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Achieving Sustainable Development: Balancing Carbon Dioxide Emissions Reduction and Poverty Alleviation in Less Developed Countries

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ABSTRACT

Carbon dioxide emissions (CO_2) reduction and poverty have always been conflicting subjects regarding national policy implementation, particularly in less developed countries (LDCs). Based on energy consumption as a driving mechanism, this study investigates whether reducing CO_2 aggravates poverty in LDCs. To achieve this aim we analyze a 30-year panel data of 15 LDCs and deploy fixed-effects regression models. We used two-stage least square (2SLS) regressions to address endogeneity concerns. Our results suggest that (CO_2) emission has a negative relationship with poverty, which means reducing CO_2 emissions increases poverty in LDCs. Our results provide important implications for policymakers, showing that a green structural transformation implementation that highlights the balance between environmental protection and economic development would be recommended for LDCs.

INTRODUCTION

As countries worldwide strive to lower their greenhouse gas emissions to minimize global warming, many need to be aware of these policies' potential negative effects on poverty alleviation. Carbon emissions reduction measures can significantly impact low-income households, as they may lack the resources necessary to make up for any decreases in income resulting from policy changes. Reducing carbon emissions and poverty have always been conflicting subjects. Indeed, considering the level of economic development and other indicators, the impact of CO_2 reduction differs from one country to another. According to the Low Carbon Index, several G20 countries have lowered their carbon intensity while sustaining GDP growth, including emerging countries such as China, India, and Mexico. A thirty-year increase in carbon emissions indicates a reduction in poverty in East Asia, the Pacific, and South Asia. Sub-Saharan Africa, however, has reduced emissions while nearly tripling the number of people living in poverty (World Economic Forum). So what is the reason for the contrast observed in Sub-Saharan Africa, home to most LDCs?

Regarding carbon emissions reduction, South Africa, a developing country, has recently been urged by its European and American partners to close its charcoal thermal power plants to reduce carbon emissions. Knowing that 80% of South African electricity is produced using charcoal and more than 100 000 persons are employed in those charcoal thermal power plants, South Africa is suffering from a lack of energy and unemployment, increasing at the same time poverty (Zack Mwekassa, 2022). At the same time, with the Russia-Ukraine crisis, Germany opened the biggest charcoal thermal power plant in Germany to increase its energy production. Even though South Africa is not a LDC, considering the given example, is reducing carbon emissions beneficial to LDCs? Carbon emissions reduction affects the poverty patterns of a nation. For instance, increasing the economic activities within the boundaries of a country has the sporadic effect of increasing carbon emissions (Amini *et al.*, 2021). The progress of LDCs away from poverty will require investing in industries that release effluents, causing air, water, and soil pollution (Sarker *et al.*, 2021). Increasing the agricultural activities of LDCs will also result in a rise in greenhouse gases due to using chemicals, such as fertilizers and herbicides (Kumar *et al.*, 2019).

Further, implementing crucial infrastructure activities in these areas increases CO_2 emissions (Stefanakis, 2019). The increase in economic activity is not beneficial to climate preservation efforts. Not all countries have equal CO_2 emissions and do not share the burden of climate change due to CO_2 emissions (Meng *et al.*, 2018). Furthermore, LDCs typically rely more on fossil fuels for energy. So reducing carbon emissions could lead to higher energy prices and reduced economic activity. That could, in turn, lead to increase poverty. So this research uses econometrics way to prove the aforementioned assumption.

This study examines whether reducing carbon emissions in LDCs exacerbates poverty. The analysis of the most recent research on the topic reveals a shortfall in the number of studies done on LDCs, particularly those in Sub-Saharan Africa, where most of the LDCs are located. Most current research material is limited to more developed countries like China and the USA (Obaideen *et al.*, 2022). Further, there has yet to be a conclusive finding regarding the association between CO_2 emissions reduction and poverty; hence, more research needs to be done. So regarding what is previously said, this study is mainly focused on LDCs and takes extreme poverty and

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carbon emission per capita indicators as main variables.

Another point that this research considers is the integration into the analysis of the Green Structural Transformation for LDCs. According to the UNCTAD, Structural transformation refers to the transformation from low productivity and labor-intensive production to high value-added and high productivity economic activities. Green structural transformation combines responsible economic, social, and environmental growth with structural economic transformation. It includes the transition from a "recession" carbon-intensive sector to a "prosperity" low-carbon economic activity, promoting the effective use of resources (materials, energy, land, water) throughout the development process.

This research is essential in providing data that will be used for future planning purposes. CO_2 emissions reduction activities must consider their impact on Poverty mitigation to ensure sustainability among LDCs. A further novelty is incorporated through the attempt of this study to contribute to the existing knowledge on the topic. Involvement in the research will result in a heightened understanding of the impact of CO_2 emission reduction on poverty in LDCs.

Along with the introduction, this paper is organized as follows: the second is the literature review, the third is the data and methodology, and the fourth is the discussion and conclusion.

LITERATURE REVIEW

Poverty Alleviation

According to an article published by Concern Worldwide (a non-governmental organization), around ten per cent of the global population lives in severe poverty. It has pointed out eleven leading causes of extreme poverty: inequality, conflict, malnutrition and stunting resulting from hunger, inadequate medical systems, particularly for women and kids, insufficient access to clean water and sanitation facilities, climate change, limited educational opportunities, inadequate public works and infrastructure, global health crises such as epidemics and pandemics, insufficient social services, and an absence of personal security nets. Our focus will be on the extreme poverty caused by climate change. According to the same article, by 2030, global warming may result in the displacement of over one hundred million individuals into conditions of severe impoverishment. Impoverished communities frequently depend on agricultural practices, hunting, and gathering as a means of sustenance or income generation. However, there are challenges with these jobs, like insufficient food reserves in the case of a poor harvest--which is part of why climate change and natural disasters can push them into poverty and make a recovery much harder (Concern Worldwide, 2020).

Wolla pointed out that to close the gap between prosperous and less-developed economies, individuals need to focus on economic growth. Disparities in a nation's economic advancement often stem from variations in inputs like production and productivity (Wolla, 2017). Organizations need incentives for innovation and production to improve productivity and growth, while the government plays a crucial role in enhancing capital resource availability. Access to international trade benefits the global economy by providing markets for the goods and products produced in less-developed countries. In addition, it increases productivity by increasing access to capital resources. Sarlo argues that luck, choice, and enablement drive poverty. These three things can help explain longer duration and persistent poverty. He pointed out some ideas that should be tried: reduce the bad luck in people's lives (poor parenting, the genetic transmission of diseases, negative influences on children, etc.; promote good choices (giving people opportunities and quality education); work to eliminate those things that make people stay in poverty (benefits programs that discourage or limit work) (Sarlo,2019). Jose analyzes the cause-and-effect explanations of poverty in ldcs, focusing on 1092 undergraduate participants from Nicaragua, El Salvador, Chile, and Spain. The world's economic structure, fate, nature, cultural practices, political misconduct, and the population of developing countries were identified as components. To identify five distinct subject categories, the study used undergraduates' causal attributions of poverty, country of origin, perceived social class, economic situation, political ideology, and religious beliefs. The findings indicate that poverty in developing nations is predominantly influenced by the interviewees' home country's development level, political ideology, and economic circumstances (Jose *et al.*, 2017).

According to Badreldin, poverty has become a global issue, particularly in LDCs. Their study examines social poverty, measurement techniques, and contributing factors. It uses three models: low and medium-income countries, medium-income countries, and low-income countries. The primary drivers of human poverty are overall spending on education and healthcare and the increasing share of the total GDP. The research suggests that governments should prioritize increasing spending on education and healthcare to eliminate various types of poverty (Badreldin *et al.*, 2014). Gore and Charles suggest that understanding chronic poverty requires exploring poverty traps, identifying underlying factors, and analyzing poverty at household, community, and national levels. Globalization requires a global perspective, as the prevalence and persistence of poverty in LDCs are attributed to an international poverty trap reinforced by trade and finance relationships (Gore & Charles, 2003). Castaneda identifies individuals experiencing severe and low poverty, focusing on those with daily incomes below $1.90. Rural and youthful populations dominate extreme poverty, with children under 15 comprising over 45%. The study highlights the importance of rural households and urbanization in mitigating poverty, with improved educational achievement and urbanization contributing to poverty alleviation (Castaneda *et al.*, 2016). Mahembe analyzes the prevalence of extreme poverty in developing nations and evaluates the Millennium Development Goal

of reducing extreme poverty by 50 percent by 2015. The research employs a descriptive methodology to classify countries into the following five geographic regions: sub-Saharan Africa, East Asia, South Asia, Europe, and Latin America and the Caribbean. The global poverty rate is 9.6%, but the concentration of severe poverty in sub-Saharan Africa and Southern Asia poses challenges (Mahembe *et al*., 2018).

Carbon Emission Reduction in LDCs

Zhang examines the association between carbon emissions and five influential factors in 50 developing nations from 1995-2017. Results show steady-state equilibrium, with some countries showing the Environmental Kuznets Curve phenomenon. Energy consumption impacts CO_2 positively, while international trade negatively affects developing countries, fossil fuel usage affects the environment (Zhang *et al*., 2019). Hanif examines the influence of sustainable and non-sustainable energy consumption and economic development on carbon emissions in developing Asian economies. It finds that sustainable energy sources reduce emissions, while non-sustainable sources increase them. Shifting to sustainable energy sources is crucial for carbon-free economic growth and regional collaboration (Hanif *et al*., 2019). Hu examines the impact of renewable energy consumption and commercial services trade on global carbon emissions from 1996-2012. They find a significant relationship between economic growth and greenhouse gas emissions; a rise in renewable energy usage is crucial for mitigating emissions (Hu *et al*., 2018). Wang *et al*. (2011) analyze CO_2 emission patterns and economic progress in 128 countries and regions using models like σ-convergence, absolute β convergence, and conditional β-convergence. Results show a convergence in emissions over the past four decades, with LDCs narrowing the gap. Factors influencing emissions include GDP per capita, population size, and resource utilization (Wang *et al*., 2011). Pareto, Romer, Georgescu-Roegen, Coase, and Arthur Cecil Pigou are renowned academics researching the ramifications of polluting agents on human conduct. Pareto espoused the notion that a laissez-faire economic system would result in the optimal allocation of resources. However, externalities, such as pollution, can give rise to sub-optimal outcomes. Coase proposed a solution to address the issue of pollution by recommending that polluters be compensated with tradable goods by consumers. In 1979, Georgescu-Roegen proposed the notion of entropy, which suggests that the depletion of the environment is a consequence of economic expansion. Theories of endogenous growth posit that innovation can be fostered by environmental resources, a view espoused by economists such as Romer and Aghion-Howitt, as a means of achieving sustained growth over the long run. Nevertheless, there is a contention that altering consumption patterns is imperative to alleviate the burden on natural resources. The crux of the argument centers on the valuation of natural resources and the appropriate means of incorporating such valuation into pricing mechanisms.

Relationship between Carbon Emission Reduction and Poverty Alleviation

Some more recent research and papers about the relationship between CO_2 emissions and poverty reduction initiatives have been carried out. Jin applied the extended linear expenditure system model to measure poverty levels among Chinese citizens. The CO_2 emissions accounting method was then utilized to keep track of the CO_2 emissions in the country to establish the relationship between CO_2 production and poverty levels. The research found a decoupling relationship between CO_2 emissions and economic development, which means the research confirmed the existence of a correlation between CO_2 emissions and poverty levels (Jin *et al*., 2020). Malerba noted that despite calls by the international community to address poverty and climate degradation simultaneously, more was needed to know about the relationship between the two variables. The study attempted to demystify this undertaking by establishing the carbon intensity of poverty reduction (CIPR) as a combined model to measure poverty and CO_2 emissions. The research demonstrated that the CIPR in most countries was heterogeneous; economic growth was found to harm CIPR below a certain income level (Malerba, 2020). Fu reviewed the research data obtained from the provinces within China to identify a coupling relationship between carbon emissions and poverty alleviation activities. The research established that implementing poverty reduction initiatives in China was responsible for the economic growth between 2009 and 2019. The researchers observed that increased economic development reduced CO_2 emissions in 26 provinces. Only three provinces in China showed an increase in CO_2 production. The research showed that investment in poverty alleviation does not necessarily result in CO_2 emissions increase (Fu *et al*., 2021). Leal Filho established that there needed to be more research articles addressing the issue of the relationship between climate change and economic outcomes (Leal Filho, 2019). This aspect limited the guidance to different nations regarding the most appropriate interventions they needed to implement to address poverty (Miladinov, 2020).

The researchers noted that although some regions were ideally placed to address climatic stressors, such as increased urban heat, few did so. Wang and Li utilized the grey Verhulst model to determine the impact of economic development on climate change. Using the model, it was evident that the current economic growth within China would result in growth in CO_2 emissions. However, the research established that the peak CO_2 emissions will not be attained by 2030, which provides the Chinese government with enough time to implement conservation efforts (Wang & Li, 2019). The U.N. Framework Convention on Climate Change (UNFCCC) intends to maintain the rate of warming to 2°C and

eliminate extreme poverty. Achieving poverty elimination objectives does not threaten climate goals, but achieving a minimum expenditure of $2.97 PPP could impact emission targets. The top 10% of global income earners contribute 36% of households' carbon footprint, so addressing poverty does not jeopardize the climate target (Hubacek *et al.*, 2017).

History of Emission Reduction Policies in LDCs

LDCs face unique challenges in formulating policies related to global warming due to their reliance on natural resources, insufficient adaptation capabilities, and limited economic progress. To address this issue, LDCs have implemented various policy decisions, including international involvement, national adaptation plans, access to climate finance, capacity building, regional and international cooperation.

International involvement involves expressing concerns and promoting a global initiative to reduce greenhouse gas emissions. National adaptation plans outline the nation's susceptibilities, adjustments, and fiscal requirements to improve indigenous communities, economic sectors, and ecological systems. Access to climate finance, such as the Green Climate Fund, is crucial for supporting mitigation and adaptation actions. Capacity building involves providing personnel training, technology transfer, fortification of national institutions, and public awareness. Regional and international cooperation is a common strategy employed by LDCs to enhance their standing in global climate negotiations, fostering collaboration and coordination among member nations. This involves knowledge sharing, exchange of best practices, and resource allocation to tackle shared challenges related to global warming.

The aforementioned political decisions were made within the context of established international conventions, the historical background of which can be outlined as follows: (1) The UNFCCC, ratified in 1992, is a global accord aimed at stabilizing the levels of greenhouse gases in the atmosphere. LDCs (LDCs) have ratified this convention and have pledged to undertake measures to alleviate the impact of climate change. (2) The Kyoto Protocol was adopted in 1997 under the UNFCCC. The established objectives aimed at reducing greenhouse gas emissions for developed nations. LDCs (LDCs), categorized as developing nations, were not obligated to decrease their emissions under the protocol. However, they were qualified to obtain financial and technological assistance to implement mitigation measures. (3) The Global Environment Facility (GEF) was founded in 1991 to provide financial assistance to Least Developed Countries (LDCs) and other developing nations to facilitate environment-related undertakings, such as climate change initiatives. LDCs (LDCs) have derived advantages from the financial support provided by the Global Environment Facility (GEF) to implement measures to adjust and minimize the impacts of climate change. (4) The Rio+20, which took place in 2012, aimed to foster intergovernmental discourse on sustainable development among United Nations member countries. LDCs (LDCs) have underscored the necessity for heightened support to tackle the obstacles posed by climate change, with a particular focus on adaptation. (5) In 2015, the Paris Agreement was adopted at the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). The agreement requires all countries, including those categorized as LDCs (LDCs), to implement actions with the goal of limiting the increase in worldwide temperatures to a degree substantially lower than 2 degrees Celsius above the levels documented during the pre-industrial period. The Paris Agreement acknowledges the significance of heightened assistance for developing nations, particularly the LDCs, in addressing the obstacles posed by climate change. Following the adoption of the Paris Accord, the global warming policies of the LDCs (LDCs) have centered on the execution of their Nationally Determined Contributions (NDCs) and facilitating climate finance to bolster their endeavors in adaptation and mitigation.

Energy Consumption as A Driving Mechanism of Carbon Emission in LDCs

In a context of concern, the function of energy in the economic transformation of LDCs is a critical issue that deserves further attention (UNCTAD, 2015). In a growing context of the international community regarding climate change, renewable energy options have been put forward to meet this unmet theoretical demand without compromising efforts to reduce global GHG emissions (IEA, 2020). Access to energy services is crucial for economic development and structural transformation, contributing to sustainable and inclusive structural transformation. This is essential for eradicating poverty and achieving other Sustainable Development Goals. However, neglecting the economic dimension of the problem has led to a neglect of this crucial aspect. The productive use of electricity is essential in this regard because it provides access to energy for the economy's structural transformation and helps create sufficient demand for investment in generation and distribution to be sustainable.

To reduce global energy consumption and mitigate the impacts of climate change, many countries have implemented policies to reduce energy consumption, including ratifying the Paris Climate Agreement. However, this has hurt some LDCs, as poverty rates have risen due to rising energy costs (UNCTAD, 2015; IEA, 2019; World Bank, 2020).

Energy consumption is a critical driving mechanism of carbon emissions in LDCs (IPCC, 2014). These countries require significant energy to develop their economies, improve living standards, and reduce poverty (UNDP, 2018). However, the vast majority of energy production in these countries is derived from fossil fuels, a significant carbon emission source (World Bank, 2019).

LDCs face unique challenges regarding energy consumption and carbon emissions (IEA, 2020). They are at a crucial economic development stage and require significant energy to power their industries, transport systems, and households. However, they need more financial resources and technological capacity to invest in renewable energy sources or implement energy-efficient practices. As a result, they rely heavily on fossil fuels to meet their energy needs, contributing to high carbon emissions.

Population growth is one of the main factors driving energy consumption and carbon emissions in LDCs. Many of these countries have high population growth rates, which puts pressure on their energy systems. As the population increases, so does the demand for energy to power homes, schools, hospitals, and other essential services. Using fossil fuels is often the most cost-effective way to meet this demand, leading to high levels of carbon emissions (IPCC, 2014).

Industrialization is another significant factor driving energy consumption and carbon emissions in LDCs. These countries are often rich in natural resources and have vast coal, oil, and gas reserves. They seek to exploit these resources to develop their economies and improve their citizens' living standards. However, these resources extraction and processing require significant energy, leading to high carbon emissions (IEA, 2020).

Transportation is another significant factor driving LDCs' energy consumption and carbon emissions. These countries are experiencing rapid urbanization, which has led to a surge in the number of vehicles on their roads. Most of these vehicles run on fossil fuels, contributing to high carbon emissions. In addition, many less-developed countries lack adequate public transportation systems, which forces people to rely on private vehicles, further exacerbating the problem (World Bank, 2019). The role of international trade and investment in driving energy consumption and carbon emissions in LDCs must be considered. Many developed countries outsource their manufacturing and other industries to LDCs, contributing to high energy consumption levels and carbon emissions in these countries. The demand for goods and services in developed countries also contributes to high energy consumption levels and carbon emissions in LDCs (UNFCCC, 2021).

LDCs' Poverty Rate And CO_2 Emissions Reduction Features Description

An Overview of Poverty in LDCs

Ninety percent of the world's population lived in extreme poverty before the 19th century; capitalism led to increased human well-being (Dylan *et al.*, 2023). However, it remains a significant challenge worldwide, especially in LDCs in the 21st century. Generally, some indexes are used to quantify or give an overview of the poverty phenomenon. Those indexes are the Extreme Poverty Index, the Poverty Headcount Ratio, the Multidimensional Poverty Index, the Income Inequality Index, the Child Poverty Index, Hunger and Malnutrition Index, the Gender Disparities Index, and Rural Poverty Index.

In 2021, approximately 706 million individuals lived in extreme poverty, with a daily income below $1.90. This poverty headcount ratio is prevalent in many LDCs, with 41% of the population in Sub-Saharan Africa experiencing extreme poverty in 2020. The Multidimensional Poverty Index (MPI) identifies 1.3 billion individuals across 101 nations as being multidimensionally impoverished, with a significant proportion in regions with lower levels of development, such as South Asia and Sub-Saharan Africa. Income inequality is a significant issue in LDCs, with Oxfam's 2021 report showing a $5.3 trillion increase in

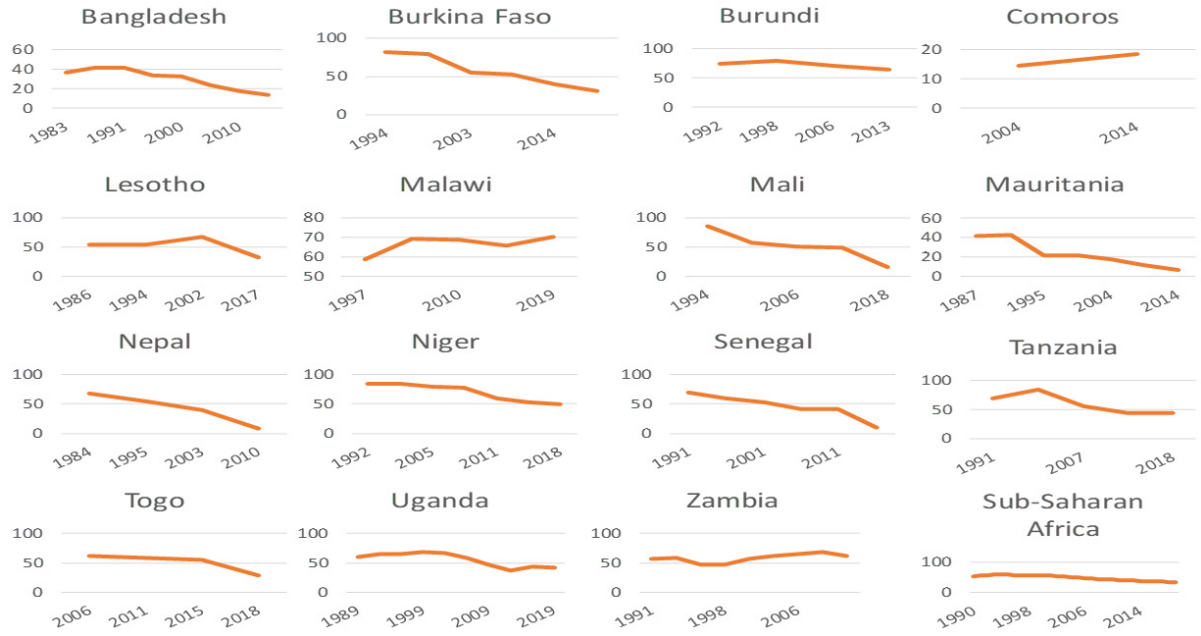

Figure 1: Share of the population living in extreme poverty
Source: World Bank Poverty and Inequality Platform

billionaires' wealth while a 200 million increase in poverty. Child poverty is a significant concern, with UNICEF estimating 385 million children in extreme poverty, accounting for almost 50% of the global population of impoverished individuals. Persistent hunger affected 690 million individuals in 2019, primarily in less developed regions, particularly in Sub-Saharan Africa and Southern Asia. Gender disparities are also a significant issue in LDCs, with 330 million females, including girls, experiencing restricted access to educational institutions, medical services, and financial opportunities. Rural poverty is a prevalent issue in LDCs, with 80% of the global population living in extreme poverty concentrated in rural areas, where access to basic amenities and economic prospects is often restricted. The graph below displays the share of the population living in extreme poverty within our sample group.

Energy Consumption in LDCs

LDCs typically exhibit low levels of energy consumption. These countries face significant challenges in terms of energy access and energy infrastructure development.

In many LDCs, a significant portion of the population lacks access to electricity. Traditional energy sources such as wood fuel and coal are often used to meet basic energy needs. However, these energy sources could be more efficient and positively impact health and the environment. Energy consumption in LDCs is also limited due to the need for developed industries. Energy-intensive sectors such as manufacturing and steel production are often underdeveloped or non-existent in these countries. Moreover, LDCs often struggle with energy supply issues. Production, transmission, and distribution infrastructure for electricity are often inadequate, limiting energy availability for local populations and businesses. It is important to note that energy consumption in LDCs can vary significantly from country to country. Some LDCs have access to significant natural resources such as oil or hydroelectric power, which can increase their energy production and consumption capacity.

Many LDCs are implementing initiatives to improve energy access and promote clean and sustainable energy sources to address these challenges. This may include the deployment of solar, wind, and hydroelectric technologies and policies aimed at improving energy efficiency and reducing dependence on fossil fuels. The graph below shows an overview of some LDCs energy consumption.

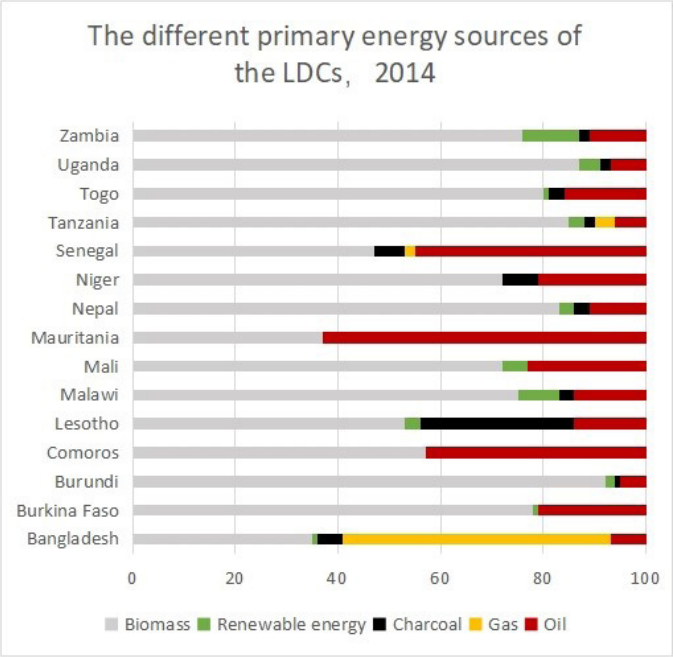

Figure 2: The different primary energy sources of LDCs, 2014
Source: UN DESA (2016b)

MATERIALS AND METHODS

Samples Selection

According to Marcil , poverty is when some members of a nation do not have the income required to afford essential utilities, such as food and shelter (Marcil *et al.*, 2021). While poverty exists in every country, some countries experience it more than others (Karpman *et al.*, 2020). For research purposes, poverty will be expressed as a percentage, which depicts the number of poor people in a country (Lakner *et al.*, 2022). As a result, the higher the percentage, the more people live in poverty (Sherman *et al.*, 2021). The list of countries classified as less developed has been derived from the World Bank, a reliable source of information regarding which countries fall under the classification of poverty-burden nations (World Population Review, 2022).

A LDC has a lower standard of living than other more industrialized nations. These countries are typically characterized by a higher infant mortality rate, lower gross national income (GNI) per capita, higher levels of

poverty, higher level of inequality, dependence on natural resources, lack of economic diversification, reliance on agriculture, etc. However, not all of the LDCs are included in this study. Due to the quality and availability of data, 15 counties (table 1) are included in the study as a sample. However, unbalanced panel data was utilized for thirty years for each country. The range selected was from 1990 to 2020. Using panel data increased the accuracy of the findings.

Further, the research process has resulted in the collection of raw data on the poverty indexes of the countries included in the study, along with their corresponding CO_2 emissions rates. The CO_2 emission rates are graded based on each country's per capita metric ton emissions (Helmers *et al.*, 2021). This data is useful when determining the relationship between poverty and CO_2 emissions in LDCs. The CO_2 emissions per capita data were collected from the Global Carbon Project, and the poverty rate from Global Extreme Poverty. Both sources are reliable.

Table 1: List of the sample countries

Country	Poverty index (30 years)	Metric tons CO_2 per capita (30years)
Bangladesh	26.49%	0.31
Burkina Faso	61.95%	0.12
Burundi	80.05%	0.22
Comoros	16.64%	0.32
Lesotho	46.14%	1.11
Malawi	69.11	0.08
Mali	61.91%	0.12
Mauritania	17.87	0.53
Nepal	38.71%	0.19
Niger	66.22%	0.07
Senegal	45.59%	0.49
Tanzania	66.12%	0.13
Togo	52.87%	0.29
Uganda	53.77%	0.08
Zambia	55.93%	0.25

Variables Selection

Dependent Variable

The logarithm form of the poverty rate (LnPov) has been selected as the dependent variable. The poverty rate in this specific case, as defined by the United Nations, is the share of the population living on less than 1.90 us dollars per day qualified as extreme poverty. The poverty rate has been added as a key measurement for poverty alleviation observation. Measuring global poverty has difficulties, such as the difference in price levels in different countries. In order to understand how consumption levels differ from country to country, it is mandatory to adjust for differences in purchasing power which are also associated with differences in market exchange rates between countries (Purchasing Power Parity adjustment PPP). As a result, it is not sufficient to convert consumption levels by market exchange rates alone.

Key Independent Variable

The logarithm form of CO_2 per capita ($LnCo_2$) has been selected as the key independent variable. Emissions of CO_2 result from the combustion of fossil fuels and the production of cement. Included are CO_2 from the combustion of solid, liquid, and gaseous fuels, as well as gas venting (World Bank). The $LnCo_2$ will be an indicator for measuring carbon emission in this research.

Control Variables

According to some researchers, poverty reduction cannot be solely attributed to economic growth, as evidenced by the works of Datt and Ravallion (Datt & Ravallion, 1992) and Fosu (Fosu, 2017). The authors posited that alterations in inequality have a statistically noteworthy impact on the mitigation of poverty, as evidenced by the works of Datt and Ravallion (Datt & Ravallion, 1992) and Kraay (Kraay, 2006). Considering those previous arguments, the GINI index (1) has been selected to indicate inequality. The Gini coefficient is a statistical measure that quantifies the degree of income inequality within a given population. Elevated values denote an increased degree of disparity. The highest level is 100 or 1.

Agriculture Annual Growth Rate

The aggregates for agriculture in 2015 are formulated using a fixed value in US dollars. The agriculture domain is classified under ISIC divisions 01-03, including forestry, hunting, fishing, and crop cultivation. Value added is the final output of a sector, obtained by aggregating outputs and deducting intermediate inputs. The calculation does not consider depreciation or natural resource depletion. The origin of value added is established by the World Bank's ISIC, revision 4. First, this indicator was employed to measure the impact of agriculture on carbon emissions as a driving mechanism, and second, it was used as a control variable for the poverty rate.

Electricity Access

Access to electricity is the proportion of the population that has access to electricity. The World Bank collects information regarding electrification from industry, national surveys, and international sources. (World Bank). This indicator was used as a driving mechanism of energy consumption on carbon emissions in LDCs and as a control variable for the poverty rate.

Mortality Rate

The gross mortality rate is a statistical measure of fatalities per 1000 individuals. Natural growth rate is calculated by subtracting crude mortality rate from birth rate, resulting in population change rate without immigration (World Bank).

Health Expenditure

The health expenditure of the government, with the

exception of social security, is primarily borne by the central, state/regional, and local government departments, while social insurance plans are excluded from this category. This refers to entities under government units' control and is primarily funded through non-market and non-profit means, as defined by the OECD.

Birth Rate

The term "crude birth rate" denotes the annual number of live births per 1000 individuals in a given population. The computation of the natural growth rate involves the deduction of the crude mortality rate from the crude birth rate, resulting in the population change rate in the absence of immigration (World Bank).

Household Final Consumption

Refers to the market value of household goods and services includes enduring items like cars, laundry, and computers. It excludes real estate purchases and government payments for licenses and permits. This indicator also includes non-profit institutions' expenditures. (World Bank).

The Level of Opening up

Is the sum of exports and imports of a country accounts for its share of GDP.

Education Level

The gross enrolment ratio measures the proportion of enrollment in secondary education, which is the next stage after primary school. It serves as the foundation for basic education and personal growth. Secondary education aims to provide discipline and skill development through highly qualified instructors, ensuring enduring education and personal growth. (World Bank).

Table 2: List of the different variables

Variables	Log form	Measure units	Sources
Poverty rate	LnPov	Headcount ratio at 1.90 USD a day	Global Extreme Poverty
Carbon emission per capita	LnCo2	Metric tons	Global Carbon Project
Gini index	LnGini	Gini index 100	World Income Inequality Database
Agriculture's annual growth rate	LnAgri	Total percentage	World Bank WDI
Electricity access	LnElec	Total Percentage	World Bank WDI
Mortality rate	LnDeath	Crude per 1000 people	World Bank WDI
Birth rate	LnBirth	Crude per 1000 people	World Bank WDI
Health expenditure	LnHeal	Percentage of GDP	World Bank WDI
Households final consumption	LnHouse	USD	World Bank WDI
Level of openness	LnTrade	Share of imports and exports in GDP	Penn World Table 10.0
Education level	LnSchool	Gross enrolment ratio	World Bank WDI

Specification of the Econometric Model

Integrating econometric models in the research is essential to determining the association between CO_2 emissions reduction and poverty in LDCs. An econometric model consists of two necessary parts: equations derived from economic theory and a set of variables applied to the equation (Maciejewski & Wach, 2019). Econometrics has been selected since it enables the investigation of real-world phenomena of the association between CO_2 emissions reduction and poverty. The study has selected the regression model as the most appropriate econometric model. It is one of the simplest econometric models for researchers (Werth & Sigman, 2021). Regression is an effective tool for determining the relationship between the variables in a data set (Kibria & Lukman, 2020). These variables are mapped on a curve, which is essential for modeling and analyzing the data. The model establishes a relationship between the direct and indirect variables in the research (Rajabov & Mustafakulov, 2020). The key independent variable is CO_2 emissions per capita, while the dependent variable is the poverty rate.

The three main regression models for panel data are the Pooled Ordinary Least Square, Fixed effect, and Random Effects models. The right model selection has been decided according to the results of the different tests. In this study, the Hausman test and the Breuch and Pagan Lagrangian Multiplier test were conducted. According to the P-value Hausman test (0.0119) and the L.M. test (0.0000) of the respective test, the fixed effect model has been selected as the most accurate for this research. The equation of the fixed effect model is:

$$LnPov_{it} = \alpha_i + \beta_1 LnCo2_{it} + \beta_2 LnGini_{it} + \beta_3 LnAgri_{it} + \beta_4 LnElec_{it} + \beta_5 LnBirth_{it} + \beta_6 LnDeath_{it} + \beta_7 LnHeal_{it} + \beta_8 LnHouse_{it} + \beta_9 LnTrade_{it} + \beta_{10} LnSchool_{it} + \varepsilon_{it} \quad (1)$$

Where i represents entity, t represents time, αi (i=1 ::: n) is the unknown intercept for each entity (n entity-specific intercepts), Yit is the dependent variable LnPov; Xit represents the independent and control variables; βi is the coefficient for respective independent and control variables; and ε_{it} is the error term.

In order to verify the veracity of energy consumption as the driving mechanism of carbon emissions in LDCs, the following intermediary effect test model is constructed referencing to the methodology introduced by Wen Zhonglin

and Ye Baojuan (Wen Zhonglin & Ye Baojuan, 2014):

$$LnCo2_{it} = \alpha_0 + \alpha_1 LnPov_{it} + \alpha_2\ control\ + \mu_i + \lambda_t + \varepsilon_{it1} \quad (2)$$

$$LnElec_{it} = \beta_0 + \beta_1 LnPov_{it} + \beta_2\ control\ + \mu_i + \lambda_t + \varepsilon_{it2} \quad (3)$$

$$LnCo2_{it} = \gamma_0 + \gamma_1 LnPov_{it} + \gamma_2 LnElec_{it} + \gamma_3\ \text{control}\ + \mu_i + \lambda_t + \varepsilon_{it3} \quad (4)$$

Where $LnCo2_{it}$ represents the dioxide carbon emissions,LnPov represents the poverty rate, LnElec represents the mediation variable, control represents the control variables, t represents the year, μ_i the individual regional effect, λ_t the time effect, and ε_{it} the random error terms.

Descriptive Statistics

Table 3: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Poverty rate	450	50.628	22.059	4.782	87.11
CO_2 per capita	455	.25	.253	.02	1.535
Gini index	450	43.788	10.071	25.876	65.756
Agriculture's annual growth rate	463	2.983	9.122	-33.071	68.112
Electricity access	395	27.352	22.056	.53	96.2
Birth rate	465	39.145	7.847	17.549	55.485
Death rate	465	11.621	4.275	5.481	22.97
Expenditure on health	300	5.163	1.974	2.064	11.579
Households final consumption	385	4.595e+10	9.577e+10	6.000e+08	6.200e+11
Openness	450	56.904	32.008	18.972	201.331
School enrollment	310	30.234	17.601	5.221	85.522

RESULTS AND DISCUSSION

Benchmark Estimation Results

Fixed effects regression is a method that allows the item to be linked with observed self-reliant things. It limits selection bias in the association by minimizing massive incidences of variation (Mummolo & Peterson, 2018). A fixed effect model involves the independent variable being constant. Meanwhile, the dependent variable will shift based on the fluctuations of the independent variables. Model (1) is the regression outcome without any control variables, model (2) is composed of three control variables, and model (3) represents the return result containing all control variables. The outcomes in Table 4 below display that the per capita CO_2 coefficient is -0.52 (model 3); therefore, the CO_2 per capita increase reduces the poverty rate. All control variables are negative coefficients except for the Gini index and birth rate. The p-value of CO_2 per capita is 0.000, and its range is less than 0.05. Therefore, the correlation between per capita CO_2 and the poverty rate is very significant.

Table 4: Benchmark estimation results

Variables	(1)	(2)	(3)
LnCo2	-0.795***	-0.674***	-0.521***
	(0.184)	(0.0517)	(0.111)
LnGini		0.0103	0.155
		(0.124)	(0.215)
LnAgri		-0.00414	-0.00618
		(0.00657)	(0.00811)
LnElec		-0.0951***	-0.0187
		(0.0308)	(0.0940)
LnBirth			2.669***
			(0.571)
LnDeath			-1.256***
			(0.268)
LnHeal			-0.128
			(0.114)
LnHouse			-0.324
			(0.273)
LnTrade			-0.103
			(0.126)

LnSchool			-0.143
			(0.138)
Constant	2.341***	2.771***	4.261
	(0.334)	(0.494)	(7.967)
Observations	441	371	177
R-squared	0.514	0.547	0.736
LM test	Prob > chibar2 = 0.0000		
Hausman test	Prob>chi2 = 0.0009		
Number of c_{id}	15	15	13

*Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1*

Robustness and Endogeneity Test

This study's dependent and key independent variables are poverty rate and carbon emissions per capita, respectively. In order to check the robustness of the results, we use an alternative variable and rerun the regression model. We use the gross domestic product (LnGdp) and per capita ecological footprint (LnEco) as alternative variables to run the model.

The ecological footprint measures resource consumption and waste generation in relation to nature's ability to absorb them. It calculates total requirements for biologically productive areas, such as cropland, cotton, and forests, and converts them into standardized units called global hectares. This aggregate Ecological Footprint is equivalent to the sum of the global hectares needed to sustain an individual.

Our variable replacement method is divided into three phases. The first phase implies the substitution of only the dependent variable; the second phase implies the substitution of the key independent variable. The last phase implies the substitution of both dependent and independent variables. In model (4), the dependent variable (LnPov) has been replaced by the GDP (LnGdp). The result of model (4) shows that an increase in carbon emissions boosts the economy. In model (5), the independent variable ($LnCo_2$) has been replaced by the ecological footprint per capita (LnEco).

Moreover, the result shows that an increase in (LnEco) leads to decreased poverty (LnPov). In model (6), the poverty rate (LnPov) and the carbon emissions per capita ($LnCo_2$) have been both replaced by (LnGdp) and (LnEco), respectively. The result shows a positive effect on GDP which confirms our first finding. Therefore, our results are robust. It is to be noted that the data (LnGdp) and (LnEco) variables are from the World Bank database. The results obtained from this regression confirm the robustness of our first result. Since LnEco has a positive impact on LnGdp, the increase of LnEco contributes to poverty reduction, which has been supported by some researchers on economic growth and poverty reduction, such as Roemer and Gugerty (Roemer & Gugerty, 1997). In order to avoid the endogenous problem of variables, referring to Coles (Coles *et al.*, 2008), McKnight and Weir (Mcknight & Weir, 2009), we conducted a 2sls regression model using the lagged value of endogenous variables as the instrument variable. The coefficients of our key independent variables are still negative and significant (model 7).

Table 5: Robustness and 2sls regression

Variables	**(4)**	**(5)**	**(6)**	**(7)**
$LnCo_2$	0.392***			-0.193**
	(0.0352)			(0.0841)
LnGini	-0.158*	0.188	-0.217**	1.259***
	(0.0844)	(0.143)	(0.101)	(0.278)
LnElec	0.428***	-0.323***	0.520***	-0.465***
	(0.0210)	(0.0265)	(0.0187)	(0.0675)
LnAgri	0.00516	-0.00356	0.00510	-0.0108
	(0.00447)	(0.00720)	(0.00509)	(0.0139)
LnBirth				1.467***
				(0.192)
LnDeath				0.537***
				(0.181)
LnHeal				-0.00300
				(0.128)
LnHouse				0.261***

				(0.0357)
LnTrade				-0.152
				(0.165)
LnSchool				0.541***
				(0.0980)
LnEco		-0.616***	0.380***	
		(0.126)	(0.0891)	
Constant	22.92***	4.082***	22.06***	-13.78***
	(0.336)	(0.552)	(0.391)	(1.911)
Observations	371	365	365	177
R-squared	0.816	0.390	0.730	0.769
Number of c_{id}	15	15	15	

*Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1*

Intermediary Effect Analysis

The following are the basic steps of the intermediary effect analysis proposed by Baron and Kenny (Baron & Kenny, 1986). Mediation analysis included three sets of regression: X → Y, X → M, and X+M → Y. In Table (6), we examine the association between energy consumption using electricity consumption as a measurement and poverty rate. After controlling the year, LnElec (electricity consumption) is selected as the mediation variable. The regression results confirm a mediating effect between electricity consumption and poverty because both have significant coefficients. Indeed, after running the bootstrap test (coef = -0.08, p<0.000) and with a confidence interval of (-. 130208 -. 0431908), a significant mediator effect was found between LnElec and LnPov (see table 6).

Table 6: Intermediary analysis results

Variables	**(8)**	**(9)**	**(10)**
$LnCo_2$	-0.538***	0.00432	-0.517***
	(0.0669)	(0.0879)	(0.0605)
LnElec			0.125***
			(0.0436)
Constant	-12.08***	-17.42***	6.382
	(2.730)	(5.522)	(3.877)
Bootstrap test coef	coef = -0.08, p<0.000		
Confidence interval	(-. 130208 -. 0431908)		
F.E.	Yes	Yes	Yes
Control variable	Yes	Yes	Yes
Control time	Yes	Yes	Yes
Observations	331	297	297
R-squared	0.714	0.813	0.790
Number of c_{id}	14	14	14

*Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1*

CONCLUSIONS

As nations globally endeavor to diminish their carbon emissions to counteract climate change, they must consider the possible adverse impacts of such policies on poverty alleviation. The implementation of carbon emissions reduction policies can substantially affect low-income households, given their potential inability to compensate for any reduction in income resulting from such measures. LDCs register diminished socio-economic indicators and low human development index ratings. CO_2 emissions are a critical indicator of environmental degradation and conservation. The list of LDCs was sourced from the World Bank, a reliable data source on the economic potential of different regions. The validity and reliability of the study were also considered and determined to be high. This outlook underlined the study as a competent source of information on the topic.

The research utilized panel data from 15 LDCs from 1990 to 2020, and a fixed effect regression model was run. The study finds that:

(1) A significant association between carbon emissions and poverty rates in LDCs. Carbon emissions reduction aggravates poverty in LDCs through energy consumption reduction policies. (2) The research indicates an inverse relationship between CO_2 emission and poverty rate. Its finding shows that poverty alleviation can occur by setting up viable economic opportunities for people in LDCs. (3) Energy consumption is a driving mechanism of CO_2 emission in LDCs.

LDCs depend extensively on fossil fuels for their energy needs, and reducing emissions would mean reduced demand for these fuels. That, in turn, would lead to less investment in these countries and higher energy prices, which would disproportionately impact people experiencing poverty.

Policy Implications

The Outcomes Mentioned Above Hold Significant Policy Implications for LDCs

First, poverty alleviation can occur by setting up viable economic opportunities for people in LDCs. Opportunities can be implemented with little consequence to the CO_2 emissions. However, a concern arises when poverty alleviation activities are implemented without regard for the resulting impact on the climate. While the attempts to reduce the endemic poverty in these regions

are justified, they must be done sustainably. Organizations such as the U.N. and the World Bank need to consider investing in projects that enhance the earning potential of the citizens in LDCs without causing severe damage to the climate of those regions.

Second, the "Green Structural Transformation." Researchers like the Chinese scholar Justin Yifu pointed out the concept of structural transformation as a main way for LDCs to end poverty and engage in economic development. The LDCs are in a "traditional economy" and "dual structure" where agriculture dominates, the transition period to initial industrialization. We must first increase the labor productivity of agriculture and solve the fundamental survival problem of "sufficiency." Then, we must liberate the labor force from agriculture and transfer it to the labor-intensive processing industry. At the same time, we must also promote urbanization and build export processing zones to improve infrastructure and transportation conditions. This series of structural transformations, if there is no role of the government and only relies on the market mechanism, will either take a long time or will not happen at all. However, it is to be noted that for the sake of climate change, the economic structural transformation must change its traditional application to a more "green" application called "Green Structural Transformation."

Third, the pursuit of CO_2 reduction activities must be strengthened within the more developed countries since they have low poverty levels. It is imperative for developed nations to allocate resources toward sustainable energy sources as a means of mitigating CO_2 emissions. In the future, LDCs shall bear more burden of carbon emission reduction, but for now, it will negatively impact their economies and people. Two-thirds of the population of LDCs need access to electricity, particularly in Africa. The African continent, where most less advanced countries are located, consumes less energy than a developed country like Spain (Koffi Annan, 2015).

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