(1.079)	(0.943)	(0.812)	(0.738)	(0.688)	(0.666)	(0.679)	(0.715)	(0.772)
Observations	1,052	1,052	1,052	1,052	1,052	1,052	1,052	1,052	1,052	1,052	1,052

Table 12 presents the results of the nexus titled high income. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

The effect of environmental taxes on vulnerable employment in low-income countries in Table 13 shows that these environmental taxes reduce vulnerable employment. However, the impact gradually moves from insignificant at the earlier quantiles to an incremental significance towards countries within this group characterised by highly vulnerable employment. Given that low-income countries are the most vulnerable employed enclaves and correspondingly represent one of the highest-charged environmental taxes, this is evidence of a more concerted effort at doubling up on measures undertaken thus far. Abundant potential exists to ramp up the tax rate or widen the tax bracket to ensure the needed impact to reduce vulnerable employment. In a small open economy with structural unemployment, Bovenberg and Ploeg (1998) conducted a second study to examine the impact of an environmental tax reform on wage formation, employment, and environmental quality. According to the study, environmental tax reform, specifically, using money from a higher energy tax rate to cut the labour tax rate can increase employment if it moves the tax burden from employees to individuals with no formal job. This shows that, in low-income countries with large rates of informal work, environmental tax reform may benefit employment, which agrees with the findings of this study.

Table 13: Low-income results of the effect of environmental tax on vulnerable employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	location	scale	qtile__1	qtile__2	qtile__3	qtile__4	qtile__5	qtile__6	qtile__7	qtile__8	qtile__9
Environmental tax	-0.0233*	-0.0113	0.00246	-0.0130	-0.0209	-0.0258**	-0.0280***	-0.0303***	-0.0321***	-0.0346***	-0.0369***
	(0.0129)	(0.0109)	(0.0348)	(0.0213)	(0.0147)	(0.0114)	(0.0104)	(0.00974)	(0.00955)	(0.00981)	(0.0105)
GDP	-0.0356***	0.0280***	-0.0996***	-0.0611***	-0.0416***	-0.0293***	-0.0240***	-0.0182***	-0.0137**	-0.00735	-0.00172
	(0.00958)	(0.00805)	(0.0257)	(0.0178)	(0.0117)	(0.00863)	(0.00754)	(0.00702)	(0.00690)	(0.00705)	(0.00737)

Energy use	0.00370	-0.00968	0.0258	0.0125	0.00577	0.00150	-0.000334	-0.00232	-0.00387	-0.00607	-0.00802
	(0.00810)	(0.00681)	(0.0218)	(0.0134)	(0.00928)	(0.00718)	(0.00652)	(0.00609)	(0.00598)	(0.00614)	(0.00656)
Urbanization	0.0704***	-0.0392***	0.160***	0.106***	0.0788***	0.0615***	0.0541***	0.0460***	0.0397***	0.0308**	0.0230*
	(0.0173)	(0.0146)	(0.0467)	(0.0306)	(0.0206)	(0.0155)	(0.0138)	(0.0129)	(0.0126)	(0.0130)	(0.0137)
Globalization	-0.227***	0.0129	-0.257**	-0.239***	-0.230***	-0.224***	-0.222***	-0.219***	-0.217***	-0.214***	-0.211***
	(0.0380)	(0.0319)	(0.102)	(0.0615)	(0.0429)	(0.0335)	(0.0307)	(0.0287)	(0.0282)	(0.0289)	(0.0311)
Constant	5.263***	0.0718	5.099***	5.198***	5.248***	5.279***	5.293***	5.308***	5.319***	5.335***	5.350***
	(0.164)	(0.138)	(0.442)	(0.266)	(0.186)	(0.145)	(0.132)	(0.124)	(0.122)	(0.125)	(0.134)
Observations	269	269	269	269	269	269	269	269	269	269	269

Table 13 presents the results of the nexus titled low income. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Upper middle-income level countries' experience of environmental tax-vulnerable employment, as shown in Table 14, shows that environmental taxes have a multifaceted impact on vulnerable employment across all quantiles, and the nexus can be described as dynamic, taking the typical asymmetric and non-linear form. The impact in the earlier quantiles is negative and significant, but the level of significance begins to wane towards the middle quantile, after which the relationship begins to turn positive but insignificant and, from the high quantiles to the highest, gradually becomes positive and incrementally significant. The outcome of the nexus within the context of the upper middle-income signifies that the implementation of an environmental tax regime yields multiple impacts depending on a country's level of vulnerable employment; that is, those within the lower bracket have a huge impact of a reduction in their vulnerable employment, but as the level of the country's level of vulnerability increases, the potency of the tax reduces until the point where it turns positive and insignificant; then, with the highest levels of vulnerability, the effect turns out to be negative. Similar findings were revealed by Schellings, who investigated the impact of environmental policies on employment using a general equilibrium two-sector search model. They found that imposing a pollution tax leads to

reduced employment in the regulated industry but increased employment in the unregulated sector. Similar findings were obtained by Arilla-Llorente et al. (2024), who provided strong evidence that eco-innovation is a key driver for achieving Sustainable Development Goal 8 (Decent Work and Economic Growth). It also sheds light on the complex relationship between eco-innovation and human resources. The study's findings further suggest the value of creating a platform for national and international comparisons along with the development of benchmarking indicators specifically for eco-innovations and their impact on green growth.

Table 14: Upper middle-income results of the effect of environmental tax on vulnerable employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	location	scale	qtile__1	qtile__2	qtile__3	qtile__4	qtile__5	qtile__6	qtile__7	qtile__8	qtile__9
Environmental tax	-0.0531**	0.0846***	-0.212***	-0.142***	-0.103***	-0.0691***	-0.0381*	-0.0101	0.0154	0.0397**	0.0617***
	(0.0220)	(0.0143)	(0.0427)	(0.0336)	(0.0278)	(0.0242)	(0.0215)	(0.0196)	(0.0186)	(0.0183)	(0.0193)
GDP	0.108***	-0.0401***	0.183***	0.150***	0.132***	0.115***	0.101***	0.0875***	0.0755***	0.0640***	0.0535***
	(0.0119)	(0.00774)	(0.0232)	(0.0181)	(0.0150)	(0.0131)	(0.0116)	(0.0105)	(0.0100)	(0.00998)	(0.0105)
Energy use	-0.00951	-0.0196*	0.0274	0.0111	0.00207	-0.00580	-0.0130	-0.0195	-0.0254*	-0.0310**	-0.0361**
	(0.0163)	(0.0106)	(0.0320)	(0.0243)	(0.0205)	(0.0175)	(0.0154)	(0.0141)	(0.0136)	(0.0138)	(0.0145)
Urbanization	0.0236	0.0984***	-0.162**	-0.0796	-0.0345	0.00495	0.0409	0.0735**	0.103***	0.131***	0.157***
	(0.0371)	(0.0241)	(0.0725)	(0.0559)	(0.0467)	(0.0403)	(0.0356)	(0.0325)	(0.0311)	(0.0312)	(0.0329)
Globalization	-1.320***	0.0249	-1.367***	-1.346***	-1.335***	-1.325***	-1.316***	-1.308***	-1.300***	-1.293***	-1.286***
	(0.121)	(0.0783)	(0.237)	(0.180)	(0.152)	(0.130)	(0.114)	(0.104)	(0.101)	(0.102)	(0.108)
Constant	7.963***	0.200	7.587***	7.754***	7.845***	7.925***	7.998***	8.064***	8.125***	8.182***	8.234***
	(0.464)	(0.300)	(0.909)	(0.690)	(0.581)	(0.498)	(0.437)	(0.400)	(0.386)	(0.392)	(0.413)
Observations	611	611	611	611	611	611	611	611	611	611	611

Table 14 presents the results of the nexus titled above in upper-middle income. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

As shown in Table 15, lower-middle-income level countries show that environmental taxes dampen vulnerable employment across all quantiles, with the significance very large in the early quantiles but diminishing gradually across the higher quantiles and eventually becoming insignificant at the highest levels of vulnerable employment. The results relative to the lower middle-income band imply that environmental tax policies are more potent in countries with the lowest levels of vulnerable employment, but become insignificant at the highest levels of vulnerability. Similarly, Bella et al. (2023) investigated the macroeconomic effects of tobacco taxation in Indonesia and discovered that greater cigarette taxes would directly affect growing government income, encourage economic activity, and possibly result in increased employment.

Table 15: Lower middle-income level results of the effect of environmental tax on vulnerable employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
Environmental tax	-0.0433***	0.0231***	-0.0767***	-0.0656***	-0.0563***	-0.0486***	-0.0397***	-0.0335***	-0.0251**	-0.0167	-0.00659
	(0.0124)	(0.00892)	(0.0209)	(0.0174)	(0.0149)	(0.0133)	(0.0120)	(0.0116)	(0.0119)	(0.0130)	(0.0151)
GDP	0.135***	-0.0840***	0.256***	0.216***	0.182***	0.154***	0.122***	0.0991***	0.0688***	0.0380*	0.00131
	(0.0183)	(0.0131)	(0.0309)	(0.0243)	(0.0214)	(0.0195)	(0.0176)	(0.0170)	(0.0179)	(0.0194)	(0.0224)
Energy use	0.0348**	-0.0148	0.0562**	0.0490**	0.0431**	0.0381**	0.0325**	0.0285*	0.0231	0.0177	0.0112
	(0.0168)	(0.0121)	(0.0282)	(0.0236)	(0.0202)	(0.0180)	(0.0162)	(0.0157)	(0.0160)	(0.0175)	(0.0204)
Urbanization	0.0657*	-0.0735***	0.172***	0.137**	0.107**	0.0825**	0.0543	0.0344	0.00790	-0.0190	-0.0512
	(0.0385)	(0.0276)	(0.0648)	(0.0536)	(0.0462)	(0.0412)	(0.0371)	(0.0359)	(0.0369)	(0.0403)	(0.0468)
Globalization	-2.002***	0.325***	-2.471***	-2.315***	-2.184***	-2.076***	-1.951***	-1.864***	-1.747***	-1.628***	-1.486***
	(0.131)	(0.0942)	(0.221)	(0.182)	(0.157)	(0.140)	(0.127)	(0.122)	(0.126)	(0.137)	(0.160)
Constant	10.24***	0.0885	10.12***	10.16***	10.19***	10.22***	10.26***	10.28***	10.31***	10.35***	10.38***
	(0.509)	(0.365)	(0.855)	(0.716)	(0.613)	(0.544)	(0.491)	(0.475)	(0.485)	(0.530)	(0.619)
Observations	538	538	538	538	538	538	538	538	538	538	538

Table 15 presents the results of the nexus described above in lower-middle-income countries. The dependent variable is **vulnerable employment, which** is an index of the level of each country's vulnerable employment: total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. **Gross Domestic Product** is used as a proxy for economic growth which is GDP per capita. **Urbanisation** is also shown as urbanisation; **energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All

variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

For Robustness purposes, the hierarchical regression model was employed to test the same relationships in the different classes of analysis, from global to continental and income levels. As indicated in Table 16, the results essentially represent a linear confirmation of the relationship established in the quantile regression model with similar nexus signs. Therefore, the outcome supports the potency of our findings and recommendations.

Table 16: Hierarchical Regression results of the effect of environmental tax on vulnerable employment

	Global	Africa	America	Asia	Europe	High	Low	Upper middle	Lower middle
Environmental tax	-0.036***	-0.007	0.001	0.068*	0.248***	0.237***	-0.023**	-0.053**	-0.043***
	(0.011)	(0.013)	(0.028)	(0.040)	(0.037)	(0.035)	(0.011)	(0.021)	(0.012)
GDP	0.057***	0.098***	0.024*	-0.001	0.059***	-0.001	-0.036***	0.108***	0.135***
	(0.006)	(0.011)	(0.013)	(0.021)	(0.009)	(0.008)	(0.009)	(0.012)	(0.014)
Energy use	-0.038***	-0.043***	-0.087***	-0.023	0.047***	-0.011	0.004	-0.010	0.035**
	(0.008)	(0.012)	(0.014)	(0.044)	(0.013)	(0.012)	(0.009)	(0.015)	(0.016)
Urbanization	-0.149***	-0.099**	0.176***	-0.068	-0.398***	-0.245***	0.070***	0.024	0.066*
	(0.026)	(0.039)	(0.052)	(0.077)	(0.048)	(0.059)	(0.018)	(0.040)	(0.036)
Globalization	-2.722***	-1.990***	-2.928***	-2.493***	-2.120***	-1.330***	-0.227***	-1.320***	-2.002***
	(0.044)	(0.091)	(0.125)	(0.170)	(0.085)	(0.132)	(0.043)	(0.115)	(0.105)
_cons	15.011***	11.729***	15.347***	14.095***	11.846***	8.871***	5.263***	7.963***	10.243***
	(0.175)	(0.381)	(0.528)	(0.630)	(0.349)	(0.566)	(0.174)	(0.434)	(0.424)
N	2470	646	503	295	1026	1052	269	611	538
r2	0.687	0.476	0.541	0.593	0.498	0.221	0.235	0.261	0.453
F	1081.685	116.061	117.256	84.230	202.465	59.467	16.182	42.719	88.027
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 16 presents the results of the nexus above per continent and income level. The dependent variable is **employment vulnerability, which** is an indicator of the level of each country's vulnerable employment, total (% of total employment). **Environmental tax** is environmental tax revenue as a percentage of GDP. The control variables were **Gross Domestic Product** (GDP per capita) as a proxy for economic growth. **Urbanisation** is also seen as urbanisation. **Energy use** is used as a proxy for energy use, while **globalisation** is shown as globalisation. All variables were logged. ***Significance level at 1%, **Significance level at 5%, *Significance level at 10%. The quantiles represent the least (qtile_1), low (qtile_2 and 3), moderate or medium (qtile_4 and 5), high (qtile_6 and 7), and highest (qtile_8 and 9).

Conclusions

This study explores the relationship between environmental taxes and employment vulnerability across different continents and income levels. Using panel data from 92 countries spanning 1994 to 2020, we conducted preliminary diagnostic checks to determine the appropriate model before proceeding with a non-parametric panel econometric quantile regression. The tests included slope homogeneity, cross-sectional dependence (Pesaran, 2014), normality of series (Shapiro-Wilk test), Westerlund (2007) error correction cointegration, and unit root tests. These diagnostics revealed non-normality of the data, justifying the use of non-parametric quantile regression. We also assessed cross-sectional dependence and slope coefficient heterogeneity, and found mixed stationarity in the data (I(0) and I(1)). Finally, the cointegration test confirmed the long-term relationships between the study variables.

Moreover, the Method of Moments Quantile Regression by Machado and Santos Silva (2019), a non-parametric panel quantile regression approach, was employed as the main estimation model. This study's main findings show that environmental taxes represent a very good fiscal policy intervention to reduce vulnerable employment globally, particularly in countries with smaller-to-moderately high employment vulnerability. This is a finding that has ramifications for the "big picture effect" and all the global cooperation efforts to mitigate climate change and on the road to realising the SDGs, where many areas require acceleration. A disintegrated analysis on a continental basis showed that in Africa and America, even though the effect of an environmental tax on vulnerable employment has been mixed, it vastly reduces employment on both continents. However, in Asia, the effect has been an increase in vulnerable employment, which is attributable to the inability to raise the revenues needed from the tax to tackle the menace, given the low tax levels and already high levels of tax. For Europe, the levels of environmental taxes are high enough to have yielded enough revenue and enabled the continent to drastically reduce its levels of vulnerability, hence making the tax counterproductive.

A sub-analysis of the global-level analysis based on income levels proves that environmental tax policy strategies will be a very good tool to dampen vulnerable employment enormously in low-income countries, mixed but largely reduces it also in upper-middle-income level countries, and unequivocally reduces vulnerable employment in lower-middle-income countries. However, it is only in high-income countries that environmental taxes uncharacteristically increase employment vulnerability, and this is understandable because that is where the abnormally least vulnerable employment exists.

Policy Implications

This study presents findings with significant policy insights and relevance for countries at the global, continental, and income levels. First, countries can collectively promote environmental taxes without jeopardising vulnerable employment (Chen et al., 2023). Second, given the negative and significant coefficients found between global environmental taxes and vulnerability, a blueprint should be developed and implemented as part of global cooperation to combat climate change. This blueprint should aim to increase environmental taxes, especially in countries with low to moderately high vulnerability, to comprehensively address vulnerability (Yerrabati, 2022). Governments and policymakers should incorporate this blueprint into their Nationally Determined Contributions to reducing greenhouse gas emissions, providing measurable outcomes for tracking each country's progress towards the global agenda. This approach will help achieve development goals related to decent work and economic growth (SDG 8) and support the broader SDGs aligned with COP28 (Arilla-Llorente et al., 2024). Practical roadmaps should also be established globally to enhance globalisation, urbanisation, and energy use, and to support effective environmental tax policies to reduce vulnerable employment. Furthermore, the results demonstrate the progress of environmental taxes at the global level.

Environmental taxes in Africa are generally progressive, suggesting that these findings can guide policymakers and governments to implement more robust environmental tax structures. Despite Africa having the highest environmental tax rates, the impact is minimal owing to the continent's highly vulnerable economy, leading to progressive but insignificant results. Therefore, pragmatic steps, such as providing resources and technical support along with strengthening environmental taxes, are crucial to significantly reducing vulnerable employment in Africa, which has broader implications for other continents (Iyke-Ofoedu et al., 2024). In America, environmental taxes should target countries in the medium to higher quantiles to achieve a more progressive outlook. The American continent has the lowest global environmental tax rate, indicating policy insufficiency; thus, implementing a more restrictive tax rate could reduce the relatively high level of vulnerable employment (Meng and Kozybay, 2024). In Asia, the environmental taxes on vulnerable employment are regressive. The continent exhibits high levels of vulnerable employment due to its production-based, capitalist economy, yet maintains the second-lowest environmental tax level. This tax insufficiency hinders governments from adequately compensating for the high carbon emissions. Incremental policy updates are necessary to enhance revenue generation and address vulnerable employment effectively. In Europe, environmental tax policies were

regressive during the study period. However, Europe's low levels of vulnerable employment are attributed to robust climate change interventions and well-managed social and economic support systems for vulnerable groups, alongside favourable labour policies. Consequently, environmental taxes, initially burdensome on employment, have become regressive because of policy overemphasis. This evolution provides valuable policy insights for stakeholders.

In high-income countries, environmental taxes have been found to be regressive. Given that these nations have already implemented high environmental tax rates and have low levels of vulnerable employment, less restrictive tax policies could be beneficial. This aligns with the findings of Tomaskovic-Devey et al. (2020), suggesting that these countries should redistribute resources to empower vulnerable labour. The implementation of command-and-control environmental policies may also be effective (Sun et al., 2024). In low-income countries, where environmental taxes are largely progressive, moderately restrictive tax policies are more relevant in addressing vulnerable employment. Exceptions include countries with high vulnerability to climate change, in which less restrictive policies might be more effective. These nations require more than environmental taxes to combat vulnerability due to extreme poverty. High-income countries could support these efforts by expanding social protection and climate insurance to the most vulnerable, while command-and-control measures could also be beneficial (Bernardo et al. 2024). In upper-middle-income countries, the impact of an environmental tax on vulnerable employment varies: it is progressive for low to moderately high levels of vulnerable employment, but regressive for countries with very high vulnerability in employment. It is necessary to implement moderately restrictive environmental tax policies in countries with lower to moderate vulnerability in employment. In countries with high levels of vulnerable employment, lower environmental taxes should be combined with other policy instruments such as social protection schemes and climate-based financial support for less-endowed countries (Kong et al., 2024). For lower-middle-income countries, evidence suggesting that environmental taxes are largely progressive indicates that a more restrictive environmental tax policy would help improve vulnerable employment across all countries within this income bracket (Dradra, 2024).

Limitations and future research directions

This study only analysed the environmental tax-vulnerable employment nexus at the global and income levels. Given our empirical focus, we suggest that future research address the two key limitations of our study. A continental-based analysis using the four components of environmental taxes (i.e., energy, transport, pollution, and resource taxes)

would be a complementary and worthy pursuit of scholarly enquiry in extending the literature in an important direction. Based on our study's insights, we urge researchers interested in the environmental tax-vulnerable employment nexus to conduct a comparative study of developed and developing countries or countries under sub-regional blocks using the four components of environmental taxes: energy, transport, pollution, and resource taxes. Unravelling this dynamic is a key topic for future research.

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Appendix A

Table 1b: LIST OF COUNTRIES

Argentina	Congo, Dem. Rep.	Germany	Korea, Rep.	Netherlands	Serbia	Uruguay
Australia	Congo, Rep.	Ghana	Latvia	New Zealand	Singapore	Vietnam
Austria	Costa Rica	Greece	Lithuania	Nicaragua	Slovak Republic	
Belgium	Cote d'Ivoire	Guatemala	Luxembourg	Niger	Slovenia	
Bolivia	Croatia	Honduras	Madagascar	Nigeria	South Africa	
Botswana	Cyprus	Hungary	Malawi	Norway	Spain	
Brazil	Czech Republic	Iceland	Malaysia	Panama	Sweden	
Bulgaria	Denmark	India	Mali	Paraguay	Switzerland	
Burkina Faso	Dominican Republic	Ireland	Malta	Peru	Togo	
Cameroon	Ecuador	Israel	Mauritania	Philippines	Tunisia	
Canada	Egypt, Arab Rep.	Italy	Mauritius	Poland	Turkey	
Chad	El Salvador	Jamaica	Mexico	Portugal	Uganda	
Chile	Estonia	Japan	Mongolia	Romania	Ukraine	
China	Finland	Kazakhstan	Morocco	Rwanda	United Kingdom	
Colombia	France	Kenya	Namibia	Senegal	United States	