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An assessment of the potential of using carbon tax revenue to tackle poverty

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Abstract

A carbon tax is one of the measures used to reduce GHG emissions, as it provides a strong political instrument for reaching the goal, stated in the Paris Agreement, of limiting the global mean temperature increase to well below 2 °C. While one aspect of a carbon tax is its ability to change income distribution, no quantitative assessment has been made within the context of global poverty. Here, we explore future poverty scenarios and show the extent to which carbon tax revenue, obtained to limit global warming to well below 2 °C, has the potential to help eradicate poverty. In order to better understand the relationship between poverty and climate change mitigation policy, we developed a novel modelling framework that includes a module representing poverty indicators in the conventional integrated assessment model. We found that the poverty gap, which is a measure of the shortfall in income relative to the poverty line, is 84 billion US dollars (USD) and that the carbon tax revenue potential for the above-mentioned 2 °C consistent climate change mitigation would be 1600 billion USD in 2030. Many low-income countries cannot fill the poverty gap using only their own domestic revenue; however, this shortfall could be met by using a portion of the revenue in high-income countries. Our results demonstrate that climate change mitigation can have a great potential in synergy effects for resolving poverty and illustrates the importance of international cooperation.

1. Introduction

Currently, the number of people worldwide under severe poverty, below the threshold for decent living ($1.90 per day in terms of international purchasing power parity, PPP), known as the poverty headcount, is reported as 736 million [1]. The number has historically decreased, and is now over 1 billion less than in 1990, despite significant population increases in low-income countries during this period. This progress has been driven by strong global income growth and rising wealth in many low-income countries. Although a large number of people still suffer from absolute poverty, poverty reduction has been very successful over the last couple of decades, as recognised by the success of the Millennium Development Goal (MDG) programme [2]. Sustainable Development Goals (SDGs) have been established as post-MDG UN goals. There are 17 goals and one of them is SDG1 which clearly states that its goal is to end poverty. Numerically, the target is 'to achieve the target of less than 3% of the world living in extreme poverty by 2030'. Continuing efforts toward achievement of SDG1 may lift people out of poverty conditions.

With respect to climate actions, the Paris Agreement [3] defines the long-term international climate policy goal as: 'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels'. Along with this long-term climate goal, countries submitted nationally determined contributions (NDCs), describing their individual near-term actions toward greenhouse gas (GHG) emissions reduction.

Carbon pricing [4, 5], which is often discussed as an economic measure that will result in reduction of GHG emissions, would be a key incentive for actors to reduce the CO_2 emissions of their activities. Among carbon pricing measures, a carbon tax is a useful and efficient economic policy instrument for reducing GHG emissions, one that has already been implemented in many countries [5] or is currently under discussion [6]. A carbon tax could have various economic consequences through market mechanisms, such as changes to the prices of goods, tax revenue, and the recycling of such revenue [7].

Considering the potential interactions between poverty and climate change mitigation, one fundamental question is that of whether a carbon tax implemented for climate change mitigation can be used to reduce poverty [8]. In addition to reducing GHG additions, carbon tax implementation could be used to help eradicate poverty by changing income distribution through revenue recycling. It may be used to help eradicate poverty. Some previous studies in the context of climate change impacts on poverty [9–12] have shown changes in income inequality associated with climate change mitigation, as well as in energy poverty, in some countries [13–15]. Moreover, the income equality implications of a carbon tax have been investigated using national-scale modelling [16–19]. While there can be another instrument changing income equality, for example, using Personal Carbon Trading [20, 21], no study to date has addressed the use of carbon tax revenue to poverty globally, despite this topic being highly relevant to international development and climate change policies.

Here, we show the extent to which carbon tax revenue could potentially help with poverty eradication and demonstrate the importance of international cooperation in meeting that goal. A scenario analysis is undertaken that explores the potential carbon tax revenues that could be derived under the climate mitigation goals stated in the Paris Agreement and estimate and estimate the poverty headcount and poverty gap, which represents the deficit of income below the poverty line, for around 200 countries (supplementary tables 1 and 2). We also derived the absolute poverty gap and the poverty gap as a portion of GDP for comparisons with carbon tax revenue.

2. Materials and methods

We used a state-of-the-art integrated assessment modelling framework, the Asia-Pacific integrated model (AIM) [22, 23] (supplementary figure 1) (available online at https://stacks.iop.org/ERL/15/114063/mmedia). The AIM has been applied for the global and national climate change mitigation assessment, and the core of the framework is built upon a computable general equilibrium (CGE) model that represents all goods and services transactions within the economic system. The climate policy is represented by imposing carbon tax, which is endogenously determined to meet the emissions constraints, and carbon tax is collected from industrial and household activities emitting GHG gases, and then its revenue is recycled to the household. In reality, carbon pricing and carbon taxes may not operate this effectively, but the methodology is thought to offer a suitable simplification of these mechanisms. Within this CGE model, macroeconomic indicators and those associated with energy, agriculture, land use are, and GHG emissions are computed. In this study, we also developed a new sub-model enabling the simulation of income distribution and consumption patterns of households so that individual income class income and expenditure patterns are represented within the model because the CGE model classifies only single represented households for each region. Accordingly, this sub-model consists of income and expenditure modules. The former estimates the income distribution using thousands of income segments, while the latter computes changes in the consumption pattern associated with price changes, given the income for each segment. The primary analysis was conducted using a poverty line of \$1.90 a day (2011 PPP), which is widely used in international contexts [1]. The macroeconomic indicators (regional average income loss rates), and price indices computed by the CGE model are fed into the poverty module (see supplementary note 1).

We developed scenarios based on various climate policies being implemented by 2050, mainly focusing on the year 2030, which is the target year of current international near-term climate policy decisions associated with the Paris Agreement. We analysed four scenarios: baseline, NDC, well below 2 °C, and 1.5 °C (hereafter WB2C and 1.5 C). Baseline reflects the historical trend up to 2015, extended without additional climate policy. NDC assumes that each nation's emissions are in line with the NDC submitted to the United Nations Framework Convention on Climate Change for the Paris Agreement by that nation. The WB2C and 1.5 C scenarios are consistent with changes of 2 °C and 1.5 °C, respectively, assuming a globally uniform carbon price and implying that all countries participate in emissions reduction efforts with cost-efficient mechanisms. The emissions under both scenarios are consistent with the recent IPCC report [24]. We adopted the shared socioeconomic pathways (SSPs) assumptions as a background for socioeconomic dynamics [25]. The middle-of-the-road scenario, SSP2, is the default scenario used in this study, and sensitivity analysis under varying socioeconomic assumptions was carried out. Carbon tax revenue was calculated from the residual CO_2 emissions and carbon tax rates (for more details, see **Supplementary Note 1**).

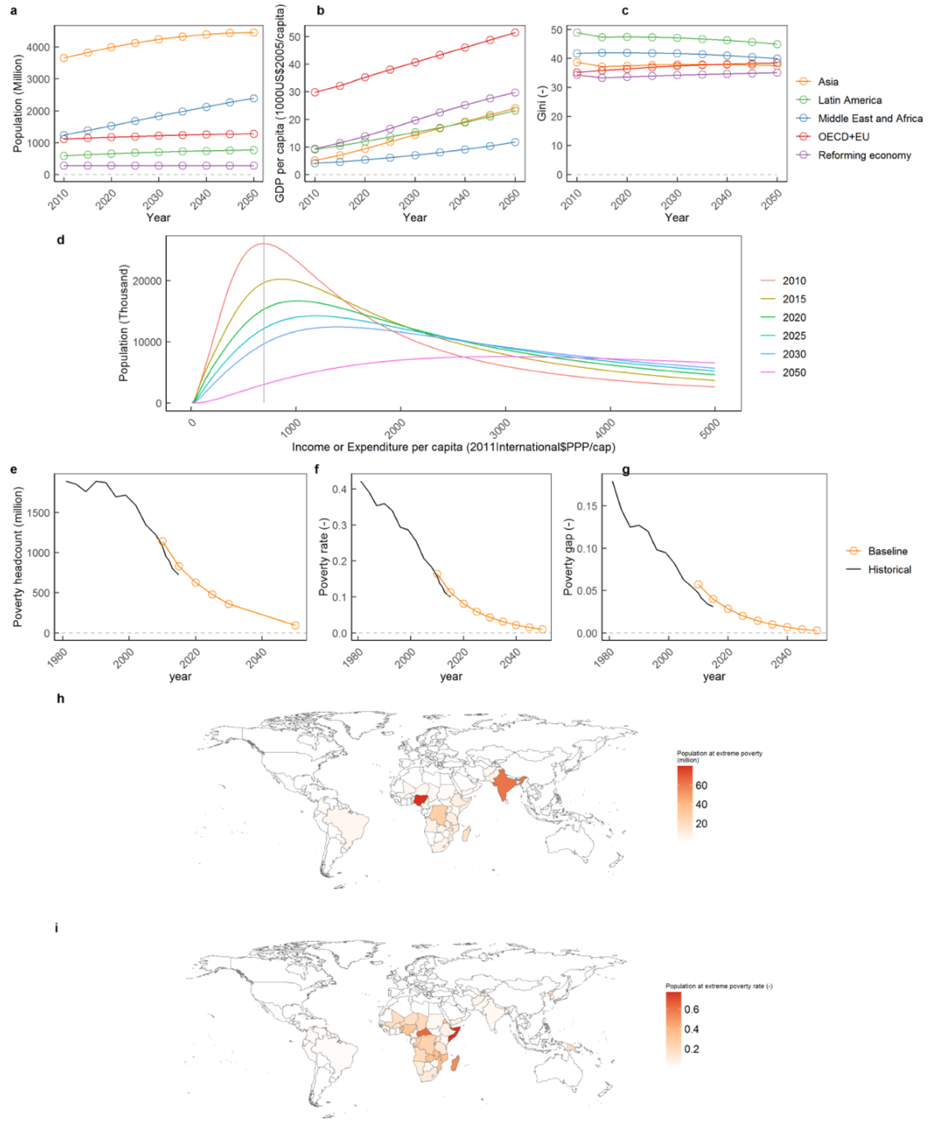

Figure 1. Global and regional trends in socioeconomic indicators and income distribution. Panels (**a**)–(**g**) indicate population, GDP per capita, Gini coefficient, poverty headcount, poverty headcount ratio, and poverty gap rate based on a threshold of $1.9/day per capita, respectively. Panel d shows the income distribution under $5000 per capita. Panels (**h**) and (**i**) illustrate the population under the poverty line and poverty rate, which is the population ratio under the poverty line, of each country in 2030.

3. Results

3.1. Exploring poverty toward 2030

The global poverty headcount is projected to decrease continuously over the coming decades, from 736 million in 2015 to 360 million in 2030 and 91 million in 2050 (figure 1(e)). The socioeconomic assumptions behind our estimates drive these trends, as they indicate steady income growth (figure 1(b)) and population increase (figure 1(a)), as well as stable income equality within countries, represented by the Gini coefficient (figure 1(c)). The poverty rate is projected to reach 4.3% after falling from 9.9% in 2015, nearly reaching the goal stated in the SDGs. Along with macro-level socioeconomic dynamics, such as mean GDP per capita and the Gini coefficient, the global income distribution is predicted to shift such that the peak of income becomes lower and moves to the right in the income distribution figure (figure 1(d) and see supplementary figure 2 for regional results).

The poverty gap shows a similar decreasing trend to the poverty headcount, falling from 4% in 2015 to 1.4% in 2030 (figure 1(g)) (a discussion of the small gaps between the historical record and predicted scenario can be found in the Methods and Supplementary Information). The absolute poverty gap is projected to be $82 billion by 2030 (2011 international PPP) (hereafter, $ indicates 2011 international PPP), which is equivalent to 0.042% of total global GDP, and it looks likely to approach zero in 2050.

The poverty rates and population under the poverty line vary among countries (figures 1(h) and (i)). Currently, the least developed countries, which are mainly located in the African continent, are likely continue to host relatively large populations under extreme poverty (figure 1(i)). For instance, we found

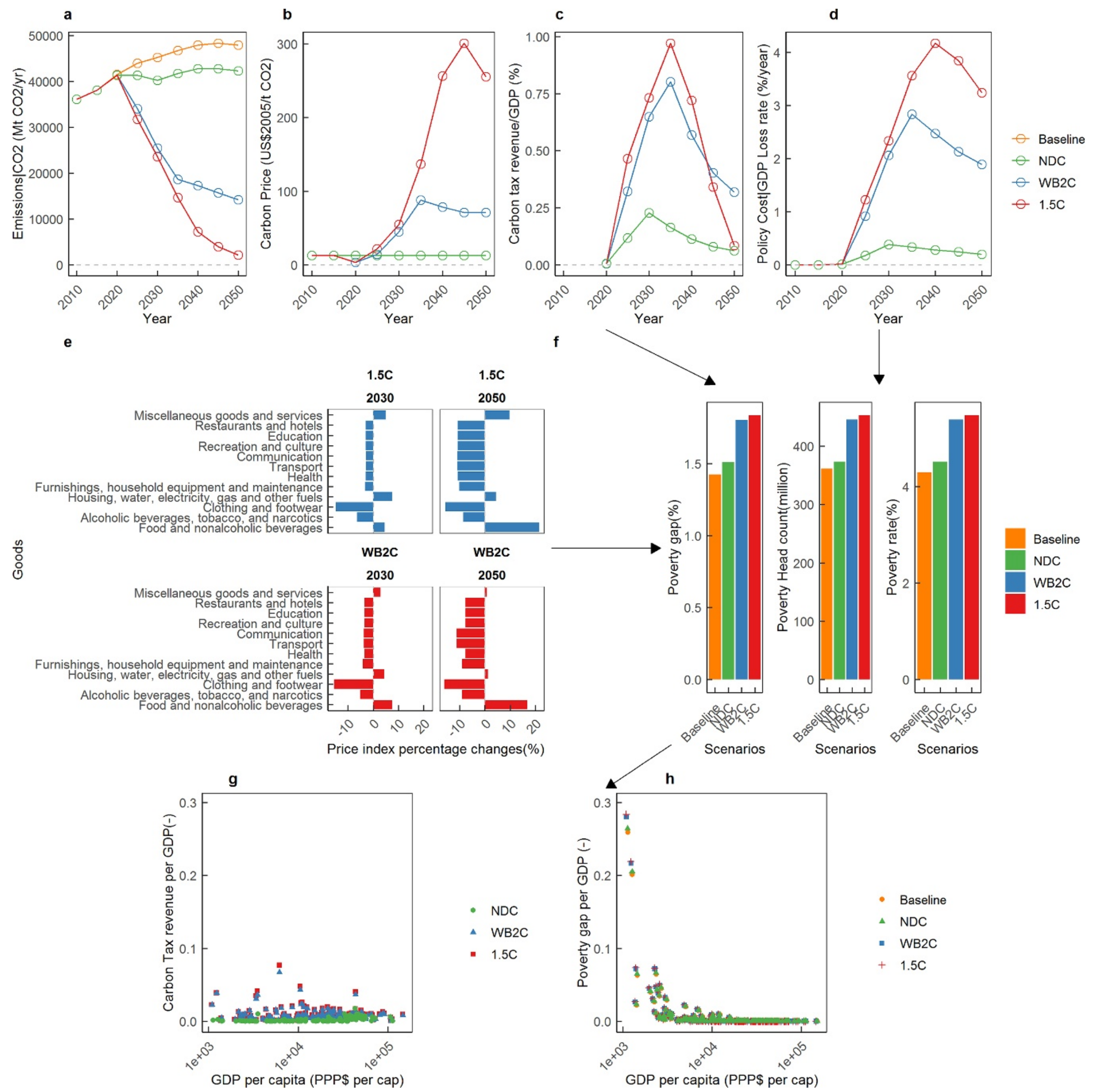

Figure 2. Climate change mitigation effects on poverty. (**a**)–(**d**) present global CO_2 emissions, carbon price, GDP loss rate, and carbon tax revenue relative to GDP, respectively. Panel (**e**) shows global mean price changes under the mitigation scenarios relative to the baseline level in 2030 and 2050. Panel (**f**) indicates poverty-related index changes under all scenarios (poverty gap, poverty headcount and poverty rate). Panels (**g**) and (**h**) illustrate carbon tax revenue and poverty gap relative to GDP, respectively, of all countries in comparison with the GDP per capita under each mitigation scenario (shown with a log scale).

that Somalia, Central African Republic and Madagascar are the countries with the highest poverty rates, which are projected to be 0.77, 0.63 and 0.52, respectively, in our scenario in 2030. Meanwhile, the population living under the poverty line is remarkable in Nigeria, India, and the Democratic Republic of the Congo. These countries will have 79, 60 and 28 million people living in poverty in 2030, respectively, which are larger numbers than in other countries; however, the corresponding poverty rates of 0.31%, 0.040% and 0.23% are not among the highest values (figure 1(h)).

3.2. Carbon tax revenue and effects of climate change mitigation

Stronger climate mitigation measures require reductions in emission levels (figure 2(a)), which can be achieved using higher carbon taxes (prices) (figure 2(b)). Likewise, tax revenues–derived by multiplying total emissions by tax level–are higher under more stringent climate litigation levels and are expected to peak around the year 2030. Levels are likely to decline after this as a result of lowering emissions and moderate increases in carbon price. The carbon tax revenue is derived from multiplying emissions by tax level and increases as a result of increases in the climate change mitigation policy (figure 2(c)). The global total carbon tax revenue potential is projected to be $436 billion in 2030 under the NDC scenario, whereas the 1.5 C and WB2C climate change mitigation scenarios lead to revenues of $1360 and $1210 billion, which are 2.0% and 2.3% of GDP respectively in 2030. The carbon price rises to around $50 under the 1.5 C and WB2C scenarios, which leads to differences in carbon tax revenue.

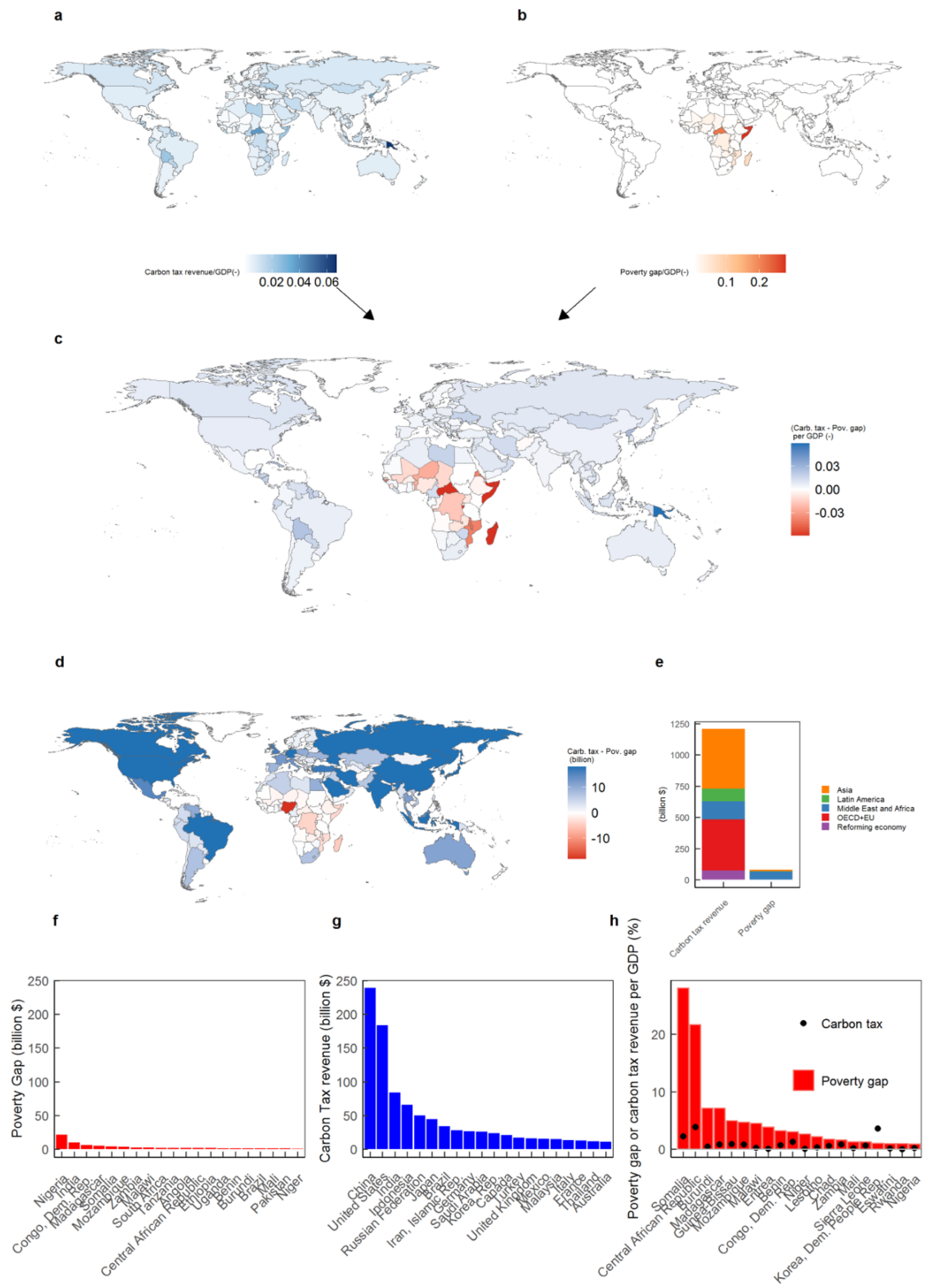

Figure 3. Distribution of carbon tax revenue and the poverty gap by nation in 2030 under the WB2C scenario. Panels (**a**)–(**c**) present carbon tax revenue relative to GDP, poverty gap relative to GDP and the difference between carbon tax revenue and the poverty gap relative to GDP, respectively. Panel (**d**) shows the difference (in absolute terms) between carbon tax revenue and the poverty gap. Panel (**e**) illustrates global carbon tax revenue and poverty gaps in five major regions. Panels (**f**) and (**g**) show the 20 countries with the greatest poverty gaps and carbon tax revenues under the WB2C scenario, respectively. Panel (**h**) presents the 20 countries with the greatest poverty gap relative to GDP along with carbon tax revenue relative to GDP.

In addition to carbon tax revenue, carbon pricing has certain adverse side effects in terms of macroeconomic factors and household consumption. The global income loss associated with additional climate change mitigation costs could reach 2.0% in 2030 under the WB2C scenario and 1.5 C scenario shows similar trend by 2030 (figure 2(d)). Prices of goods, in particular energy and food, showed increases of 7.5% and 4.4%, respectively, which could have regressive effects on consumption levels of low-income households (figure 2(e)). The ultimate consequences of these price and income changes associated with climate mitigation scenarios basically cause adverse side effects in poverty headcount, poverty gap, and poverty rates similarly. As the stronger the climate mitigation increases, the magnitude of the above-mentioned side effects gets larger. Taking an example of the WB2C scenario, poverty gap would increase by 23% compared with Baseline scenario (figure 2(f)). The poverty gap shifts from a baseline of 1.4% to 1.6% under WB2C. This number might appear large, but is small compared with the other uncertainties described below (e.g. socioeconomic uncertainty). Note that the ratio of the poverty gap to GDP for

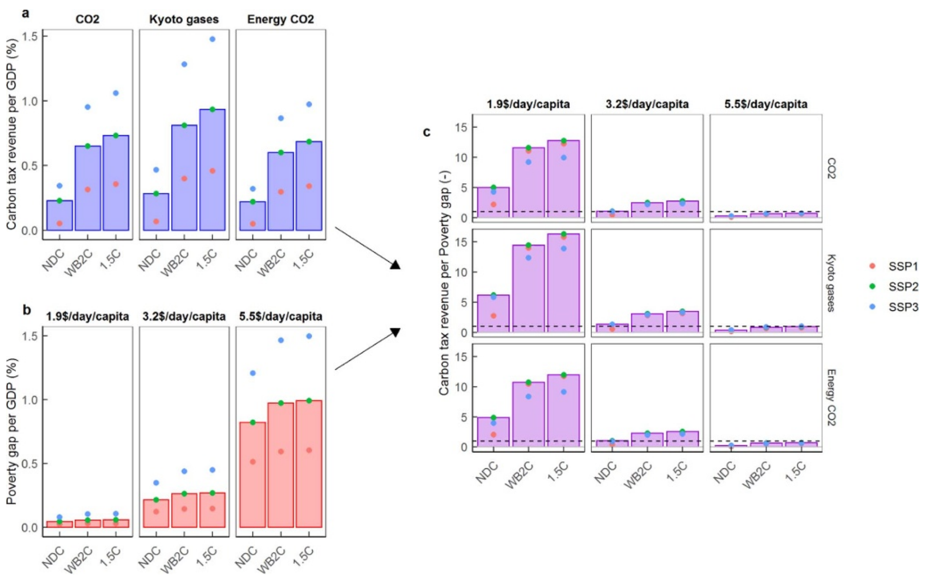

Figure 4. Uncertainties in global carbon tax revenue and the poverty gap associated with socioeconomic assumptions, stringency of climate policies, gas coverage of the carbon tax and the poverty threshold. Panels (**a**) and (**b**) present carbon tax revenue relative to GDP and poverty gap relative to GDP and are grouped by gas coverage of the carbon tax and poverty threshold. Panel (**c**) shows the ratios of carbon tax revenue to poverty gap for each case. The bar indicates the default socioeconomic condition represented by SSP2 and dots indicate the variations under SSP1 and SSP3.

each nation is not so much affected by the stringency of climate change mitigation (figure 2(h)). Importantly, the damage caused by climate change to the low-income class would be much larger than the average GDP changes and, thus, would be of more serious concern than the effects of climate change mitigation on poverty [9].

We compared global carbon tax revenue with the poverty gap for all countries (figures 3(a)–(d)). The poverty gap varies geographically among countries both in absolute and per GDP terms (figures 3(b) and (c)). This result is easily explained because the poverty gap measures the level of absolute poverty, which should be concentrated on low-income countries. However, carbon tax revenue is more equally distributed among countries in per GDP terms (figure 3(a)). Basically, all nations, including high-income nations emit a certain level of GHGs and the imposition of the same carbon tax level across counties would yield relatively equal distribution. It is also worth noting that the carbon tax revenue per GDP in all nations is less than 0.1. Subtracting the poverty gap from carbon tax revenue, we can derive shortages of carbon tax revenue, which occurs in some African countries, such as Nigeria and the Central African Republic (figure 3(f)). Eventually, for the global aggregates, we found that the poverty gap is 15 times larger than the carbon tax revenue (figure 3(e)). Carbon tax revenue potential is distributed among countries (figure 3(a)), but is greater in countries with a large population of middle income earners such as China and India ($240, $80 billion, respectively) and in countries with relatively large OECD economies such as the United States and Japan ($190 and $50 billion). Importantly, the heterogeneity of carbon tax revenue relative to GDP among countries is much smaller than that of the poverty gap. The 20 countries with the greatest poverty gaps are generally short of carbon tax revenue because these countries emit relatively less GHG emissions, leading small carbon markets (figures 3(g) and (h)). The degree of this shortage is incredibly small compared with the surpluses of carbon tax revenue predicted, mainly in high-income countries. For example, 20% of the carbon tax revenue in developed countries (current OECD + EU), which is around 0.1% of GDP, could be used to supplement the poverty gap. We observed high similarity throughout the geographical distribution of the difference between projected revenue and the poverty gap in the 1.5 C scenario, while carbon tax revenue was more concentrated in OECD countries in the NDC scenario (supplementary figure 7).

3.3. Uncertainty analysis

The results presented above may vary with 1) the stringency of climate change mitigation, 2) socioeconomic assumptions such as population changes and economic development, 3) the poverty line, and 4) the GHG coverage of the carbon tax imposed. Three additional sensitivity analysis shown below were carried out to test these uncertainties (climate policy variations have already been computed above).

- Three socioeconomic assumptions represented by SSPs (SSP1: sustainable and high growth in developing countries, SSP2: middle-of-the-road scenario, SSP3: low growth and high population in developing countries)

- Additional poverty lines of \$3.2 and \$5.5/day per capita
- Carbon taxes covering all gases stated in the Kyoto Protocol, CO_2 only and energy-related CO_2 only.

Almost all cases show carbon tax revenue that is greater than the poverty gap (figure 4). In particular, under the \$1.9/day per capita poverty threshold, we confirmed the robustness of our findings under all assumptions (figure 4(c) left). Under climate policy in line with 2 °C or 1.5 °C stabilisation, even with a poverty line of \$3.2/day per capita, carbon tax revenue is sufficient to cover the poverty gap (figure 4(c) left). However, to fill the poverty gap at the \$5.5/day per capita threshold requires a much larger amount of money, which would no longer be covered by the carbon tax revenue. Socioeconomic uncertainty affects the amounts of both carbon tax revenue and the poverty gap. Interestingly, both indicators varied in the same direction, with carbon tax revenue and the poverty gap following the pattern of SSP3 > SSP2 > SSP1, causing the uncertainty range for the ratio of carbon tax revenue to poverty associated with socioeconomic assumptions to be small. In SSP3, the carbon prices become higher than in other scenarios due to the high challenges in mitigation, which leads to larger carbon taxes. Finally, carbon tax coverage was not an influential factor in this assessment, although its coverage may be controversial due to food security concerns [26, 27]. Regional results are provided in supplementary figure 8.

4. Discussion and conclusions

We found that carbon tax revenue has a great potential to help eradicate poverty, and our findings provide critical information for international climate change and sustainable development policy. In many countries, a carbon tax is currently being considered to reduce GHG emissions, but how the tax revenue should be used remains under debate. Our findings provide meaningful insights that may contribute to the formulation of domestic policies in numerous nations.

Another important implication of this study is that international cooperation is essential to filling the poverty gap, as carbon tax revenue is received primarily by high-income countries (e.g. the United States, Japan and Germany) and emerging countries (e.g. China and India). A small fraction of the carbon tax revenues of high-income countries could be used to fill the overall global poverty gap.

Clarifying the scale of the global poverty gap and carbon tax revenue through comparison with currently approved climate funding is also informative. At conferences of the parties 17 which was held in Durban, the parties set up the Green Climate Fund (GCF) as an operating entity of the Financial Mechanism of the Convention, in accordance with Article 11 of the Paris Agreement. The agreement sets a new collective quantified goal with a floor of \$100 billion per year, accounting for the needs and priorities of developing countries. The scale of the poverty gap is comparable with the size of this GCF while the GCF is still struggling with collecting money (e.g. due to the withdrawal of United States) and currently it was around 10 billion\$ in 2019. From the perspective of development policies, global net official development assistance (ODA) was \$133 billion (0.3% of GNI) in 2015 [28], which is comparable to the poverty gap and much smaller than projected carbon tax revenue. Another way to interpret the level of aid is based on SDG 17 (partnership), which sets a target ODA level of 0.7% of ODA/GNI (gross national income). If the carbon tax revenue transfer to developing countries suggested in this study were to be added to the current ODA totals, SDG 17 would be more easily achieved. As past emissions have predominantly originated from developed countries, such transfers are thought to be justifiable.

Several possible arguments with our conclusions are discussed below. As shown in figure 3, large amounts of carbon tax revenue will be collected not only in the current group of developed countries but also in middle-income countries (e.g. China and India) and wealthy countries in the middle East (e.g. Saudi Arabia). Given the current complexity of international affairs, reaching a single international agreement would be difficult. Therefore, we show the potential of carbon tax revenue for poverty eradication, and note that actual political implementation depends on numerous considerations. At the same time, we believe that this study offers a foundation to start that discussion.

Obviously, we cannot use carbon tax revenue only for reduction of income inequality or poverty eradication. As shown in previous studies [5], carbon tax revenue already supports multiple functions in countries that have implemented such a tax, such as subsidising renewable energy generation. Thus, a direct comparison of total carbon tax revenue with the poverty gap may not fairly represent reality. However, even one tenth of the carbon tax revenue estimated in this study is sufficient to fill the poverty gap under the 1.5 C and WB2C scenarios, supporting the importance of international cooperation in this area.

A globally uniform carbon tax rate (per ton of CO_2) may not be a realistic assumption which is assumed in the 1.5 C and WB2C scenarios as well as in many global studies [4]. Firstly, although many countries have already implemented carbon taxes, its usage is still limited and collection of carbon taxes, particularly from the least developed countries, will remain difficult in the near future. Secondly, carbon tax levels currently vary among countries, from a few dollars to around a hundred dollars per ton of CO_2 [5]. To achieve uniform global carbon pricing would require a well-established global carbon market or equivalent institution. Such a market or market mechanism must be beneficial to many actors around the world, but this is not be easily achieved. However, as we have demonstrated, carbon tax revenue in the major emitting countries, i.e. high- and middle-income countries, would be sufficient to fill the poverty gap. Thus, the more important topic of discussion is how to use carbon tax revenue from relatively high-income countries rather than how to implement a carbon tax in low-income countries. There is opposition to carbon tax even in high-income nations, mainly driven by low-income people. Also, low-income nations could face much stronger resistance than high-income nations. Thus, the real applicability of carbon tax would be another key discussion point, and the multiple instruments would be better to be considered in reality (PCT and ETS). However, to achieve the long-term climate goal, every nation somehow needs to reduce emissions and carbon tax would be a secure option in the future.

This analysis is based on the assumption that carbon tax revenue goes directly to people living in poverty. This may be possible in some countries, but we cannot expect that governments can easily distribute carbon tax revenue, collected either domestically or from abroad, to the poorest people. Moreover, directly giving money to those in poverty may not be an appropriate development policy. Poverty should be addressed as a multi-dimensional condition [29, 30], where education, access to clean water and energy, and many other social aspects are considered, and cannot be resolved by a simple transfer of money. The cost of poverty eradication would be much higher than a subsidy directly to low-income people. More importantly, development policy should aim to have long-term effects, such as increasing human capacity and developing social infrastructure. For instance, the estimated costs of education, health and social protection transfers would be $2.4 trillion per year[31]. Accordingly, the plan to help eradicate poverty should include various instruments, both directly and indirectly.

The distributional effects of a carbon tax are controversial [32, 33]. The literature about national-scale assessments is relatively wide ranging and the conclusions to date tend to vary depending on individual nations and on the assumptions of each study. Three main mechanisms affect how a carbon tax changes household income (consumption), namely, the income source, direct and indirect expenditure effects, and carbon tax recycling schemes. This paper does not aim to address these points, but they are a relevant topic for future research using the methodology developed in this study, and may be discussed in forthcoming studies.

Although we consider the overall conclusions of our study to be robust, there are several aspects for which slight differences are expected. For example, we estimated income and consumption by each segment based on a one-way coupling model that uses a CGE model to compute the macroeconomic response which is then passed to a poverty model to account for effects on income distribution and household expenditure. Certain feedback effects are expected from the income distribution to macroeconomic factors, and identifying these effects is the next challenge. The household survey data are another source of uncertainty, as data quality from such surveys may be poor. As such, we must acknowledge that our methodology relies on uncertain data. These things can be addressed by future researches by making additional model tests and data updates. While we need further investigations, the findings of this study can stimulate a debate on the poverty and climate change mitigation policies, and the methodology would be a milestone for a new research area.

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Conflict of interest

The authors declare no competing interests.

Author contributions

S F designed the research; S F carried out analysis of the modelling results; S F and K O created the figures; S F drafted the paper; S F, K O and T H contributed to the discussion and interpretation of the results.

Data availability statement

The data that support the findings of this study are openly available at the following DOI: https://doi.org/10.7910/DVN/JHIGMN.

Code availability

The source code for generating the figures used in the main text and supplementary information is available from Harvard Dataverse (https://doi.org/10.7910/DVN/JHIGMN) under the name 'Sourcecode.tar'.

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