Implications of Climate Mitigation Measures for Poverty and Inequality in Sub-Saharan Africa: Framework for Multiple Country Research Study

Rashid Mekki Hassan
and
Ramos Mabugu

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Abstract

This research report developed a framework for studying the implications of climate mitigation measures for poverty and inequality (P&I) in Sub-Saharan Africa (SSA). The framework paper undertook a comprehensive survey of relevant literature to examine how much attention has been given in climate mitigation science and policy analysis to aspects of P&I. The paper then proposed an analytical framework and empirical methodology for conducting multi-country investigations of the P&I implications of the various climate mitigation policy measures introduced or proposed at national and global scales. The paper mapped the main channels through which climate mitigation measures get transmitted or mediated to P&I impacts. Mediation analysis enables identification of appropriate methods to measure and evaluate the merits of alternative mitigation policy measures. Approaches that can be used to model and quantify the impacts of climate mitigation on P&I were presented. The paper concluded with proposing datasets to use and suggesting a pilot case studies' approach that can be followed. To guide selection of countries to conduct studies that will be implementing the analytical framework and empirical methods proposed, the paper examined the extent to which SSA countries have participated in global and regional climate mitigation initiatives. The results indicate that while all countries in SSA ratified major climate mitigation agreements, the degree of participation varies significantly between the different protocols. The largest amount of funding to mitigation in SSA came from the International Emissions Trading instruments, exceeding US$ 57 billion in 2018. The results obtained from implementing the framework for the selected countries are expected to inform the design of climate mitigation measures that aim to maximize co-benefits and avoid negative P&I outcomes.

Keywords: *Climate Change, Mitigation Policy, Africa, Poverty and Inequality*

JEL Classification: *Q54, Q56, D63*

1. Introduction

In recognition of the mounting scientific evidence and observed recent climate related trends, the international community has come to consensus on the urgency of actions to avoid predicted serious implications of global warming for life on earth. Of particular concern is the complex dynamics and strong interlinkages between climate change (CC), poverty and inequality (P&I) (Jakob and Steckel, 2014; Hallegatte et al., 2016; Hallegatte Rozenberg, 2017; Markhanen and Anger-Kraavi, 2019). The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report argues, with high confidence, that *"socially and geographically disadvantaged people exposed to persistent inequalities"* are the most vulnerable to the adverse effects of climate change. The report also states that *"climate change and climate variability worsen existing poverty, exacerbate inequalities, and trigger both new vulnerabilities and some opportunities for individuals and communities"* (Olsson et al., 2014). Diffenbaugh and Burke (2019) reach similar conclusions in a more recent work. Mitigation and adaptation have been the two central climate response strategies of the international community (IPCC, 2014b and 2014c). Mitigation refers to reducing emission of greenhouse gases (GHSs) to stabilize the climate system temperature while adaptation refers to assisting the most vulnerable to cope with the adverse impacts of climate change.

Climate science and policy analysis acknowledge differences between countries and social groups in the responsibility for causing the global warming problem, and the degree of vulnerability and capacity to cope with the adverse impacts of climate change (United Nations Framework Convention on Climate Change - UNFCCC, 1992;1998; Fleurbaey et al., 2014). However, literature on the two main response measures (i.e. adaptation and mitigation) proposed for managing climate change impacts address concerns about its P&I implications in different ways and degrees of attention. The adaptation literature, for instance, explicitly recognizes *intra-generational* inequities by identifying the vulnerable and informing policy on targeting adaptation strategies and actions to assist the poor and most vulnerable (World Bank, 2010; UNFCCC, 2013; IPCC, 2014c). Mitigation strategies and measures focus primarily on *inter-generational equity*, i.e. protecting future generations against the hazards and burdens of climate change (Stern, 2007; Nordhaus, 2008; Gollier, 2012; IPCC, 2014b). While mitigation will be beneficial to both the rich and poor in the future, the implications of proposed mitigation measures and policy practices on P&I among the present generation are not well understood (Hussein et al., 2013; Klinsky and Winkler, 2018; Markhanen and Anger-Kraavi, 2019). Given that the main purpose of adaptation is to increase the resilience of vulnerable groups to climate change risks, the focus of this study will be on consequences of climate mitigation strategies and response measures on intra-generational P&I.

The literature seems to suggest that current mitigation policies, such as the Clean Development Mechanism (CDM) and Reduction of Emissions from Deforestation and Forest Degradation (REDD+) had no, and often detrimental, effects on the poor and marginalized people (Olsson et al., 2014). This assessment, however, is based on limited evidence particularly for countries in Sub-Saharan Africa (SSA) participating in the various global and regional climate mitigation initiatives and programmes, and adopting their own national mitigation measures (Somanthan et al., 2014).

The main purpose of this paper is to develop a framework for studying the implications of climate mitigation measures for P&I in Sub-Saharan Africa (SSA). In pursuance of this, this framework paper undertook a comprehensive survey of relevant literature to examine how much attention has been given in climate mitigation science and policy analysis and practice to aspects of P&I, and to identify gaps in existing knowledge. Based on the survey of relevant literature, the paper then proposed an analytical framework and empirical methodology for conducting multi-country investigations of the P&I implications of the various climate mitigation policy measures introduced or proposed at national and global scales. The results obtained from implementing the framework for the selected countries are expected to inform the design of climate mitigation measures that aim to maximize co-benefits and avoid negative P&I outcomes.

The next section of this paper provides concise overview of the state of climate mitigation science and policy practices covering main global, regional and national protocols and policy measures. Section 3 examines the degree of participation of countries in SSA in current climate mitigation initiatives and their national policy efforts. A survey of the status of evaluating the P&I impacts of climate mitigation policy and practice in available literature is presented in section 4. The paper then develops in section 5 an analytical framework and proposes empirical approaches to undertaking research for studying the P&I impact of climate mitigation in SSA. Section 6 concludes the paper by giving a recommendation towards identifying case study candidates for implementing and testing the proposed framework, and a summary.

2. Climate mitigation science and policy practices

Climate science provides evidence of the strong causal linkages between human activity, emission of GHGs, and global warming. The science has also established the association between global warming (elevated temperatures) and the various observed geophysical phenomena characterizing climate change, such as incidents and frequency of extreme events (flooding, storms, and drought), sea level rise, snow melts, outbreaks of disease vectors and pest infestation, among others (IPCC, 2014a). The mounting scientific evidence of the extent and speed at which climate change is unfolding has led to the almost universal consensus on the necessity and urgency for global action to curb its serious harmful consequences for life on earth (Stern, 2007; UNFCCC, 2009; World Bank, 2010).

All sorts of climate mitigation policies and measures to reduce emissions and stabilize atmospheric concentration of GHGs at less dangerous levels have consequently been identified (IPCC, 2014b). Those span various technological, institutional, economic policy measures and innovations developed to enable low carbon growth. We identify in this section key global and national climate mitigation strategies and associated policy instruments considered in studying the impact of climate mitigation on poverty and inequality.

Global climate mitigation protocols

One important contribution of climate science has been the recognition that climate change is a global commons' problem that requires collective action by all members of the global community; i.e. all countries (Stavins et al., 2014). The international community has consequently formulated and ratified several protocols for CC mitigation. The United Nations Framework Convention on climate change (UNFCCC), Kyoto Protocol, Copenhagen Accord, Cancún and Paris Agreements (among many others) are examples of required global collaborative arrangements for collective climate change action. Following from these protocols, a number of policy measures and instruments have been proposed for intervention at global, regional, and national levels. Low-carbon energy technology options and efficiency in use, and regulatory and economic incentives' instruments (e.g. carbon credits) are examples of such policy measures. The measures have important implications for the status of the poor and underdeveloped communities throughout the world.

Binding climate mitigation commitments have been specified for several countries (primarily industrialized - Annex I) in the UNFCCC (1992) and the Kyoto Protocol (Annex B) (UNFCCC, 1998). Some flexibility has been provided through the Kyoto Mechanisms to assist Annex B countries achieve their emission-reduction targets. The Kyoto flexibility mechanisms complement regulatory regimes with instruments that promote creation and use of markets for trading emissions' allowances. Three flexible mechanisms are provided in the Kyoto Protocol, namely: Joint Implementation (JI), Clean Development Mechanism (CDM), and International Emissions Trading (IET) (UNFCCC, 1998). These mechanisms allow all countries to generate emissions' offset credits (EOCs) that can be rewarded through a number of arrangements. CDM and JI have been operationalized through emissions' reducing projects (independently or jointly implemented). Annex I countries can use EOCs generated through such projects (either self-implemented or acquired/bought from other countries hosting the projects) towards offsetting their emissions' reduction obligations. IET allows governments to directly trade their EOCs (UNFCCCC, 1998). A number of funds have been created under the administration of the Global Environment Facility (GEF) to support UNFCCC protocols on climate change, including the GEF Trust Fund, Special Climate Change Fund (SCCF), and Least Developed Countries Fund (LDCF) (Stavins et al., 2014).

Other major arrangements for promoting international cooperation on climate mitigation include the Copenhagen Accord (UNFCCC, 2009) and Cancún Agreement (UNFCCC, 2010) which, unlike Kyoto, did not impose obligatory targets but required pledges (voluntary commitments) to emissions' reduction goals by both developed and developing countries. Two other important instruments have been created under the Copenhagen and Cancún agreements, namely the Green Climate Fund (GCF) and the Climate Technology Centre and Network (CTCN). Both of these two institutions (GCF and CTCN) have been established to promote international cooperation in financing climate mitigation and technology development and transfer (UNFCCC, 2010).

Several other collaborative initiatives complementing the UNFCCC climate mitigation protocols have also been created. One important example is the partnership for reducing emissions from deforestation and degradation (REDD+), to which more than US$ 4 billion were pledged by 50 countries in 2010 (Bodansky and Diringer, 2010). Another example is the International Renewable Energy Agency (IRENA) established in 2009 to finance development and transfer of renewable low-carbon energy technologies (IPCC, 2011). The multi-donor Climate Investment Funds (CIFs) administered by the World Bank is another global financial instrument established to fund climate mitigation activities, which consists of two trust funds: the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF) (World Bank, 2012).

The Paris Agreement (PA) is the most recent global convention under which all parties to the agreement commit to submit their nationally determined contribution (NDC) detailing strategic plans for low GHG emission development path. Financial mechanisms are proposed under the Paris Agreement (PA) to support parties that may need such assistance for the preparation and communication of the intended NDCs (UNFCCC, 2015). The Montreal Protocol is another important climate mitigation instrument that promotes international cooperation in controlling production and consumption of substances that destroy the Ozone layer (United Nations, 1989).

Regional and national climate mitigation instruments

A number of climate mitigation agreements have recently emerged, involving only sub-groups of the United Nations (UN) member countries. With the exception of the European Union (EU) Emissions Trading Scheme (ETS), such regional coalitions are mostly based on non-binding voluntary governance arrangements (Agrawala et al., 2014).

The EU ETS is the largest emission trading system and major driver of the global carbon market prices (Nazifi, 2010). The EU registered entities (companies) are allowed under the EU ETS to import credits (EOCs) only from CDM (Certified Emission Reductions - CERs) and JI (Emissions Reduction Units - ERUs), but not from IET, and with a large bias to projects located in least developed countries - LDCs (Skjærseth and Wettestad, 2010). It is estimated that between 2008 and 2012, about 84% of CERs and ERUs have been used by over 4,000 EU companies (Kossoy and Guigon, 2012).

Cooperation on energy provided the basis for several climate-related regional arrangements. The EU directives on renewable energy sources (RES) and energy efficiency (EE) represent one good example of the potential of regional collaboration for transition to low-carbon growth (Agrawala et al., 2014). Regional initiatives to promote energy efficiency through standards and labelling include those established for West Africa and the Pacific Island countries (ECREEE, 2012; IIEC Asia, 2012). Other examples of regional climate mitigation instruments include the successful transboundary pooling of power sources (e.g. cross-border electricity and gas grids) in Europe, Africa, and Asia; the Congo Basin REDD+ initiative; the Energy and Climate Partnership of the Americas (ECPA); and the Great Green Wall of the Sahara (Agrawala et al., 2014).

Regional development banks provide significant financial support to climate mitigation efforts in their respective regions. Examples include the clean energy finance and future carbon instruments of the Asian Development Bank (ADB), and the Congo Basin Forest Fund of the African Development Bank - AfDB (Agrawala et al., 2014).

Global and regional climate mitigation agreements have, in many ways, influenced climate mitigation actions at the national level. The EU ETS provides a good example of successful linking of national policy to global initiatives by allowing EU member countries to share the burden of their aggregate Kyoto emissions reduction commitment using emission credits obtained from participation in CDM and JI projects (Michaelowa and Buen, 2012). Japan, Australia, New Zealand, among many others, also participated in the global cap-and-trade system (CDM, JI, etc), which has been the main driver of their national carbon pricing policies. The cap-and-trade system has also shaped national climate policies in developing countries hosting CDM and JI projects (see list in following sections). Some countries revised their national energy plans to accommodate their voluntary Copenhagen pledges (e.g. South Africa) (Stavins et al., 2014).

Although global and regional mitigation initiatives relied primarily on the emission trading mechanism (quantity instruments), introduction of other measures such as taxes and subsidies (price instruments) or regulation have been more successful at the national level. Use of sector-specific rather than economy-wide mitigation measures have been the common practice at national levels. Taxes on fossil fuels and subsidies to renewable energy sources (e.g. feed-in tariffs - FIT and renewable portfolio standards - RPS) are widely used, but carbon taxes have been introduced in some select countries (Somanathan et al., 2014).

Another process shaping national climate policies is the Bali Action Plan (UNFCCC, 2007), which calls on developing countries to prepare Nationally Appropriate Mitigation Actions (NAMAs). Many countries have submitted their NAMAs, proposing introduction of regulatory instruments (e.g. energy efficiency standards, building codes, labelling, etc) and market-based mitigation measures (taxes, subsidies, tradable permits, etc) as integral elements of their broader green growth strategies (Somanathan et al., 2014). Some countries also made good progress on voluntary emissions reduction commitments by major private and public firms as part of their social responsibility (Rezessy and Bertoldi, 2011). National Communication (NC) reports describing measures to mitigate GHG emissions is another type of report submitted by countries that ratified the UNFCCC. However, only Annex I countries are obliged to submit regular NCs. All parties to the Paris Agreement file NDCs that are less detailed.

3. Participation of sub-Saharan Africa in climate mitigation efforts

We investigate in this section climate mitigation efforts by countries in Sub-Sahara Africa (SSA). The information summarized in this section should be useful in guiding the selection of countries to conduct studies that will subsequently be implementing the analytical framework and empirical methods proposed below. Table 1 provides information on the extent to which SSA countries have participated in global and regional climate mitigation initiatives, and their own national measures. Although it is clear that all countries in SSA ratified major climate mitigation agreements (i.e. Kyoto, Cancun, Montreal, Paris) the degree of participation vary significantly between the different protocols. The highest utilization rates by SSA are found in renewable energy (SCF, 54%), GEFREF, 18.1%) followed by the Montreal Protocol (32%), REDD+ (24.9%), GEF Mitigation (16.6%), GCF (11.7%) and CTF (10.5%). The largest amount of funding to mitigation in SSA, however, came from the IET instruments, exceeding US$ 57 billion in 2018, in which the share of the European Union ETS amounted to about 25% (European Environmental Agency - EEA, 2019). In addition to the EU, IET includes Korean, New Zealand, Western Climate Initiative, Switzerland, Tokyo Metropolitan Government, and Australia's ETS. Kenya is considering launching an emission-trading platform (Promethium Carbon, 2019).

While the share of SSA in the global investments in CDM projects remains very low (3.2%), it represents the second largest source of external funding (US$ 17.277 billion) for climate mitigation in the region. The total number of projects under the CDM is 1,304; from which SSA have 497 projects. South Africa alone hosts one-third (167) of the 497 projects. Table 1 shows that the bulk (75%) of CDM projects are hosted in the west (34%) and southern (41%) Africa. The Great Green Wall Initiative (GGWI), REDD+, CTF, GEF Mitigation, SREP, and GCF follow in size of investments in climate mitigation in SSA. The GGWI is an African initiative launched in 2007 by the African Union to ''restore Africa's degraded landscapes and transform millions of lives in one of the world's poorest regions, the Sahel''. The GGWI's objective is to sequester 250 million tons of carbon by 2030 (Great Green Wall Initiative - GGWI, 2018). Twenty (20) partners including the European Union, World Bank, and the GEF support the GGWI. The initiative has received about US$ 8 billion of pledged funding (Puiu, 2019; and Bilski, 2018).

International climate finance to SSA was US$ 3.7 billion between 2010 and 2012 (11% of total on average) and the majority of support was focused on the energy sector. According to ODI (2015), 14% of Joint Multilateral Development Bank (MDB) climate finance targets are in SSA. Obviously, global and regional climate mitigation protocols and agreements had major influences on national efforts to reduce the emission of GHGs. The international climate funds which include GEF, GCF, AF, and the funds from the Multilateral Development Banks and bilateral funds, are the most important sources of finances for developing countries to develop and implement their NDCs and climate actions (SIDA, 2017). SSA countries that benefited from these resources are shown in Table 1. Preparation of nationally appropriate mitigation plans (NAMAs) and nationally determined contributions (NDCs) by developing countries are the two major mechanisms directly supported by the international community under global conventions.

Table 1: Participation of Sub-Saharan Africa countries in global and regional instruments for climate change mitigation

Mitigation agreements and mechanisms	Number of SSA countries	Degree of participation (total investment up to 2019 or when data is available)	
		Total by all SSA (US$ million)	% of total by all countries
Kyoto Protocol	47 [a]	NA [b]	NA
Copenhagen and Cancun	38 [c]	NA	NA
Montreal Protocol	All 48	171 [d] (1991-2016)	32% (91-2016)
Paris Agreement	All 48 [e]	NA	NA
Clean Development Mechanism (CDM) • Eastern Africa 24% • Middle Africa 1% • Western Africa 34% • Southern Africa 41%	45	17.277 [f]	3.2%
International Emissions Trading (IET)	DNA	DNA	US$ 57 (3 billion) in 2018 [g]
Climate Technology Centre and Network (CTCN)	38 [h]	DNA [i]	DNA
Voluntary Carbon Markets	23 [j]	DNA	DNA
Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	13 [k]	DNA	DNA
GCF (Mitigation only)	9 [l]	209	11.7%
Clean Technology Fund (CTF)	3 [m]	524	10.5%
REDD+	24 [l]	522 [n]	24.2%
Congo Basin Forest Fund (CBFF)	4	83 (16%) [o]	0.7%
Strategic Climate Finance (SCF) [p] Scaling Up Renewable Energy Programme (SREP)	6 [l]	243.94	54%

continued next page

Table 1 Continued

Mitigation agreements and mechanisms	Number of SSA countries	Degree of participation (total investment up to 2019 or when data is available)	
		Total by all SSA (US$ million)	% of total by all countries
Global Energy Efficiency and Renewable Energy Fund (GEFREF)	DNA	40.50 [l]	18.1%
GEF (Mitigation +Multiple Foci)	48	410 [l]	16.6%
Carbon Tax	2 [q]	NA	NA
Great Green Wall Initiative (GGWI)	21 [r]	8,000	DNA
Nationally Appropriate Mitigation Actions (NAMAs)	13 [s]	NA	NA
Nationally Determined Contribution (NDC)	23 [t]	DNA	DNA

Notes:

a) All 48 countries are parties to the Kyoto Protocol except South Sudan as the country did not exist at the time the protocol was ratified (UNFCCC1, 2020), List of Parties to Kyoto Protocol and Paris Agreement. Available at: https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states (Accessed on the 28th February 2020). Note that the Joint Implementation Mechanism is not applicable for Africa as it refers to climate change mitigation projects between two Annex 1 countries (developed countries/ and countries with economies in transition)

b) NA: Not applicable

c) UNFCCC2. 2020. Information provided by Parties to the Convention relating to the Copenhagen Accord. Available at: https://unfccc.int/process/conferences/pastconferences/copenhagen-climate-change-conference-december-2009/statements-and-resources/information-provided-by-parties-to-the-convention-relating-to-the-copenhagen-accord (Accessed on the 13th March 2020)

d) This amount covers Northern Africa countries as well; i.e. Algeria, Egypt, Tunisia, Morocco, and Sudan. These countries received 51% of the total fund made available to African countries (UNEP, 2016)

e) UNFCCC4. 2020. The Paris Agreement. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (Accessed on the 15th March 2020)

f) These investments include some projects that are not only implemented in SSA (CDM, 2020, Database for PAs and PoAs. Available at: https://cdm.unfccc.int/Projects/projsearch.html (Accessed on 20th February 2020). A number of CDM investments that are considered in the calculation above are not only directed to SSA as they include some other regions as well

g) This represents the total global investment in 2018 (ICAP, 2019)

h) Climate Technology Centre and Network - CTCN (2018)

i) DNA: Data not available

j) From 2008 to 2018, voluntary carbon offsets projects implemented in Africa represented only 11% from a total of 2,008 projects. Voluntary Carbon Standards included in this share are American Carbon Registry, Climate Action Reserve, Gold Standard, Plan Vivo, and Verra’s Verified Carbon Standard (Forest Trends, 2018)

k) International Civil Aviation Authority - ICAO. 2019.

l) Climate Funds Update - CFU. 2019.

m) Namely Kenya, Nigeria, and South Africa CFU (2019)

n) Four of the REDD+ projects included in this amount were funded by GEF in Benin, Rwanda, Equatorial Guinea, and Democratic Republic of Congo. Only one project under the REDD+ is funded by the Least Developed Countries Fund (LDCF), which was implemented in Cameroon with an amount of US$ 4,350,000

o) SSA countries that received support from the CBFF are Cameroon, Democratic Republic of Congo, Republic of the Congo, and Equatorial Guinea

p) Strategic Climate Finance - SCF has three targeted programmes under it: (1) The Forest Investment Program (FIP), which is already covered in the REDD+ investments; (2) The Pilot Programme for Climate Resilience (PPCR) considered more of an adaptation measure; and (3) The Programme for Scaling-Up Renewable Energy in Low Income Countries (SREP). The SREP beneficiaries have been Ethiopia, Kenya, Liberia, Mali, Rwanda, and Tanzania

q) South Africa started implementation and Côte d`Ivoire and Senegal are considering introduction of a carbon tax (World Bank, 2019). Sudan introduced carbon tax on vehicles (Widaa, 2017)

r) The Great Green Wall Initiative - GGWI is being implemented across 21 African countries, namely: Algeria, Burkina Faso, Benin, Chad, Cape Verde, Djibouti, Egypt, Ethiopia, Libya, Mali, Mauritania, Niger, Nigeria, Senegal, Somalia, Sudan, Eritrea, Togo, Cameroon, Gambia, and Tunisia (GGWI, 2018)

s) These SSA countries submitted information of their NAMAs. All of them are under development; only two NAMAs (South Africa and Kenya) are under implementation

t) SSA countries supported by GEF (6) to prepare their Intended NDCs to the 2015 Paris agreement under the UNFCCC are: Burundi, Congo, Niger, Senegal, Chad, Lesotho, Mauritania, Mozambique, Seychelles, Zambia, Benin, Gabon, Guinea-Bissau, Namibia, Rwanda, Sao Tome and Principe, Swaziland, Eritrea, Democratic Republic of the Congo, South Africa, and Zimbabwe. In addition, Ghana received funds from the GEF to strengthen the national system to plan, implement, monitor and report on NDC

Although several countries received support, some have not submitted their reports or started implementing their mitigation plans. Only South Africa and Kenya began implementation of their NAMAs, while the rest are still being developed (Table 1). Sources other than the GEF also fund preparation of NDCs, including the Global Green Growth Institute - GGGI and NDC Alliance, which supports countries where GGGI operates. SSA countries supported by the GGGI are Burkina Faso, Ethiopia, Mozambique, Rwanda, Senegal, and Uganda (GGGI 2020). In 2018, a total of US$ 44 billion was raised by governments in carbon pricing revenues (this includes both carbon taxes and ETS). Most of the revenue came from the European Union ETS. The carbon price initiatives covered 46 national and 28 sub-national jurisdictions (World Bank, 2019).

Introduction of carbon taxes in countries of SSA, however, is recent. Among the 32 countries in SSA, which mentioned carbon pricing in their NDCs mitigation activities, only two countries (South Africa and Gabon) are planning or considering domestic initiatives (World Bank, 2019). Based on a Carbon Tax Act that came into effect on 1st June 2019, a carbon tax of R120 (US$ 10) per ton of carbon was introduced in South Africa (Winkler and Marquard, 2019). The Partnership for Market Readiness (PMR), in which Côte d`Ivoire is a member approved in 2018 total fund of US$ 500,000 to support the policy design of a carbon tax in Côte d`Ivoire (Carbon Tax Leadership Coalition - CPLC, 2018). In 2016, Kenya announced that it would launch a carbon-trading platform where local companies can sell their carbon credits to foreign buyers (Promethium Carbon, 2019). In addition, Ethiopia and Senegal joined the Carbon Market Platform initiated by the G7 (Promethium Carbon, 2019). In 2008, Mauritius introduced a fund to subsidize switching to renewable energy financed from revenues raised through taxation of fossil fuels (Promethium Carbon, 2019). Similar initiatives in SSA include, the GIZ Global Carbon Markets Programme in East Africa to implement their NDCs and attempts by Mozambique and Kenya to source funding for investments in gas and coal explorations (Promethium Carbon, 2019). Table 2 shows that SSA's participation and utilization of global and regional climate mitigation mechanisms and financing instruments has been on a steady but low growth trend.

Table 2: Size of SSA countries participation in global and regional instruments for climate change mitigation between 2008 and 2019 (depending on availability of data)

Mitigation agreements and mechanisms	2008		2012		2019	
	Million US$	% of total	Million US$	% of total	Million US$	% of total
CDM	77.0	0.3	9,340.0	2.6	17,277.0	3.2
SREP	0.0	0.0	0.0	0.0	244.0	54.0
REDD+	4.0	0.0	92.6	15.1	522.0	24.3
GEF Mitigation	63.5	12.4	163.0	12.4	410.0	16.6
GCF Mitigation	0.0	0.0	0.0	0.0	209.4	11.7
CTF	0.0	0.0	433.0	20.1	524	10.5
SCCF	10.4	22.5	23.8	14.6	33.5	11.7

4. Poverty and inequality impacts of climate mitigation

This section explores how climate mitigation science and policy has addressed poverty and inequality. The relevance of inequities between and within generations is explicitly recognized in the climate mitigation literature. For instance, the purpose of mitigation strategies and actions is to protect future generations against potential damages of climate change. Significant research efforts went into evaluating the optimal timing and magnitude of required climate mitigation efforts; i.e. how much, when, and by whom (IPCC, 2014b). The choice of the socially right rate to use to discount the welfare of future generations occupied a central place in the debate on evaluating the costs and benefits associated with alternative climate mitigation strategies (Stern, 2007; Nordhaus, 2008; Hof et al., 2010; Dasgupta, 2008; Sterner and Persson, 2008, Arrow et al., 2013, Heal and Milner, 2014). This has influenced mitigation policy design and actions in many ways, including provoking the need for "urgent actions by all" and the importance of investing in climate mitigation assets (infrastructure, technology, social, human) (Stern, 2007; World Bank, 2010).

Intra-generational equity has been partially recognized and acknowledged, primarily between countries on basis of differences in *responsibility* for causing, vulnerability to and capacity to cope with climate change impacts, and the power to decide on solutions/actions (UNFCCC, 1992). This led to adopting the principle of *"equitable burden-sharing – common but differentiated responsibilities and respective capabilities* (CBDRRC)", based on which countries have been classified into categories. In this grouping, developed (Annex 1) countries have been separated from developing (Annex III) countries and assigned binding emission reduction targets. A subset of developed (Annex II) countries were given the obligation to provide the necessary financial and technological support to enable Annex III countries achieve their UNFCCC commitments (UNFCCC, 1992;1998). Major global climate mitigation protocols, such as Kyoto, Copenhagen, Cancún and Paris, have been designed and ratified based on the *"common but differentiated responsibilities and respective capabilities"* equity principles. This equity principle has accordingly become one key criteria for ex-ante (i.e. proposal stage) and ex-post evaluation of emission-reduction projects (Fischer and Morgenstern, 2010).

Emission trading mechanisms (e.g. CDM, JI, IET; EU ETS; etc.) dominated the impact evaluation literature, compared to other climate mitigation measures such as taxes, subsidies and regulation. The focus of the bulk of this literature, however, was on environmental outcomes (i.e. emission-reduction) and cost effectiveness, with some assessment of socio-economic impacts (Olsen, 2007; Michaelowa and Michaelowa, 2011; Yamada and Fujimori, 2012; Stavins et al., 2014). The studies assessed the socio-economic impacts of emission trading, especially CDM projects. The assessment was in terms of interventions' contribution to sustainable development in host countries using livelihood indicators such as income, employment, and access to basic amenities such as clean energy, health and education services, etc (Olsen, 2007; Olsen and Fenhhann, 2008; Sutter and Parreno, 2007; Drupp, 2011; He et al., 2014; Dirix et al., 2016). The UNFCCC (2012) reports that only 31% of the 2,864 projects checked in 2011 evaluated socio-economic impacts, including employment and poverty alleviation. Majority of these studies relied primarily on qualitative assessment of information contained in project design documents, which represents the potential but not actual impacts' data (Crowe, 2013; Fernandez et al., 2014). Moreover, the cited impact evaluation studies analyzed changes in aggregate indicators of sustainable development benefits generated at national levels (i.e. between countries' variations), but did not examine distributional patterns of sharing these benefits among social groups (or individuals) within countries (He et al., 2014).

Few studies attempted to evaluate within-country distributional impacts of emission trading mechanisms using various analytical models and empirical methods to analyze actual observational data (i.e. *ex-post* assessments). Examples include the work of Pecastaing et al. (2018) using panel data econometric analysis approach to evaluate the effects of CDM investments on the economic welfare of households in Peru. Within country distribution of a select of sustainable development benefits from CDM projects in Brazil has been investigated by Mori-Clement (2019) using the difference-in-difference (DID) method. The DID approach was also used by Du and Takeuchi (2019) to analyze poverty impacts of renewable energy-based CDM projects in China. Concentration of the CDM impacts' literature in few countries, especially China, India, and Brazil, reflects the distribution of CDM projects. The share of SSA in this literature is notably quite small, compared to major CDM host countries such as China, India, and Brazil (Agrawala et al., 2014). In general, the evidence of pro-poor impacts of CDM projects have been weak (Crowe, 2013; Aggarwal, 2014), and often CDM projects have been blamed for deepening the powers of industrial elites (Baker and Newell, 2014). A study by Baker and Newell (2014) showed that providing support for large-scale industrial or chemical process through CDM projects has further entrenched the power of elite industrial actors central to the country's economy.

Due to its recent introduction, the literature on assessment of the P&I impacts of REDD+, the other major project-based emission-reduction instrument, is limited compared to the CDM (Olsson et al., 2014; Palomo et al., 2019). A study by Caplow et al. (2011) revealed the poor ex-post impact assessments carried for some limited number of pre-REDD+ forest carbon projects. While early studies predicted a good potential of REDD+ to contribute to poverty reduction, available research work suggests undesirable equity and poverty implications of the mechanism. The undesirable outcomes are particularly through green land grabbing and displacement of local communities (Mahanty et al., 2012; Neupane and Shrestha, 2012; Krause and Loft, 2013; Pfaff et al., 2013; Chomba et al., 2016; Bayrak and Marafa, 2016; Corbera et al., 2017; Saeed et al., 2018; Markkanen and Anger-Kraavi, 2019). Recent work on the impacts of forest carbon sequestration incentive policies (carbon credit/subsidy for avoidance of deforestation) confirms the adverse implications for poverty of these policies (such as REDD+) as they lead to significant increases in food prices in non-Annex I countries (Popp et al., 2011, Hussein et al., 2013). Promotion of biofuels is another climate change mitigation policy considered poverty-increasing as it leads to higher food prices in developing countries (Cororaton et al., 2010). Similar studies on biofuel production applied to Mozambique, Tanzania, Malawi and Zambia (Arndt et al., 2010; 2012; Hartley et al., 2017; 2019; Schuenemann et al., 2017) assess the economic, welfare and food security impacts of the development of a biofuel industry. They generally find development of bioethanol value chains as a new industry to be associated with positive impacts on economic growth and employment. However, for the positive effects to materialize, biofuel production needs to be carried out in an efficient manner, which has not been the case in the past. Limited attempts have been made to analyze the social impacts of voluntary carbon offsets (VCOs) projects, showing contradicting outcome results (Antle and Stoorvogel, 2008; Jindal, 2010; Jindal et al., 2012; Stringer et al., 2012; Estrada and Corbera, 2012).

Among the price instruments, the impacts of fuel taxes have received significant attention in the literature. Several studies investigated the welfare implications of energy taxes using partial (e.g. econometric techniques) and general equilibrium models to analyze impacts on various dimensions of social welfare and energy security (Rausch et al., 2011; Datta, 2010; Sterner, 2012; Coady et al., 2015; Ohlendorf et al., 2018). A general finding of the bulk of these studies is that fuel emission taxes tend to be progressive (pro-poor). Some authors concluded the opposite (regressive) depending on the type of fuel, levels of income, and whether tax revenues are recycled or not (see for example van Heerden et al, 2005; Yusuf and Resosudarmo, 2008; Feng et al., 2010; Devarajan et al., 2011; Clements et al., 2013; Rao, 2013; Dartanto, 2013; Durand-Lasserve et al., 2015; Nurdianto and Resosudarmo, 2016; Renner et al., 2018 and 2019; Renner, 2018; Markkanen and Anger-Kraavi, 2019; Wang et al., 2019; Dorband et al., 2019).

A new body of literature on the interdependence and synergy between mitigation response strategies and the Sustainable Development Goals (SDGs) has emerged after adoption of the Paris Agreement and the UN 2030 agenda for sustainable development in 2015 (von Stechow et al., 2015, Gomez-Echeverri, 2018, Markhanen and Anger-Kraavi, 2019). Synergies and trade-offs between measures aiming at reducing GHG emissions and various SDGs, particularly developmental objectives and security of access to basic socio-economic services (e.g. poverty and hunger eradication; reduced inequity; food, water, and energy security; universal education and health services) have been investigated by a number of authors. A study by Hubacek et al. (2017) on the linkages between poverty and mitigation efforts to achieve climate stabilization showed that making progress towards achieving the poverty eradication SDG (lifting people out of poverty) would require larger efforts to realize emission reduction targets. Using systems of simultaneous equations' analysis, Jin et al. (2018) established a negative relationship between poverty and mitigation of CO2 emissions in China. Markhanen and Anger-Kraavi (2019) provided comprehensive synthesis of evidence in the literature on potential developmental and social impacts (distributional equity) outcomes of a range of mitigation policy measures and technology options.

It is important to note that the majority of the studies cited above are project-based assessments of impacts (particularly on livelihood aspects) of certain emission-reduction measures (e.g. promotion of renewable energy by source and types of technologies, forest carbon options, carbon taxes, removal of fossil fuels' subsidies, etc) in certain geographical locations/regions. A number of studies attempted to assess the implications of economy-wide efforts to mitigate the adverse consequences of climate change for poverty and distributional equity among current generations (Ohlendorf, et al., 2018). Wang et al. (2013) developed and applied multi-regional input-output (I-O) framework to analyze the impact of CDM projects on the sub-national distribution of employment benefits in China. The multi-regional I-O tool has also been applied by Wang et al. (2019) to evaluate distributional impacts of carbon pricing in China and by Dorband et al. (2019) for comparative regional analysis. Similar results (regressive effects) were also obtained by Renner (2018) I-O analysis of the impact of fuel taxes in Mexico.

As common in the literature on economy-wide distributional aspects, Computable General Equilibrium (CGE) modelling has been used by several authors to study the implications of climate mitigation on P&I among social groups at country level. This has particularly been the case with impacts of intervention through market price instruments such as fuel and carbon taxes (Feng et al., 2010; Rausch et al., 2011; Nurdianto and Resosudarmo, 2016; van Heerden et al., 2005; Devarajan et al., 2011; Brenner et al., 2007; Callan et al., 2009; Corong, 2008; Coxhead et al., 2013; Ohja, 2009; Oladosu and Rose, 2007; Dissou and Siddigui, 2014; Flues et al., 2015; Grainger and Kolstad, 2010; del Granado et al., 2012; Beck et al., 2015; Boccanfuso et al., 2011; da Silva et al., 2016). Based on CGE analysis, the work of Hussein et al. (2013) suggested that carbon sequestration incentive policies such as REDD+ tend to negatively affect the poor in 14 non-Annex I countries. The same Hussein et al. (2013) study reached an opposite conclusion with respect to impact of fossil fuel tax policies in developed (Annex I) countries, particularly for the poor non-Annex I net oil importers.

Some research was carried out on the temporal dynamics between mitigation efforts and poverty (Dennig et al., 2015; Hubacek et al., 2017; Leach, 2009). Hubacek et al. (2017), uses a multi-region I-O framework complemented by a household energy budget shares and associated carbon emission levels module. The findings indicated that the burden on mitigation efforts required for climate stabilization increases with progress towards reduced poverty. Similar negative results have been found by Palomo et al. (2019), investigating the trade-offs between emissions' reduction and biodiversity conservation outcomes and equitable distribution of REDD+ funds among beneficiaries. Leach (2009) investigated intra-generational equity benefits of climate mitigation policy.

The above survey reveals that very few studies have been carried out on the P&I impacts of climate mitigation policies in SSA. Exceptions include the study by Saeed et al. (2018) on REDD+ in Ghana, using exploratory qualitative case study assessment. Jindal et al. (2012) examined the impact of REDD+ on poverty in Mozambique. We are aware of only two studies applying the CGE approach to analyze economy-wide implications of taxing carbon emissions in South Africa (van Heerden et al., 2005; Devarajan et al., 2011). The said studies, however, carried ex-ante assessments (i.e. before introduction of the tax) since at that time, carbon tax had not been imposed yet. The other country where a carbon levy on vehicles has been tested in a pilot phase is Sudan, but no research has been undertaken yet on the implications of the tax for poverty and inequality (P&I).

It is clear from the preceding survey of the relevant literature that provisions, conditionality, and instruments in global initiatives to direct national mitigation measures to address within country P&I impacts require more attention and assessment. Similarly, little is found in the literature on the extent to which national level mitigation policy has responded to the need to address inequality within countries (Fleurbaey et al., 2014). Integrated assessment models (IAMS), for instance, generally lack indicators of poverty and inequality in their criteria evaluating scenarios on transition pathways to low carbon development and climate stabilization. While poverty is mainly addressed through adaptation actions' research, adaptation and vulnerability science and policy analysis do not feed into and inform design of mitigation policies. Comprehensive and deeper assessment of the impacts of global and national mitigation response measures on food, water and energy security; access to basic services (clean water and sanitation, health, education, etc); protection against/reduction of risks of natural disasters, among others, is needed. This will require analytical frameworks that allow for systematic integration of the dynamic interlinkages and impact pathways between P&I and climate mitigation, an aim we attempt to pursue in the next section.

5. Analytical framework and methodologies for evaluating the poverty and inequality impacts of alternative climate mitigation policies

As discussed in the preceding sections, climate change mitigation measures that have been experimented with include several policies designed to regulate and disincentivize production and consumption activities, leading to high GHG emissions. These targeted all sectors, and in particular energy generation and use, transport, buildings, industry, agriculture, forestry and other land use, and waste management. While developed countries have set economy-wide caps for national emissions, developing countries largely focused on specific voluntary programmes aimed at enhancing sinks and reducing emissions. Major examples among those are the CDM and REDD+ projects. In addition, in many countries, certain economic measures are being taken to mitigate climate change at the national level, including carbon credits and taxes.

An important issue in making the choice of what analytical approach and empirical models to use concerns the relationship and impact pathways between climate mitigation and poverty and inequality (P&I). To address this issue, we first discuss the main channels through which climate mitigation measures get transmitted or mediated to P&I impacts. Mediation analysis enables identification of the appropriate methods to use to measure and evaluate the merits of alternative mitigation policy measures.

The rest of this section presents these mediation layers and linkages, then discusses ways of conceptualizing and measuring P&I. Approaches that can be used to model and quantify the impacts of climate mitigation on P&I are then presented in section 5.3. The section concludes with proposing datasets to use and suggesting pilot case studies' approach that can be followed.

Impact pathways framework

Drawing on the broader literature, Markkanen and Anger-Kraavi (2019) outline the complex dynamic relationships and feedback loops characterizing the P&I impacts of climate mitigation. Policies can generate both positive or negative outcomes for P&I depending on the context, nature of the policy design and how it is implemented and extra measures that may be undertaken to alleviate their negative consequences (e.g. revenue recycling). While the literature acknowledges the effects of contextual factors and policy design on outcomes, the relative importance of contextual factors and effects on P&I is either not well understood or overlooked. Figure 1 presents an illustration of the transmission channels depicting impact pathways and feedback linkages between climate mitigation actions and P&I.

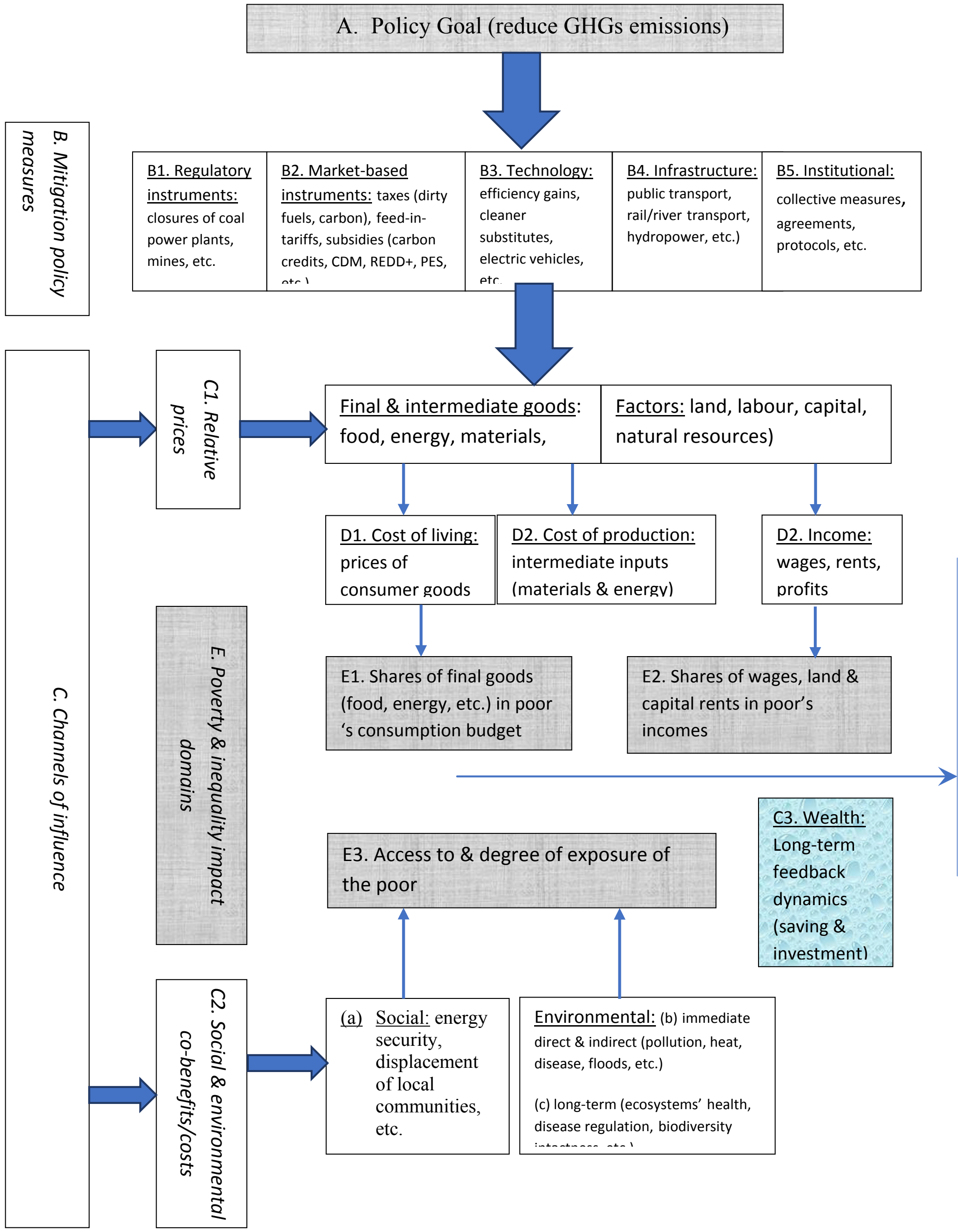
The literature provides examples of impact pathways through which such benefits manifest in terms of gains in incomes, relative prices and costs as a result of positive changes in factor and commodity markets. For example, Markkanen and Anger-Kraavi (2019) point that positive outcomes are usually associated with instances where employment and income generation opportunities are created by new climate mitigation projects such as forest carbon markets, improved access to electricity, better public sector transport connectivity, retrofitting of existing buildings and development of energy efficient technologies, and locating large-scale renewable energy systems in deprived areas. Such jobs tend to be more secure and better remunerated than ones in the informal economy are. Worse, inequality outcomes tend to obtain when policies raise costs of essential goods (including basic consumer goods and services) and harm employment opportunities. Because the poorest and most vulnerable tend to spend a disproportionate amount of their income on basic goods and services, they are hurt the most. This can spill over poor health outcomes.

There are instances when projects such as REDD+ programmes reinforce income inequalities and increase risks of conflict – such instances prevail when the benefits of the programmes are inequitably distributed often in favour of the local elite. Large up-front investments required for participation in such programmes as renewable electricity programmes, forest protection initiatives and biofuel cultivation have also been shown to have regressive outcomes in many areas (see examples in Markkanen and Anger-Kraavi, 2019). Mitigating measures such as revenue recycling mechanisms, subsidies, exemptions or other access barrier lowering interventions (e.g., exemptions, micro-credit, extended payment schedules, grants and interest-free loans) generate positive distributional outcomes. There is also a gender dimension, particularly where female-headed households and minority ethnic populations are more predominant. More generally, policies that improve women's access to economic or educational opportunities or reduce unremunerated workload for women and minority ethnic populations improve equity outcomes for these groups.

Modelling and estimation approaches

There are two modelling techniques often used to assess the effects of climate mitigation policies both at national and global levels: general equilibrium and partial equilibrium models (often bottom-up energy system models). Such models are practical tools to support evidence-based planning and implementation of climate mitigation strategies and policies. They have gained popularity largely because they allow the simulation of ex-ante impacts of strategies and policies. The empirical frameworks that can be used to quantify the impacts of mitigation on P&I can broadly be grouped into benefit incidence, econometric, and economywide approaches such as IAMs. The nature of the question, resources and time available and data availability will be central when deciding which approach to follow.

Figure 1: Impact pathways of climate mitigation to poverty and inequality



Benefit incidence attempts to identify the direction of impacts of reforms when the objective is to reduce P&I, particularly among the most vulnerable populations. Benefit incidence attempts also have the advantage that they require minimal data, making them amendable to implementation in developing countries where little data is available. However, benefit incidence attempts have some limitations in that they only capture direct effect of mitigation and thus ignore indirect effects that the reform may have on individuals and their behavioural responses. This shortcoming can partly be addressed by developing econometric estimations of the impact of mitigation on well-being by controlling for other variables that may influence the estimations.

Panel data econometrics (Pecastaing et al., 2018) and difference-in-difference (DID) methods (Mori-Clement, 2019; Du and Takeuchi, 2019) are examples of empirical approaches employed to evaluate the P&I impacts of climate mitigation. These, however, remain partial equilibrium approaches, and thus do not capture the feedback effects induced by other sectors or actors in the economy, which are important to consider for major mitigation measures with economy-wide implications. Social Accounting Matrix (SAM), Input-Output (IO) and Computable General Equilibrium (CGE) models are the most comprehensive tools to study the impact of such policy reforms.

In analyzing distributional impacts of climate mitigation, general equilibrium modelling techniques have often been preferred because they can be adapted to include the demand response to changes in supply and, thus, capture changes in market prices. Thus, not only can such models capture direct consumption effects but they can also include both consumption and income effects. Moreover, they can capture relevant mitigation policies and specific features such as a carbon tax and recycling. They include disaggregated sectors to better capture the backward and forward linkages of the sectors and thus the multiplier and economy-wide effects of changes occurring in the sector.

Within the area of climate mitigation, many of the studies using general equilibrium approaches to assess the distributional impacts of mitigation have mostly been for the US and Europe. Prominent examples include Rausch et al., 2011; Liang and Wei, 2012; Callan et al, 2009; Siriwardana et al., 2011; Bureau, 2011; Rausch and Schwarz, 2016; Mathur and Morris, 2014; Combet et al., 2010; Buddelmeyer et al., 2012; Sterner, 2012; Cullenward et al., 2016). There are a limited number of studies for developing countries in general (see for example Naranpanawa and Bandara, 2012; Yusuf and Resosudarmo, 2015; Coxhead et al., 2013; Dartanto, 2013). As recent reviews in Babatunde et al (2017) and Cockburn et al (2018) illustrate, such analysis is under-represented in SSA, though it can constitute an excellent tool to analyze complex macro-micro issues and distributional impacts of mitigation policies.

The CGE literature presents a variety of ways in which distributional impacts on households are incorporated in the models. In terms of representing households, the three main approaches are: simply imposing distributions (Van der Mensbrugghe, 2015; Sánchez and Cicowiez, 2014) using microsimulation models (Buddelmeyer et al., 2012; Hertel et al., 2010 and Bussolo et al., 2010), and representing multiple household types within models (Rausch et al., 2011; Bouet et al., 2013 and van Ruijven et al., 2015). *The norm for studies in this realm continues to be the use of single representative households or multiple representative household types. While microsimulation models are routinely used by researchers and policy makers in developed countries, few developing countries have access to such tools. They are even less commonly used in SSA particularly in assessing climate mitigation* (Chitiga et al., 2012).

Micro-simulation appears to be essential in modelling the distributional impacts of climate mitigation. This is because P&I are measured at the individual or household level and use micro level information; i.e., nationally representative survey data. However, the microeconomic model on its own does not address issues related to economic growth, investments, and external trade, as does the CGE model. Furthermore, the environmental analysis provides further insights not available in the first two models. The inability of microsimulation to model prices and macro variables inspires an increasing number of analysts to opt for both macro- and micro-models to reconcile the use of macro-models with distributional impact analysis. Thus, microeconomic models address P&I while macro models address prices and macro phenomenon. *It is for this reason that we propose the use of a three-layer economic modelling framework to assess the strategic options available to a country, considering climate mitigation policies and strategies implementation. The framework consists of an environmental module, an economy wide general equilibrium model and a microeconomic model. We discuss below these layers.*

Environmental CGE models

As the discussion above illustrated, the methods used to assess P&I impacts of policy shocks can broadly be split into econometric and simulation models. Simulation models can also be categorized into multi-country models and single-country models and the choice between these is justified by the nature of the research question. As an example, multi-country CGE models are generally justified in cases where there is need to carefully address economic ties between and among countries, or an interest in a regional or global perspective of an environmental issue. Even though multi-country CGE models can be designed to capture the specific country-level effects of a shock, single country models are more flexible in that they can easily integrate desirable specificities of a given economy, and the rest of this section discusses this kind of model.

A CGE model recognizes the many inter-linkages in the economy and allows for price-induced behaviour and resource constraints in determining both the direct and indirect effects of a shock to the economy over time. This interconnectedness of demand and supply of CGE models, use of full production functions, and the detailed representation of the energy system allow projection of the environmental and climatic pressures linked to specific elements of economic activity. The starting point in drawing linkages between P&I and climate mitigation is to identify the important effects and pathways conceptualized in the analytical framework presented above. The channels that are likely to be the most relevant in analyzing the P&I impacts of climate mitigation are: *the price effects* or change in prices of endowed and purchased resources; *the reallocation effects*, i.e. change in the occupation of resource; *endowment effects* or change in the available quantity of a resource. Environmental CGE (ECGE) models adequately account for these impact transmission channels. ECGE models, *however, make a departure from standard models in two main aspects: the energy supply and demand specification, and the specification of goods and services consumed by households. ECGE models distinguish various types of fuel, and separate energy input-intensive sectors from non-energy input intensive sectors.* Dependent on data availability for a given country, the model typically has four types of energy: crude fuel, refined fuel products, coal, and electricity (including gas and renewable energy).

On the production side, to capture environmental dimensions, the supply and demand of energy fuel should be explicitly elaborated. Most ECGE models aggregate different types of fossil and non-fossil fuels in composite functions with relatively high elasticities of substitution between them. On the consumption side, a single commodity category (e.g. petroleum product) enters into one or several groups of consumption by purpose (e.g. household fuel and transport) to capture consumption effects of environmental shocks (e.g. climate mitigation). *The sectoral and consumption details embodied in CGE models can be exploited to assess the benefits of policy action, considering policy-induced changes in consumption, production and trade.* Careful attention should be given when identifying the sectors, energy types and groups of goods and services consumed because this has far-reaching consequences for mitigation targets but ultimately on distributional impacts of the mitigation policy. In other words, the choices made here have far-reaching implications on the results regarding the economy modelled.

P&I are directly assessed using a microeconomic model. As indicated earlier, poverty and hunger are measured at the individual or household level and use micro level information, i.e. nationally representative survey data. *For each level of poverty, there will be an associated income level and its distribution across the population. This then means that income inequality constitutes an important determinant of poverty and hunger outcomes. The microeconomic model captures changes in income distribution and inequality measures across the population.* The use of the growth-to-poverty elasticity parameter (Thurlow et al., 2007) does not capture the changes in income inequality.

Microeconomic models

Microeconomic models enable prediction of an individual's reaction to a policy shock when confronted with different economic and institutional environments or constraints, a key aspect that the CGE model on its own cannot do. *A key value add of microsimulation models is thus to enable integration of the heterogeneous behaviour of economic agents and accounting for the aggregate costs and benefits of an intervention or shock* (Bourguignon and Spadaro, 2006). There are a myriad of approaches in linking the microsimulation and the CGE framework. Ultimately, the choice over which approach to use is determined by the research question, data availability and resource/time (Cockburn et al., 2014).

When it comes to modelling individual behaviour responses, essentially two conventions can be distinguished: parametric behavioural approaches (e.g. Bourguignon et al., 2005) and non-parametric approaches (e.g. Vos and Sanchez, 2010). Parametric behavioural approaches capture the distribution of earnings through labour market participation and consumption choices based on individual characteristics and those of the household and community from which the individual belongs. The parameters estimated from survey data using econometric techniques are used. As the name implies, non-parametric approaches are applied to labour market participation and distribution of earnings using a randomized process to determine the resulting change in labour force status. Debowicz (2016) has compared the parametric behavioural approach and the non-parametric approach in Argentina and found that the results in both cases are consistent with the data. *Given that the non-parametric approach is less demanding in terms of data requirements but produces similar results, it is advisable to use the non-parametric approach to capture the micro impact of macro shocks when time and data are limited.*

Conceptualizing and measuring poverty and inequality

As discussed above, climate mitigation potentially affects poverty and inequality (P&I) through many channels to both the production and consumption spheres of the economy, e.g. levels and distribution of income in factor markets, relative prices of production inputs and consumer goods, and access to health and other basic services. This suggests that P&I should ideally be viewed through a broader lens of basic human development, or multidimensional livelihood indicators that recognize the multifaceted nature of human well-being. The appropriate space can be unidimensional or multidimensional, depending on the nature of what is being studied. The more traditional definition of inequality now referred to as vertical inequality, lines households or individuals vertically and measures inequality over the range of households or individuals. Horizontal equity, a relatively new term associated with the pioneering work of Stewart (2002) uses groups (as opposed to individuals or households) as units of analysis and is inherently multidimensional, encompassing multiple dimensions beyond economic ones, including ownership of assets, access to services and group identities (e.g. social, cultural, and ethnic, etc).

Inequality can be with respect to outcome or opportunity. Inequality of outcome can be due to both exogenous and endogenous circumstances (Roemer, 2002). Inequality of opportunity in most instances is driven by endowments associated with what one may inherit and other exogenous environmental conditions (Arneson, 1989; Cohen, 1989). Thus, it becomes important to understand both inequality of outcomes (well-being) and inequality of opportunities as proposed in a theoretical model by Roemer (2002) with empirical applications in Lefranc et al. (2008). The literature uses parametric and non-parametric methods when characterizing inequality by say income sources, causal factors, sub-groups, etc. Until recently, regression-based approaches to decomposing inequality have been rare (Bourguignon et al., 2008). There are now many applications of the income inequality regression-based decomposition (Yuko et al., 2006; Kimhi, 2007).

The classical literature on inequality concentrated on the observed inequality of outcomes and as a result completely ignored inequality of opportunity, which can be considered extremely important from a social, economic and moral perspective. Also, most opportunity-based literature to inequality used Ordinary Least Squares (OLS) estimations when constructing relevant benchmarks to use equalizing circumstance-related variables to generate inequality free distributions, which are then compared with inequality of observed outcomes to capture the effect of inequality of opportunities (Nunez and Tartakowsky, 2007). This approach has been criticized for not addressing econometric estimation problems such as endogeneity, sample selectivity, and unobserved heterogeneity. These problems have been recently addressed in the works of Mwabu (2009) and Marchetta and Sahn (2015), among others. Finally, within this literature, there have been frantic searches for measures and indicators of whether growth has been pro-poor or not (see for example Son, 2007; Essama-Nssah and Lambert, 2006).

Thus, as outlined in Kakwani et al. (2006), the framework to address inequality comprehensively would ideally consist of: (i) a household welfare generating function to identify determinants of household well-being; (ii) a regression-based decomposition framework to generate the relative magnitude of sources of inequality of outcomes; (iii) a factual-counterfactual analysis to identify the components of inequality due to effort and the ones due to differential opportunities; (iv) a relative pro-poor growth framework to study the pro-poorness of specific sources of well-being; and (v) shared prosperity analysis to assess the impact of selected income sources on shared prosperity.

Among the many measures applicable to both vertical and horizontal inequality, the following are the most common:

- *Coefficient of variation.* This has the advantage of achieving independence from the mean but attaches equal weights to distributions at different income levels while giving more weight to extremes (given that it involves squaring deviations from the mean).

- *The Gini coefficient,* which can be derived from the Lorenz curve, measures statistical dispersion and graphically is worth half the area between the Lorenz curve and the first bisector. The Gini has the advantage that it has long been in use, compares every individual (group) with every other and does not square differences. It may, however, be sensitive to the middle of the distribution. Some authors have argued that it is not exactly decomposable into within group and between group components when applied to individuals, unless there is no overlap between groups (Cowell, 1995).

- *The Theil index* is a special case of the generalized entropy index in information theory and is used to measure inequality. It is especially sensitive to the lower end of the distribution and is precisely decomposable. The Theil is similar to the Gini with the difference that it compares each group with the mean while the Gini compares each group with every other group.

- *Utility-based indices* have a normative basis and derive from social welfare functions. Examples include Dalton's and Atkinson's index (Dalton, 1920; Atkinson, 1970). Dalton's measure compares actual aggregate utility with the total level of utility if incomes were equally divided, assuming diminishing marginal utility whereas Atkinson's measure (the equally distributed equivalent measure) varies according to the value assumed for inequality aversion (derived from the social welfare function).

- *The Esteban/Ray polarisation index* (Esteban and Ray, 1994; Duclos et al., 2004): In many ways, this is similar to the Gini in that it is weighted by population but it includes a special index – $1+\alpha$, where $1 \leq \alpha < 1.6$ – which is higher the greater the weight attached to the share of group population in total population. The parameter α serves to increase the weight given to particular groups, say larger groups.

- *The odds ratio*, due to Chakrabarty (2001), calculates the odds of individuals in a particular group falling into a particular category (e.g. rich or poor). It then expresses the group differences as the ratio of these odds.

The same discussion broadly applies to poverty measures. *Poverty of outcomes, opportunities and impact are interdependent and mutually reinforcing.* As recently pointed out by Lakner et al. (2018), monetary poverty captures the capacity of households to meet their basic needs in food, housing, clothing and other goods and services. Thus, tackling monetary poverty will most likely positively affect other dimensions of poverty, such as education, safe drinking water and health. *The poverty measures often used in the money metric approach include those of* Foster, Greer and Thorbecke (FGT) (1984). Evidence can be provided for P&I levels, based on the FGT measures (incidence, spread and severity of poverty) for each SSA country for which there is sufficient data. Both the national and the international poverty lines can be used to measure the poverty headcount index.

Finally, the dimension over which P&I can be assessed can be monetary (income, wealth) or other such as indicators of energy or food security (through energy, and food prices and the cost of those given their budget shares among the poor and other social groups). There is a range of measures in the literature, including differentiation by various social groups such as gender, regional, religious, ethnicity, etc). There are a number of data sources that can be used ranging from national censuses, household surveys, living standard measurement surveys (LSMSs) and also labour force or employment surveys.

Implementation of the modelling frameworks and case study choice

Implementation of the above-described modelling framework requires the use of country-level macro and micro datasets and appropriate software. CGE models are implemented and solved using either GAMS suite of programmes (see for example Lofgren et al., 2002) or the GEMPACK suite of programmes described in Horridge et al. (2013). Microsimulation analysis requires use of a statistical software with ability to handle large scale datasets such as STATA, or the statistic software R, with the package "ineq" (Zeileis, 2014). Macro data sets are usually in the form of a SAM while micro data consists of household survey data. Furthermore, implementation of the model also relies on a stocktaking of the current performance of the environmental (GHGs) sector and the national economy in general. This information defines the baseline or reference scenario to be compared against alternative scenarios for climate mitigation. Finally, simulations can be designed and results for an alternative scenario for climate mitigation identified.

CGE modelling and analysis alone cannot fully analyze the distributional impacts of climatic policy, a major part of this project. Thus, the second layer uses a micro-simulation model framework to analyze the distributional impacts of climate policy on poverty and inequality at the individual household level. One way to do this for illustrative purposes is to follow the top-down approach (see discussion above). Concisely, macroeconomic variables simulated by the CGE model are passed onto the micro household data derived from the survey data. Practically, the poverty line used by authorities is multiplied by the change of the consumer price index and the expenditures of households are similarly multiplied by the corresponding change of real total consumption from the CGE model.

To simulate the value of the inequality index, the sample in the survey is multiplied by the corresponding change of consumption. The Gini-Index can then be computed for the full sample of respective observations by applying the statistic software R, with the package "ineq" (Zeileis, 2014). Similarly, a variety of poverty indices can also be computed. As an example, as poverty indices researchers can compute the three Foster–Greer–Thorbecke indices: FGT0, FGT1 and FGT2 differentiated for the rural and the urban population. The index FGT0 measures the prevalence of poverty (also called headcount index); that is, how many households are poor (below the benchmarks) compared to the total of households. The index FGT1 measures the depth of poverty, indicating how far below the poverty line the poor households are. It is also called the poverty gap index. The index FGT2 measures the poverty severity, by not only considering the distance of the poor households to the poverty line, but also considering the inequality among the poor households (also called squared poverty gap index). After applying the macroeconomic indicators from the micro economic data (top-down), we compute the values for the poverty indicators for rural and urban population and the inequality indicator for the whole population. The difference between the values for the indicators in the scenarios and the base year informs on the change of poverty and inequality in the scenarios.

To reiterate, the present paper has proposed adapting prototype layered modelling approaches sketched along lines discussed above that follow existing studies. The prototype models can then be adapted to capture the specific country-level situation important in understanding the effects of a shock, as such models are highly flexible in that they can easily integrate desirable specificities of a given economy. To operationalize the approach, the model can employ household income and expenditure surveys conducted across SSA over the last several years (2010-2019) to account for country specificities and initial conditions, supplemented by data from the respective countries SAMs and environmental data. Surveys conducted under the Living Standard Measurement Study (LSMS) of the World Bank and similar surveys can be especially useful in this regard, and are often publicly available. Based on these data, evidence will be presented showing SSA's performance on P&I when reliable data is available using for example the FGT and Gini measures discussed earlier. As shown in Table 3, a sample of 30 surveys conducted across SSA over the last five years (2013-2017) can be used immediately. Most countries have a SAM or one can be built relatively cheaply and fast with appropriate expertise in place.

Table 3: Household survey data for sub-Sharan Africa countries

Country	Year
Angola	2009
Benin	2011
Botswana	2015/16*
Burkina Faso	2014
Cote d'Ivoire	2015
Eswatini	2009/2018
Ethiopia	2015
Gambia	2010
Ghana	2006
Guinea Bissau	2002
Guinea	2012
Kenya	2016
Lesotho	2018
Liberia	2016
Malawi	2016
Mali	2014
Mauritius	2016
Mozambique	2014/15
Namibia	2016
Niger	2014

continued next page

Table 3 Continued

Country	Year
Nigeria	2012
Rwanda	2017
Senegal	2012
Seychelles	2013
South Africa	2011
Tanzania	2007 (LSMS)/2018 (HBS)
Togo	2011
Uganda	2017
Zambia	2010/2015
Zimbabwe	2012/2017

*Multi topic survey

While ideally each member state of SSA should be included in such a study, resource constraints including data and software limitations may warrant a sequential approach. This could involve, for example, targeting a whole region (e.g. any of the economic regions of SSA: Economic Community of West African States - ECOWAS, the East Africa Community - EAC, Southern African Development Community - SADC), and then including additional countries subsequently as resources and data become available. In choosing the sample, the membership of SSA countries in the major regional cooperation bodies that can be used can follow, for simplicity and later comparisons, that of the IMF and World Bank, as summarized in Box 1.

Box 1: Sub-Sahara Africa member countries grouping

CFA Franc Zone, comprising the West African Economic and Monetary Union (WAEMU) [Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo] and Economic and Monetary Community of Central African States (CEMAC) [Cameroon, Central African Republic, Chad, Congo, Republic of Equatorial Guinea and Gabon]

The Common Market for Eastern and Southern Africa (COMESA); Burundi, Comoros, Congo, Democratic Republic of Congo, Eritrea, Eswatini, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Uganda, Zambia and Zimbabwe

The East Africa Community (EAC-5): EAC-5 aggregates include data for Rwanda and Burundi, which joined the group of Kenya, Tanzania and Uganda only in 2007.

The Economic Community of West African States (ECOWAS); Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo

The Southern African Development Community (SADC); Angola, Botswana, Congo, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe

The Southern Africa Customs Union (SACU): Botswana, Eswatini, Lesotho, Namibia and South Africa

The oil exporters are countries where net oil exports make up 30% or more of total exports. These are Angola, Cameroon, Chad, Congo, Republic of Equatorial Guinea, Gabon, Nigeria and South Sudan

Middle income countries consist of Angola, Botswana, Cabo Verde, Cameroon, Congo, Republic of Côte d'Ivoire, Equatorial Guinea, Eswatini, Gabon, Ghana, Kenya, Lesotho, Mauritius, Namibia, Nigeria, São Tomé and Príncipe, Senegal, Seychelles, South Africa and Zambia

Low income countries include Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Eritrea, Ethiopia, Gambia, The Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, South Sudan, Tanzania, Togo, Uganda and Zimbabwe

Countries in fragile situations are Burundi, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Republic of Côte d'Ivoire, Eritrea, Gambia, The Guinea, Guinea-Bissau, Liberia, Malawi, Mali, São Tomé and Príncipe, South Sudan, Togo and Zimbabwe

Source: Adapted from International Monetary Fund (20192020)

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2. Emeritus Professor, University of Pretoria and Secretary General, The Higher Council for Environment and Natural Resources, Government of Sudan (rashid.hassan@up.ac.za)

3. Professor, Sol Plaatje University, South Africa (rmabugu@gmail.com)

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Contact Us
African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org