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Does growth reduce poverty? The mediating role of carbon emissions and income inequality

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Abstract
As economies continue to grow in the face of global climate change, international policy is focusing on the combined pursuit of social and environmental development, or 'sustainable development goals'. Whilst such goals are often framed from the perspective of high-income countries, low-income countries struggle to balance their carbon-intensive growth strategies with poverty alleviation, and carbon emission reduction. Combined with the prospect of economic growth driving income inequality higher, the potential for a vicious cycle to emerge in low-income countries in particular is considerable. Whilst the negative association between economic growth and poverty is well established, the effectiveness of growth-based programmes as a poverty reduction strategy in the context of climate change and inequality is less certain. We explore the prospects of balancing these development goals and their consequences using an international dataset, and generalized method of moments estimators. We find that although economic development reduces poverty, carbon emissions (from carbon-intensive growth) coupled with inequality, exacerbates poverty. Secondly, we find that in terms of poverty reduction, poor countries are negatively impacted by both carbon emissions and income inequality, while rich countries are primarily impacted by income inequality. Finally, we find the effect of emissions on poverty is stronger for countries at higher poverty levels, suggesting that international policies aimed at achieving equitable emissions reduction should consider the potential for disproportionate negative impacts on poorer countries.

Keywords Economic growth · Climate change · Income inequality · Poverty

JEL Classification C33 · O44 · Q54

Abbreviations
3SLS Three-stage least square estimator;

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AR2	Arellano–bond test for serial correlation at order two
EKC	Environmental kuznets curve
GDP	Gross domestic product
GDPPC	GDP per capita
GINI	Income inequality index
GMM	Generalized method of moments
IKC	Inequality Kuznets curve
IPCC	Intergovernmental panel on climate change
PCSE	Panel-corrected standard error estimates
SDG	Sustainable development goals
USGCRP	U.S. global change research program

1 Introduction

In recent years, the concept of sustainable development has received increasing attention not only from scientists and politicians, but also economists, environmentalists, and sociologists. It is an issue of growing concern, as the impact of climate change becomes more apparent, and evidently bound with processes of national economic development. Conceptually, 'sustainable development' aims to organize human activities in order to achieve specified development goals, while ensuring the integrity and balance of ecological and social systems. The goal of sustainable development is to harmonize human activities and environmental impacts, thereby maintaining resource systems for future generations (Daly, 2006). Yet the scope and application of such concepts of 'sustainable development' is somewhat vague with respect to its simultaneous impact on environment and society, and how such impacts may manifest in complex ways (Flaherty, 2019).

Among the key global issues that challenge sustainable development at country level are climate change, poverty, and inequality (Jorgenson et al., 2019, 2016; Soener, 2019; Thombs, 2021). These issues are especially urgent as it becomes ever more apparent that climate change is worsening (Masson-Delmotte et al., 2018). Two are formalized under the United Nations' Sustainable Development Goals (SDGs) of SDG#1—"No poverty" and SDG#13—"Climate Action". In the process of balancing these goals against the need for economic development in transition countries, SDG#8 (Decent Work and Economic Growth) considers the need for any 'just transition' to factor issues of quality of work (Fonseca et al., 2020). The relationship between economic growth and work, climate change, and poverty is not isolated, but intertwined with another development goals such as SDG#10—"Reduced Inequality". The reason for this close relationship may lie in the uneven distribution of the impacts of climate change on economies, and economic sectors, or more precisely, social classes with different income levels (Hallegatte et al., 2018). In addition, Cappelli et al. (2021) and Islam and Winkel (2017) also found the link between climate change and income inequality to create a vicious cycle. In sum, the interconnections between these goals are complex, to the extent that our theories and models must be capable of accounting for how they impact on each other in complex ways.

With regard to poverty, the poor of low-income countries are most vulnerable to the impacts of climate change, as they lack the financial capacity to prepare for or mitigate losses due to natural disasters or risks (USGCRP, 2018). The United Nations Development Programme (2007) also shows that developing countries bear a disproportionate share of the negative impacts of climate change. The World Bank estimates that climate change will push more than 32 million people into extreme poverty by 2030 (Jafino et al., 2020). Indeed, Hallegatte et al. (2018) argue that poverty should be a central focus of socioeconomic research on the consequences of climate change. Rather than focusing on loss of economic output, their work suggests that whilst the poor are the most affected by climate change, their contribution to total economic output is minimal. Conversely, the rich exhibits a disproportionate impact on emissions, such that the top 10% of earners accounted for over half of cumulative global emissions from 1990 to 2015 (Oxfam, 2020). Inequality is thus central not only to understanding the disproportionate impacts of climate change, but also its root causes.

The next section of this paper (*Literature review*) provides an overview of existing literature on the relationship between climate change and poverty, the poverty-alleviating effect of economic growth, and finally the role of reducing inequalities in development policies. The central contribution of this research is uncovering the new triangle between economic growth, income inequality and carbon emissions which, as we later demonstrate, partially hinders the beneficial effect of growth on poverty reduction. From here, we pose the question of how economic growth be expected to reduce poverty, given the mediating role of carbon emissions and inequality—two factors conventionally conceptualized as endogenous to the process of economic development. To answer this question, we build an analytical framework and specify a formal model, defining the estimators and analysis techniques in the Data and methodology section. The Results and discussions presents the main results of our study, showing that although economic growth can alleviate poverty, this process is partly hindered by the mediating role of carbon emissions and income inequality. Interestingly, we find that carbon emissions impact poverty through the mechanism of inequality, rather than from economic development alone. We also find important differences when repeating our modelling exercise on two sub-datasets of rich and poor countries, and at different levels of poverty. Here, we find important differences for the role of carbon emissions reduction in improving poverty rates in rich and poor countries. Additionally, this study also demonstrates the 'poverty trap' effect arising from the enduring impact of past values within countries, and the extent to which this trap is partially reinforced by income inequality. The paper ends with a Conclusion, providing a brief overview of the main findings.

2 Literature review

In this section, we first consider some mechanisms by which climate change affects poverty. In order to reduce poverty, low-income countries often implement policies focused on economic growth (Dollar et al., 2016; Dollar and Kraay, 2002), for example in India (Singh, 2022) and China (Ho and Iyke, 2018); however, carbon-intensive growth strategies are likely to raise aggregate carbon emissions—the main driver of climate change. The adverse impact of climate change on poverty, as discussed below, can also further offset the effectiveness of development policies aimed at poverty reduction. In addition to climate change, income inequality can also reduce the effectiveness of poverty-alleviating growth policies, by widening the gap between rich and poor, and focusing income accumulation in upper percentiles. As such, the interactions between economic growth, climate change, and income inequality may create a vicious cycle for poverty reduction.

2.1 The relationship between climate change and poverty

Research on the relationship between climate change and poverty is of international concern, not merely an issue for low income or transitional economies. Climate change is a global problem requiring international cooperation, and one where the relative culpability of individuals, organizations, or corporations is contested (Barrett, 2005). Understanding the relationship between climate change and poverty reduction is crucial for development in all countries, but especially in poor countries where, according to Fankhauser and Stern (2020) the poor are the main victims of climate hazards. The impact of climate change on poverty is conceptualized through three mechanisms (as illustrated in Fig. 1). *Firstly*, climate change makes a people poorer in material and monetary terms—as living conditions and income security worsen due to climate change, especially through severe weather events (Hallegatte et al., 2014). The spread of famine and drought in susceptible areas, along with potential social unrest, can in turn affect a country's economic activity. Whilst these effects may be widespread nationally, the poor are typically most vulnerable. Emissions in poor countries are also found to be associated with reduced life expectancy, increased infant mortality, and higher health expenditure costs (Alimi and Ajide, 2021).

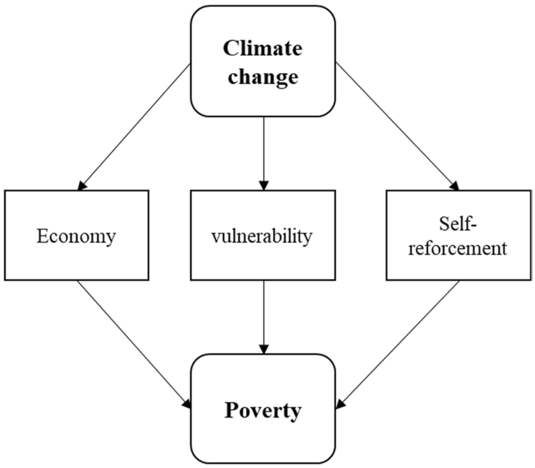


Fig. 1 The impact of climate change on poverty through three mechanisms

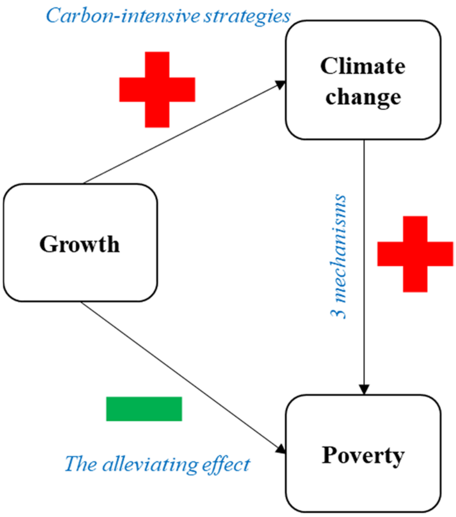
Second, climate change affects the poor more readily, as high poverty rates and low levels of human development in less developed countries may limit their ability to effectively manage climate risks (IPCC, 2007). Environmental risks are unevenly distributed geographically, depending largely on local geographical and climatic conditions (Narloch and Bangalore, 2018). The poor of low-income countries often live in remote and extreme climates or regions with high levels of environmental risk exposure, where they depend disproportionately on natural resources or agricultural production (Barbier, 2010; Carter et al., 2007). This explains why they are also the main victims of the consequences of climate change. The injustice of this internationally is emphasized by the disproportionate contribution of upper income groups to global emissions, and thus to climate change more generally (Oxfam, 2020).

Finally, according to Leichenko and Silva (2014), climate change may also have longer-lasting effects on poor households and communities, contributing to the creation or exacerbation of poverty traps, which are defined as self-reinforcing mechanisms that create significant barriers to escaping poverty. At household level, measures to reduce risks and cope with the consequences of climate change—such as selling assets, leaving children out of school, or cutting expenditures—can lower a household's ability to escape poverty (Carter et al., 2007). At regional level, extreme events can severely damage national assets such as infrastructure, and spending on measures to prevent them (e.g. coastal dams) may reduce long-term economic output in these areas (Hallegatte, 2012). More generally, the impact of the causal factors of climate change depends on the national characteristics of growth policies and pathways. In Vietnam, for example, financial development is associated with greater emissions due to the lower level of technology employed in natural resource extraction (Hung, 2022). Thus the manner in which growth is pursued in national and regional contexts matters in explaining the connection, hence the need for a more regionally decomposed analysis.

2.2 The climate change—poverty nexus: where does economic growth fit?

The relationship between climate change and poverty becomes more complicated when economic growth is considered, and this is borne out by several studies. Using data from 92 countries over the period 1950–1999, Dollar and Kraay (2002) discovered a positive and strong relationship between economic growth and poverty reduction. Building on this research, Dollar et al. (2016) continued to investigate the link between economic growth and changes in the incomes of the poor, analysing 151 countries for the period 1967–2011. This study confirmed that the incomes of the poorest group change proportionally with average national income. Recent research by Bergstrom (2020) also showed a beneficial effect of economic growth on poverty reduction between 1974–2018 in 135 countries. This research found that GDP per capita accounted for 90% of poverty reduction, with the remainder due to the effects of inequality. These effects are complicated by recent work on inequality however, which shows how finance-driven growth in the twenty-first century resulted in both decreased output, and rising inequality in high-income countries

Fig. 2 How climate change may offset the positive effects of growth on poverty



(Tomaskovic-Devey et al., 2015), which in turn set the preconditions for the financial crisis of 2008 (Stockhammer, 2015).

Climate change is implicated in poverty reduction strategies driven by economic growth as countries (especially developing ones) often depend on carbon-intensive technologies and sectors to increase economic output (Fankhauser and Jotzo, 2018). As discussed above, while economic growth appears to contribute to poverty reduction, climate change in general has a negative recursive impact on this process (as illustrated in Fig. 2). The complexity of these factors is further compounded given the interdependence between economic growth and climate change, and complexities in the temporal ordering of effects (Hung, 2022). Several studies have assessed the environment-economy nexus, exploring the long-term relationship between growth and environmental impact. Prominent among these is the environmental Kuznets curve (EKC), suggesting that the environmental impacts of economic growth will improve when the economy is highly developed.

Initially proposed by Simon Kuznets (1955) to describe the link between economic development and income inequality, the model was adapted by Grossman and Krueger (1991) to describe the connection between economic and environmental impact. It assumes that although economic growth in early stages of a country's development may impact negatively on the environment, when a certain threshold of development is reached, environmental impacts are reduced. Therefore, the relationship between economic development and environmental impact is considered an inverted U-shape. Several empirical studies subsequently offered support for this theory (Galeotti and Lanza, 1999; Holtz-Eakin and Selden, 1995; Shafik and Bandyopadhyay, 1992; Timmons Roberts and Grimes, 1997). This positive view of growth is challenged by sociological studies emphasizing how the link between emissions mitigation and development is often dependent on technology, the uncertain adoption of green technology, or sectoral changes arising from de-industrialization. Technology of itself is no panacea and also depends very much on national growth policy frameworks, and in contexts with greater development of finance in the growth-technology nexus, finance is shows to impede green technological development (Kim et al., 2022). Accordingly, much critique of the 'EKC' approach has pointed both to the central and uncertain role of technology as a panacea in these studies, and the impact of rising inequality as a consequence of economic growth strategies, which may in turn mitigate some of the positive effects of growth such as poverty reduction (Kirby and O'Mahony, 2018).

2.3 The cyclical traps of poverty, economic growth, and inequality

Tackling climate change calls for mutual collaboration on a global scale from many different countries and social groups (Barrett, 2005). This is difficult to achieve because the effects of climate change are not uniform across regions, countries, and income classes (Hallegatte et al., 2018). Existing inequalities, exacerbated by climatic stressors and shocks, have once again made poverty reduction a dilemma, especially for nations that rely heavily on carbon-intensive growth strategies. From a socioeconomic perspective, inequality as exacerbated by climate change can be considered on two levels: international (between-country) and social (within-country) (Islam and Winkel, 2017). Within-country inequality shows that if the assets of the poor are more vulnerable than those of the rich, then climate change could increase inequality considerably. However, this can be difficult to detect at the national level as climate change currently has a minimal impact on GDP, but a significant impact on poverty (Hallegatte et al., 2018; Islam and Winkel, 2017). In terms of differences between countries, Mendelsohn et al. (2006), Tol (2009), and Malerba (2020) argue

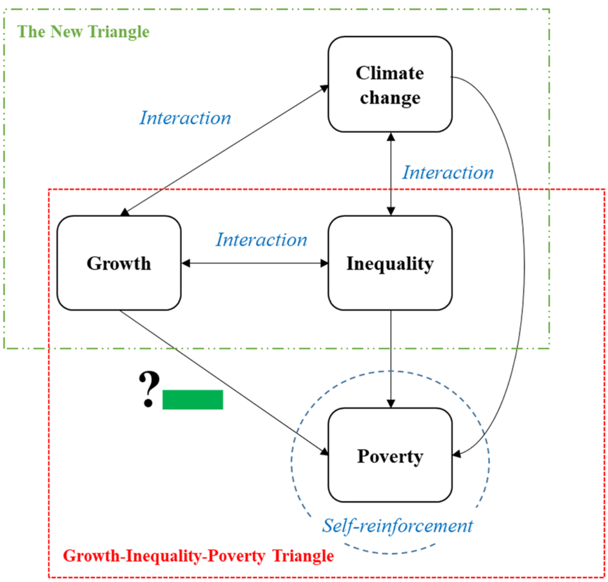


Fig. 3 Does growth reduce poverty?

that the distribution of impacts across countries is heterogeneous, and using GDP to measure the costs of climate change is not reasonable for poor countries or regions. Grunewald et al. (2017) and Ravallion et al. (2000) also point out that for poor countries, inequality is negatively related to carbon emissions, while for high-income countries, the opposite is true.

Studies on poverty reduction through economic growth—in a manner that accounts for both emissions and inequality—face many methodological obstacles because of the interdependence of growth–inequality, and of inequality–climate change (as illustrated in Fig. 3). As discussed above, one of the earliest studies on the growth-inequality relationship was from Kuznets, who suggested that inequality follows an inverted U-shaped curve with economic development—that is, increase would increase and then decrease as per capita income rises (Galbraith, 2007). Later studies have refuted this however in the face of rising personal and factor inequality (Fields, 2001), whilst, Kalwij and Verschoor (2007) and Bourguignon (2003) found an interaction relationship between growth and inequality related to poverty reduction. The second relationship (inequality–climate change) is more complicated. Cappelli et al. (2021) and Islam and Winkel (2017) found that higher levels of income inequality were associated with greater numbers affected by climate change disasters. The cumulative effects of repeated disasters in several locations can thus create a vicious cycle. Meanwhile, Ravallion et al. (2000) asserted a trade-off between reducing carbon emissions and reducing inequality within and between countries, though the relationship between these factors was found to be nonlinear. Malerba (2020) also suggest that there is a turning point when it comes to the relationship between economic growth and the carbon intensity of poverty reduction (CIPR), using a newly defined indicator.

In summary, the influence of climate change on poverty is of interest at many levels (i.e. household, regional, international) but its complexity leaves many outstanding questions. We are reasonably sure that economic growth is negatively associated with poverty, but the effectiveness of growth-based programmes as a poverty reduction strategy in the context of climate change and increasing inequality is less certain. The evidence for pairwise connections between economic growth, climate change, and income inequality has been individually rather than jointly demonstrated. The "new triangle" formed by these three variables (as shown in Fig. 3) is clearly related to the Growth-Inequality-Poverty Triangle developed by Bourguignon (2003), but not fully considered as such in previous studies. Accordingly, we pose the questions of (1) *whether poverty alleviation can be achieved by focusing solely on economic development*. Exploring this question requires both rigorous modelling techniques, as well as appropriate theories accounting for potential nonlinearities in the relationships between these properties. In terms of modelling, economic development will inevitably give rise to increased carbon emissions and income inequality (as per the literature review above), both of which have a dynamic impact on poverty (via the climate change-inequality interaction, and poverty traps as specified above). Additionally, both within and between-country inequalities should be factored into our models through two additional research questions: (2) *the differences between rich and poor countries in term of poverty-alleviating policies* and (3) *the differences in the sensitivity of these polices at different levels of* *poverty*. There is also potential for endogeneity and interaction amongst independent variables, as well as autoregressive effects of the dependent variable which must be accounted for through dynamic model specification. Finally, given the macro-panel nature of the data in question, unit heterogeneity in the form of unobserved country-specific effects is likely. We outline our strategy for addressing this in the following section.

3 Data and methodology

3.1 Data and variable definition

In the following section, we build an analytical model including four key variables: poverty, economic growth, carbon emissions, and income inequality—shown in detail in Fig. 4. The first relationship (#1, Fig. 4) is the direct impact of economic growth on poverty reduction (see Dollar et al. (2016) and Bergstrom (2020)). The two indirect effects of economic growth on poverty are considered by #2 and #3, respectively, moderated by two variables: carbon emissions—according to the Environment Kuznets Curve hypothesis (EKC) (Grossman and Krueger, 1991), and income inequality—according to the 'classic' income Kuznets Curve (IKC) (Galbraith, 2007). The interaction between carbon emissions and income inequality is illustrated by #4 (see Cappelli et al. (2021) and Islam and Winkel (2017)). Meanwhile, the poverty trap is illustrated by #5, capturing the enduring impact of past values on present poverty (Leichenko and Silva, 2014). This study also considers two types of inequality (Islam and Winkel, 2017). Between-country inequality can be expressed as the differences between groups of poor and rich countries, classified based on the income criteria of the World Bank, whilst and within-country

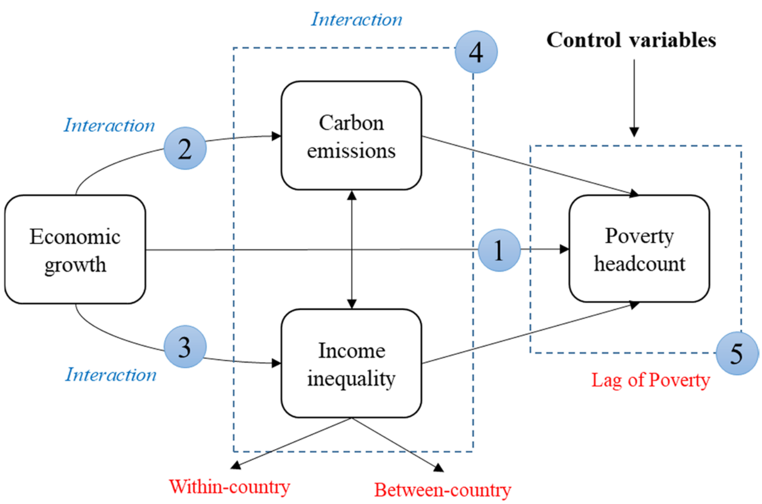


Fig. 4 Analytical framework

inequality is limited to changes in effects across different levels of poverty. In addition, we also evaluate the sensitivity of the poverty trap to variation in growth (Dollar et al., 2016) based on the estimated results (further details below).

From the above figure, we build an equation to estimate the impact of economic growth on poverty directly and indirectly through carbon emissions and income inequality. Equation (1) includes the dependent variable, the natural logarithm of the poverty rate set at \$5.5 per day ($Poverty_{it}$), the intercept (β_0), panel-specific effects (ϑ_i), the error term (ε_{it}), and explanatory variables—each representing a relationship as shown in Fig. 4. $Poverty_{it-1}$ (a lagged dependent variable) captures the impact of the poverty trap (#5, Fig. 4), or how the past impact of poverty contributes to current values. As this is conceptualized as a reinforcing and persistent trap, the coefficient β_1 is expected to be positive. $GDPPC_{it}$—GDP per capita at constant prices—captures relationship #1, the direct impact of growth on poverty, and we expect the coefficient β_2 to have a negative sign, indicating that economic growth generally contributes to poverty improvement (Dollar et al., 2016). The two interaction variables $GDPPC_{it} * Emissions_{it}$ and $GDPPC_{it} * Inequality_{it}$ represent the indirect effects of growth on poverty, and due to a lack of existing background studies, we do not predict the impact direction of these two variables (β_3 and β_4). Relationship #4 (carbon emissions–income inequality) measures the interaction between $Emissions_{it}$ (carbon emissions per capita) and $Inequality_{it}$ (the GINI index), and similarly to the previous, there is insufficient background evidence to predict the sign of coefficient β_5. Finally, $Controls_{it}$ (population, renewable energy consumption, and urbanization) were selected according to the studies of Thombs (2021) and Jorgenson et al. (2016), and are representative of standard structural controls used in political economy models of poverty and climate.

$$\begin{aligned} Poverty_{it} = \beta_0 + \beta_1 Poverty_{it-1} + \beta_2 GDPPC_{it} + \beta_3 GDPPC_{it} * Emissions_{it} \\ + \beta_4 GDPPC_{it} * Inequality_{it} + \beta_5 Emissions_{it} * Inequality_{it} \\ + \beta_6 Controls_{it} + \vartheta_i + \varepsilon_{it} (1) \end{aligned}$$

In addition, this study also analyses two types of inequality by splitting the dataset and the dependent variable. For between-country inequality, in order to explore the differences between poor and rich countries, we reapply our analysis to two different sub-datasets, corresponding to groups of countries classified according to World Bank criteria. For within-country inequality, we include different poverty rates in different specifications of the dependent variable. The three dependent variables analysed by this study include poverty rates at income levels of \$0.0—\$1.90 per day, of \$1.90—\$3.20 per day, and of \$3.20—\$5.50 per day. For ease of visualization, we summarize all the variables used in this study in "Appendix A" and all their values are in natural logarithmic form.

We also address potential growth elasticity in the poverty trap reinforcement effect. Elasticity measures the percentage change of one variable with respect to change in another variable in percentages. Similar to the derivative that measures the sensitivity of one variable to another, elasticity is superior to the derivative in the case of different measurement systems (Sydsaeter et al., 2016, pp. 246–250). The relationship between these two values is shown by Eq. (2), with two variables x and y, and the elasticity of two variables will correspond to the derivative of the natural logarithm of those two variables. From Eq. (1), we replace the variables with their natural logarithm, then apply the formula according to Eq. (2), and ultimately get a new Eq. (3), where *rf* is the ratio between the current poverty rate and its own contribution in the past (this value now measures reinforcement of the poverty trap caused by climate change and income inequality).

$$\mathrm{El}_x^y = \frac{\mathrm{d}y}{\mathrm{d}x} * \frac{x}{y} = \frac{\mathrm{d}(\ln x)}{\mathrm{d}(\ln y)}, (2)$$

$$\mathrm{El}_{growth}^{rf} = \frac{d\ln rf_{it}}{d\ln growth_{it}} = \beta_2 + \beta_3 \ln Emissions_{it} + \beta_4 \ln Inequality_{it}, (3)$$

$$\forall rf = \frac{poverty_{it}}{{poverty_{it-1}}^{\beta_1}}$$

3.2 Methodology

Given the nature of our model as specified above, an appropriate estimation method is required to solve several statistical problems including endogeneity, multicollinearity, heterogeneity, heteroscedasticity, and serial correlation. These problems can cause coefficients to be biased, rendering results and conclusions unreliable, and are especially important in time-series data where results can be sensitive to changes in specification (Wooldridge, 2009). First, endogeneity—widely understood as the correlation between the explanatory variable and the error component—likely exists in our model because of the presence of lags of the independent variable $Poverty_{it-1}$ as an explanatory variable, and mediation effects from $GDPPC_{it}$ to $Poverty_{it}$ and $Emissions_{it}$ and $Inequality_{it}$ as our two mediators. Multicollinearity is also likely when the explanatory variables are strongly correlated with each other, in this case $Emissions_{it}$ and $Inequality_{it}$. Unit heterogeneity is an issue in the analysis of international panel data, and if the presence of unobserved country-specific effects ϑ_i is ignored, estimated coefficients may be erroneous (Baltagi, 2021). Given the model specification incorporates both temporal and cross-sectional effects, heteroscedasticity and serial correlation are also both likely (Pesaran, 2015).

To address these issues, we refer to some estimation methods from recent studies taking a similar approach, and consider the suitability of their statistical properties in light of our data structure. Ravallion et al. (2000) used a fixed-effects model to analyse the relationship between growth, carbon emissions, and income inequality in 42 countries over the period 1975–1992. This approach only solves the heterogeneity problem however, and others may remain. The second method commonly used by researchers is the panel-corrected standard errors approach (PCSE) which has been applied in studies of Thombs (2021) and Jorgenson et al. (2016). Although PCSE solves several of these statistical problems, it does not account for endogeneity. In contrast, the Three-Stage Least Square estimator (3SLS)—a simultaneous equation model—designed to solve the endogeneity problem, was applied in the study of Cappelli et al. (2021), however this method overlooks heterogeneity and serial correlation. The estimation method we consider most appropriate is the Generalized Method of Moments (GMM)—see Malerba (2020) for an example of application to the same topic as this study. It is designed to address issues in cross-sectional and time-series data, including but not limited to: endogeneity, heterogeneity, heteroscedasticity and serial correlation (Roodman, 2009). Full or near-multicollinearity is also detected in the GMM procedure, which in turn drops variables violating this error.

4 Results and discussions

First, we examine the direct and indirect impact of economic growth on poverty rates by presenting GMM estimates for three models (Table 1, O1, M1, and S1). O1 measures the direct impact of GDPPC, emissions and inequality on poverty. M1 includes mediation effects—that is, the indirect impact of GDPPC through emissions and inequality—as predicted by the Environmental Kuznets Curve

Table 1 Estimates of direct and indirect effects

	Poverty rate at $5.50 per day (ln)			
	O1	M1	S1	C1
GDPPC	− 0.648***	− 0.842***	0.917	− 0.693***
	(0.125)	(0.144)	(1.150)	(0.135)
GDPPC-squared			− 0.0945	
			(0.0603)	
Emissions	0.0284			
	(0.100)			
Inequality	0.639***			
	(0.169)			
GDPPC × emissions		− 0.00308	− 0.000809	− 0.146***
		(0.0108)	(0.00916)	(0.0339)
GDPPC × inequality		0.0733***	0.0713***	0.0470**
		(0.0183)	(0.0162)	(0.0212)
Emissions × inequality				0.400***
				(0.0791)
L.Poverty ($0.0–5.5)	0.689***	0.683***	0.671***	0.633***
	(0.0458)	(0.0475)	(0.0522)	(0.0464)
Constant	3.616***	5.891***	− 2.112	6.158***
	(1.104)	(1.081)	(5.225)	(0.989)
Observations	986	986	986	986
AR2 test (*p*-value)	0.658	0.657	0.656	0.642

Standard errors in parentheses; *$p<0.10$, **$p<0.05$, ***$p<0.010$; Control variables are not reported

(EKC) and Inequality Kuznets Curve (IKC). S1 builds on model M1 by adding the square of GDPPC to test the presence of an inverted U-shape. For all three models, we consider GDPPC variables and their squared values as predetermined variables, whose future rather than past or current values are correlated with the current error term, as a high poverty rate can negatively affect economic growth in the future. Variables related to emissions and inequality are considered endogenous because their values vary with different levels of GDPPC. Control variables (population, renewable energy consumption, and urbanization) are treated as exogenous variables, whose values are assumed to be uncorrelated with the residuals at any point in time. We obtain robust standard errors to account for heteroscedasticity, and check whether the model is mis-specified through the Arellano–Bond test for serial correlation at order two (Roodman, 2009).

Results of the first three models are shown in Table 1, and the Arellano–Bond test results for serial correlation at order two (AR2) suggest they are not mis-specified. Examining the direct effect of the key explanatory variables on poverty in model O1, only those of GDPPC and inequality are statistically significant, while the direct impact of emissions is not. This finding is further substantiated by the model M1—showing that emissions separate from inequality, also have no indirect impact on poverty. Model S1 also demonstrates that the relationship between poverty and growth does not follow an inverted U-shaped curve. With the combined results from these models, we draw several conclusions. GDPPC has a direct negative effect on poverty (finding #1–1), whilst inequality is an important factor in increasing poverty rates both directly (model O1) and indirectly (models M1 and S1)—(finding #1–2). Further we find that emissions, if separated from inequality, have no clear impact on poverty (finding #1–3); and that the poverty rate is made up of about 60–70% of its past value, from which we observe that the 'poverty trap' effect is a likely mechanism in its perpetuation (finding #1–4). Findings #1–1 & #1–2 in particular are consistent with the results of Bergstrom (2020), Bourguignon (2003), and Kalwij and Verschoor (2007), suggesting that income redistribution plays an important role in improving poverty rates.

Next, we explore the relationship between emissions and inequality as established by Cappelli et al. (2021) and Islam and Winkel (2017), by estimating a model called C1 (Table 1). This is an expansion of model M1, with an added interaction term between emissions and inequality. We find that emissions, when coupled with inequality, exacerbates poverty—partly demonstrating the existence of an emissions-inequality trap (further explained with finding #1–6). Notwithstanding, it can be seen that the overall impact of emissions on poverty is positive (exacerbating poverty) because the interaction with GDPPC yields a relatively smaller coefficient than that of inequality (finding #1–5). This conclusion does not contradict finding #1–3, which further shows that emissions can affect poverty through channels associated with inequality. Additionally, C1 reaffirms the credibility of finding #1–1 on the direct effects of GDPPC, and of finding #1–4 on the poverty trap. Table 1 also suggests that poverty reduction may has been achieved largely through economic growth rather than income redistribution, which partially affirms similar conclusions of Dollar et al. (2016) and Bergstrom (2020). This apparently contradictory position is consistent with the principles of equitable degrowth, which mandate that space for poverty-alleviating growth amongst poor countries is essential to addressing the climate crisis (Pettifor, 2020).

The elasticity discussed at the end of the Data and variable section is incorporated into model C1. Accordingly, Eq. (3) may be rewritten as:

$$El^{rf}_{growth} = -0.693 - 0.146 \ln Emissions + 0.047 \ln Inequality$$

This new equation suggests that the growth elasticity of poverty trap reinforcement is moderated by two variables, carbon emissions and income inequality. In other words, the sensitivity of poverty trap reinforcement to economic growth is negatively related to carbon emissions and positively to income inequality (finding #1–6). The positive sign of income inequality explains its hindrance of the process of poverty reduction through economic development. The negative sign of carbon emissions in this equation does not imply that it helps reduce poverty rates (primarily because of the interaction between carbon emissions and income inequality), but suggests a positive relationship with economic growth, a finding previously confirmed by Ravallion et al. (2000). The strong positive correlation between carbon emissions and economic growth is characteristic of carbon-intensive growth in most countries of the world, but especially developing ones (Fankhauser & Jotzo, 2018). In sum, carbon emissions in the equation of elasticity (based on variation in growth) implies that adopting carbon-intensive growth strategies to alleviate poverty, combined with Finding #1–5, cuts the efficiency of growth by more than half due to income inequality.

Next, we present different coefficients for model C1 for two sub-datasets based on the World Bank's classification of high and low-income countries (Table 2). These

Table 2 The disparity between high- and low-income countries

	Poverty rate at \$5.50 per day (ln)	
	High income	Low income
GDPPC	− 1.331***	− 0.293***
	(0.299)	(0.0935)
GDPPC × emissions	− 0.0113	− 0.104***
	(0.0999)	(0.0383)
GDPPC × inequality	0.193***	0.0127
	(0.0503)	(0.0140)
Emissions × inequality	0.0305	0.286***
	(0.284)	(0.0979)
L.Poverty (\$0.0–5.5)	0.509***	0.839***
	(0.0473)	(0.0286)
Constant	7.733**	2.454***
	(3.127)	(0.624)
Observations	459	527
AR2 test (*p*-value)	0.806	0.384

Standard errors in parentheses; * $p<0.10$, ** $p<0.05$, *** $p<0.010$; Control variables are not reported models include the same dependent variable as Table 1 (the natural logarithm of the poverty rate set at $5.5 per day). Economic growth in both groups has a negative effect on poverty, but the coefficient is higher in the high-income sub-dataset. The indirect impact of economic growth on poverty is mainly through inequality in the sub-dataset of developed countries, and mainly through emissions in the sub-dataset of developing countries (finding #2–1). This may be due to the presence of two distinct economic development strategies of low-carbon growth and high-carbon growth, respectively. Coefficients of the low-income sub-dataset also reaffirm finding #1–5 that emissions generally increase poverty through income inequality, rather than through economic development. The risk of poverty trap reinforcement is clearly lower in high-income countries (just over 50% contribution from past values), but high in low-income countries (more than 80%), while the average is only about 70% (see finding #1–4). In summary, we find that the ‘poverty trap’ risk is considerably higher for low, relative to high-income countries. Combined with the prospect of high-income countries being less affected by the emissions-inequality mechanism, this raises the prospect that degrowth strategies aimed at cutting emissions—that do not account for the differing characteristics of low-income countries—may end up reinforcing both inequality and poverty amongst this group.

Finally, we investigate the effects of economic growth, carbon emissions, and income inequality on poverty at different poverty thresholds. The estimated models in Table 3 are derived from model C1 but use alternative specifications of the

Table 3 Differences between levels of poverty

	Poverty rate at variable bands (ln)		
	$0.0–1.90	$1.90–3.20	$3.20–5.50
GDPPC	− 1.212***	− 0.830***	− 0.498***
	(0.198)	(0.153)	(0.150)
GDPPC × emissions	0.0984**	− 0.129***	− 0.216***
	(0.0449)	(0.0408)	(0.0396)
GDPPC × inequality	0.185***	0.0674**	− 0.00518
	(0.0376)	(0.0288)	(0.0220)
Emissions × inequality	− 0.231*	0.398***	0.597***
	(0.119)	(0.106)	(0.104)
L.Poverty ($0.0–1.9)	0.669***		
	(0.0584)		
L.Poverty ($1.9–3.2)		0.679***	
		(0.0356)	
L.Poverty ($3.2–5.5)			0.631***
			(0.0496)
Constant	4.785***	5.724***	5.569***
	(1.272)	(1.046)	(1.242)
Observations	818	811	936
AR2 test (*p*-value)	0.0305	0.539	0.104

Standard errors in parentheses; * $p<0.10$, ** $p<0.05$, *** $p<0.010$; Control variables are not reported dependent variable corresponding to three income bands: \$0.0–1.90 per day, \$1.90–3.20 per day, and \$3.20–5.50 per day. Based on AR2 test results, we find that two models "\$1.90–3.20" and "\$3.20–5.50" are not mis-specified, so we focus our reporting on these. First, we find that the poverty trap is confirmed again at alternate poverty levels, with about 60–70% of contributions from past poverty rates, further substantiating finding #1–4. Thus, a lower poverty level appears to lead to a somewhat stronger poverty trap reinforcement effect (the coefficient of 0.679 versus 0.631)—finding #3–1. However, economic growth may more easily facilitate those at higher poverty levels (the lower band measure) to escape these levels (the coefficient of − 0.830 versus − 0.498)—finding #3–2. In addition, the coefficients of emissions-related variables at higher poverty levels are more sensitive (because of the higher magnitude of their impact, almost double), while inequality associated with economic growth only impacts on poverty with statistical significance at a poverty level of \$1.90–3.20 per day (finding #3–3). Notably, the sign of the coefficient of GDPPC x emissions is the same (negative) in all three modelling exercises Tables 1, 2, and 3—demonstrating further support for finding #1–6. It thus appears that the moderating effect of carbon emissions and income inequality on poverty trap reinforcement holds irrespective of both country-group membership (whether high or low income), and poverty rate definition band (applying equally to the more stringent definitions of poverty in Table 3).

5 Conclusion

The impacts of climate change on economy and society are multifaceted and complex. A key aspect of this complexity is the potentially uneven impact of mitigation policies and measures on high and low-income countries, respectively. As international policy moves closer to the consensus that vast reductions in output are required in order to offset the already considerable harm caused by historical emissions, we must appreciate the potentially disproportionate impact that degrowth policies may have on different countries, but especially low-income. The injustice of this is emphasized by the disproportionate contribution (both contemporarily and cumulatively) of advanced capitalist democracies to global emissions (Oxfam, 2020). It is widely recognized in the literature on just transitions and ecosocialism that developmental space is needed for low-income countries to grow their economies and income bases, to a point where more citizens could be lifted from severe poverty, thus lessening the future impact of economic degrowth and sectoral transitions (Kirby and O'Mahony, 2018; Pettifor, 2020). This would involve concessions in the form of greater degrowth in high-income countries to allow poverty-alleviating development in the low-income bloc. Our findings underscore the potentially damaging impact that would arise from global 'one size fits all' policies that do not account for the specific characteristics of low-income countries, and how variation in poverty is related to emissions, growth, and inequality. The contribution of this paper lies in the discovery of a 'Growth-Inequality-Emissions' triangle, expanding on the 'Growth-Inequality-Poverty' triangle proposed by Bourguignon (2003).

Our results reveal some of these complexities and offer a more solid evidence base from which to develop international policy. In our global models, we find that, with regard to emission elasticity, the adoption of carbon-intensive growth strategies is rendered inefficient due to the presence of income inequality (finding #1–5), whilst our low-income sub-dataset shows that emissions increase poverty through the mechanism of inequality, rather than economic development. Thus, *any emissions-intensive development policies aimed at addressing poverty alleviation in low-income countries must factor the mediating and negative role of inequality in the poverty-emissions pathway*. This is an important finding, as evidence mounts on the role of inequality as a driver of climate change, and on the potential distributional impacts of decarbonization policies (Green and Healy, 2022; Zimmermann and Pye, 2018). In the literature, inequality reduction is recognized as a precondition in high-income countries for the adoption of redistributive carbon-focused policies aimed at curbing consumption (Kirby and O'Mahony, 2018). Here we highlight another mechanism through which failures to factor inequality may work against climate change mitigation—specific to low-income countries. This is an important as, contrary to the findings of global pooled models alone, we find that *the risk of inequality-driven poverty combined with a higher risk of poverty trap reinforcement, means that general mitigation policies aimed at 'degrowth in general' are unlikely to result in just outcomes for low-income countries* (Kallis, 2011; Pettifor, 2020).

Overall, we emphasize some of the risks involved in economic adjustments towards sustainability amongst poor countries. The relationship between poverty and climate change in the process of economic development is not straightforward but entails addressing the problem of associated rising income inequality. By adopting a socioeconomic perspective, we show how economic growth may reduce poverty, and how this works in association with income inequality and carbon emissions in the generation of feedback effects and traps. Accordingly, our GMM estimates indicate that emissions have a negative impact on poverty reduction when coupled with inequality, rather than being endogenous to economic growth. Furthermore, we also confirm that *in high-income countries, inequality is the main obstacle to poverty reduction, while in developing countries it is emissions in association with income inequality*. Ultimately, this study provides statistical corroboration that those at higher poverty levels and lower national income levels are more vulnerable to climate change, and less likely to achieve equitable decarbonization through growth-centred policies alone. Given the uneven nature of climate change's impacts, and globally uneven exposure to climate hazards (IPCC, 2014), this is an issue of immediate and urgent concern.

Appendices

Appendix A: Data and variable definitions

Variables	Definitions
Inequality	Gini index (World Bank estimate)
Emissions	Carbon emissions (metric tons per capita)
GDPPC	GDP per capita, PPP (constant 2017 international $)
Poverty190	Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
Poverty320	Poverty headcount ratio at $3.20 a day (2011 PPP) (% of population)
Poverty550	Poverty headcount ratio at $5.50 a day (2011 PPP) (% of population)
Poverty190-320	Difference between Poverty320 and Poverty190
Poverty320-550	Difference between Poverty550 and Poverty320
Population	Population, total
Renew. cnsmp	Renewable energy consumption (% of total final energy consumption)
Urbanization	Urban population (% of total population)

All variables are taken in natural logarithm form

Source: World Development Indicators 2021

Appendix B: List of countries under this study

Code	Long name	Income group
AFG	Islamic State of Afghanistan	Low income
ALB	Republic of Albania	Low income
DZA	People's Democratic Republic of Algeria	Low income
ASM	American Samoa	Low income
AND	Principality of Andorra	High income
AGO	People's Republic of Angola	Low income
ATG	Antigua and Barbuda	High income
ARG	Argentine Republic	Low income
ARM	Republic of Armenia	Low income
ABW	Aruba	High income
AUS	Commonwealth of Australia	High income
AUT	Republic of Austria	High income
AZE	Republic of Azerbaijan	Low income
BHS	Commonwealth of The Bahamas	High income
BHR	Kingdom of Bahrain	High income
BGD	People's Republic of Bangladesh	Low income
BRB	Barbados	High income
BLR	Republic of Belarus	Low income
BEL	Kingdom of Belgium	High income

Code	Long name	Income group
BLZ	Belize	Low income
BEN	Republic of Benin	Low income
BMU	The Bermudas	High income
BTN	Kingdom of Bhutan	Low income
BOL	Plurinational State of Bolivia	Low income
BIH	Bosnia and Herzegovina	Low income
BWA	Republic of Botswana	Low income
BRA	Federative Republic of Brazil	Low income
VGB	British Virgin Islands	High income
BRN	Brunei Darussalam	High income
BGR	Republic of Bulgaria	Low income
BFA	Burkina Faso	Low income
BDI	Republic of Burundi	Low income
CPV	Republic of Cabo Verde	Low income
KHM	Kingdom of Cambodia	Low income
CMR	Republic of Cameroon	Low income
CAN	Canada	High income
CYM	Cayman Islands	High income
CAF	Central African Republic	Low income
TCD	Republic of Chad	Low income
CHI	Channel Islands	High income
CHL	Republic of Chile	High income
CHN	People's Republic of China	Low income
COL	Republic of Colombia	Low income
COM	Union of the Comoros	Low income
COD	Democratic Republic of the Congo	Low income
COG	Republic of Congo	Low income
CRI	Republic of Costa Rica	Low income
CIV	Republic of Côte d'Ivoire	Low income
HRV	Republic of Croatia	High income
CUB	Republic of Cuba	Low income
CUW	Curaçao	High income
CYP	Republic of Cyprus	High income
CZE	Czech Republic	High income
DNK	Kingdom of Denmark	High income
DJI	Republic of Djibouti	Low income
DMA	Commonwealth of Dominica	Low income
DOM	Dominican Republic	Low income
ECU	Republic of Ecuador	Low income
EGY	Arab Republic of Egypt	Low income
SLV	Republic of El Salvador	Low income
GNQ	Republic of Equatorial Guinea	Low income
ERI	State of Eritrea	Low income

Code	Long name	Income group
EST	Republic of Estonia	High income
SWZ	Kingdom of Eswatini	Low income
ETH	Federal Democratic Republic of Ethiopia	Low income
FRO	Faroe Islands	High income
FJI	Republic of Fiji	Low income
FIN	Republic of Finland	High income
FRA	French Republic	High income
PYF	French Polynesia	High income
GAB	Gabonese Republic	Low income
GMB	Republic of The Gambia	Low income
GEO	Georgia	Low income
DEU	Federal Republic of Germany	High income
GHA	Republic of Ghana	Low income
GIB	Gibraltar	High income
GRC	Hellenic Republic	High income
GRL	Greenland	High income
GRD	Grenada	Low income
GUM	Guam	High income
GTM	Republic of Guatemala	Low income
GIN	Republic of Guinea	Low income
GNB	Republic of Guinea-Bissau	Low income
GUY	Co-operative Republic of Guyana	Low income
HTI	Republic of Haiti	Low income
HND	Republic of Honduras	Low income
HKG	Hong Kong (China)	High income
HUN	Hungary	High income
ISL	Republic of Iceland	High income
IND	Republic of India	Low income
IDN	Republic of Indonesia	Low income
IRN	Islamic Republic of Iran	Low income
IRQ	Republic of Iraq	Low income
IRL	Ireland	High income
IMN	Isle of Man	High income
ISR	State of Israel	High income
ITA	Italian Republic	High income
JAM	Jamaica	Low income
JPN	Japan	High income
JOR	Hashemite Kingdom of Jordan	Low income
KAZ	Republic of Kazakhstan	Low income
KEN	Republic of Kenya	Low income
KIR	Republic of Kiribati	Low income
PRK	Democratic People’s Republic of Korea	Low income
KOR	Republic of Korea	High income

Code	Long name	Income group
XKX	Republic of Kosovo	Low income
KWT	State of Kuwait	High income
KGZ	Kyrgyz Republic	Low income
LAO	Lao People's Democratic Republic	Low income
LVA	Republic of Latvia	High income
LBN	Lebanese Republic	Low income
LSO	Kingdom of Lesotho	Low income
LBR	Republic of Liberia	Low income
LBY	Socialist People's Libyan Arab Jamahiriya	Low income
LIE	Principality of Liechtenstein	High income
LTU	Republic of Lithuania	High income
LUX	Grand Duchy of Luxembourg	High income
MAC	Macao (China)	High income
MDG	Republic of Madagascar	Low income
MWI	Republic of Malawi	Low income
MYS	Malaysia	Low income
MDV	Republic of Maldives	Low income
MLI	Republic of Mali	Low income
MLT	Republic of Malta	High income
MHL	Republic of the Marshall Islands	Low income
MRT	Islamic Republic of Mauritania	Low income
MUS	Republic of Mauritius	Low income
MEX	United Mexican States	Low income
FSM	Federated States of Micronesia	Low income
MDA	Republic of Moldova	Low income
MCO	Principality of Monaco	High income
MNG	Mongolia	Low income
MNE	Montenegro	Low income
MAR	Kingdom of Morocco	Low income
MOZ	Republic of Mozambique	Low income
MMR	Republic of the Union of Myanmar	Low income
NAM	Republic of Namibia	Low income
NRU	Republic of Nauru	High income
NPL	Nepal	Low income
NLD	Kingdom of the Netherlands	High income
NCL	New Caledonia	High income
NZL	New Zealand	High income
NIC	Republic of Nicaragua	Low income
NER	Republic of Niger	Low income
NGA	Federal Republic of Nigeria	Low income
MKD	Republic of North Macedonia	Low income
MNP	Commonwealth of the Northern Mariana Islands	High income
NOR	Kingdom of Norway	High income

Code	Long name	Income group
OMN	Sultanate of Oman	High income
PAK	Islamic Republic of Pakistan	Low income
PLW	Republic of Palau	High income
PAN	Republic of Panama	Low income
PNG	The Independent State of Papua New Guinea	Low income
PRY	Republic of Paraguay	Low income
PER	Republic of Peru	Low income
PHL	Republic of the Philippines	Low income
POL	Republic of Poland	High income
PRT	Portuguese Republic	High income
PRI	Puerto Rico	High income
QAT	State of Qatar	High income
ROU	Romania	Low income
RUS	Russian Federation	Low income
RWA	Republic of Rwanda	Low income
WSM	Samoa	Low income
SMR	Republic of San Marino	High income
STP	Democratic Republic of São Tomé and Principe	Low income
SAU	Kingdom of Saudi Arabia	High income
SEN	Republic of Senegal	Low income
SRB	Republic of Serbia	Low income
SYC	Republic of Seychelles	High income
SLE	Republic of Sierra Leone	Low income
SGP	Republic of Singapore	High income
SXM	Sint Maarten (Dutch part)	High income
SVK	Slovak Republic	High income
SVN	Republic of Slovenia	High income
SLB	Solomon Islands	Low income
SOM	Somali Democratic Republic	Low income
ZAF	Republic of South Africa	Low income
SSD	Republic of South Sudan	Low income
ESP	Kingdom of Spain	High income
LKA	Democratic Socialist Republic of Sri Lanka	Low income
KNA	St. Kitts and Nevis	High income
LCA	St. Lucia	Low income
MAF	St. Martin (French part)	High income
VCT	St. Vincent and the Grenadines	Low income
SDN	Republic of the Sudan	Low income
SUR	Republic of Suriname	Low income
SWE	Kingdom of Sweden	High income
CHE	Switzerland	High income
SYR	Syrian Arab Republic	Low income
TJK	Republic of Tajikistan	Low income

Code	Long name	Income group
TZA	United Republic of Tanzania	Low income
THA	Kingdom of Thailand	Low income
TLS	Democratic Republic of Timor-Leste	Low income
TGO	Republic of Togo	Low income
TON	Kingdom of Tonga	Low income
TTO	Republic of Trinidad and Tobago	High income
TUN	Republic of Tunisia	Low income
TUR	Republic of Turkey	Low income
TKM	Turkmenistan	Low income
TCA	Turks and Caicos Islands	High income
TUV	Tuvalu	Low income
UGA	Republic of Uganda	Low income
UKR	Ukraine	Low income
ARE	United Arab Emirates	High income
GBR	United Kingdom of Great Britain and Northern Ireland	High income
USA	United States of America	High income
URY	Oriental Republic of Uruguay	High income
UZB	Republic of Uzbekistan	Low income
VUT	Republic of Vanuatu	Low income
VEN	República Bolivariana de Venezuela	Low income
VNM	Socialist Republic of Vietnam	Low income
VIR	Virgin Islands of the United States	High income
PSE	West Bank and Gaza	Low income
YEM	Republic of Yemen	Low income
ZMB	Republic of Zambia	Low income
ZWE	Republic of Zimbabwe	Low income

Low income (in this study) = low income, lower middle income, and upper middle income (under the World Bank classification); and high income (in this study) = high income (according to the World Bank classification)

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References

Alimi OY, Ajide KB (2021) The role of institutions in environment–health outcomes Nexus: empirical evidence from sub-Saharan Africa. Econ Chang Restruct 54(4):1205–1252. https://doi.org/10.1007/s10644-020-09299-0

Baltagi BH (2021) The one-way error component regression model. Springer, Cham. https://doi.org/10.1007/978-3-030-53953-5_2

Barbier EB (2010) Poverty, development, and environment. Environ Dev Econ 15(6):635–660. https://doi.org/10.1017/S1355770X1000032X

Barrett S (2005) Environment and statecraft: the strategy of environmental treaty-making: the strategy of environmental treaty-making. Oxford University Press, Oxford. https://doi.org/10.1093/0199286094.001.0001

Bergstrom K (2020) The Role of Inequality for Poverty Reduction. World Bank, Washingtonhttps://doi.org/10.1596/1813-9450-9409

Bourguignon F (2003) The poverty-growth-inequality triangle. In: Conference on poverty, inequality and growth, Paris, France

Cappelli F, Costantini V, Consoli D (2021) The trap of climate change-induced "natural" disasters and inequality. Glob Environ Chang 70:102329–102329. https://doi.org/10.1016/j.gloenvcha.2021.102329

Carter MR, Little PD, Mogues T, Negatu W (2007) Poverty traps and natural disasters in Ethiopia and Honduras. World Dev 35(5):835–856. https://doi.org/10.1016/j.worlddev.2006.09.010

Daly HE (2006) Sustainable development—definitions, principles, policies. Future Sustain. https://doi.org/10.1007/1-4020-4908-0_2

Dollar D, Kleineberg T, Kraay A (2016) Growth still is good for the poor. Eur Econ Rev 81:68–85. https://doi.org/10.1016/j.euroecorev.2015.05.008

Dollar D, Kraay A (2002) Growth is good for the poor. J Econ Growth 7(3):195–225. https://doi.org/10.1023/A:1020139631000

Fankhauser S, Jotzo F (2018) Economic growth and development with low-carbon energy. Wires Clim Change. https://doi.org/10.1002/wcc.495

Fankhauser S, Stern N (2020) Climate change, development, poverty, and economics. In: Basu K, Rosenblatt D, Sepúlveda C (eds) The state of economics, the state of the world. The MIT Press, Cambridge, pp. 295–348. https://doi.org/10.7551/mitpress/11130.003.0012

Fields GS (2001) Distribution and Development: a new look at the developing world. The MIT Press, Cambridge 71. https://doi.org/10.7551/mitpress/2465.001.0001

Flaherty E (2019) Complexity and resilience in the social and ecological sciences. Palgrave Macmillan, London. https://doi.org/10.1057/978-1-137-54978-5

Fonseca, L. M., Domingues, J. P., & Dima, A. M. (2020). Mapping the sustainable development goals relationships. Sustainability 12(8), 3359–3359. https://doi.org/10.3390/SU12083359

Galbraith JK (2007) Global inequality and global macroeconomics. J Policy Model 29(4):587–607. https://doi.org/10.1016/j.jpolmod.2007.05.008

Galeotti M, Lanza A (1999) Richer and cleaner? A study on carbon dioxide emissions in developing countries. Energy Policy 27(10):565–573. https://doi.org/10.1016/S0301-4215(99)00047-6

Green F, Healy N (2022) How inequality fuels climate change: the climate case for a Green New Deal. One Earth 5(6):635–649. https://doi.org/10.1016/j.oneear.2022.05.005

Grossman G, Krueger A (1991) Environmental impacts of a north american free trade agreement. National Bureau of Economic Research Inc, Cambridge

Grunewald N, Klasen S, Martínez-Zarzoso I, Muris C (2017) The trade-off between income inequality and carbon dioxide emissions. Ecol Econ 142:249–256. https://doi.org/10.1016/j.ecolecon.2017.06.034
Hallegatte S (2012) A framework to investigate the economic growth impact of sea level rise. Environ Res Lett 7(1):15604–15604. https://doi.org/10.1088/1748-9326/7/1/015604
Hallegatte S, Bangalore M, Bonzanigo L, Fay M, Narloch U, Rozenberg J, Vogt-Schilb A (2014) Climate change and poverty—an analytical framework. The World Bank. https://openknowledge.worldbank.org/handle/10986/20639
Hallegatte S, Fay M, Barbier EB (2018) Poverty and climate change: introduction. Environ Dev Econ 23(3):217–233. https://doi.org/10.1017/S1355770X18000141
Ho S-Y, Iyke BN (2018) Finance-growth-poverty nexus: a re-assessment of the trickle-down hypothesis in China. Econ Chang Restruct 51(3):221–247. https://doi.org/10.1007/s10644-017-9203-8
Holtz-Eakin D, Selden TM (1995) Stoking the fires? CO2 emissions and economic growth. J Public Econ 57(1):85–101. https://doi.org/10.1016/0047-2727(94)01449-X
Hung NT (2022) Time–frequency nexus between globalization, financial development, natural resources and carbon emissions in Vietnam. Econ Chang Restruct 55(4):2293–2315. https://doi.org/10.1007/s10644-022-09391-7
IPCC. (2007). Climate change 2007: impacts, adaptation and vulnerability. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf
IPCC. (2014). Synthesis report summary chapter for policymakers. IPCC, 2014, pp 31–31. https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf
Islam N, Winkel J (2017) Climate change and social inequality. UN/DESA working papers. https://www.un.org/esa/desa/papers/2017/wp152_2017.pdf
Jafino BA, Walsh B, Rozenberg J, Hallegatte S (2020) Revised estimates of the impact of climate change on extreme poverty by 2030. World Bank, Washington. https://doi.org/10.1596/1813-9450-9417
Jorgenson AK, Fiske S, Hubacek K, Li J, McGovern T, Rick T, Schor JB, Solecki W, York R, Zycherman A (2019) Social science perspectives on drivers of and responses to global climate change. Wiley Interdiscip Rev Clim Change 10(1):e554–e554. https://doi.org/10.1002/WCC.554
Jorgenson AK, Schor JB, Knight KW, Huang X (2016) Domestic inequality and carbon emissions in comparative perspective. Sociol Forum 31:770–786. https://doi.org/10.1111/socf.12272
Kallis G (2011) In defence of degrowth. Ecol Econ 70(5):873–880. https://doi.org/10.1016/j.ecolecon.2010.12.007
Kalwij A, Verschoor A (2007) Not by growth alone: the role of the distribution of income in regional diversity in poverty reduction. Eur Econ Rev 51(4):805–829. https://doi.org/10.1016/j.euroecorev.2006.06.003
Kim D-H, Wu Y-C, Lin S-C (2022) Carbon dioxide emissions, financial development and political institutions. Econ Chang Restruct 55(2):837–874. https://doi.org/10.1007/s10644-021-09331-x
Kirby P, O'Mahony T (2018) The Political economy of the low-carbon transition. Springer, Berlin. https://doi.org/10.1007/978-3-319-62554-6
Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28
Leichenko R, Silva JA (2014) Climate change and poverty: vulnerability, impacts, and alleviation strategies. Wires Clim Change 5(4):539–556. https://doi.org/10.1002/wcc.287
Malerba D (2020) The trade-off between poverty reduction and carbon emissions, and the role of economic growth and inequality: an empirical cross-country analysis using a novel indicator. Soc Indic Res 150(2):587–615. https://doi.org/10.1007/s11205-020-02332-9
Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R. (2018). Global warming of 1.5 C. In: An IPCC special report on the impacts of global warming of 1(5)
Mendelsohn R, Dinar A, Williams L (2006) The distributional impact of climate change on rich and poor countries. Environ Dev Econ 11(2):159–178. https://doi.org/10.1017/S1355770X05002755
Narloch U, Bangalore M (2018) The multifaceted relationship between environmental risks and poverty: new insights from Vietnam. Environ Dev Econ 23(3):298–327. https://doi.org/10.1017/S1355770X18000128
Oxfam. (2020). Confronting carbon inequality: putting climate justice at the heart of the COVID-19 recovery. Oxfam International. http://hdl.handle.net/10546/621052
Pesaran MH (2015) Time series and panel data econometrics. Oxford University Press, Oxford
Pettifor, A. (2020). The case for the green new deal. Verso Books, London

Ravallion M, Heil M, Jalan J (2000) Carbon emissions and income inequality. Oxf Econ Pap 52(4):651–669. https://doi.org/10.1093/oep/52.4.651
Roodman D (2009) How to do Xtabond2: an introduction to difference and system GMM in Stata. Stata J Promot. Commun Stat Stata 9(1):86–136. https://doi.org/10.1177/1536867X0900900106
Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality: time-series and cross-country evidence. World Bank Publications, Washington
Singh T (2022) Economic growth and the state of poverty in India: sectoral and provincial perspectives. Econ Chang Restruct 55(3):1251–1302. https://doi.org/10.1007/s10644-021-09345-5
Soener M (2019) Profiting in a warming world: investigating the link between greenhouse gas emissions and capitalist profitability in OECD states. Sociol Forum 34(4):974–998. https://doi.org/10.1111/socf.12559
Stockhammer E (2015) Rising inequality as a cause of the present crisis. Camb J Econ 39(3):935–958. https://doi.org/10.1093/CJE/BET052
Sydsaeter K, Hammond P, Strom A, Carvajal A (2016) Essential mathematics for economic analysis, 5th edn. Pearson Education, London
Thombs RP (2021) In-and-beyond state power: how political equality moderates the economic growth-CO 2 emissions relationship, 1990–2014. Sociol Q 62(3):528–547. https://doi.org/10.1080/00380253.2020.1776174
Timmons Roberts J, Grimes PE (1997) Carbon intensity and economic development 1962–91: a brief exploration of the environmental Kuznets curve. World Dev 25(2):191–198. https://doi.org/10.1016/s0305-750x(96)00104-0
Tol RSJ (2009) The economic effects of climate change. J Econ Perspect 23(2):29–51. https://doi.org/10.1257/jep.23.2.29
Tomaskovic-Devey D, Lin K-H, Meyers N (2015) Did financialization reduce economic growth? Soc Econ Rev 13(3):525–548. https://doi.org/10.1093/ser/mwv009
United Nations Development, P. (2007). The 21st century climate challenge. Palgrave Macmillan UK, pp 19–69. https://doi.org/10.1057/9780230598508_2
USGCRP. (2018). Impacts, Risks, and adaptation in the United States: the fourth national climate assessment, Volume II. https://nca2018.globalchange.gov/
Wooldridge JM (2009) Introductory econometrics: a modern approach (Fourth ed.). South-Western
Zimmermann M, Pye S (2018) Inequality in energy and climate policies: assessing distributional impact consideration in UK policy appraisal. Energy Policy 123:594–601. https://doi.org/10.1016/j.enpol.2018.08.062