The Roles of Poverty and Inequality as Factors in the Impact of Climate Change

by

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DECLARATION

This thesis is primarily based on my published paper titled ‘Does growth reduce poverty? The mediating role of carbon emissions and income inequality’ in *Economic Change and Restructuring* 56, 3309–3334 (2023), https://doi.org/10.1007/s10644-022-09462-9. As the first and corresponding author, I made substantial contributions to the conceptualization, data curation, formal analysis, methodology, and writing of the original draft. My supervisor also provided contributions, including assistance with the writing, editing (redrafting the final manuscript), and structuring of the sections.

In this thesis, I expand on the paper, incorporating a stronger sociological component that highlights climate justice at an international level, both between countries and within countries. It recognizes the vulnerability of the poor in low-income countries to the consequences of climate change. The research suggests that addressing income inequality is crucial in conjunction with climate action because income inequality serves as the underlying cause of the climate consequences faced by the poor.

Availability of data and materials:

The materials available include the original dataset, cleaned dataset, and the running code. These resources are made available under the Creative Commons Zero v1.0 Universal license. The repository for this project can be found at

https://github.com/duongkhanhk29/CLIMATEQUAL.

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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. I explore the prospects of balancing these development goals and their consequences using an international dataset, and generalized method of moments estimators. I find that although economic development reduces poverty, carbon emissions (from carbon-intensive growth) coupled with inequality, exacerbates poverty. Secondly, I 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. Lastly, my analysis reveals that the impact of emissions on poverty is more pronounced at higher poverty bands, particularly among individuals teetering on the edge of poverty. This could be attributed to the heightened vulnerability of their assets to climate change-induced risks. Conversely, those at the bottom end of the poverty spectrum may have no assets that could be affected by climate stressors. These findings suggest that international policies aimed at achieving globally equitable emissions reduction should take into account the potential for disproportionate negative impacts on the impoverished population within a country.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to the Irish Research Council (IRC) for funding my research project. The IRC scholarship has been critical to my research career, allowing me to enter a new world after a long period of self-doubt and disorientation. This scholarship is more than just a grant to me; it is a recognition that helps me regain my self-confidence and passion for research. And, above all, I adore Ireland, where I can find my true love for research, a fantastic supervisor, and the best landlord.

I found my supervisor (Dr. Eoin Flaherty) in the most difficult circumstances - the serious pandemic and my self-isolation in Vietnam. My first emails with him were sent in the middle of the night in Vietnam while I was recovering from a severe fever. When I was debating whether to pursue a career in economics or sociology, he encouraged me to ‘do research you love’ from the start. What I liked best about him was that he encouraged independent thinking rather than negating and directing it, as some of my academic fellows do.

I did not know much about any department other than Maynooth University's Department of Sociology, but I had heard many stories from my research fellows all over Ireland, and I was proud to have a highly friendly and supportive home department with wonderful academic staff: my head of Department (Prof. Mary P. Murphy), my first lecturer in Ireland (Prof. Pauline Cullen), and dedicated admins (Trish and Áine). Furthermore, I was fortunate to meet great research fellows from various backgrounds, particularly Robert Keogh (in the Geography Department), who shared the same research interest in sustainable development, and Ciarán Nugent (an economist at the Nevin Economic Research Institute), who gave constructive comments for my research papers.

As an international student, I have often felt lost and lonely. It was extremely difficult for me to integrate into a new environment with a different language during the first year. And I would like to thank my best landlord, Peadar Ó Fearghaile, who is also my English teacher and psychological consultant, for everything he has done for me. I would also like to thank my Vietnamese friends, who have always been by my side during my ups and downs. Finally, I would like to express my gratitude to all the lovely and friendly Irish people who make me feel as if I am living in a second home.

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CHAPTER 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 its exacerbation is 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' are somewhat vague with respect to their simultaneous impact on the 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; Jorgenson et al., 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 formalised 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 other 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 my theories and models must be capable of accounting for how they impact on each other in complex ways.

With regard to poverty, the poor in 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 the 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 exhibit a disproportionate impact on emissions, such that the top 10% of earners accounted for over half of cumulative global emissions from 1990-2015 (Oxfam, 2020b). Inequality is thus central not only to understanding the disproportionate impacts of climate change, but also its root causes.

The two next sections of this thesis (**Background theories** and **Literature review**) provide 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 I later demonstrate, partially hinders the beneficial effect of growth on poverty reduction. From here, I pose the question of how economic growth can be expected to reduce poverty, given the mediating role of carbon emissions and inequality – two factors conventionally conceptualised as endogenous to the process of economic development. To answer this question, I 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** section presents the main results of my 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, I find that carbon emissions impact poverty through the mechanism of inequality, rather than from economic development alone. I also find important differences when repeating my modelling exercise on two sub-datasets of rich and poor countries, and at different levels of poverty. Here, I find important differences in 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.

CHAPTER 2. BACKGROUND THEORIES

Growth (commonly measured by GDP per capita in level or difference) has long been the centre of socioeconomic policies relating to poverty alleviation (Dollar et al., 2016; Dollar & Kraay, 2002), health-enhancement (Olsen & Dahl, 2007; Wilkinson, 1992), and happiness-raising (Easterlin, 2015; Quispe-Torreblanca et al., 2021; Stelzner, 2022). In order to achieve economic growth, countries have attempted to take advantage of globalisation which made East Asia Miracle (Stiglitz, 1996) in the last decades; however, this pie (referring to benefits of globalisation) was disproportionally shared between countries and within a country – which is increasingly widening global inequality. According to the Elephant Curve developed by Lakner and Milanovic (2013), middle-income groups in emerging countries and the super-rich in developed countries benefit the most from globalisation, while other income groups benefit little or almost none (Alvaredo et al., 2018).

Nevertheless, growth alone was 'still good for the poor' (Dollar et al., 2016) until climate change (mainly attributed to carbon-intensive strategies) became an alarming problem for humanity (Masson-Delmotte et al., 2018). In fact, despite a negligible impact on the whole economy (Hallegatte et al., 2018; Islam & Winkel, 2017), climate change significantly impacts the poor's livelihood (Jafino et al., 2020; USGCRP, 2018). It is an injustice that the poor – the least contributors to this phenomenon – are the most vulnerable to climate change consequences (Hallegatte et al., 2018; Oxfam, 2020b). Therefore, dealing with climate change is not only ecological but also socioeconomic – which challenges carbon-centric measures with their focus on reducing carbon emissions only. In fact, inequality fuels climate change (Green & Healy, 2022) and exacerbates its consequences (Islam & Winkel, 2017).

2.1. Is growth needed to alleviate poverty?

Research has firmly established that economic growth is a key driver of poverty reduction, but it has also recognized the significant potential of reducing inequality in the pursuit of lower poverty rates (Basu et al., 2019; Bourguignon, 2003; World Bank, 2006). While economic growth remains crucial, addressing inequality has gained prominence as an essential strategy for combating poverty. Recognizing that reductions in inequality can complement and enhance poverty reduction strategies underscores the need for comprehensive approaches. Simultaneously pursuing robust economic growth and targeted measures to reduce inequality enables societies to work towards more sustainable and inclusive development. This holistic approach ensures that the benefits of progress are widely shared, particularly among the most vulnerable segments of society. Several studies have contributed to this growing body of evidence.

In a comprehensive analysis conducted by Bergstrom (2020), the dynamics of extreme poverty rates across 135 countries from 1974 to 2018 were examined. The study revealed that approximately 90 percent of the variation in poverty rates could be attributed to changes in GDP per capita. However, the remaining portion was influenced by changes in inequality. Interestingly, the research highlighted that a 1 percent decline in inequality, measured as the standard deviation of log income, had a more pronounced impact on reducing poverty than a 1 percent increase in GDP per capita for most countries in the sample. These findings suggest that while economic growth has historically been the primary force behind poverty reduction, addressing inequality can have a complementary and potentially transformative effect.

Additionally, Dollar et al. (2016) conducted an updated analysis of the systematic relationship between average growth and the growth of the poorest segments across 151 countries from 1967 to 2011. Their study reiterated the findings of Dollar and Kraay

(2002), emphasizing that income in the poorest deciles exhibited proportional changes relative to average incomes. Furthermore, their research revealed that the income shares of the poorest 20th and 40th percentiles remained relatively stable over time. These findings highlight the potential impact of growth-enhancing policies in lifting the average income of the lowest deciles of the income distribution, thereby contributing to poverty reduction efforts.

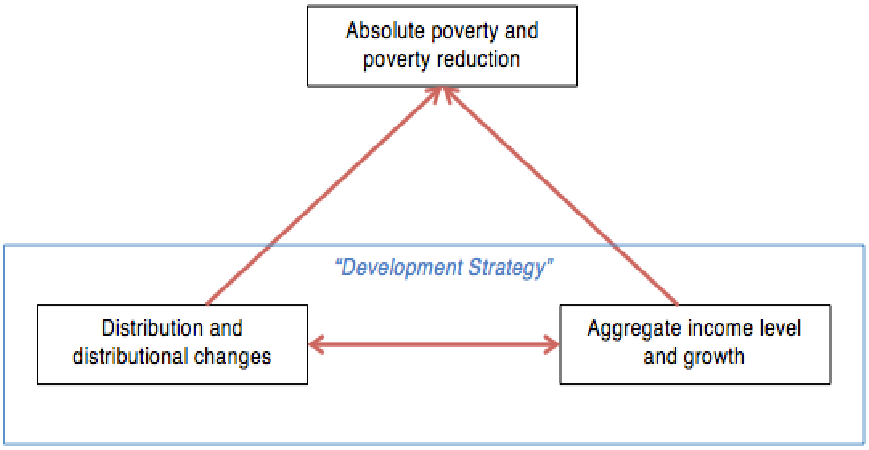

Figure 2-1. The Poverty-Growth-Inequality Triangle.

The Poverty-Growth-Inequality Triangle is a framework that illustrates how a nation's poverty levels are influenced by its income growth and income inequality. The lower points of the triangle fall under the 'development strategy' category, as the combination of policies needed to alleviate poverty is dependent on the interplay between growth and inequality.
Source: François Bourguignon (2003)

One relevant theoretical framework that promotes both growth and reduces inequality to alleviate poverty is the Poverty-Growth-Inequality Triangle (2003). Introduced by François Bourguignon, the former Chief Economist of the World Bank, this conceptual framework acknowledges the interrelationships between poverty, economic growth, and income inequality (see **Figure 2-1**). Economic growth plays a crucial role in reducing poverty by creating job opportunities, increasing incomes, and improving living standards. However, the impact of economic growth on poverty reduction can be hindered by high levels of income inequality. Concentration of growth's benefits among a privileged few exacerbates disparities and limits the potential for poverty alleviation. Conversely, income inequality can impede economic growth and perpetuate poverty by impeding social mobility, limiting access to education and healthcare, and undermining social cohesion. These factors hinder essential drivers of sustainable economic growth, such as human capital development, innovation, and entrepreneurship.

The Poverty-Growth-Inequality Triangle can be represented as a diagram with three interconnected corners: absolute poverty, inequality, and growth. The arrows extending from each corner depict the causal relationships between these factors. According to the model, both inequality and growth influence each other and have an impact on absolute poverty. Analytical frameworks, such as Bourguignon's model, use indicators such as per capita income (GDP per capita) to measure growth and the Gini Index to gauge inequality. By understanding the interactions and dependencies within the Poverty-Growth-Inequality Triangle, policymakers can develop more effective strategies to address poverty and inequality while fostering sustainable economic growth.

2.2. The two sides of growth: Who receives the benefits?

Growth has long been seen as a ‘panacea’ for poverty alleviation, especially in developing countries (World Bank, 2006). However, ‘growth alone’ policies in fact are not the best cures for poverty (Basu et al., 2019), but should go in hand with curbing inequality (Bourguignon, 2003). In the context of environmental problems in general and climate change in particular becoming more and more serious, ‘just promoting growth’ has ceased to be appropriate for the poor, the most vulnerable to climate shocks and stressors (Hallegatte et al., 2018). The role of curbing inequality in poverty reduction policies (Bourguignon, 2003) and along with climate mitigation policies (Rao et al., 2017) is highlighted by scientists. From a social perspective, the question of whether mere economic growth is sufficient to improve the welfare of all members of a society is dependent on how evenly the income distribution in society (Cerra et al., 2021). After all, development policies are generally aimed at a happy society, but economic growth alone actually only brings immediate, non-long-term happiness to the community (Easterlin, 2015). In today's digital age, technology and globalization are seen as the main drivers for economic growth (World Bank, 2008), but their distributional impacts on society remain a problem for policymakers (Cerra, 2021; Korinek et al., 2021). There will always be winners and losers in this development, and the increase in inequality is inevitable (Jaumotte et al., 2013). Therefore, restraining inequality and sustaining growth is ‘two sides of the same coin’ (Berg & Ostry, 2017).

In this section, I discuss Thomas Piketty's book ‘Capital in the Twenty-First Century,’ which addresses the issue of increased global inequality and advocates for its reduction. Piketty (2014) argues that inequality is not solely a result of economics or technological change, but rather has its roots in ideology and politics. In his influential book, Piketty argues that, in capitalist economies, the rate of return on capital (r) tends to exceed the overall economic growth rate (g) over the long term. This means that the owners of wealth, who earn returns on their capital, see their wealth grow at a faster pace than the income earned by workers, which is tied to the overall growth of the economy. The concept is rooted in the fundamental dynamics of capitalism. Those who possess capital, such as financial assets or property, can generate income through the returns on their investments. This can include profits from businesses, dividends from stocks, or interest from bonds. Meanwhile, the labour income earned by workers is generally tied to their wages or salaries, which are influenced by factors such as productivity, labour market conditions, and bargaining power. Piketty's analysis suggests that when the rate of return on capital is greater than the overall growth rate, wealth concentration tends to increase over time. This is because the wealth-owners' assets grow at a faster rate than the income earned by workers, leading to a widening gap between the rich and the rest of society.

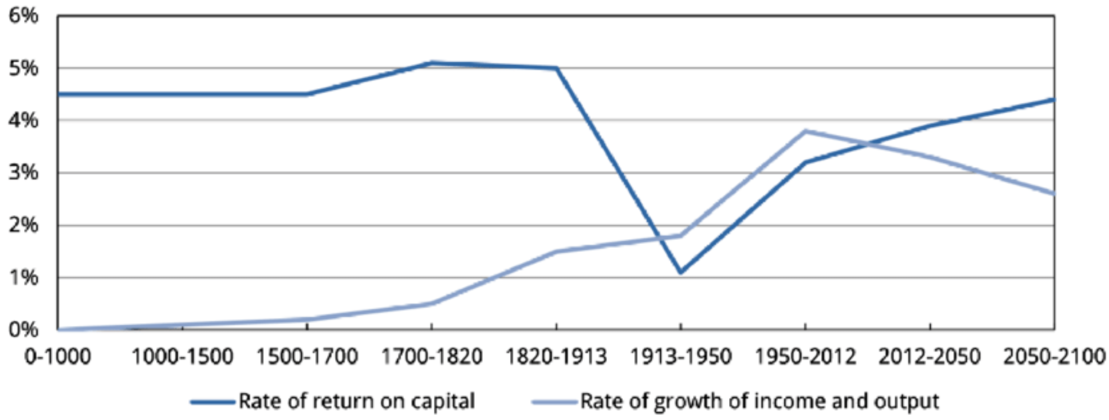

Figure 2-2. After-tax capital returns and global growth rates until 2100

Source: Capital in the Twenty-First Century by Thomas Piketty (2014)

To support his argument, Piketty (2014) presents historical data from various countries, spanning several centuries, to demonstrate the long-term trends in wealth and income distribution. He finds that periods of high economic growth, such as the post-World War II era, can temporarily reduce inequality. However, over the long run, the tendency for r to exceed g reestablishes and reinforces wealth concentration. The evidence Piketty presents includes a graphical representation of the after-tax rate of return on capital compared to the overall growth rate at the global level until 2100. This data suggests that if the rate of return on capital remains consistently higher than the growth rate, wealth inequality is likely to continue increasing, exacerbating economic disparities within societies. Piketty's work has sparked extensive debates among economists, policymakers, and the general public. It has prompted discussions about the consequences of rising inequality, potential policy interventions to address the issue, and the impact of wealth disparities on social cohesion and economic stability.

Figure 2-2, sourced from Piketty's book, portrays a period spanning from the aftermath of World War II to around 2010 when global inequality had the potential to decrease. However, it is crucial to acknowledge the period of globalization from 1988 to 2008, during which the benefits were unevenly distributed both between and within countries, resulting in a significant widening of the wealth gap. Christoph Lakner and Branko Milanovic's work in 2013 presented this phenomenon through the 'Elephant Curve,' a graph depicting changes in income growth from 1988 to 2008 (see **Figure 2-3**). The x-axis represents the percentiles of the global income distribution, while the y-axis reflects the cumulative growth rate percentage of income.

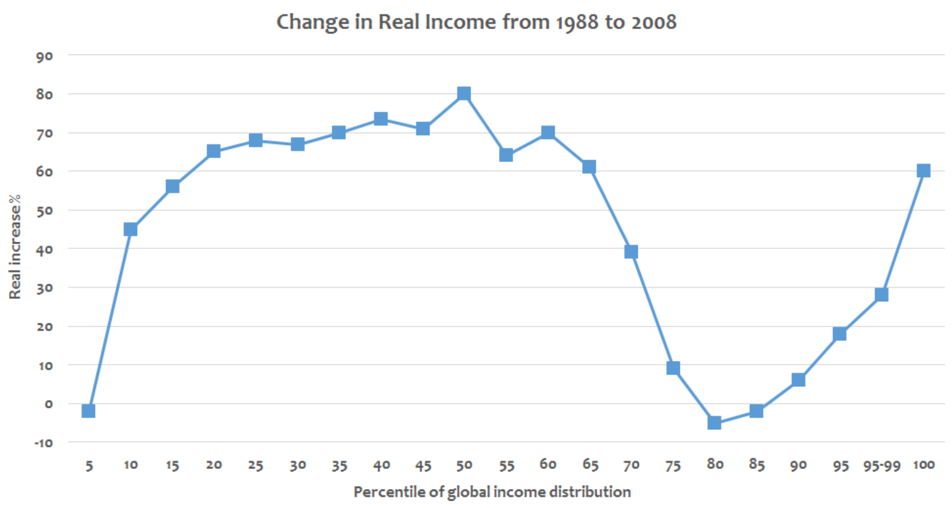

Figure 2-3. The Elephant Curve

Source: Lakner and Milanovic (2013)

The Elephant Curve represents different segments of the global income distribution. The graph shows the bottom 10% gradually rising (the tail), followed by a curve from the 10th to the 50th percentile (the torso). A sharp spike occurs from the 50th to the 60th percentile (the head). Then, there's a sharp downward curve from the 60th to the 80th percentile (the trunk), followed by an upward curve from the 80th to the 100th percentile (the tip of the trunk). The graph also includes a horizontal line representing the global mean growth rate of income. Interpreting the elephant curve in terms of globalization's impact on income inequality, I can draw four main conclusions. The very poorest have seen little benefit from globalization, mainly due to low growth in Sub-Saharan Africa. The global middle class (10th to 50th percentile) has experienced significant growth, driven by countries like China and India. The upper-middle class (60th to 80th percentile) has seen limited or no wage growth from globalization. The global elites, particularly the top 1%, have enjoyed substantial income growth, making them the ‘winners’ of globalization's income effects.

The complex relationship between economic growth and inequality was once described by Simon Kuznets (1955) as an inverted U-shaped curve (see **Figure 2-4**). By studying historical data from various countries, Kuznets observed a distinct pattern in the relationship between income inequality and economic development. According to the Classic Kuznets curve, during the early stages of economic development, income inequality tends to rise. This is due to factors such as industrialization, urbanization, and wealth concentration among a few individuals. However, as the economy advances and reaches a certain level of development, income inequality begins to decline. This decline can be attributed to factors like improved education, technological advancements, and the growth of the middle class. Graphically, the curve takes the shape of an inverted U, indicating that income inequality initially increases and then decreases as a country develops.

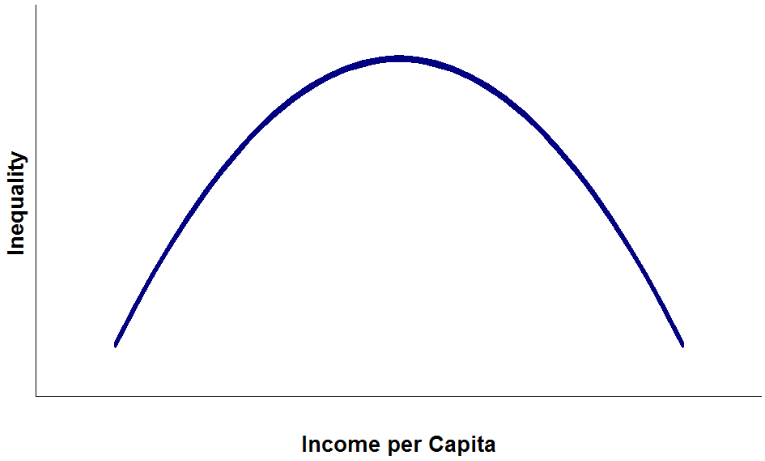

Figure 2-4. Classic Kuznets Curve

Notes: According to this hypothesis, as an economy progresses, economic inequality initially rises and then falls due to the influence of market forces. Source: Simon Kuznets (1955)

The Kuznets Curve (hereafter also referred to as the Classic/ Inequality Kuznets Curve) suggests that as a nation industrializes, the economy undergoes a shift from rural to urban areas, resulting in a disparity between rural and urban populations. This occurs as farmers migrate to cities in search of better-paying jobs, leading to a decrease in rural populations and an increase in urban populations. Initially, inequality increases as firms profit while workers' incomes rise slowly or even decline. However, once a certain level of average income is reached and industrialization is accompanied by democratization and the rise of the welfare state, inequality is expected to decrease. Kuznets proposed that inequality follows an inverted ‘U’ shape, rising and then falling as income per capita increases. He attributed this phenomenon to workers transitioning from agriculture to industry and rural workers moving to urban jobs. In both cases, inequality is expected to decrease once around 50% of the workforce has shifted to the higher-paying sector (Kuznets, 1955).

2.3. Climate justice: Who bears the costs?

Economic growth not only leads to increased inequality but also contributes to environmental pollution, particularly during the era of industrialization. Inspired by the Classic Kuznets Curve, Gene Grossman and Alan Krueger (1991) explored the relationship between economic development and environmental degradation. Their findings indicate that environmental quality initially deteriorates as a nation develops due to industrialization and increased production, resulting in higher pollution and resource depletion. However, as income levels rise further and a certain threshold is reached, countries begin to prioritize environmental protection, investing in cleaner technologies and policies. Consequently, pollution declines, and environmental quality improves, following an inverted 'U' shape represented by the Environmental Kuznets Curve (EKC) – see **Figure 2-5**. The EKC enhances my understanding of the environmental consequences of economic growth, highlighting the potential for economic development to eventually result in improved environmental quality through technological advancements and the implementation of regulatory measures.

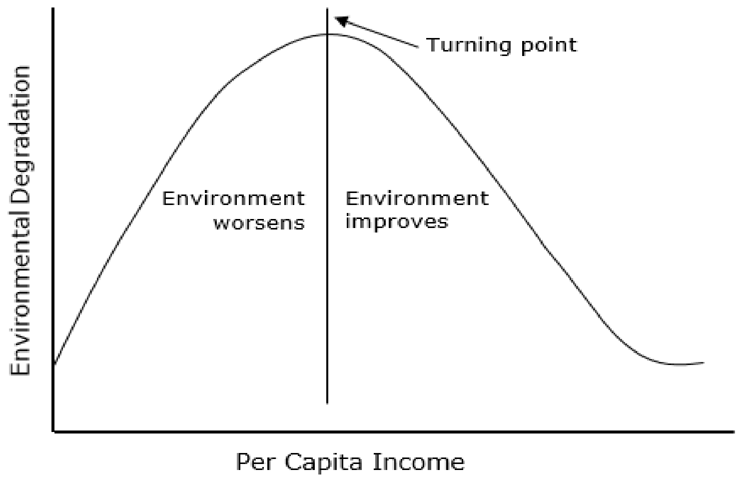

Figure 2-5. Environmental Kuznets Curve

Notes: According to this hypothesis, various indicators of environmental degradation tend to get worse as modern economic growth occurs until average income reaches a certain point over the course of development.
Source: Grossman and Krueger (1991)

Carbon-intensive growth has traditionally been seen as a solution to alleviate poverty and increase income in developing countries; however, it has also resulted in a rise in carbon emissions, the primary driver of climate change (Hubacek et al., 2017). Ironically, the most vulnerable to climate change are the impoverished, who contribute the least to carbon emissions (Oxfam, 2020b). This raises concerns about achieving climate justice, which entails a fair distribution of the burdens of climate change and its mitigation, as well as addressing responsibilities for addressing climate change (Dooley et al., 2021). Low-income communities, indigenous groups, and communities of color are particularly impacted by climate change, perpetuating existing inequalities (Jafry, 2018). Wealthy individuals, who have a higher socioeconomic status, are found to have the greatest environmental impact due to their consumption patterns and access to resources (Nielsen et al., 2021). Despite technological advancements, the growth of affluence worldwide has led to increased resource consumption and pollution emissions. Therefore, achieving sustainability requires not only technological progress but also significant lifestyle changes (Wiedmann et al., 2020).

A 2020 report by Oxfam reveals that the richest 1% of the global population were accountable for emitting over twice the amount of carbon dioxide compared to the poorer half of the world between 1990 and 2015. Despite a 60% overall increase in carbon dioxide emissions during this period, the increase among the richest 1% was three times greater than that among the poorest half. The bottom half of the population bears less than 20% of energy footprints and consumes less than the top 5% when considering trade-adjusted energy. High-income individuals tend to have larger energy footprints due to their greater financial resources, which they can freely allocate for energy-intensive goods. Notably, the most significant disproportionality is observed in the transportation sector, where the top 10% consume 56% of vehicle fuel and make 70% of vehicle purchases (Oswald et al., 2020). According to the Emissions Gap Report 2020[1] published by UNEP, in 2015, the top 1% of income earners globally generated over double the amount of carbon emissions compared to the bottom 50% of income earners (see **Figure 2-6**). This stark disparity highlights the unfortunate reality that those who are most impacted by climate change are often the least responsible for its causes (Xu et al., 2020).

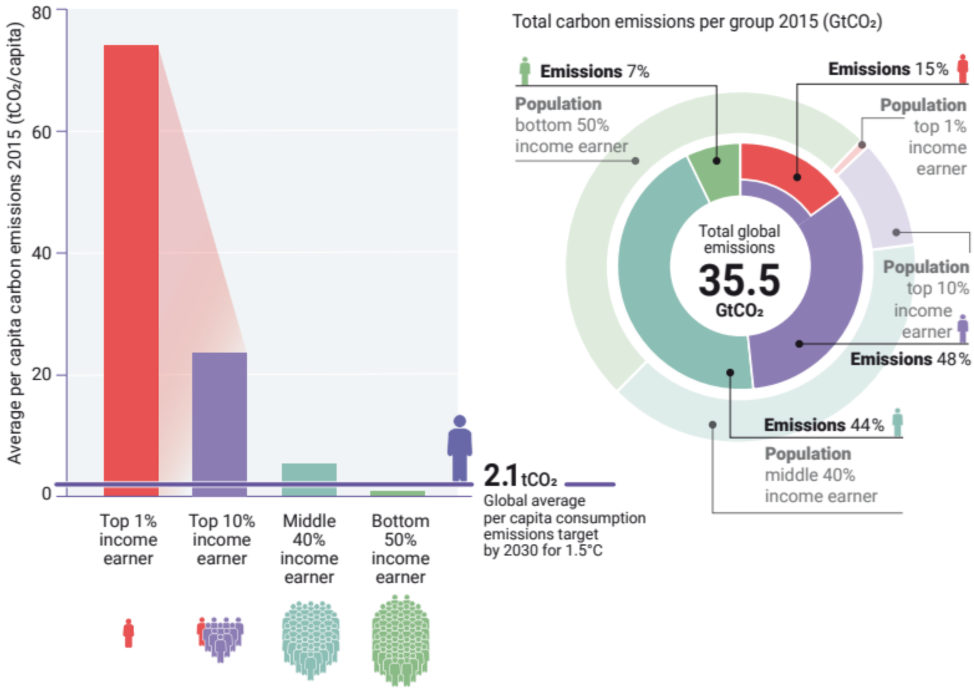

Figure 2-6. CO2 emissions in 2015 by global income groups

The top 1% income earners produce more than twice the amount of carbon emissions compared to the bottom 50% income earners.
Source: Emissions Gap Report 2020 by UNEP[2]

At the international level, the concept of unequal exchange sheds light on the disproportionate carbon emissions between countries of the Global North and the Global South (Dorninger et al., 2021). This framework recognizes the stark disparity in carbon footprints, with Global North countries emitting significantly higher levels of carbon compared to their Global South counterparts (see **Figure 2-7**). The roots of this inequality

[1] Available at https://www.unep.org/emissions-gap-report-2020
[2] UNEP = The United Nations Environment Programme.

can be traced back to historical power dynamics and the exploitative trade system (Hickel, Dorninger, et al., 2022). The carbon emissions resulting from the industrial activities and lifestyles of Global North countries have far-reaching consequences. They are the primary drivers of global warming and climate change, leading to devastating impacts such as rising temperatures, extreme weather events, and ecological disruptions. These emissions contribute to the deterioration of air quality, posing severe risks to human health and well-being. Furthermore, unequal exchange perpetuates the carbon emissions gap by maintaining an unsustainable model of resource exploitation. Global North countries, which consume vast amounts of resources and materials from the Global South, continue to perpetuate their high carbon emissions. This interdependence further exacerbates the disparities in carbon footprints between these regions, as the South bears the brunt of the environmental consequences (Hickel, 2020). Addressing carbon emissions has become an urgent imperative for global sustainability. It requires concerted efforts from all nations to transition to low-carbon and renewable energy sources, implement sustainable practices, and adopt environmentally friendly technologies.

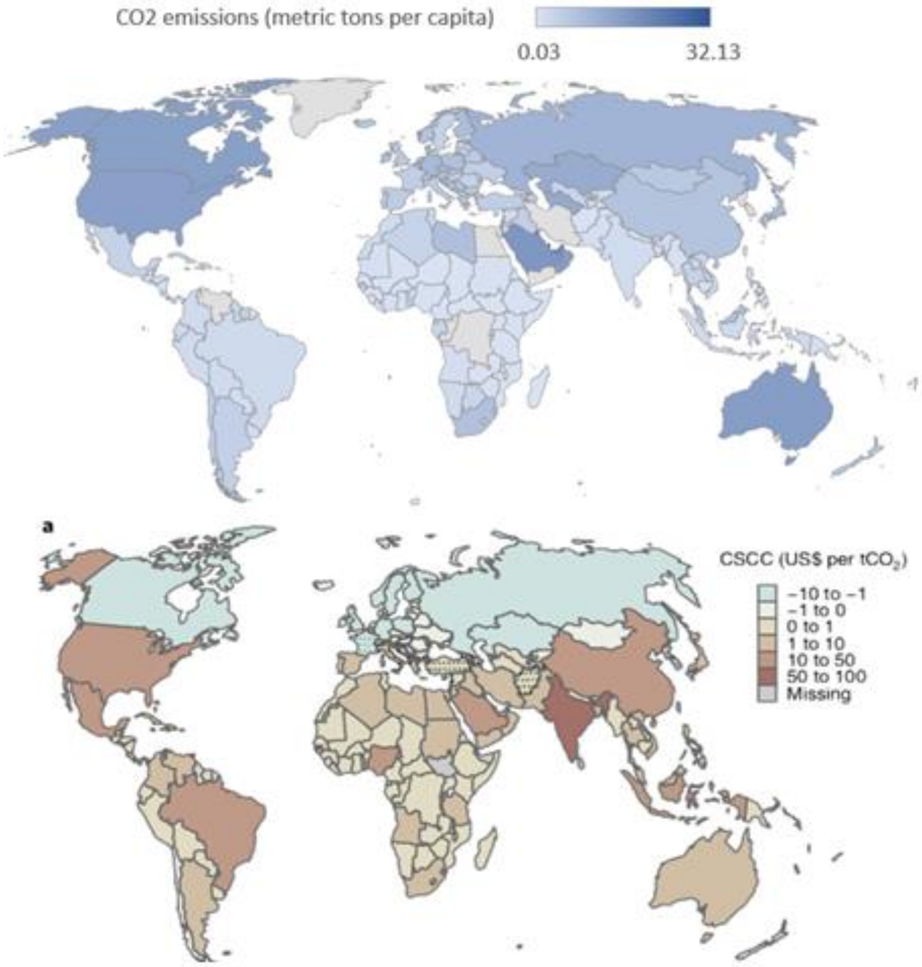

Figure 2-7. Country-level social cost of carbon

Notes: The social cost of carbon (SCC) serves as a widely used metric to estimate the economic impacts anticipated from carbon dioxide (CO2) emissions.
Source: Ricke et al. (2018)

2.4. Green growth or post growth?

In response to climate change and ecological breakdown, a policy known as green growth was initiated by South Korea in 2005 at the Fifth Ministerial Conference on Environment and Development (MCED) in Seoul. Green growth theory posits that economic expansion can be achieved while remaining compatible with ecological sustainability through technological advancements and resource substitution, aiming to decouple GDP growth from resource use and carbon emissions. However, critics such as Jason Hickel and Giorgos Kallis (2020) argue that green growth is likely to be misguided due to the lack of empirical evidence supporting global-scale absolute decoupling from resource use and the unlikelihood of achieving rapid decoupling from carbon emissions to prevent significant global warming. As a result, they propose the exploration of alternative strategies for policymakers to address these challenges effectively.

The primary challenge of green growth lies in its endorsement of continued economic expansion, contradicting the concept of post-growth that recognizes the 'limits-to-growth dilemma' (see **Figure 2-8**). This argument traces its roots back to a 1972 report that examined the consequences of exponential economic and population growth against finite resource availability through computer simulation. The report warned that without significant changes in resource consumption, there would likely be an abrupt and uncontrollable decline in both population and industrial capacity. The report employed the World3 model, which incorporated five key variables: population, food production, industrialization, pollution, and consumption of non-renewable resources. These variables were observed to increase and were assumed to continue growing exponentially, while technological advancements were projected to exhibit linear growth (Turner, 2008).

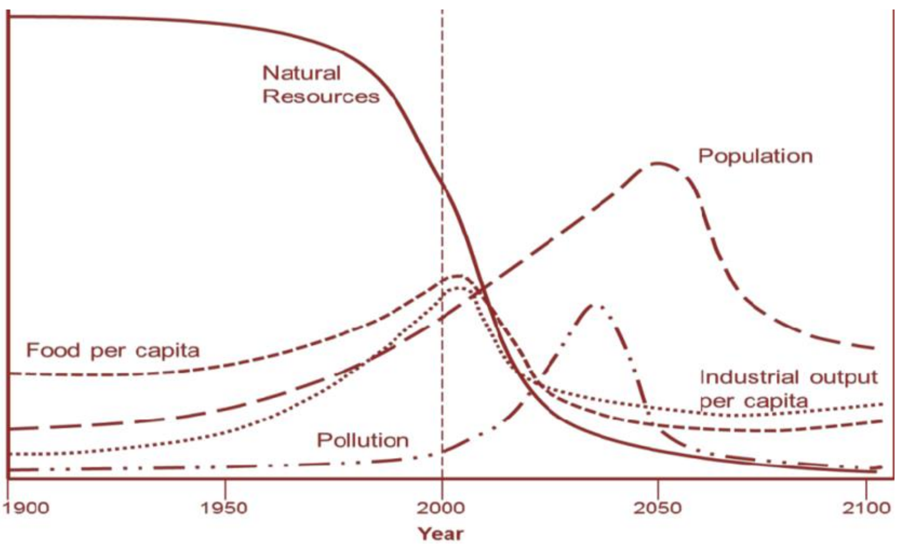

Figure 2-8. Limits-to-growth dilemma

Source: A Report for the Club of Rome's Project on the Predicament of Mankind (1972)

In response to the limits-to-growth dilemma, the post-growth concept has emerged, as discussed by Paulson and Büchs (2022). Post-growth recognizes that while economic growth can have positive impacts up to a certain threshold, identified as $25,000 GDP/capita by Pickett and Wilkinson (2010), alternative indicators and approaches are needed to enhance human well-being (Jackson & Senker, 2011). The economist Tim Jackson, in his book 'Prosperity Without Growth,' argues that beyond a certain point, material concerns alone do not contribute to true prosperity. He highlights evidence that suggests that growth does not necessarily lead to increased human well-being. 'Prosperity Without Growth' explores the intricate connections between economic growth, environmental crises, and social challenges, offering a pathway towards a sustainable economy. It calls for a re-evaluation of the concept of 'prosperity' based on evidence regarding factors that genuinely contribute to people's well-being.

Post-growth advocates aim to foster, connect, and advance existing ideas, concepts, technologies, systems, initiatives, and actions (Jackson, 2019). Unlike 'steady-state economics'[3] and 'degrowth,'[4] which propose specific responses to the limits-to-growth predicament, the term 'post-growth' adopts an evolving complex systems perspective. It seeks to comprehend and address this challenge by considering the interconnected nature of various aspects of individuals and society, including psychology, human nature, human evolution, cultures, social systems, and economies. Consequently, post-growth represents an approach that encompasses all these facets, while degrowth and steady-state economics serve as agendas within the broader post-growth framework.

[3] A steady-state economy aims to balance growth with environmental integrity by achieving equilibrium between production and population. It focuses on efficient resource use and equitable wealth distribution.

[4] Degrowth is a movement that challenges economic growth, advocating for societies focused on social and ecological well-being instead of excessive consumption and corporate profits. Practical actions may include consuming less, growing food, and repurposing vacant spaces.

2.5. Just transition to a low carbon economy

Whether it is green growth or postgrowth, the global trajectory is shifting towards a low-carbon economy. However, similar to globalization, this transition will have winners and losers, leading to significant social changes. In line with the principle of distributive justice, it is essential to ensure that the benefits and costs of this transition are shared equitably, particularly to protect the interests of those who may be adversely affected (Heffron, 2021). To address these concerns, the concept of a just transition has emerged, primarily championed by the trade union movement. It encompasses a range of social interventions aimed at safeguarding workers' rights and livelihoods during the shift towards sustainable production, particularly in the context of combating climate change and protecting biodiversity. In the realm of climate change mitigation, the Intergovernmental Panel on Climate Change (IPCC) defines a just transition as ‘a set of principles, processes, and practices that strive to ensure that no individuals, workers, places, sectors, countries, or regions are left behind in the transition from a high-carbon to a low-carbon economy’ [5]. In Europe, advocates for a just transition seek to unite social and climate justice. For instance, they work to address the needs of coal workers in coal-dependent developing regions who may lack alternative employment opportunities beyond the coal industry. By incorporating the principles of just transition, societies can foster a more equitable and inclusive approach to tackling climate change and driving sustainable development.

From an international perspective, postgrowth addresses the issue of ecological breakdown caused by excessive consumption in the global North, which disproportionately harms the South. By releasing Southern communities from the

[5] Bashmakov, I. A., Nilsson, L. J., Acquaye, A., Bataille, C., Cullen, J. M., Fischedick, M., ... & Tanaka, K. (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 11. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

pressures of atmospheric colonization and material extractivism, degrowth in the North may represent a process of decolonization in the South (Hickel, 2021). However, the strategy of decolonization may not be relevant or applicable to all developing countries (see Figure 2-9), particularly those in emerging countries such as China and Brazil that have already undergone significant economic and social development in recent decades (Hawksworth & Cookson, 2008). Green growth is the most likely future for countries that still need growth, as developing nations need it to reduce poverty (World Bank, 2021), and some developed countries have room for growth like South Korea (Swiston, 2021). Furthermore, both developed and developing countries must transition to a green economy due to the global nature of environmental problems like climate change, with wealthier countries having greater responsibility for this transition while developing countries bear more severe environmental pollution.

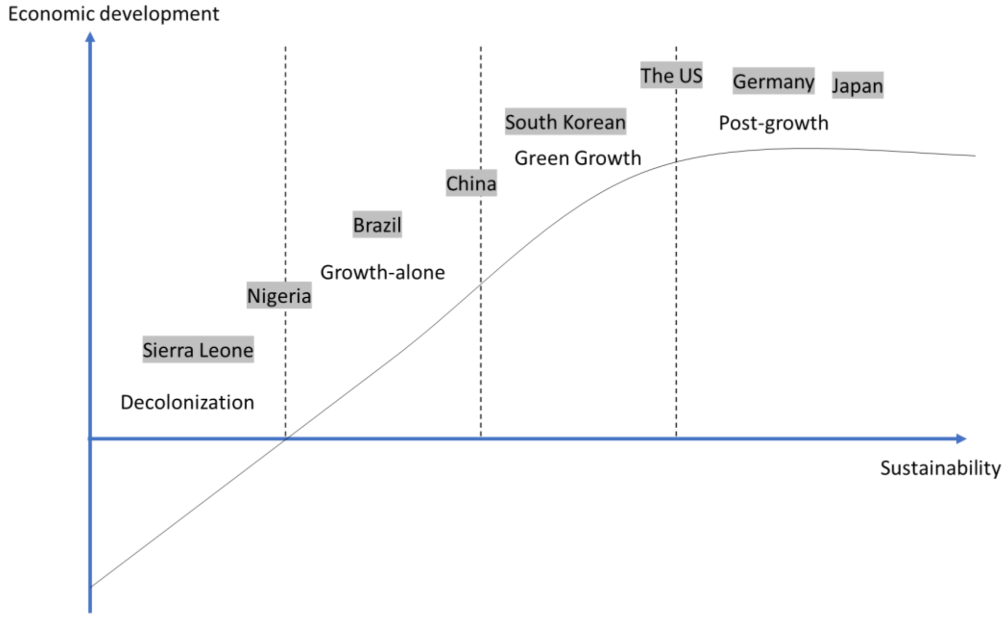

Figure 2-9. The post-growth internationalism

This illustrates potential national development strategies post-growth, including decolonization (Sierra Leone), growth-alone (Brazil), green growth (South Korea), and post-growth (Germany). Some countries may transition between strategies, like Nigeria moving from decolonization to growth-alone, and China undergoing a green transition. Post-growth may not be suitable for all high-income countries, such as the US, where a partial realization is more likely (Bliss, 2016).
Source: The author

The **Figure 2-9** illustrates potential national development strategies that can be pursued after post-growth considerations. The first strategy is decolonization, exemplified by the case of Sierra Leone. The second strategy is the pursuit of growth-alone, demonstrated by Brazil. The third strategy is green growth, based on South Korea's experience. Lastly, the figure includes the post-growth strategy observed in the European Union, with Germany as an example. It is important to recognize that some countries may be in transitional phases between different development strategies. For instance, Nigeria may have shifted from a decolonization phase to a growth-alone strategy, while China, having achieved remarkable growth rates, is currently undertaking a green transition. It should be noted that post-growth may not be suitable for all high-income countries, particularly for highly stratified societies such as the US, where social classes have distinct development goals (Bliss, 2016). In the US, a more plausible outcome is a partial realization of post-growth.

CHAPTER 3. LITERATURE REVIEW

In this section, I 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 & Kraay, 2002), for example in India (Singh, 2022) and China (Ho & 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 the upper percentiles. As such, the interactions between economic growth, climate change, and income inequality may create a vicious cycle for poverty reduction.

3.1. 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, organisations, 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 conceptualised through three mechanisms (as illustrated in **Figure 3-1**). *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 & Ajide, 2021).

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 & Bangalore, 2018). The poor in 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 emphasised by the disproportionate contribution of upper income groups to global emissions, and thus to climate change more generally (Oxfam, 2020b).

Finally, according to Leichenko and Silva (2014), the impacts of climate change can extend far beyond immediate consequences, particularly for impoverished households and communities. These long-term effects can give rise to the formation or exacerbation of poverty traps, characterized by self-reinforcing mechanisms that create formidable barriers to upward mobility and escaping the cycle of poverty. *At the household level*, the implementation of measures aimed at mitigating risks and managing the repercussions of climate change can have significant implications for a family's ability to break free from poverty. Strategies like selling assets, sacrificing educational opportunities for children, or reducing expenditures may indeed provide immediate relief and help cope with the challenges posed by a changing climate (Carter et al., 2007). However, these adaptive actions can simultaneously diminish a household's long-term capacity to overcome poverty and achieve upward mobility. *At the regional level*, the occurrence of extreme events poses a substantial threat that can lead to significant detrimental impacts on national assets, particularly critical infrastructure. Consequently, allocating resources towards implementing preventive measures, such as the construction of coastal dams, becomes essential to mitigate the potential risks and safeguard these vulnerable areas from devastating consequences (Hallegatte, 2012). However, it is worth noting that while these protective measures are crucial for the immediate protection of assets, they might also introduce a trade-off by potentially impeding the long-term economic output of the affected regions.

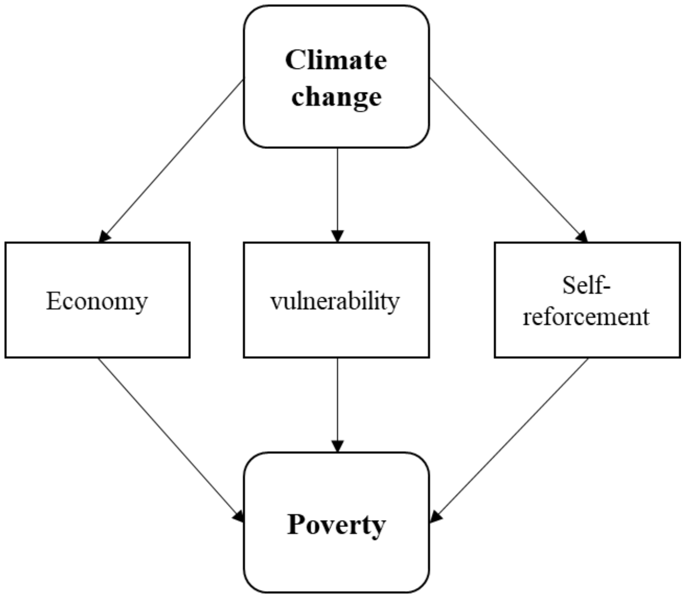

Figure 3-1. The impact of climate change on poverty through three mechanisms

Source: The author

3.2. 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 (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 & 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 **Figure 3-2**). The complexity of these factors is further compounded given the interdependence between economic growth and climate change, and the 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 the 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 & Lanza, 1999; Holtz-Eakin & Selden, 1995; Shafik & Bandyopadhyay, 1992; Timmons Roberts & Grimes, 1997). This positive view of growth is challenged by sociological studies emphasising 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-industrialisation. 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 & O'Mahony, 2018).

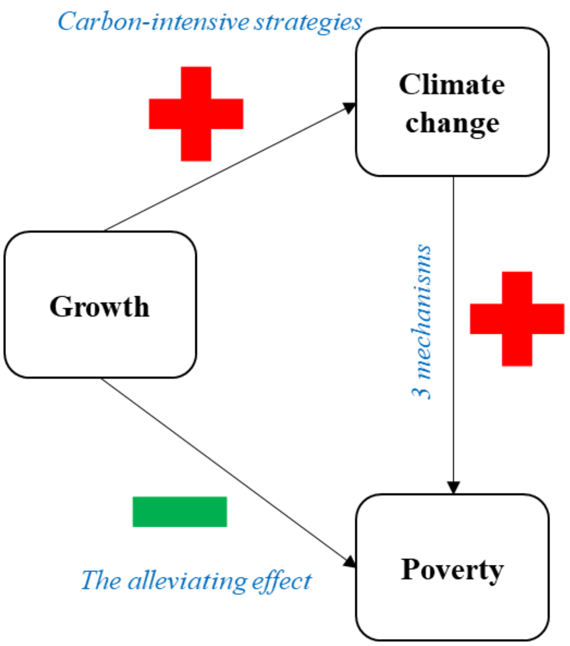

Figure 3-2. How climate change may offset the poverty-reducing effects of growth

Source: The author

3.3. 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 & 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 & Winkel, 2017). In terms of differences between countries, Mendelsohn et al.

(2006), Tol (2009), and Malerba (2020) argue 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 **Figure 3-3**). 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 non-linear. 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.

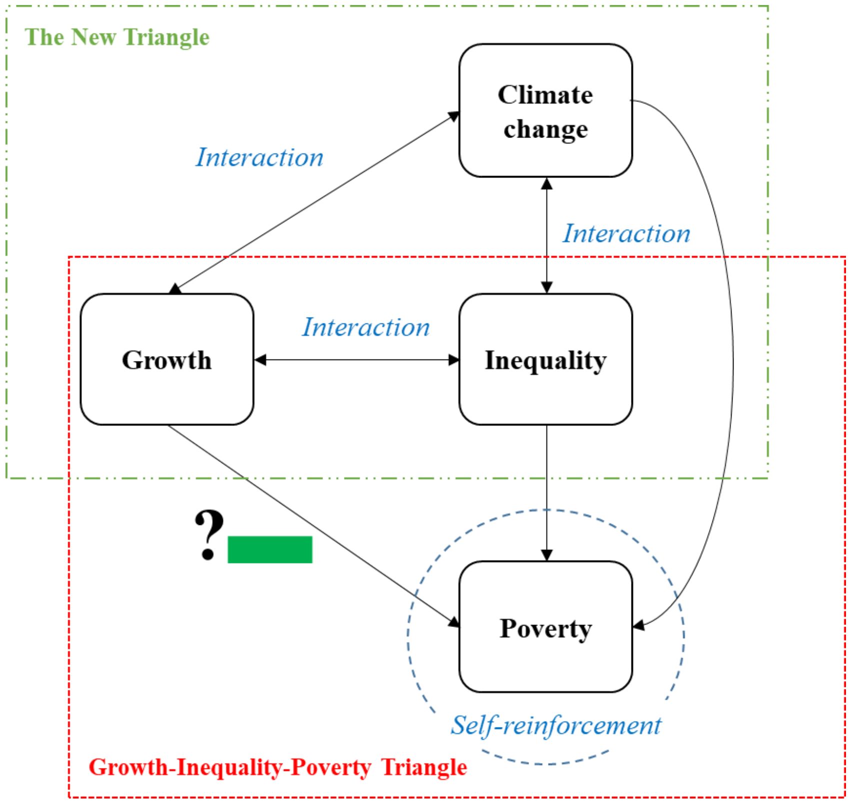

Figure 3-3. Does growth reduce poverty?

Source: The author

In summary, the influence of climate change on poverty is of interest at many levels (i.e. household, regional, and international) but its complexity leaves many outstanding questions. I am 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 **Figure 3-3**) is clearly related to the Growth-Inequality-Poverty Triangle developed by Bourguignon (2003), but not fully considered as such in previous studies. Accordingly, I 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 non-linearities 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 my models through two additional research questions: (2) *the differences between rich and poor countries in terms of poverty-alleviating policies* and (3) *the differences in the sensitivity of these policies 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. I outline my strategy for addressing this in the following section.

CHAPTER 4. DATA AND METHODOLOGY

4.1. Data and variable definition

In the following section, I build an analytical model including four key variables: poverty, economic growth, carbon emissions, and income inequality – shown in detail in Figure 4-1 below. The first relationship (#1) is the direct impact of economic growth on poverty reduction (see Dollar, Kleineberg and Kraay (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 & 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 & Silva, 2014). This study also considers two types of inequality (Islam & 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 inequality is limited to changes in effects across different levels of poverty. In addition, I also evaluate the sensitivity of the poverty trap to variation in growth (Dollar et al., 2016) based on the estimated results (further details below).

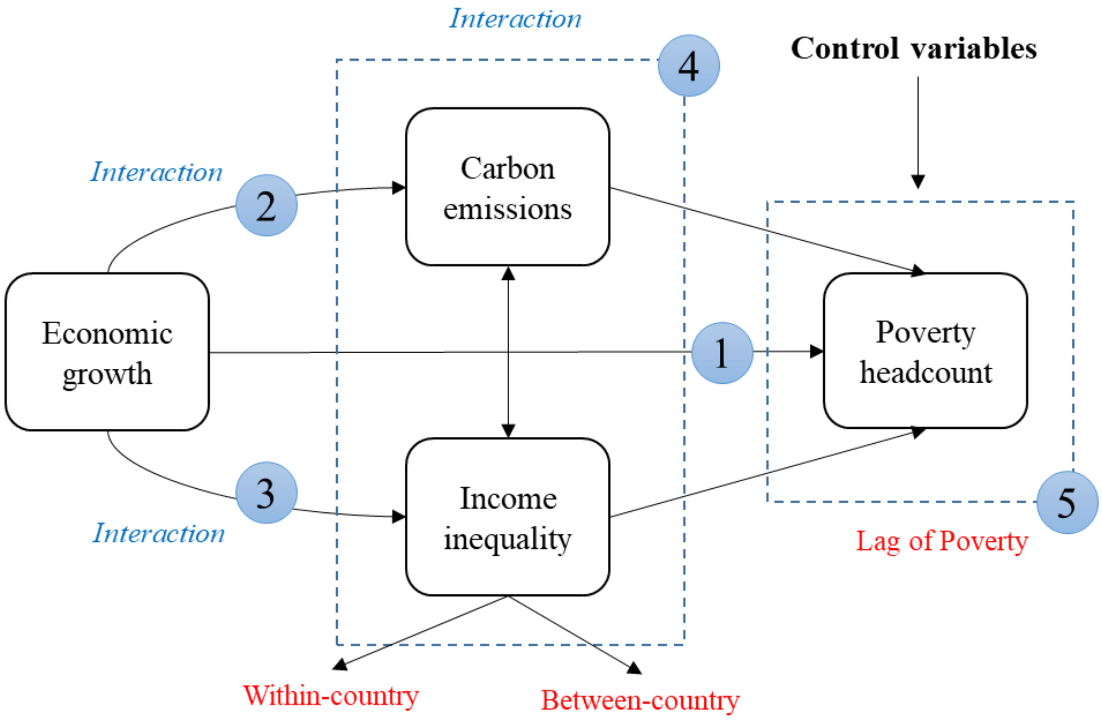

Figure 4-1. The analytical framework

Notes: Control variables = population, renewable energy consumption, and urbanization

From the above figure, I 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}$), the intercept ($\beta_0$), panel-specific effects (ϑ_i), the error term (ε_{it}), and explanatory variables – each representing a relationship as shown in **Figure 4-1**. $Poverty_{it-1}$ (a lagged dependent variable) captures the impact of the poverty trap (#5, figure 4), or how the past impact of poverty contributes to current values. As this is conceptualised 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 I 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, I 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.

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

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, I reapply my analysis to two different sub-datasets, corresponding to groups of countries classified according to World Bank criteria (see **Appendix 1**). For *within-country inequality,* I 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, I summarize all the variables used in this study in **Table 4-1** and all their values are in natural logarithmic form.

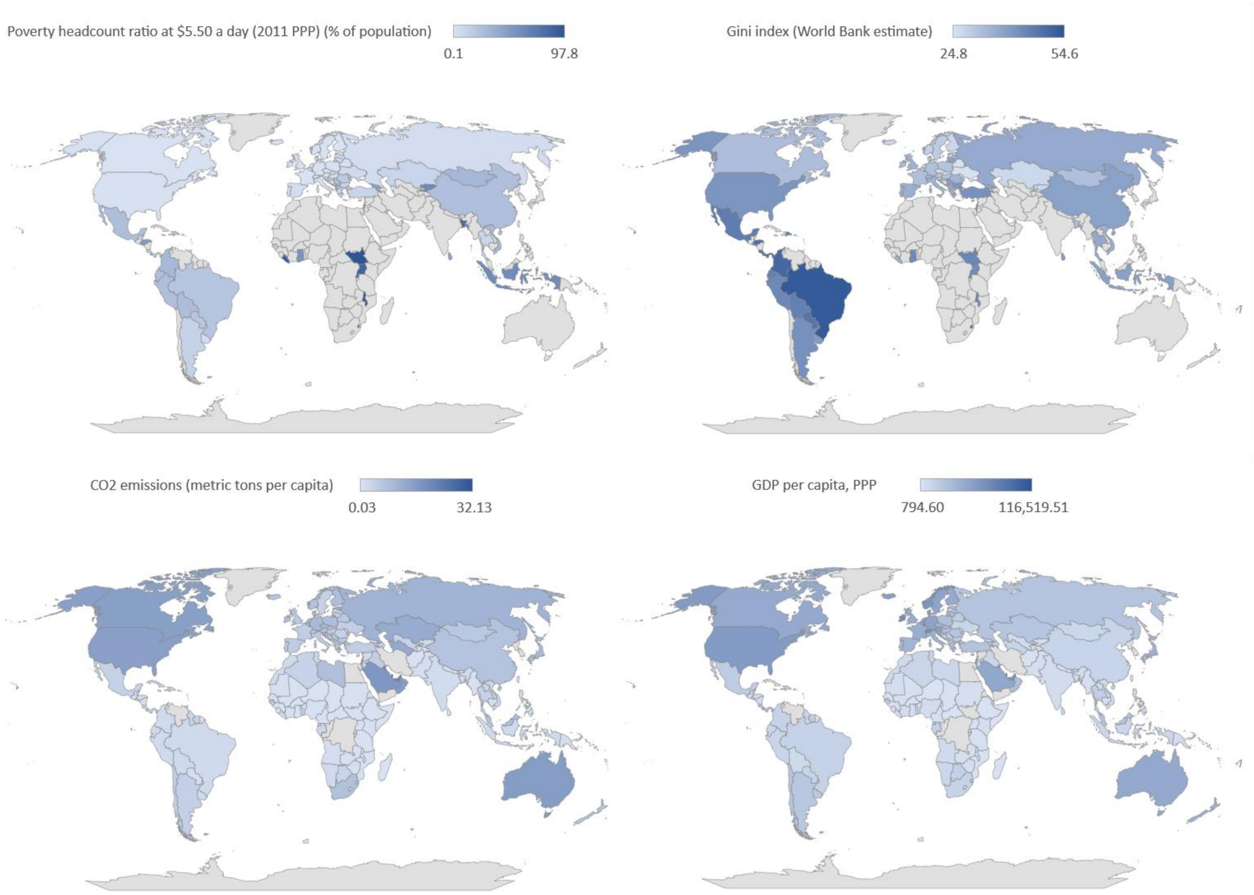

Figure 4-2. Poverty, inequality, emissions, and GDP per capita around the world

Notes: According to World Bank statistics from 2016, the poverty rate remains significantly high in certain countries in Africa and Asia. Additionally, the inequality graph reveals a substantial disparity between the wealthy and impoverished populations in the Western Hemisphere, specifically the Americas. Furthermore, there exists a striking similarity between the pattern of carbon emissions worldwide and the GDP per capita.
Source: World Bank 2016

We also address potential growth elasticity in the poverty trap reinforcement effect. Elasticity measures the percentage change of one variable with respect to the 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 equation (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 equation (1), I replace the variables with their natural logarithm, then apply the formula according to equation (2), and ultimately get a new equation (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).

$$El_x^y = \frac{dy}{dx} * \frac{x}{y} = \frac{d(\ln x)}{d(\ln y)}, (2)$$

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

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

Table 4-1. Data and variable definitions

Variables	Definitions
Inequality	Gini index (World Bank estimate)[6]
Emissions	Carbon emissions (metric tons per capita)
GDPPC	GDP per capita, PPP[7] (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)

Notes: all variables are taken in natural logarithm form
Source: World Development Indicators 2021

[6] The Gini index is a measure of income inequality within a population. It is calculated by the World Bank and ranges from 0 to 100, with 0 representing perfect equality (where everyone has the same income) and 100 representing perfect inequality (where one person has all the income).

[7] Purchasing Power Parity (PPP) is a metric used in macroeconomics to compare currencies between countries. It considers a 'basket of goods' approach to assess relative values. PPP allows economists to compare economic productivity and living standards across nations.

The data obtained from the World Bank undergoes a pre-processing stage prior to analysis. This stage involves cleaning and transforming the data to address inconsistencies, errors, or missing values, thereby ensuring the reliability and suitability of the dataset for analysis. Subsequently, categorical variables are encoded with unique identifiers to facilitate data management and analysis. For instance, numeric codes are assigned to the 'country' and 'income group' variables. The panel structure of the data is established using the 'xtset' command, which organizes observations by unique country identifier and corresponding time variable, enabling panel data analysis. Additional variables are generated through mathematical operations and transformations, including logarithmic transformations applied to variables such as poverty levels, GDP per capita, emissions, inequality, population, among others (see **Appendix 2**). These transformations serve to normalize data distribution and facilitate analysis. Interaction terms are also created by multiplying specific pairs of variables together to capture their combined effect or relationship and provide insights into their joint influence on the outcome of interest. Through these methods, the data is cleaned, transformed, and expanded with new variables and interaction terms, enabling researchers to conduct more meaningful analyses and uncover valuable insights from the dataset.

4.2. The empirical strategy

Given the nature of my 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[8] - widely understood as the correlation between the explanatory variable and the error component - likely exists in my 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 my two mediators. Multicollinearity[9] is also likely when the explanatory variables are strongly correlated with each other, in this case $Emissions_{it}$ and $Inequality_{it}$. Unit heterogeneity[10] 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 that the model specification incorporates both temporal and cross-sectional effects, heteroscedasticity[11] and serial correlation[12] are also both likely (Pesaran, 2015).

To address these issues, I refer to some estimation methods from recent studies taking a similar approach, and consider the suitability of their statistical properties in light of my data structure. Ravallion et al. (2000) used a fixed-effects model[13] to analyse the relationship between growth, carbon emissions, and income inequality in 42 countries

[8] Endogeneity refers to situations where an explanatory variable is correlated with the error term in a statistical model, leading to biased estimates. It can stem from factors like measurement error or omitted variables. To mitigate endogeneity, researchers employ techniques like instrumental variable estimation.

[9] Multicollinearity refers to high correlation between independent variables in a multiple regression model, which can impact the reliability of statistical inferences. It makes it challenging to isolate the individual effects of each variable on the dependent variable. Researchers typically detect multicollinearity by calculating correlation coefficients between predictors. If a coefficient is close to or exactly +1 or -1, it suggests the need to remove one variable if feasible.

[10] Heterogeneity refers to differences among units in economic theory and econometrics. Unobserved heterogeneity involves relevant but unobserved variables that can lead to inaccurate statistical inferences. To address this, researchers use methods like instrumental variables, multilevel models, fixed effects and random effects models, or the Heckman correction.

[11] Heteroscedasticity is when the variance of a variable is not constant across different values or over time. It can impact the precision of regression estimates, making them less reliable. Detecting heteroscedasticity involves observing the spread of residual errors. While it does not introduce bias, it affects the validity of econometric analysis and financial models.

[12] Serial correlation, or autocorrelation, occurs when errors in one time period influence future periods. This can cause issues in time-series studies, such as inefficient estimates, exaggerated goodness of fit, underestimated errors, inflated significance, and false conclusions.

[13] A fixed effects model is a statistical model where the parameters are fixed or non-random. In this model, the focus is on specific units, such as individuals or treatments, which represent the entire population of interest. The fixed effects model accounts for the average effects of variables that may influence the analysis outcome, holding them constant throughout the analysis.

over the period 1975-92. 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)[14] which has been applied in studies by 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)[15] – 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 I consider most appropriate is the Generalized Method of Moments (GMM)[16] – 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.

4.3. System generalized method of moments

Equation (1) can be rewritten as $Y_{i,t} = \theta_0 + \theta_1 Y_{i,t-1} + \theta_2 X_{i,t} + \mu_i + \epsilon_{i,t}$ (2), where $i = [1, N]$ represents many cross-sectional units and $t = [1, T]$ represents few time periods, with country-specific effects μ_i and the idiosyncratic error term ϵ_{it}. The regressors X_{it} can have different properties with respect to their correlation with the error term ϵ_{it}. If the regressors are *strictly exogenous*, it means that the variables X are

[14] Panel-Corrected Standard Errors (PCSE) is a regression model for panel data that addresses contemporaneous correlations and improves inference in linear models. It calculates estimates for cross-sectional time-series models using either OLS or Prais-Winsten regression, providing more reliable statistical analysis.

[15] The Three-Stage Least Squares (3SLS) estimator is a statistical method introduced by Zellner and Theil. It is commonly used in econometrics to address endogeneity in multi-equation models. 3SLS is a variant of the Generalized Method of Moments (GMM) that utilizes a set of instrumental variables shared across all equations. This enables simultaneous estimation and provides a solution for endogeneity issues in complex modeling scenarios.

[16] See the next section

uncorrelated with past, present, and future values of the error term. In other words, $\mathbb{E}[X_{it}\epsilon_{is}] = 0$ for all t and s. This implies that the values of X do not depend on the values of the error term at any point in time. If the regressors are *predetermined*, it means that the variables X are correlated with past values of the error term but not present or future values. In other words, $\mathbb{E}[X_{it}\epsilon_{is}] \neq 0$ for $s < t$, but $\mathbb{E}[X_{it}\epsilon_{is}] = 0$ for $s \geq t$. If the regressors are *endogenous*, it means that the variables X are correlated with past and present values of the error term but not future values. In other words, $\mathbb{E}[X_{it}\epsilon_{is}] \neq 0$ for $s \leq t$, but $\mathbb{E}[X_{it}\epsilon_{is}] = 0$ for $s > t$. The choice of whether to treat the regressors as strictly exogenous, predetermined, or exogenous depends on the nature of the data and the research question being addressed.

To account for the *country-specific effects* μ_i, we[17] employ the first difference transformation: $\Delta Y_{i,t} = \theta_1 \Delta Y_{i,t-1} + \theta_2 \Delta X_{i,t} + \Delta\epsilon_{i,t}$ (3). Afterwards, we generate instruments for the lagged dependent variable by using the second and third lags of Y, either as differences or lagged levels. Utilizing the Arellano–Bond approach, we construct instrumental variables Z_i by imposing these moment conditions on the first difference model: $\mathbb{E}\left[Y_{i,t-s}\Delta\epsilon_{it}\right] = 0$ for $s = [2, t]$. When the individual effect term exhibits high variance across individual observations, the Arellano-Bond estimator may yield poor performance in finite samples. This occurs because the lagged dependent variables become weak instruments under such circumstances. Blundell and Bond (1998) derived a condition that allows for the utilization of an additional set of moment conditions for the level model: $\mathbb{E}\left[\Delta Y_{i,t-1}\Delta\epsilon_{it}\right] = 0$ for $t = [2, T]$. Similarly, depending on the nature of the variables X, other instruments for those variables are incorporated as well. Overall, we assemble the stacked moment conditions as: $\mathbb{E}[Z_i{}'\Delta\epsilon_i] = 0$, where the instrumental

[17] When I refer to 'we' in the context of general knowledge, it includes both the author and the audience.

variables Z_i are constructed from values of X and Y. Hence, we refer to this approach as '*the method of moments*.'

The moment conditions form a system of equations with unknown coefficients θ: $\mathbb{E}[Z_i{}'\Delta\epsilon_i] = \mathbb{E}[m_i(\theta)] = 0$. It is evident that the vector of moment conditions (m_i) is larger than the vector of coefficients θ, meaning that $\mathbb{E}[m_i(\theta)]$ cannot simultaneously satisfy the condition of being equal to zero. Therefore, we aim to minimize the squared distance between the sample moment conditions and zero, which can be represented as $\|\widehat{m}_i(\theta)\|_W^2 = \widehat{m}_i(\theta)^T W \widehat{m}_i(\theta) = f(\theta)$, where W is the weight matrix of moments and m^T denotes transposition. By using a generalized metric for moment conditions $f(\theta)$, this method is referred to as '*generalized*.' The minimal value of $f(\theta)$ occurs when its derivative with respect to θ is equal to zero, i.e., $df/d\theta = 0$. Obviously, the GMM estimator depends on the choice of the weight matrix W. A commonly used proposal for the weight matrix is $\widehat{W} = \left(\frac{1}{N}\mathrm{Z'HZ}\right)^{-1}$, where Z is the instrument matrix. Under the Blundell and Bond approach for the system GMM estimator, H is equal to the identity matrix (I). The estimation generated by this method is called the one-step system GMM estimator, and its weighting matrix is denoted as $\widehat{W}_1$. The two-step estimator utilizes $\widehat{W}_2 = \left(\frac{1}{N}\mathrm{Z'}\hat{\mathrm{s}}_1\hat{\mathrm{s}}'_1\mathrm{Z}\right)^{-1}$, where $\hat{\mathrm{s}}_1$ represents the residuals obtained from the one-step estimation.

The absence of higher-order serial correlation in $\Delta\epsilon_{i,t}$ is crucial for the validity of using $Y_{i,t-2}$, $Y_{i,t-3}$, and other variables as instruments in the generalized method of moments (GMM) framework. Similarly, it is important for the instruments of predetermined and endogenous variables. To test for this, the *Arellano-Bond serial-correlation test* should be conducted. The test statistic, following an asymptotic $\mathcal{N}(0,1)$ distribution, examines the null hypothesis H_0: $Corr(\Delta\epsilon_{i,t}, \Delta\epsilon_{i,t-j}) = 0$ for $j > 0$. If the null hypothesis is rejected for j = 1 but not rejected for j > 1, it suggests that the model passes this specification test. Additionally, in overidentified models (e.g. GMM), where the number of moment conditions L exceeds the number of unknown coefficients K, it is important to test the validity of the L - K overidentifying restrictions. These tests assume that at least K instruments are valid. The *Sargan overidentification test* is commonly used for this purpose. The test statistic follows an asymptotic χ^2 distribution with df degrees of freedom, where df is equal to L - K. The Sargan overidentification test statistic $J(\hat{\theta}, W)$ is calculated as: $\left(\frac{1}{\sqrt{N}}\sum_{i=1}^{N} m_i(\hat{\theta})\right)' W \left(\frac{1}{\sqrt{N}}\sum_{i=1}^{N} m_i(\hat{\theta})\right)$, where N represents the number of observations or individuals in the sample.

In the presence of *heteroskedasticity*, panel-robust standard errors can be computed using system GMM estimation. In this case, the one-step GMM estimator remains consistent under heteroskedasticity but is no longer efficient. The two-step standard errors are biased in finite samples, so the Windmeijer finite-sample correction should be applied. The corrected standard errors are still biased but less severely. However, when using panel-robust standard errors, the Sargan overidentification test cannot be computed because the asymptotic distribution is unknown. In this study, I use the one-step GMM estimator with panel-robust standard errors, so only the Arellano-Bond serial-correlation test is applicable. It should be noted that *multicollinearity* is not a problem when using instrumental analysis, such as the method in this study, which isolates the effect of explanatory variables from group effects and other variable effects. In instrumental analysis, the focus is on the strength of the instruments rather than the correlation among independent variables. Multicollinearity among exogenous independent variables (i.e., variables not affected by endogeneity) generally does not affect the validity of the instruments or the identification strategy used in instrumental analysis. However, perfect multicollinearity among the instruments themselves can weaken their ability to address endogeneity, and system GMM will drop variables with perfect multicollinearity. In short, introducing interaction variables does not cause a bias problem in this study.

CHAPTER 5. RESULTS AND DISCUSSIONS

5.1. How effective does growth reduce poverty?

First, I visualize the relationships among variables by creating scatter plots with smoothed lines, known as LOWESS curves, to represent the relationship between different pairs of variables. Each scatter plot compares two variables by plotting their values on a graph. The x-axis represents one variable, while the y-axis represents the other variable. For example, the first scatter plot compares the logarithm of poverty at $5.5 per day with the logarithm of GDP per capita. The LOWESS curve represents a smoothed line that approximates the relationship between these two variables. Similarly, the other scatter plots and LOWESS curves depict the relationships between variables such as poverty and emissions, poverty and inequality, emissions and GDP per capita, and inequality and GDP per capita. These plots help us understand the patterns and trends in the data, visually identifying any potential relationships or correlations between the variables being studied. **Figure 5-1** depicts the relationship between poverty and GDP per capita, as well as the relationship between poverty and carbon emissions, as sharply convex curves. In contrast, the relationship between GDP per capita and carbon emissions appears to be linear, deviating from the expected pattern of the Environmental Kuznets Curve (EKC). The connection between GDP per capita and income inequality seems to adhere to the Classic Kuznets Curve, although it lacks clarity and requires further examination.

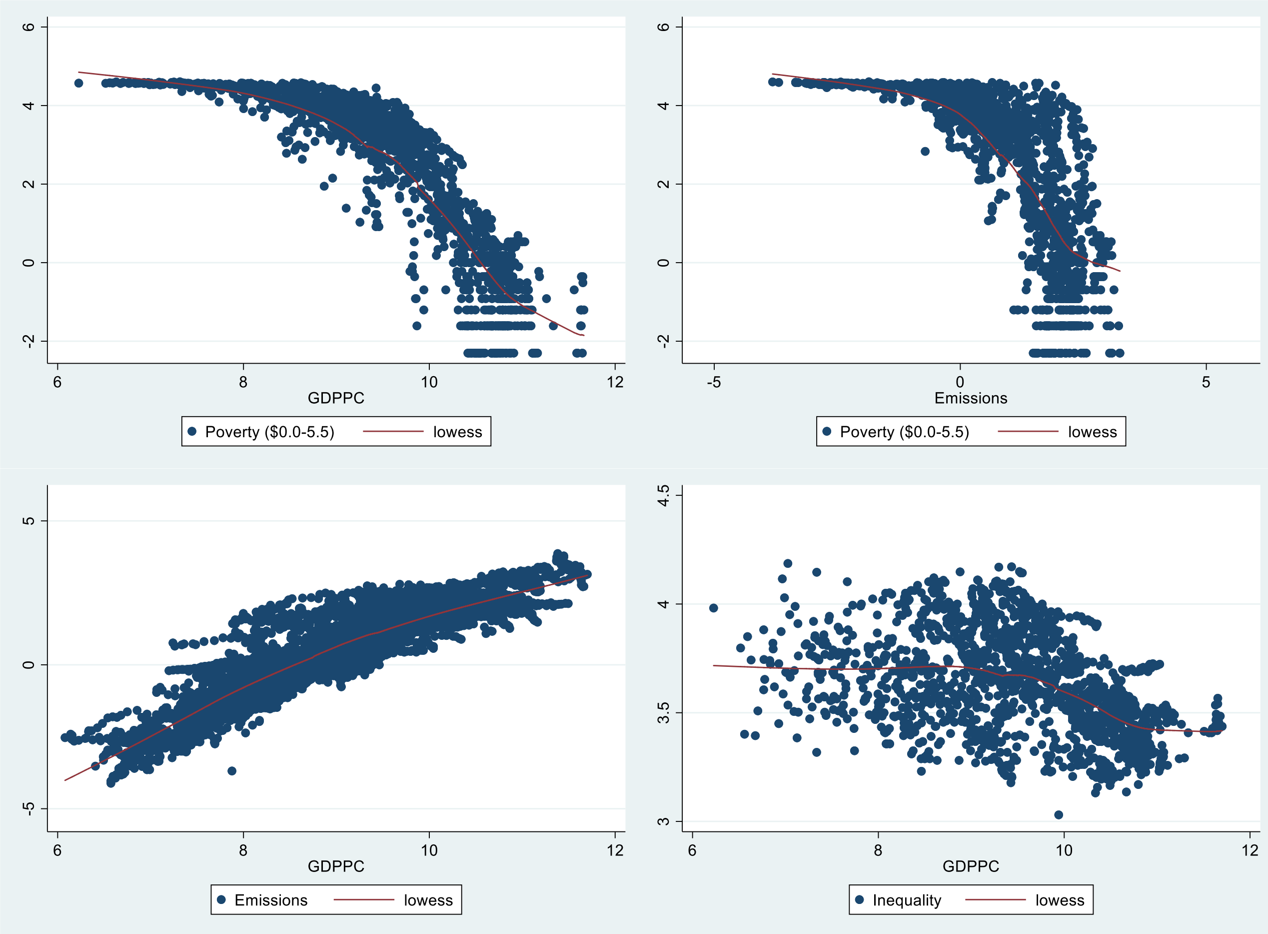

Figure 5-1. The two-way relationship among variables

Poverty is shown as a convex curve in relation to GDP per capita and carbon emissions. However, the GDP per capita and carbon emissions relationship deviates from the expected Environmental Kuznets Curve (EKC). The connection between GDP per capita and income inequality adheres to the Classic Kuznets Curve but requires further examination.
Notes: LOWESS = Locally Weighted Scatterplot Smoothing[18]*;*
Source of data: World Development Indicator 2022

Next, I examine the direct and indirect impact of economic growth on poverty rates by presenting GMM estimates for three models (**Table 5-1**, 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 (EKC) and Inequality Kuznets Curve (IKC). S1 builds on model M1 by adding the square of GDPPC to test the presence of an

[18] Locally Weighted Scatterplot Smoothing (LOWESS) is a non-parametric regression method that combines multiple models to smooth data and reveal trends or relationships not apparent from raw data.

inverted U-shape. For all three models, I 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. I 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 5-1**, 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, I 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 I 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 I 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.

Table 5-1. Estimates of direct and indirect effects

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

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

Next, I 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 5-1**). This is an expansion of model M1, with an added interaction term between emissions and inequality. I 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 5-1** 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 definition section is incorporated into model C1. Accordingly, equation (3) may be rewritten as:

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

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 to 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.

5.2. The disparity between countries

In this section, I divide the plots from **Figure 5-1** into **Figure 5-2**. **Figure 5-2** focuses on the relationships between different variables for specific groups based on high-income status. The first scatter plot and LOWESS curves compare the logarithm of poverty with the logarithm of GDP per capita, separately for the high-income group and the remaining population. Similarly, another scatter plot and LOWESS curves display the relationships between variables such as poverty and emissions, again for the high-income group and the remaining population. This figure reveals the negative relationship between poverty and GDP per capita, as well as between poverty and carbon emissions. However, these relationships exhibit different patterns across low-income and high-income country groups. In low-income countries, the negative relationship tends to be convex, indicating that the slope decreases as the national average income level increases. This suggests that the growth of lower-income countries is not as effective in reducing poverty compared to higher-income countries. On the other hand, in the group of high-income countries, a linear relationship emerges, meaning that the growth of rich countries has an equally effective impact on poverty reduction. Additionally, it is noteworthy that the mean slope of the low-income group is much smaller than that of the high-income group. Furthermore, it is important to note that the almost similar relationship between poverty and emissions, as well as poverty and GDP per capita, can be inferred from the strong positive relationship between emissions and GDP per capita in **Figure 5-1**.

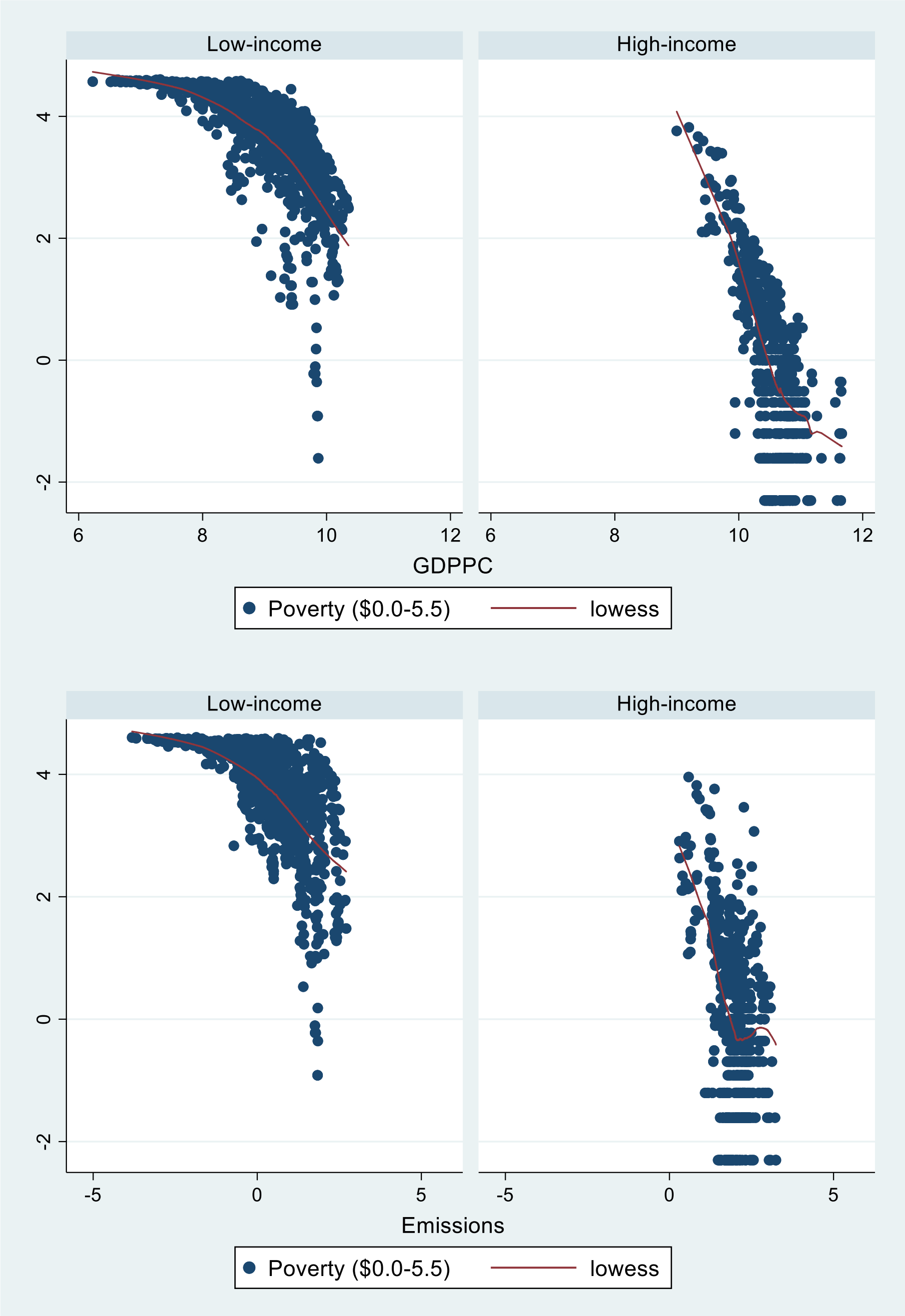

Figure 5-2. Poverty, GDP per capita, emissions by country groups

Note: LOWESS stands for Locally Weighted Scatterplot Smoothing. The data source is the World Development Indicator 2022. High-income refers to country groups classified as high-income by the World Bank, while the rest refers to low-income country groups.

To assess the disparities between low-income and high-income countries depicted in **Figure 5-2**, I conducted two-sample mean-comparison tests (t-tests) for four variables: poverty, GDP per capita, carbon emissions, and income inequality. The results of these tests are presented in **Table 5-2**. The first two columns present the mean values of these variables for the low-income and high-income groups. The third column displays the difference between the means of the two groups, while the standard errors of the mean values are shown in parentheses below the means. The t-statistics for the differences between the means are presented in square brackets below the differences. The asterisks denote the level of statistical significance of the differences, with *** indicating significance at the 0.1% level, ** indicating significance at the 1% level, and * indicating significance at the 5% level. The results of the two-sample mean-comparison tests indicate that there are statistically significant differences between low-income and high-income groups across all four variables. Notably, the magnitude of the difference in income inequality, as measured by the Gini index, is relatively small (-0.251). In contrast, low-income countries exhibit substantial disparities in both poverty rates and GDP per capita, indicating that they face greater challenges in poverty reduction and lower economic development compared to high-income countries who have significantly higher per capita carbon emissions.

Table 5-2. Two-sample mean-comparison test

	Low-income	**High-income**	**Difference**
Log Poverty $5.50	3.641	-0.0254	3.640***
	(0.851)	(1.370)	[68.59]
Log GDP per capita	8.919	10.54	-1.959***
	(0.819)	(0.396)	[-87.24]
Log Emissions	0.378	1.993	-2.407***
	(1.244)	(0.526)	[-84.59]
Log Inequality	3.719	3.470	0.251***
	(0.218)	(0.159)	[25.48]

Notes: Two-sample mean-comparison tests (ttest); standard error in (parentheses); t statistics in [parentheses]; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$;

The results of the two-sample mean-comparison tests can be linked to the concept of climate justice. Climate justice refers to the fair treatment of all people and the protection of their rights in the face of climate change. The results show that while the levels of income inequality, as measured by the Gini index, are quite similar between low-income and high-income groups, there are significant differences in carbon emissions per capita and poverty headcount ratio. High-income countries have higher carbon emissions per capita, which suggests that they have contributed more to climate change through their economic growth. At the same time, they have lower poverty headcount ratios, indicating that their populations have benefited from this growth. In contrast, low-income countries have lower carbon emissions per capita but higher poverty headcount ratios. This suggests that they have not contributed as much to climate change through their economic activities, but their populations are more likely to live in poverty. As a result, they may be more vulnerable to the negative impacts of climate change, such as extreme weather events, food insecurity, and water scarcity. These results highlight the importance of addressing climate change in a way that is fair and just for all people, regardless of their income level or geographic location.

Table 5-3. 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 x emissions	-0.0113	-0.104^{***}
	(0.0999)	(0.0383)
GDPPC x inequality	0.193^{***}	0.0127
	(0.0503)	(0.0140)
Emissions x inequality	0.0305	0.286^{***}
	(0.284)	(0.0979)
L.Poverty (\$0.0-5.5)	0.509^{***}	0.839^{***}
	(0.0473)	(0.0286)

Table 5-3. The disparity between high and low-income countries

	Poverty rate at \$5.50 per day (ln)	
	High-income	**Low-income**
Constant	7.733^{**} (3.127)	2.454^{***} (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.

Next, I present different coefficients for model C1 for two sub-datasets based on the World Bank's classification of high and low-income countries (**Table 5-3**). These models include the same dependent variable as **Table 5-1** (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. The 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, I 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.

5.3. The disparity within countries

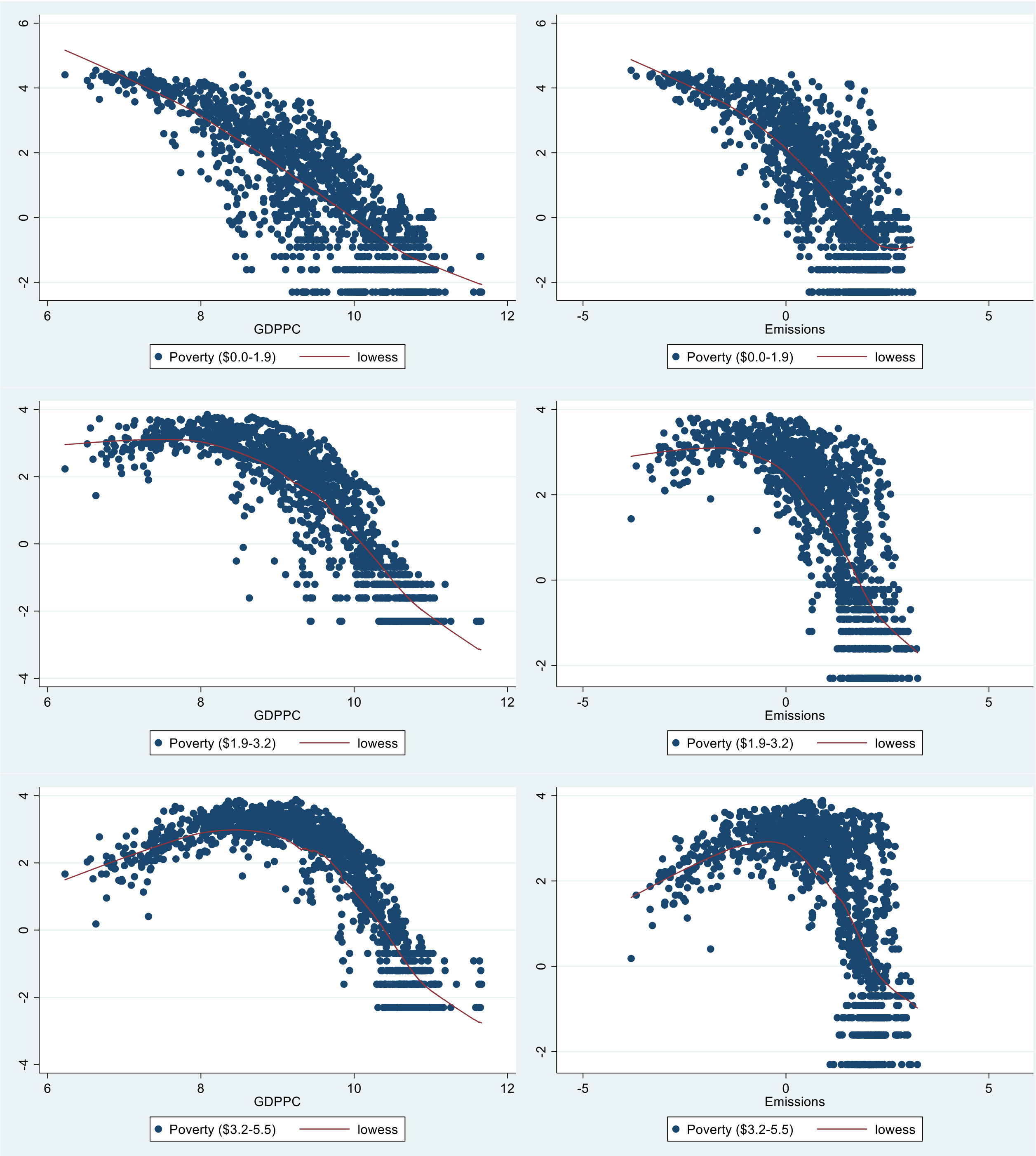

Figure 5-3. GDP per capita and emissions at different poverty lines

This section presents an analysis of the effects and disparities among the impoverished population within a country at different poverty levels. To illustrate these effects, scatter plots were created to examine the relationship between poverty and both GDP per capita and emissions across various poverty bands. The left-side scatter plots compare variables related to GDP, while the right-side scatter plots compare variables related to emissions. Each row of the analysis explores the relationship between GDP (or carbon emissions) and poverty within specific poverty bands, namely \$0.00-\$1.90 per day, \$1.90-\$3.20 per day, and \$3.20-\$5.50 per day. To provide a clearer depiction of these relationships, LOWESS curves were incorporated, enhancing the identification of potential correlations or trends within each variable set.

Figure 5-3 illustrates a noteworthy finding—the relationship between poverty and GDP per capita transitions from a linear pattern to an inverted U-curve as one moves from lower poverty bands to higher ones. This observation underscores the heterogeneity of the poverty-reducing effects of economic growth across different segments of the impoverished population. The U-shaped line in the figure reveals that economic growth does not consistently improve the well-being of the poor at all levels, particularly those on the cusp of poverty. This outcome may be attributed to the issue of carbon-intensive growth, as the relationship between poverty and emissions (depicted in the right-side plots) mirrors that of poverty and GDP per capita (the left-side plots). Such growth patterns collectively impose burdens on the environment, directly impacting the quality of life for individuals teetering on the edge of poverty (with incomes ranging from \$3.20 to \$5.50 per day). Conversely, individuals at the bottom rung of society (earning \$0.00 to \$1.90 per day) may have no assets[19] that could be adversely affected by environmental stressors.

Table 5-4. 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*** (0.198)	-0.830*** (0.153)	-0.498*** (0.150)

[19] According to the World Bank, the international poverty line is \$1.90 per person per day. People living below this line are considered to be living in extreme poverty. They are unable to meet their basic needs such as food, shelter, and clothing. They have no assets or savings and are often forced to rely on aid from others.

Table 5-4. Differences between levels of poverty

	Poverty rate at variable bands (ln)		
	$0.0-1.90	**$1.90-3.20**	**$3.20-5.50**
GDPPC x emissions	0.0984^{**}	-0.129^{***}	-0.216^{***}
	(0.0449)	(0.0408)	(0.0396)
GDPPC x inequality	0.185^{***}	0.0674^{**}	-0.00518
	(0.0376)	(0.0288)	(0.0220)
Emissions x 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.*

To further support the findings depicted in **Figure 5-3**, I investigate the effects of economic growth, carbon emissions, and income inequality on poverty at different poverty thresholds. The estimated models in **Table 5-4** are derived from model C1 but use alternative specifications of the 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, I find that two models '$1.90-3.20' and '$3.20-5.50' are not mis-specified, so I focus my reporting on these. First, I 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 band 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 lower band levels 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 bands 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 **Table 5-1**, **Table 5-3**, and **Table 5-4** – 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 5-4**).

CHAPTER 6. 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 emphasised by the disproportionate contribution (both contemporarily and cumulatively) of advanced capitalist democracies to global emissions (Oxfam, 2020b). It is widely recognised in the literature on just transitions and eco-socialism 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 & 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. My 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. One of the main contributions of this paper lies in the discovery of a 'Growth-Inequality-Emissions' triangle, thus expanding on the 'Growth-Inequality-Poverty' triangle proposed by Bourguignon (2003).

These results reveal some of these complexities, and offer a more solid evidence base from which to develop international policy. In my global models I 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). My 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 decarbonisation policies (Green & Healy, 2022; Zimmermann & Pye, 2018). In the literature, inequality reduction is recognised as a precondition in high-income countries for the adoption of redistributive carbon-focused policies aimed at curbing consumption (Kirby & O'Mahony, 2018). Here I 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, I 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, I emphasise some of the risks involved in economic adjustments toward 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 socio-economic perspective, I 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, my GMM estimates indicate that emissions have a negative impact on poverty reduction when coupled with inequality, rather than being endogenous to economic growth. This approach also confirms 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 bands are more vulnerable to climate change, and less likely to achieve equitable decarbonisation 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.

6.1. Developing countries still need growth to reduce poverty

The concept of degrowth, as proposed by researchers like Jason Hickel, Giorgos Kallis, and Tim Jackson, is a response to the dual challenge of achieving economic prosperity and environmental sustainability. It suggests that wealthy countries can create prosperity while using fewer materials and energy if they abandon economic growth as an objective. This approach, which has gained traction in recent years, can enable rapid decarbonization and stop ecological breakdown while improving social outcomes (Hickel, Kallis, et al., 2022). However, the question arises as to how developing countries, which are still struggling to alleviate poverty and improve living standards, can fit into this model? The answer lies in a nuanced understanding of growth and the measures that can facilitate a transition to a 'green growth' state.

Firstly, it is important to acknowledge that developing countries need some space for growth to alleviate poverty. This growth, however, should be guided by principles of sustainability and equity. The focus should be on 'qualitative' growth—improving the quality of life for their citizens—rather than 'quantitative' growth—increasing the output of goods and services without regard for environmental impact. Mary Murphy's work on the eco-social welfare state provides valuable insights in this regard (Murphy, 2023). She proposes transformative models of welfare change that address both social and ecological dimensions. Her concept of an eco-social welfare state includes measures beyond the economic, such as participatory income and universal basic services. Participatory income is a form of social security where people receive a basic income for participating in society (Hiilamo, 2022). This could include formal work, unpaid work such as care, volunteering, or education. It ensures that everyone contributes to society while also receiving support. Expanding this form of civic and social participation is an example of what 'qualitative growth' could look like in practice. The introduction or expansion of Universal basic services (UBS), on the other hand, refers to a range of free at the point of access, basic public services provided by a government or public institution (Coote, 2021). These services could include housing, food, healthcare, education, local transport, information access, and legal & democracy support. UBS ensures that every citizen has access to the basic necessities of life.

Finally, addressing the issue of equitable emissions reduction is indeed crucial. Rich countries, which have historically contributed more to greenhouse gas emissions, bear a responsibility to cut emissions at a faster rate than those that did not. This approach not only acknowledges historical responsibilities but also allows developing countries some leeway to grow economically while transitioning to greener alternatives. As highlighted by Rahul Tongia (2022) in his article on Brookings, 'it is unfair to push poor countries to reach zero carbon emissions too early'. Development from a very low economic capacity base inevitably means the poor must increase their emissions in the short term. Yet in the models of growth proposed by green growth advocates, this should still fit within global emissions reduction targets if high emitters reduce emissions quickly up front. Therefore, it is reasonable that governments from the developing world have called on rich countries to move faster in cutting greenhouse gas emissions and provide financial assistance to their less wealthy counterparts to cope with the climate crisis. Whilst the prospects of achieving this in light of international imbalances of political power are uncertain, this demand for clear action from the rich world before COP26, the vital UN climate talks, underscores the urgency of the situation (Harvey, 2021). In conclusion, while it is important for all countries to work towards reducing carbon emissions, it is equally important to consider the economic realities and historical responsibilities of different nations. A balanced and fair approach can ensure that all countries can contribute effectively to the global fight against climate change.

6.2. The growth of the rich is detrimental to sustainability

Economic growth is widely recognized as a necessary condition for poverty reduction. However, it is crucial to understand that not all types of growth are equally beneficial or sustainable. In particular, the wealth accumulation of the richest individuals in society can have detrimental effects on both social equality and environmental sustainability. This is a complex issue that requires careful consideration of the interplay between economic structures, wealth distribution, and environmental impact. A significant body of research, including work by renowned economist Thomas Piketty (2014) and reports from international confederation Oxfam (Oxfam, 2020a, 2020b, 2022), has highlighted the role of the top 1% or 10% of wealth holders in contributing to climate change. This group, often referred to as the ‘polluter elite’, has unique consumption habits and patterns that result in disproportionately high greenhouse gas emissions. These individuals tend to travel more frequently by air, own larger homes, and drive larger vehicles (Oxfam, 2020a). All these factors contribute to a substantial carbon footprint that far exceeds the average person’s impact on the environment.

Therefore, policy measures addressing the growth of this wealthy elite could potentially have a significant impact on reducing aggregate emissions. This approach shifts the focus from overall inequality, often measured by the Gini coefficient, to specific wealth brackets. It suggests that tackling climate change requires not just broad economic policies but also targeted interventions aimed at curbing excessive consumption and emissions among the wealthiest individuals. Further research indicates that the growth of top wealth from capital not only intensifies inequality, contributing to an imbalance between capital and labour (Flaherty & Riain, 2020), but also potentially drives higher emissions (Soener, 2019). This suggests a direct link between wealth accumulation, particularly through capital, and increased emissions. It implies that our economic systems and structures may need to be reevaluated and reformed to ensure they promote not just growth and prosperity but also sustainability and equity.

6.3. Which trajectory is for people vulnerable to climate change?

My analysis indicates that the influence of emissions on poverty becomes more conspicuous within higher poverty brackets, especially among individuals teetering on the brink of destitution. This heightened effect can be attributed to the increased vulnerability of their assets to climate change-induced risks. Conversely, those situated at the lower end of the poverty spectrum may possess no assets susceptible to climate-related stressors. These findings underscore the necessity for international policies aimed at achieving equitable reductions in emissions to consider the potential for disproportionately adverse impacts on impoverished populations within a given country. Thus, the most significant suffering is anticipated among the poor in developing countries, particularly those with assets vulnerable to climate-related challenges.

Can a strategy of 'green growth' for the impoverished suffice to address this issue? Green growth is a concept designed to harmonize economic growth and development with environmental sustainability. It holds particular relevance for low-income nations where natural resources are vital, and green growth policies can reduce vulnerability to environmental threats while enhancing the livelihood security of the poor. However, determining whether green growth alone can safeguard the impoverished from the ramifications of climate change is a multifaceted issue. Extensive exploration by the World Bank reveals that, while green growth can offer benefits, there may be trade-offs between fostering sustainable growth and reducing poverty (Dercon, 2014). For instance, certain green-oriented growth strategies relating to agriculture, trade, technology, infrastructure, and urban development may hinder the effectiveness of poverty reduction efforts. In short, while green growth can contribute to mitigating these impacts and aiding the poor in adapting to climate change, it is unlikely to be a panacea. Addressing climate change necessitates a comprehensive approach that encompasses not only green growth but also emissions reduction, climate resilience measures, and social policies aimed at safeguarding the most vulnerable populations.

The latest IPCC Assessment Report (AR6) provides a grim outlook on the impacts of climate change, highlighting significant environmental changes in developing countries. These changes are expected to accelerate in the coming decades due to climate change. The poor, who are already impoverished and heavily dependent on environmental resources for their livelihoods, are the most vulnerable. The report also warns of increasing temperatures and humidity posing threats to human health and well-being, potentially making some areas uninhabitable. Food production is also expected to be severely impacted, with crops and livestock being affected by extreme temperatures, droughts, and floods. Ecosystem degradation, species extinction, deadly heatwaves, and floods are among the 'dangerous and widespread disruptions' that the world is expected to face in the next two decades due to global warming. In 2014, the Intergovernmental Panel on Climate Change (IPCC) adopted four greenhouse gas concentration trajectories for their fifth Assessment Report (AR5), known as the Representative Concentration Pathways (RCPs). These pathways, named RCP2.6, RCP4.5, RCP6, and RCP8.5, are based on potential radiative forcing values in 2100. Higher values indicate higher greenhouse gas emissions, leading to increased global temperatures and more severe effects of climate change.

The current status of global emissions reduction efforts varies by country. Some countries are on track to meet their self-imposed targets under the Paris Agreement, while others are falling short (Buchholz, 2021). For instance, India and Kenya have rejected the accountability associated with climate goals but are still expected to achieve goals related to limiting global warming to 1.5 or 2 degrees Celsius. Conversely, Canada has pledged to the 2-degree Celsius goal, but its actions and policies until 2030 suggest a trajectory more aligned with a 4-degree Celsius warming scenario. Among larger industrialized countries, the European Union and the UK, along with South Africa, are currently the only regions expected to meet the 2-degree Celsius goal, while the U.S., Japan, and Canada are projected to fall short. Several African nations, including Nigeria, Ethiopia, Morocco, Gambia, and Kenya, as well as Costa Rica and Nepal, are identified by the Climate Action Tracker as being on track to meet the 1.5-degree Celsius goal (Buchholz, 2021). Given these circumstances, it remains challenging to predict which RCP pathway is most probable. The outcome largely hinges on whether countries can meet their emissions reduction objectives and how these targets might evolve in response to future climate policies and technological advancements. This work offers a contribution to showing what the consequences of inaction might be, and what we need to do to get there.

APPENDICES

Appendix 1. 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
BLZ	Belize	Low income
BEN	Republic of Benin	Low income
BMU	The Bermudas	High income
BTN	Kingdom of Bhutan	Low income
BOL	Pluractional 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

Code	Long Name	Income Group
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
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

Code	Long Name	Income Group
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
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

Code	Long Name	Income Group
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
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

Code	Long Name	Income Group
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
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

Notes: 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).

Appendix 2. Descriptive analysis

Variables	Observation	Mean	Standard error	Min	Max
Log poverty $5.50	1736	2.312	2.054	-2.303	4.605
Log GDP per capita	5700	9.156	1.208	6.079	11.995
Log Emissions	10482	0.320	1.757	-5.441	5.888
Log Inequality	1745	3.624	0.233	3.030	4.187
Log Renewable	5651	2.602	1.844	-7.601	4.588
Log Urbanization	13106	3.767	0.655	0.731	4.605
Log population	13195	14.761	2.452	7.949	21.068

This table presents summary statistics for several variables, including poverty, GDP per capita, emissions, inequality, renewable energy, urbanization, and population. The data is in logarithmic form and shows the mean, standard error, minimum, and maximum values for each variable. The results provide a general overview of the distribution of these variables in the sample.
Source: World Development Indicators 2022

Appendix 3. Research materials

```
* This code for the published paper: DOI:10.1007/s10644-022-09462-9
* The project materials: https://github.com/duongkhanhk29/CLIMATEQUAL

********** DATA CLEANING

* To clean data
encode Country, generate(Country_ID) /// to code country names
xtset Country_ID Time, yearly /// to declare panel data
encode Income_group, generate(Income_ID) /// to code income groups
gen Poverty190_320 = Poverty320 - Poverty190 /// to create poverty bands
gen Poverty550_320 = Poverty550 - Poverty320 /// to create poverty bands
gen log_Poverty550 = log(Poverty550) /// to tranform in log
gen log_Agriculture_employment = log(Agriculture_employment)
gen log_Poverty190_320 = log(Poverty190_320)
gen log_Poverty320_550 = log(Poverty320_550)
gen log_Poverty190 = log(Poverty190)
gen log_GDP_capita = log(GDP_capita)
gen log_Emissions = log(Emissions)
gen log_Inequality = log(Inequality)
gen log_Population = log(Population)
gen log_GDP_capita2 = log_GDP_capita ^ 2
gen log_Urbanization = log(Urbanization)
gen log_Renewable_consumption = log(Renewable_consumption)
gen low_income = Income_ID >1 /// to dummy the low-income group
gen high_income = Income_ID ==1 /// to dummy the low-income group

* to create two-way interaction
gen GDP_emissions = log_Emissions * log_GDP_capita
gen GDP_inequality = log_Inequality * log_GDP_capita
gen Emissions_inequality = log_Inequality * log_Emissions
```

```
gen Poverty190_emissions = log_Poverty190 * log_Emissions
gen Poverty550_emissions = log_Poverty550 * log_Emissions


********** DATA ANALYSIS

*  Research  method:  Arellano-Bover/Blundell-Bond  linear  dynamic  panel-data
estimation
* predetermined variables: GDP_capitar
* endogenous variables: Emissions, Inequality and their products
* exogenous variables: Agriculture, Renewable, Urbanization, Population

* to run Descriptive analysis
estpost summarize log_Poverty550 log_GDP_capita log_Emissions log_Inequality ///
                log_Renewable_consumption log_Urbanization log_Population

* to run two-sample mean-comparison tests (ttest)
qui: estpost tabstat log_Poverty550 log_GDP_capita log_Emissions log_Inequality,
///
               by(high_income) statistics(mean sd) columns(statistics) listwise
esttab using "doc.rtf", main(mean) aux(sd) nostar unstack noobs nonote nomtitle
nonumber
qui: estpost ttest log_Poverty550 log_GDP_capita log_Emissions log_Inequality ///
                , by(high_income)
esttab using "doc.rtf", nonumber mtitle("diff.") noobs replace

* Plotting the relationships among variables
twoway   (scatter   log_Poverty550   log_GDP_capita   ||   lowess   log_Poverty550
log_GDP_capita)
twoway   (scatter   log_Poverty550   log_Emissions   ||   lowess   log_Poverty550
log_Emissions)
twoway   (scatter   log_Poverty550   log_Inequality   ||   lowess   log_Poverty550
log_Inequality)
twoway   (scatter   log_Emissions   log_GDP_capita   ||   lowess   log_Emissions
log_GDP_capita)
twoway   (scatter   log_Inequality   log_GDP_capita   ||   lowess   log_Inequality
log_GDP_capita)

* Plotting the relationships by income groups
twoway   (scatter   log_Poverty550   log_GDP_capita   ||   lowess   log_Poverty550
log_GDP_capita), ///
by(high_income)
twoway   (scatter   log_Poverty550   log_Emissions   ||   lowess   log_Poverty550
log_Emissions), ///
by(high_income)
twoway   (scatter   log_Poverty550   log_Inequality   ||   lowess   log_Poverty550
log_Inequality), ///
by(high_income)

* Plotting the relationships within countries
twoway   (scatter   log_Poverty190   log_GDP_capita   ||   lowess   log_Poverty190
log_GDP_capita)
twoway (scatter log_Poverty190_320 log_GDP_capita || lowess log_Poverty190_320
log_GDP_capita)
twoway (scatter log_Poverty320_550 log_GDP_capita || lowess log_Poverty320_550
log_GDP_capita)
twoway   (scatter   log_Poverty190   log_Emissions   ||   lowess   log_Poverty190
log_Emissions)
twoway (scatter log_Poverty190_320 log_Emissions || lowess log_Poverty190_320
log_Emissions)
twoway (scatter log_Poverty320_550 log_Emissions || lowess log_Poverty320_550
log_Emissions)

* Original impacts
eststo O1: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
               pre(log_GDP_capita) ///
               end(log_Emissions log_Inequality) ///
```

```
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
* Mediation effects
eststo M1: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
* With square of income
eststo S1: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
            pre(log_GDP_capita log_GDP_capita2) ///
            end(GDP_emissions GDP_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
* Combining Emissions and Inequality
eststo C1: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality Emissions_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))

* to export the results
esttab O1 M1 S1 C1 using mydoc1.rtf, se label replace ///
       mtitles star( * 0.10 ** 0.05 *** 0.010) ///
          drop (log_Renewable_consumption log_Urbanization log_Population) ///
          order (log_GDP_capita log_GDP_capita2 log_Emissions ///
          log_Inequality GDP_emissions GDP_inequality Emissions_inequality) ///
          scalar(N "parm2 AR2 test (p-value)")

* Difference between low-income and high-income
eststo High_income: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population ///
            if high_income == 1, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality Emissions_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
eststo Low_income: xtdpdsys log_Poverty550 ///
         log_Renewable_consumption log_Urbanization log_Population ///
            if low_income == 1, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality Emissions_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))

esttab High_income Low_income using mydoc2.rtf, se label replace ///
       mtitles star( * 0.10 ** 0.05 *** 0.010) ///
          drop (log_Renewable_consumption log_Urbanization log_Population) ///
          order (log_GDP_capita ///
          GDP_emissions GDP_inequality Emissions_inequality) ///
          scalar(N "parm2 AR2 test (p-value)")

* Difference among bands of poverty
eststo P190: xtdpdsys log_Poverty190 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality Emissions_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
eststo P190_320: xtdpdsys log_Poverty190_320 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
            pre(log_GDP_capita) ///
            end(GDP_emissions GDP_inequality Emissions_inequality) ///
            vce(robust)
            estadd scalar parm2 = 2*normal(-abs(e(arm2)))
```

```
eststo P320_550: xtdpdsys log_Poverty320_550 ///
         log_Renewable_consumption log_Urbanization log_Population, ///
               pre(log_GDP_capita) ///
               end(GDP_emissions GDP_inequality Emissions_inequality)      ///
               vce(robust)
               estadd scalar parm2 = 2*normal(-abs(e(arm2)))

esttab P190 P190_320 P320_550 using mydoc3.rtf, se label replace ///
       mtitles ("$0.0-1.90" "$1.90-3.20" "$3.20-5.50") ///
          star( * 0.10 ** 0.05 *** 0.010) ///
          drop (log_Renewable_consumption log_Urbanization log_Population) ///
          order (log_GDP_capita ///
          GDP_emissions GDP_inequality Emissions_inequality) ///
          scalar(N "parm2 AR2 test (p-value)")
```

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