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Can the Paris Deal Boost SDGs Achievement? An Assessment of Climate Mitigation Co-benefits or Side-effects on Poverty and Inequality

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Summary

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Keywords: SDGs, Poverty, Inequality, CGE Model, Mitigation Policy, Paris Agreement

JEL Classification: C23, C68, Q56

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Can the Paris deal boost SDGs achievement? An assessment of climate mitigation co-benefits or side-effects on poverty and inequality

Lorenza Campagnolo[a], Marinella Davide[a, b]

Abstract

The paper analyses the synergies and trade-offs between emission reduction policies and sustainable development objectives. Specifically, it provides an ex-ante assessment that the impacts of the Nationally Determined Contributions (NDCs), submitted under the Paris Agreement, will have on the Sustainable Development Goals (SDGs) of poverty eradication (SDG1) and reduced income inequality (SDG10). By combining an empirical analysis with a modelling exercise, the paper estimates the future trends of poverty prevalence and inequality across countries in a reference scenario and under a climate mitigation policy with alternative revenue recycling schemes. Our results suggest that a full implementation of the emission reduction contributions, stated in the NDCs, is projected to slow down the effort to reduce poverty by 2030 (+2% of the population below the poverty line compared to the baseline scenario), especially in countries that have proposed relatively more stringent mitigation targets and suffer higher policy costs. Conversely, countries with a stringent mitigation policy experience a reduction of inequality compared to baseline scenario levels. If financial support for mitigation action in developing countries is provided through an international climate fund, the prevalence of poverty will be slightly reduced at the aggregate level (185,000fewer poor people with respect to the mitigation scenario), but the country-specific effect depends on the relative size of funds flowing to beneficiary countries and on their economic structure.

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1. Introduction

At the end of 2015, two summit meetings took place that will lead to a redefinition of the international policy environment in the near future. In September 2015, the United Nations adopted the Sustainable Development Goals (SDGs), updating the Millennium Development Goals by defining broader and more ambitious development objectives that apply to all countries. Through 17 SDGs, the new 2030 Agenda for Sustainable Development addresses economic, social, and environmental sustainability and designs a pathway toward inclusive green growth. Three months later, in December 2015, the 21st UNFCCC Conference of Parties (COP 21) adopted the "Paris Agreement", which aims to strengthen the global response to climate change through a new regime of country-driven emission reduction and adaptation plans. In particular, the Agreement contemplates three major objectives: i) maintaining the increase in the global average temperature to well below 2°C above pre-industrial levels, with efforts to limit the increase to 1.5°C; ii) increasing the ability to adapt to the adverse impacts of climate change and fostering climate resilience; and iii) mobilizing consistent finance flows to achieve mitigation and adaptation objectives (UNFCCC 2015).

Both frameworks represent a breakthrough from previous international attempts aimed at addressing these global challenges. In the 2030 Agenda for Sustainable Development, environmental and climate change objectives are integrated with traditional economic and development objectives, such as eliminating poverty and improving health and education, rather than treating these issues separately. In the Paris Agreement, the new bottom-up structure fosters a wider participation of countries than had been achieved under previous agreements. This includes developing countries, which are allowed to propose their national contribution to the effort to deal with climate change by taking into account their national development priorities. This shift recognizes the need to adopt a comprehensive approach to global challenges, one capable of considering developmental and environmental challenges as intertwined. Clearly, a strong potential for interactions exists between efforts to achieve sustainable development goals and efforts to address climate change.

Early research into this topic helped to conceptualize the possible links between climate change mitigation policy and sustainable development. Some have suggested ways to strengthen potential synergies (Beg et al., 2002), and others have discussed opportunities for integrated policy making (Swart et al. 2003). More recent work has focused on quantifying the synergies and trade-offs between mitigation policy and other objectives (von Stechow et al. 2015, 2016). Despite these notable efforts, current integrated modelling research remains confined to sectoral studies offering a limited view on possible co-effects and focusing on a narrow set of specific objectives, such as the effect of mitigation on economic growth (Jakob and Steckel 2014), access to energy (Steckel et al. 2013) or air pollution (Rao et al. 2016).

This paper broadens the current perspective by providing an ex-ante assessment of the co-benefits and side-effects emerging from these new policy settings. In particular, this paper analyses how the commitments made by countries under the Paris Agreement will influence those countries' achievement of two specific SDGs: the prevalence of poverty (SDG1) and inequality (SDG10). The eradication of extreme poverty and the reduction of inequality are among the highest priorities in the broader effort to ensure sustainability worldwide. Their achievement is a preliminary and necessary condition for addressing all the other SDGs, including the environmental ones. Given the linkages between environmental and sustainable development objectives, analysing the effects of environmental regulation on development is critical.

The topic has a great importance for policy, since concern about possible trade-offs between climate change interventions and economic development are still perceived by developing countries as major obstacles to taking action to limit their greenhouse gas emissions. Indeed, it has been widely recognized that poorer segments of society are generally more vulnerable to negative climate impacts, especially where such events interact with and amplify non-climatic stressors (Olsson et al., 2014). It has also been argued that the costs of emissions reduction policies may further negatively impact the poorest households, absent measures to offset the distributional impacts of those policies (Grottera et al. 2017; Goulder 2013; Büchs et al. 2011; Callan et al. 2009).

Existing cross-country research on the impact of climate change mitigation on poverty or inequality in developing countries has been narrowly focused. Prior to the the Paris Agreement, international

climate policy initiatives mainly relied on developed countries and the main research efforts have consequently been focused on the effect of the Kyoto Protocol's commitments of Annex I (or developed) countries on non-Annex I (developing) nations. Among the most prominent studies, Hussein et al (2013) estimate that a carbon tax on fossil fuels in Annex I countries leads to poverty reduction in most of the non-Annex I countries. However, when a forest carbon sequestration incentive (paid by Annex I parties) is added in the developing regions, the effect is reversed, with most low-income countries showing an increase in returns to the land, leading to reduced agricultural output and increased food prices.

Against this background, this paper aims at further enriching the debate by exploring the magnitude of impact of the new global climate policy framework - including mitigation contributions by both developed and developing countries – on poverty and inequality.

From a methodological point of view, our approach combines an empirical analysis with a modelling exercise performed by using a recursive-dynamic Computable General Equilibrium (CGE) model developed and enriched with SDGs indicators. CGE models are well-suited to assess the performance of economic indicators. Moreover, past modelling literature has highlighted the fact that they are also a powerful tool for assessing the evolution of key environmental indicators (Böhringer and Löschel 2006).

Modelling social indicators in a CGE framework, however, is a difficult task, especially when these imply dispersion measures such as poverty prevalence and inequality at the core of SDG1 and SDG10. We overcome the representative agent structure proper of CGE models by relying on empirical literature and directly estimating the relationships between indicators and endogenous variables of the model (Bourguignon et al. 2005; Ferreira et al. 2010; Montalvo and Ravallion 2010). We characterise the future trend of poverty prevalence and inequality in the SSP2 baseline scenario, which is then used as a term of comparison to assess the impact of climate policy under different recycling schemes.

This approach allows us to shed light on the possible ancillary costs and benefits of mitigation policies. We are able to assess whether there is a trade-off between climate policy and

economic/social development, and therefore how the implementation of climate policy could help to achieve other SDGs. Our results show that the full implementation of the emission reduction contributions as stated in the NDCs will slow down the effort to reduce poverty by 2030. The effect is greater in countries that have proposed a relatively more stringent carbon mitigation target, though the magnitude of the effect is limited. Countries with stringent mitigation objectives are likely, however, to experience a reduction of inequality compared to the baseline scenario levels. This suggests possible synergies between climate policy and the income increase of the poorest strata of the population. If financial support to mitigation action in developing countries is provided through an international climate fund, the prevalence of poverty is slightly reduced at the aggregate level compared to the mitigation scenario, but remains above the baseline levels.

The remainder of the paper is organized as follows. Section 2 briefly discuss the indicators selected to depict poverty and inequality, and describes their past trends. Section 3 reviews existing literature to estimate the determinants of inequality and poverty. Section 4 describes the modelling framework. Section 5 presents future projections of inequality and poverty compared to a baseline scenario. Section 6 briefly describes the policy context, including the NDCs presented under the Paris Agreement. Building on previous assumptions, Section 7 projects the future trends of inequality and poverty by assuming that the mitigation efforts under the Paris Agreement are fully implemented. Finally, Section 8 analyses the impact on SDGs of an international fund to supporting efforts in meeting NDCs by developing countries. Main conclusions are summarized in the final section.

2. Inequality and poverty within the Agenda 2030: measures and past trends

Of the seventeen Sustainable Development Goals (SDGs) outlined by the UN in Agenda 2030, two directly address poverty and inequality. In particular, SDG1 calls for ending poverty in all its forms everywhere. SDG10 calls for reducing inequality within and between countries (United Nations, 2015).

Both SDG1 and SDG10 are further articulated into more detailed targets that can be monitored through a set of quantitative and qualitative indicators (United Nations 2016). SDG1 is divided into 5 specific targets, the first of which calls for the eradication of extreme poverty, defined as the number of people living below the international poverty line of $1.25 per day. The four remaining components of SDG1 address additional important aspects, such as social protection, access to resources and basic services, and vulnerability to economic, social and environmental shocks. We agree that an effective understanding of poverty comprehends its multidimensional nature, however, for the purpose of this study we will use the poverty headcount ratio of $1.25 per day (World Bank, 2016) because of the wide data coverage and because it is readily quantified.[1]

Regarding SDG10, which addresses income inequality within and between countries, we concentrate specifically on SDG10.1. This subsection of SDG10 is focused on inequality within a single country, being specifically concerned with achieving "income growth of the bottom 40 per cent of the population at a rate higher than the national average" (United Nations 2015)[2]. Selecting the most suitable indicator to track progress on SDG10.1 is a complex matter. The Inter-agency and Expert Group on Sustainable Development Goal Indicators (United Nations 2016) chose the "per capita income growth of the bottom 40 per cent of the population." This indicator recalls target 10.1 but disregards the comparison of growth at different points of income distribution, which is at the core of the inequality concept. Therefore, we prefer a synthetic indicator of income dispersion. The Gini Index, widely adopted for national statistics, could have been the most natural candidate, but we have opted instead for the Palma Ratio, defined as "the ratio of the top 10% of population's share of gross national income (GNI), divided by the poorest 40% of the population's share of GNI" (Cobham and Sumner 2013). This indicator is an easy to compute and target-related measure of inequality. Moreover, in contrast to the Gini Index, which is oversensitive to the income of those in the middle of the distribution, the Palma ratio focuses on two specific points of distribution, which

[1] We are also aware of the fact that the International Poverty Line (IPL) was recently updated by the World Bank to $1.90 per day (Cruz et al. 2015), but the "$1.25 per day" poverty line allows us to exploit a longer and wider panel data and to obtain a measure directly comparable to SDG 1.1.

[2] Acknowledging the importance of other inequality dimensions such as social, economic and political exclusion, opportunities and representativeness, we preferred a quantitative and widely available indicator of income inequality.

show higher variability across time and countries than middle income deciles. Furthermore, its formulation is directly linkable to SDG10.1, and is easy to derive and communicate.

The figures below report the past trends for the two selected indicators worldwide and by geographic area[3]. 1990-2014 data from the World Development Indicators (WDI) show that the poverty headcount ratio constantly lowered worldwide (Figure 1), from about 35% in 1992 to 15% in 2012 (World Bank 2016). This was mainly driven by steep decreases in the East and South Asian countries, whereas the reduction was milder in sub-Saharan Africa.

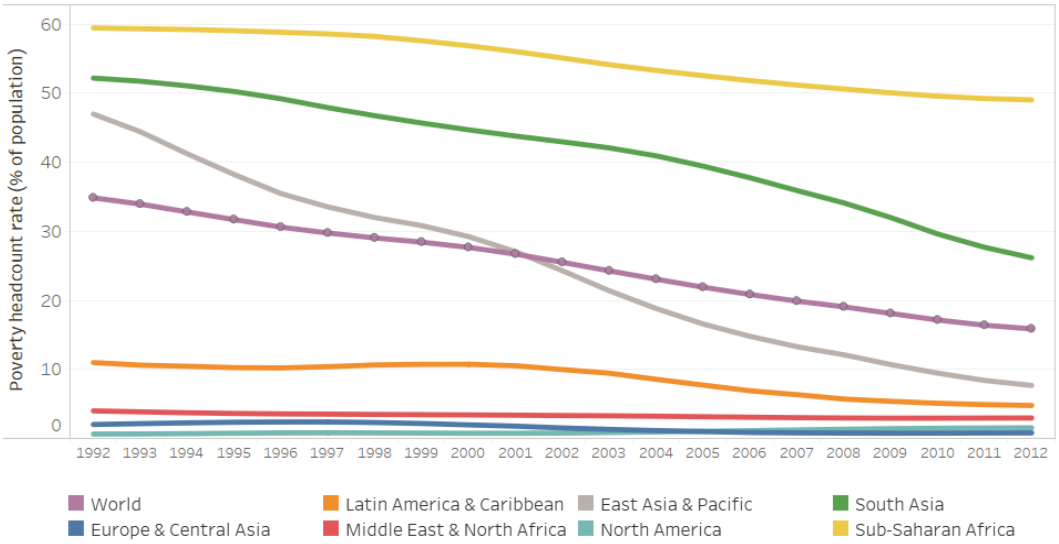


Figure 1 Poverty headcount ratio at 1.25$PPP per day for country aggregates and worldwide, 1992-2012 (5 year weighted average)

Inequality, measured as a population-weighted Palma ratio, increased slightly worldwide until 2001, and has since been decreasing (World Bank 2016). The drastic decline in inequality in Latin and South America since 2000 has driven the global pattern of inequality reduction, aided by more modest declines in sub-Saharan Africa. North America is the only region showing a clear increase in the disparities between rich and poor.

[3] World and regional-aggregate past trends of poverty and inequality are meant to give a general overview of the matter and overlook strong country-specific heterogeneity that will be better explored in Section 3.

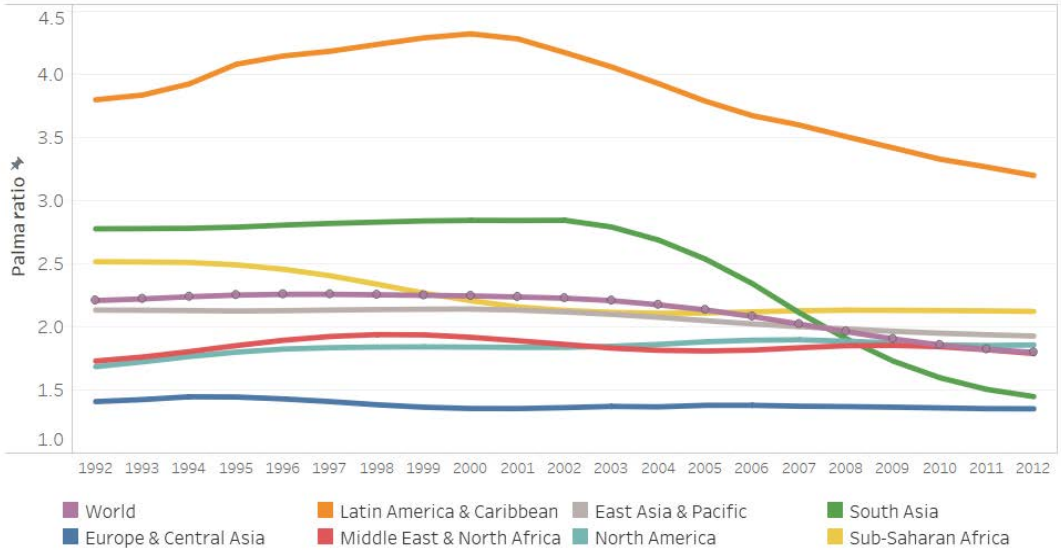


Figure 2 Palma ratio trend for country aggregates and the World, 1992 - 2012 (5 year weighted average)

Observing past trends of extreme poverty and inequality is a starting point, but it is fundamental to understand the determinants of these two indicators, in order to draw conclusions on their future patterns.

3. Inequality and poverty determinants in empirical and modelling literature

A broad empirical literature elucidates the determinants of poverty reduction from a cross-country perspective. Ravallion and Chen (1997) identify the growth of average per capita income as the main factor in reducing poverty. Ravallion (1997, 2001) and Heltberg (2002) highlight the importance of the structure of income distribution, which may undermine the inclusiveness of per capita income growth. Other country-specific empirical analyses also highlight the importance of sectoral growth patterns in explaining differentiated rates of poverty reduction across regions (Ferreira et al. 2007; Montalvo and Ravallion 2010).

Relevant literature on macro-economic modelling is more dispersed and, in general, focuses on single-country analyses. Nevertheless, two strands can be identified: the Microsimulation approach, which elaborates the outcome of the CGE model by using a microsimulation module that

downscales the macro-economic result at the individual or group-level (Lofgren et al. 2013; Hilderink et al. 2009; Hertel et al. 2011; Bussolo and Lay 2003); and the Multi-Household approach that directly integrates microdata in the macro-economic model and allows an endogenous poverty evolution (Boccanfuso et al. 2003).

Choosing the modelling approach depends greatly on data availability. The lack of country-specific data on the varied composition of income sources (and consumption expenditure) by income quantile makes it impracticable to use a Multi-Household approach and even a complex Microsimulation module, as in Bussolo and Lay (2003).

To compensate for a lack of available data, we build upon Lofgren et al. (2013), Hilderink et al. (2009), and other empirical literature on the topic, and run a panel regression in order to understand the link between the measure of poverty prevalence (Poverty headcount ratio at 2005$1.25 a day), average per capita income (GDP PPP2005 per capita), and the indicator of unequal income distribution (Palma ratio). Furthermore, we included a time trend (t) and country fixed effect.

$$\ln(POV_{i,t}) = \beta_1 \ln(GDPPPPpc_{i,t}) + \beta_2 \ln(Palma_{i,t}) + t + \varepsilon_{i,t} \quad \textbf{(1)}$$

In order to account for the heteroskedasticity and autocorrelation that characterise our panel, we use a linear regression model with robust standard errors, including a first order correlation within each panel. The data source is the World Development Indicator database (World Bank 2016). The panel considers 99 countries, both developed and developing, in the period 1990-2013.

Table 1. Linear regression model for panel corrected standard errors for Poverty headcount ratio at $1.25 a day

	$\ln(\text{POV}_{i,t})$
$\ln(GDPPPPpc_{i,t-1})$	-2.2588***
	(0.000)
$Palma_{i,t-1}$	0.2164***
	(0.000)
Constant	22.8937***

	(0.000)
Observations	511
Number of country	99
R^2	0.930

Robust pval in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The regression results are in line with existing literature and show a negative correlation between poverty prevalence and income per capita. That is, the number of people below the poverty line tends to shrink as GDP increases. However, increases in the Palma ratio is correlated with more people below the poverty line.

The determinants of income inequality are even more complex to disentangle than the causes of extreme poverty. Empirical studies suggest reductions in income inequality within and among countries have been achieved since the 1980s, especially within developing countries (Ravallion 2003; 2014). The determinants of this pattern can vary. In country-specific analyses, a major role can be played by the differential in labour productivity between agricultural and non-agricultural sectors (Bourguignon and Morrison 1998); reforms in the labour market; or an expansion of education and changes in population dynamics (Bourguignon et al. 2005). In cross-country analyses, the principle variables considered include sectoral wage differentials between skilled and un-skilled labour; globalization; education rates; market reforms; and policy interventions (Alvaredo and Gasparini 2015).

Regarding the macro-economic modelling literature (in particular CGE frameworks), income distribution is generally assumed to remain constant over time or exogenously imposed (van der Mensbrugghe 2015). An alternative option for tackling the possible evolution of inequality within a country is the Multi-Household approach, which allows for a heterogeneous response to macro-sectoral dynamics of household income and consumption choices. However, given the global perspective of our analysis and the lack of available data, modelling inequality with a Multi-Household approach is unfeasible. Instead, following the empirical strand of the literature, we run two unbalanced panel regressions for 120 countries (both developed and developing) in the period 1990-2013.

Our dependent variables are the share of GDP held by the richest 10% of the population, and that held by the poorest 40%. As explanatory variables, we consider some macroeconomic variables drawn from the World Development Indicator database and World Governance Indicators (World Bank 2016), which are consistent with the literature, characterised by a good country and year coverage, and directly linkable to endogenous variables in our CGE model.

We run two independent regressions with the following specification:

$$\begin{aligned}\ln\left(y_{i,t}^{p}\right) = {} & \beta_0^p + \beta_1^p \ln\left(PEduExpsh_{i,t-1}\right) \\ & + \beta_2^p \ln\left(AgriVAsh_{i,t-1}\right) + \beta_3^p \ln\left(IndVAsh_{i,t-1}\right) \\ & + \beta_4^p CorruptCtrl_{i,t} + \beta_5^p \ln\left(Unempl_{i,t-1}\right) + \beta_6^p d\_c\_i_{i,t} + t^p \\ & + \varepsilon_{i,t}^p \qquad\qquad p = \{low40, high10\}\end{aligned} \tag{2}$$

where $y_{i,t}^{low40}$ and $y_{i,t}^{high10}$ are the shares of GDP held by the poorest 40% and the richest 10% of the population. The explanatory variables are: the share of Public Education Expenditure ($PEduExp\_sh$); the sectoral composition of the Value Added (VA) including the share of VA from agriculture ($AgriVA\_sh$) and industry ($IndVA\_sh$); an indicator on the perception of corruption control ($CorruptCtrl$); the unemployment rate ($Unempl$); and a dummy that distinguishes whether the dependent variable derives from a consumption or income distribution[4] (d_c_i). In addition, we include a time trend (t) and country fixed effects. Also in this case, we use a linear regression model with panel corrected standard errors that account for heteroskedasticity.

Table 2. Linear regression model for panel corrected standard errors for GDP share held by the poorest 40% and richest 10% of the population.

	$y_{i,t}^{low40}$	$y_{i,t}^{high10}$
$PEduExp\_sh_{i,t-1}$	0.0227**	-0.0188***
	(0.021)	(0.009)
$\ln(AgriVA\_sh_{i,t-1})$	0.1220***	-0.0861***

[4] The dummy variable (d_c_i) assumes value 1 when the dependent variable derives from a consumption distribution, value 0 in the case of income distribution. Following Alvaredo and Gasparini (2015), we included this dummy in order to account for the wedge between income and consumption-based inequality measures.

	(0.000)	(0.000)
$\ln(IndVA\_sh_{i,t-1})$	0.1989**	-0.1358**
	(0.013)	(0.014)
$Corrupt\_cntr_{i,t}$	0.0295	-0.0186
	(0.168)	(0.334)
$Unempl_{i,t-1}$	-0.0033*	0.0024
	(0.084)	(0.113)
$d\_c\_i_{i,t}$	0.0151	0.0020
	(0.436)	(0.913)
t	0.0090***	-0.0066***
	(0.000)	(0.000)
Constant	-16.1529***	17.3423***
	(0.000)	(0.000)
Observations	663	663
Number of country	120	120
R^2	0.225	0.188

pval in parentheses

*** p<0.01, ** p<0.05, *p<0.1

The income share of the poorest 40% of the population is correlated positively with the GDP share devoted to public education, the VA share generated in agriculture and industry, and a high level of corruption control[5]. Implicitly, there is a negative correlation between the income share of the poorest and the VA share from services (residual to agriculture and industry shares). This result is in contrast with country-specific literature on poverty, which generally identifies the growth of tertiary sector output as a factor benefiting the poor (Ferreira et al. 2010). However, it is worth specifying that our analysis has a cross-country perspective: the countries experiencing the highest levels of inequality are developed countries with a big tertiary sector. The explanatory variables for the income share of the richest 10% of the population show opposite signs and similar magnitude.

It is necessary to understand the main determinants of poverty and inequality in the past to envision the future trend of these two indicators, which will then be characterized by the same relationships with explanatory variables in Equations (1) and (2), but mutated macroeconomic conditions.

4. The modelling framework

[5] The indicator on control of corruption (WB 2016) ranges from approximately -2.5 (weak control) to 2.5 (strong control).

Projecting the evolution of inequality and poverty prevalence and assessing the impact of environmental policies on these social indicators require some assumptions on the future socio-economic scenario and a modelling framework to recreate it.

The Inter-temporal Computable Equilibrium System (ICES) model (Eboli et al. 2010) is at the core of our modelling framework (see Appendix I for more details). ICES is a recursive dynamic CGE model: a multi-market model linked to current real economy data observed in the benchmark year, based upon the merging of national social accounting matrices into a global economic database GTAP8 (Narayanan et al. 2012). ICES makes it possible to draw scenario-dependent evolutions of Global socio-economic conditions; in addition, satellite databases on CO2 and non-CO2 emissions and energy volumes connected to production and consumption flows offer insights into the consequences of economic growth on the environment in an internally consistent framework.

The two targets illustrated in SDG1.1 and SDG10.1 and the related indicators described in Section 3 go beyond the socio-economic representation of the world that is proper to CGE models because they are both related to the concept of income distribution across agents within a country, which is not captured in a context of country-representative households of CGE models. In Section 3, we described some papers that introduce household heterogeneity into a general equilibrium framework, but the number of countries and macro-aggregates characterising our analysis prevent us from proceeding in that direction.

Therefore, we directly exploit the relations identified in Equation 2 that connect inequality levels to the sectoral structure of the economy, public investment in education, the unemployment rate and corruption control during the period 1990-2013. Assuming the stability of this relation across time, we run two out-of–sample predictions for the shares of GDP held by the poorest 40% ($y_{i,t}^{low40}$) and the richest 10% of the population ($y_{i,t}^{high10}$), and compute the Palma ratio for the period 2007-2030, where the historical values of dependent variables are replaced by outputs of the ICES model under the selected scenarios. A similar procedure is used for determining the future poverty rate: the coefficients estimated in Equation 1, pertaining to the period 1990-2013, are used in an out-of-sample prediction for the period 2007-2030, where the explanatory variables are an endogenous

output of the model (GDP per capita) or its derivation (the Palma ratio computed from the out-of–sample predictions of Equation 2).

Linking poverty and inequality measures to ICES makes it possible to assess in a consistent framework the influence of socio-economic variables and/or policy interventions in achieving SDG1.1 and SDG10.1. Clearly, the analysis depends heavily on the assumptions on the future socio-economic conditions that characterised the baseline scenario.

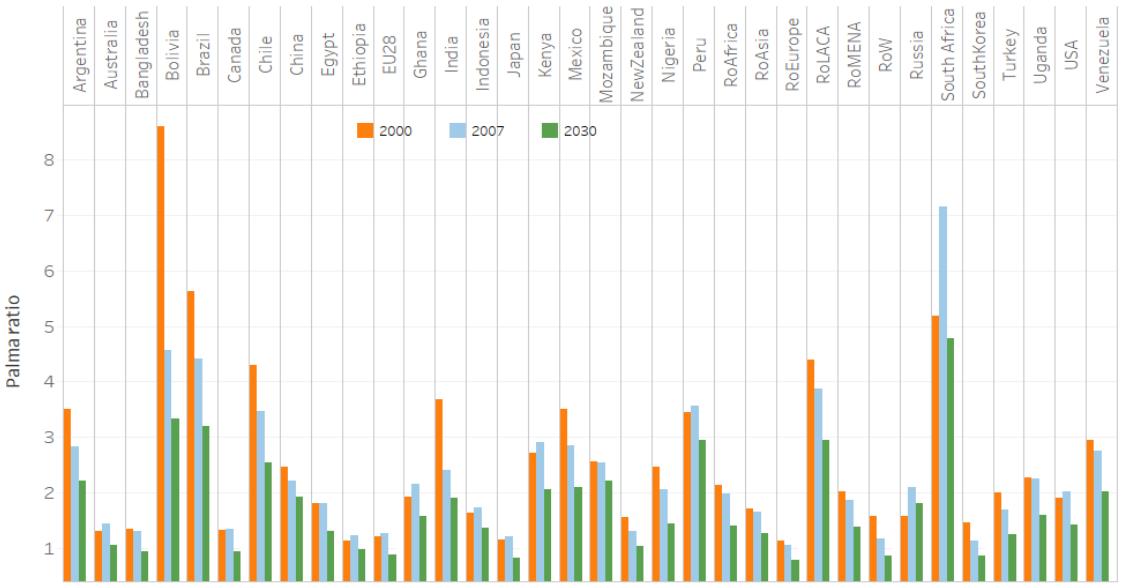
5. Inequality and poverty trends up to 2030: the baseline scenario

As a reference source for our scenario, we use the Shared Socioeconomic Pathways (SSPs) developed by the climate model community (O'Neil et al. 2017). SSPs envision possible future scenarios characterised by differentiated patterns of population, employment and economic growth, energy intensity, emissions, and land cover. These future paths are therefore related to different mitigation/adaptation challenges. Exogenous drivers in the ICES model, such as primary factor productivity, sector-specific efficiency, total factor productivity, population, employed, and energy prices are then used in order to calibrate the endogenous variables – namely GDP, energy use, emissions and value added shares – that characterize a specific SSP.

The baseline reproduces the Shared Socio-Economic Pathway 2 (SSP2) with 3.6 W/m2 radiative forcing in 2030 (on the path of 7.5 W/m2 and 4°C in 2100), and it will then be used as a benchmark to assess the effects of mitigation scenarios arising from the outcome of COP21. SSP2 is defined as the "middle of the road" scenario, characterised by similar dynamics observed in recent decades, but that imagines some progress in achieving development goals. Income per capita grows globally at a medium pace and also population follows the UN medium projection scenario. Income convergence between countries is slow, but intra-country inequality diminishes. Resource and energy intensity slows down, as well as dependence on fossil fuels.

Combining ICES results from the SSP2 scenario with the coefficients estimated in Equation 2, we are able to estimate how intra-country inequality will evolve up to 2030. Results are reported in

Figure 3, which shows the estimates of the Palma ratio in 2030, compared with the historical figures in 2007 and 2000.[6]



Source: Palma ratio in 2000 and 2007 is computed from WDI; model results are used for 2030.

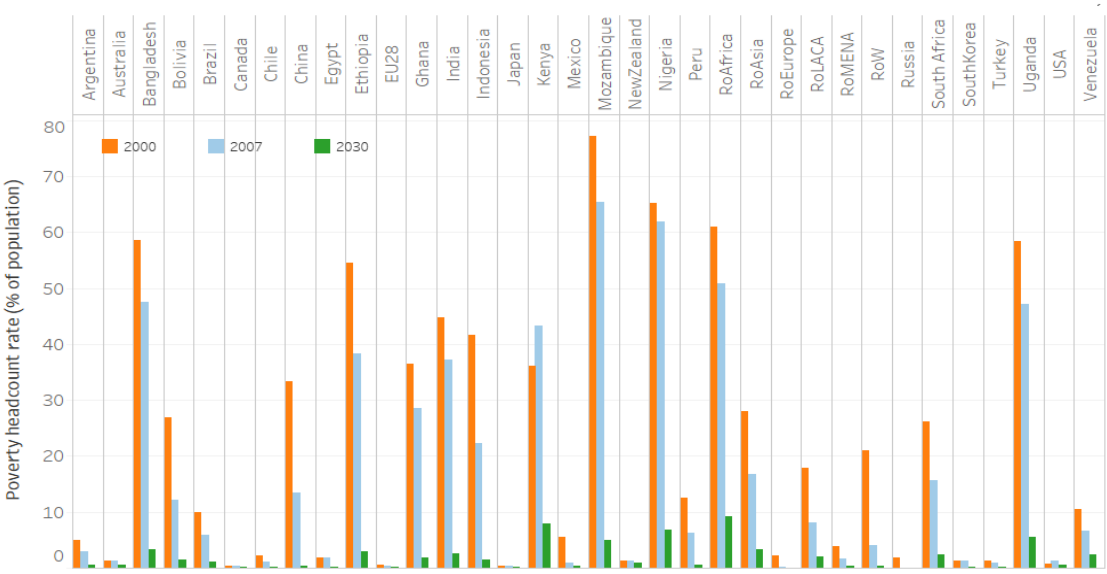
Figure 3 Palma ratio in 2000, 2007 and in 2030 SSP2 baseline scenario

Between 2000 and 2007, the worldwide average Palma ratio decreased by 9%, with significant differences amongst countries. Changes in the Palma ratio in this period range from a decrease of 47% in Bolivia to an increase of 38% in South Africa. In the SSP2 scenario, the Palma ratio is projected to continue dropping, with the worldwide average 23% lower in 2030 compared to 2007, driven by an increase of income share held by the poorest 40% of the population (+17%) and a decrease of the income share of the richest 10% of the population (-10%). By 2030, inequality decreases in all countries compared to 2007, but the rate of reduction will slow down in Latin America compared to the rate of decrease from the 2000-2007 period. Instead, the gap between the income of rich and poor in several developed countries and some developing countries decreases because of lower unemployment rates and slightly increasing agricultural VA shares in the former

[6] The out-of-sample predictions use all explanatory variables of (2; moreover, it is worth pointing out that the unemployment rate is an exogenous variable in ICES, and the perception of corruption control is maintained constant after 2013.

case, and a rise in both the VA share from industry and the public education expenditure share in the latter case.

Combining these projections for the Palma ratio with the per capita evolution of GDP, we are able to compute the future path of the poverty rate (Equation (**1**). Figure 4 illustrates the strong reduction of poverty prevalence in Asia and Sub-Saharan Africa estimated by the model, driven by rising per capita income and the decreasing intra-country inequality. The past worldwide trend showed a 28% reduction of poverty prevalence between 2000 and 2007. By 2030, the estimated number of people below the $1.25 poverty line will have decreased by 86% compared to the 2007 levels (in absolute terms, this represents 1 billion fewer people living below this poverty line as compared to 2007). Overall extreme poverty persists into 2030, however, affecting around 2% of the global population (162 million people). Despite this impressive reduction, some countries in Africa and Asia still show significant poverty rates in 2030. In particular, this is the case of Kenya, Nigeria and the Rest of the Africa region (RoAfrica), where respectively 8%, 7% and 9% of the population will live below the $1.25 poverty line in 2030 (around 65 million people). Our results stem from a socio-economic scenario characterized by sustained growth rates and decreasing inequality in developing world, but they present some similarities with the optimistic trajectory described in Ravallion (2013). It is worth mentioning that alternative scenarios considering lower GDP growth or higher population growth could determine a slower reduction of poverty prevalence.



Source: Poverty headcount in 2000 and 2007 is computed from WDI; model results are used for 2030.

Figure 4 Poverty headcount rate in 2000, 2007 and 2030 SSP2 baseline scenario

6. Policy scenario: the Paris Agreement and the NDCs

The central element of the Paris Agreement are the "Nationally Determined Contributions" (NDCs), which are plans each country autonomously determines to deal with climate change from 2020 on. All parties to the Paris Agreement, including both developed and developing countries, are called to adopt and communicate an NDC. Although the NDCs represent a breakthrough in the scope of participation in the international effort to address climate change, they are widely heterogeneous, in both stringency and coverage of mitigation efforts. While developed countries generally frame their contributions in the form of a quantified economy-wide mitigation effort in comparison to a reference year, developing countries usually refer to emission intensity, or link their emission reduction target to a Business As Usual (BAU) scenario. In addition, most developing countries define both an unconditional and a conditional target: the former to be achieved with internal funds and capabilities, and the latter including a more ambitious mitigation effort to be undertaken on the condition that external financial and technical support be provided.

To perform this modelling exercise, we focus on the conditional mitigation objectives stated in the NDCs.[7] Due to modelling limitations, the GHG emission targets that are part of the NDCs are applied only to CO2 emissions. The emission levels in 2030 are computed by using data from CAIT (WRI 2016) for countries committing to an emission reduction with respect to a specific year, whereas the SSP2 baseline scenario is used as a reference when the reduction is relative to the BAU scenario. In addition, we also want to assess the effect of these emission reduction measures in the presence of a fund that supports developing countries in realizing their climate change actions. The Paris Agreement reaffirms the commitment of the developed nations to make available increased financial flows to developing countries, starting from the 2020 pledge to mobilize USD 100 billion per year. We simulate this flow of climate finance with the objective of understanding the role that funds like the Green Climate Fund can play in supporting the developing economies in reaching their emission reduction targets.

Table 3 shows the mitigation objectives considered for each country. In some cases, countries are clustered in regional groups to which a common target is attributed.[8]

Table 3. Emission reduction target in 2030

Country	Target (%)	Target type	Country	Target (%)	Target type
Australia	-27	Emission reduction wrt 2005	**Venezuela**	-20	Emission reduction wrt 2030 BAU scenario
New Zealand	-30	Emission reduction wrt 2005	**Rest of Latin America (RoLACA)**	-20	Average mission reduction wrt 2030 BAU scenario
Japan	-26	Emission reduction wrt 2013	**EU28**	-40	Emission reduction wrt 1990
South Korea	-37	Emission reduction wrt 2030 BAU scenario	**Rest of Europe (RoEurope)**	-17	Average mission reduction wrt 2030 BAU scenario
Bangladesh	-15	Emission reduction wrt 2030 BAU scenario	**Russia**	-27.5	Emission reduction wrt 1990
China	-62.5	Emission intensity reduction wrt 2005	**Turkey**	-21	Emission reduction wrt 2030 BAU scenario
India	-34	Emission intensity reduction	**Rest of MENA**	-9	Average mission reduction wrt

[7] As reported in the UNFCCC's NDC interim registry. For Parties whose NDCs are not yet available we referred to the *I*NDCs available on the UNFCCC's INDC platform.

[8] In defining the emission reduction target per aggregates of countries, we computed each country's target emission level in 2030 by converting the otherwise specified NDCs (targets on emission reduction with respect to a specific year, emission levels, emission intensity, and deviation from BAU scenario). The macro-region target emission level is compared to emission levels in the BAU scenario, and the aggregate emission reduction is so derived.

		wrt 2005	**(RoMENA)**		2030 BAU scenario
Indonesia	-41	Emission reduction wrt 2030 BAU scenario	**Ethiopia**	-64	Emission reduction wrt 2030 BAU scenario
Rest of Asia (RoAsia)	-25	Average mission reduction wrt 2030 BAU scenario	**Ghana**	-45	Emission reduction wrt 2030 BAU scenario
Canada	-30	Emission reduction wrt 2005	**Kenya**	-30	Emission reduction wrt 2030 BAU scenario
USA	-27	Emission reduction wrt 2005	**Mozambique**	-8	Emission reduction computed from target emission levels in 2030
Mexico	-36	Emission reduction wrt 2030 BAU scenario	**Nigeria**	-45	Emission reduction wrt 2030 BAU scenario
Argentina	-30	Emission reduction wrt 2030 BAU scenario	**Uganda**	-22	Emission reduction wrt 2030 BAU scenario
Brazil	-37	Emission reduction wrt 2005	**South Africa**	-22	Emission level target in 2030 is in the range 398 and 614 Mt CO2–eq
Chile	-40	Emission intensity reduction wrt 2007	**Rest of Africa (RoAfrica)**	-33	Average mission reduction wrt 2030 BAU scenario
Peru	-30	Emission reduction wrt 2030 BAU scenario	**Rest of the World (RoW)**	-36	Average mission reduction wrt 2030 BAU scenario

The proposed mitigation scenario considers an effort to curb emissions starting in 2013 and assumes that each country achieves its NDC by 2030.

The European Union (EU28) implements an Emission Trading System (ETS), as already foreseen by the EU ETS domestic legislation, while all other countries achieve their contributions unilaterally with a domestic carbon tax. China, India and Chile have expressed their NDCs in terms of emission intensity; this peculiarity is preserved in the modelling policy scenario.

The mitigation scenario is characterised by two different recycling schemes of the revenues collected from the carbon market or the carbon taxes:

- MPOLICY scenario: revenues are redistributed internally;
- MPOLICY+GCF scenario: part of the revenues from the developed countries flows into an international fund aimed at supporting mitigation action in the developing countries. We use the allocation rules of the Green Climate Fund (GCF) as a benchmark (see Section 8). Money is transferred to the developing countries[9] in Asia, Latin America, the Middle East

[9] Among GCF recipient countries, we included those countries that have up to now selected the National Designated Authorities (excluding China) according to GCF rule: http://www.greenclimate.fund/partners/countries/nda-directory.

and Africa, and is used to subsidize specific mitigation-related sectors: namely, Clean Electricity and Research&Development (R&D)[10].

7. Poverty and inequality in the mitigation scenario

The worldwide implementation of the conditional NDCs yields a 19% reduction of CO_2 emissions at the global level in 2030 with respect to the SSP2 baseline scenario (13% reduction of GHG emissions). Achieving the mitigation targets (the MPOLICY scenario) imply an economic cost of between -6.7% and +5.6%, computed with respect to the countries' GDP in the baseline scenario in 2030 (Figure 5).

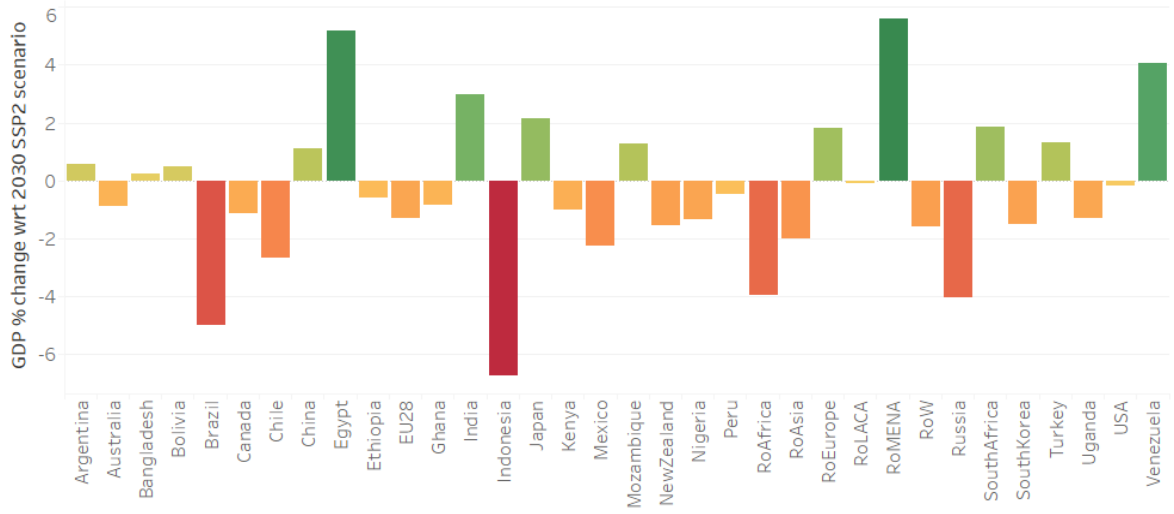


Figure 5 Mitigation policy cost in terms of GDP in 2030, MPOLICY scenario with respect to SSP2 baseline scenario

The situation at the country level is highly heterogeneous. Some countries experience GDP gains as a consequence of absent or loose NDC mitigation targets (Figure 6). This happens in Japan, China, India, Venezuela, non-EU European countries, Turkey, Egypt, and part of the Middle-East and South Africa, that have relatively lower carbon taxes and, therefore, higher competitive advantages in comparison with other countries.

[10] The allocation of subsidies across the two sectors depends on the magnitude of the sectors itself: e.g. the highest is R&D VA compared to the Clean Electricity one, the more it is subsidized.

In particular, China, India and Bolivia are projected to reach higher emission levels under the mitigation policy scenario than in the baseline, experiencing a clear leakage effect as a consequence of the weak mitigation target stated in their NDCs. On the contrary, countries such as Indonesia, Brazil, Chile, Russia and RoAfrica, whose targets appear to be relatively more stringent, are projected to experience a substantial GDP loss to achieve their mitigation objectives.

Although not fully comparable at the geographical scale, our results are consistent with other recent estimates that assess the cost of mitigation action under the Paris Agreement by using similar scenario assumptions (see Aldy et al., 2016).

Some caveats must be noted. In the case of Indonesia and Brazil, which show the highest GDP losses, we need to acknowledge that our model does not fully capture the economic potential of these countries in terms of emission reduction from the forestry sector. Although both their mitigation objectives are economy-wide, reforestation and reduced deforestation are certainly an economically viable mitigation opportunity for these countries (Smith et al. 2104). Similarly, China's action, as stated in both the NDC and the subsequent 13th Five Year Plan (2016–2020), is broader than the quantitative carbon intensity target used for our analysis. In particular, the planned increase in the non-fossil fuel share and the recently-imposed limit on coal consumption, if maintained up to 2030, might lead to steeper emission reductions (and potentially higher costs) than those projected in our mitigation scenario. In addition, mitigation actions are achieved unilaterally by each country (excluding the EU-28 members). The literature usually agrees on the fact that the costs of climate action are lower if cooperative mechanisms are implemented (Clarke et al., 2009). However, despite the fact that the Paris Agreement explicitly opens up to the possibility for countries to use "Internationally Transferred Mitigation Outcomes" (ITMOs), at the moment there are not enough elements to figure out how such a mechanism will be designed. Finally, none of the results of our scenarios considers the avoided damages (and costs) from emission mitigation action, which will be addressed in future research efforts.

Figure 6 Stringency of mitigation policy in 2030, CO2 emissions in MPOLICY scenario with respect to SSP2 baseline scenario

To better describe the effects of mitigation policies on SDG1 and SDG10, i.e. poverty prevalence and inequality, we focus only on a narrower set of countries that show high to moderate poverty headcount rates in the base year (2007).

Figure 7 portrays how poverty headcount ratio and inequality (Palma ratio) in 2030 are affected by climate policy.

In general, countries with a stringent mitigation policy experience a reduction of inequality compared to the baseline scenario levels. This is the case in Ethiopia (-8%), Nigeria (-4%), Indonesia (-3%), and Brazil (-3%). The forces behind these changes are a country-specific adjustment of sectoral VA and of public education expenditure[11]: the increase in agriculture and manufacturing shares, as well as that of public education expenditure, play a major role in Indonesia and Brazil. As explained in Section 3, the empirical analysis on cross-country historical data

[11] In all policy scenarios, government expenditure in real terms is assumed to be unchanged compared to the baseline scenario one; therefore, whether or not policy implementation determines a contraction in GDP, the share of GDP devoted to public expenditure in education increases because the government is forced to maintain its expenditure unchanged.

highlighted that these drivers have a positive impact on income share of the poorest 40% of population (and a negative impact on the income share of the richest 10%). In Ethiopia, the mitigation policy determines a small contraction of agricultural production (negatively effecting the Palma ratio), but fosters manufacturing and heavy industry (which has a positive effect on the Palma ratio). In fact, despite the contraction of fossil fuel intensive sectors, VA in heavy industry rises because of a switch to clean electricity. The increase in public expenditure in education is the main driver for Nigeria.

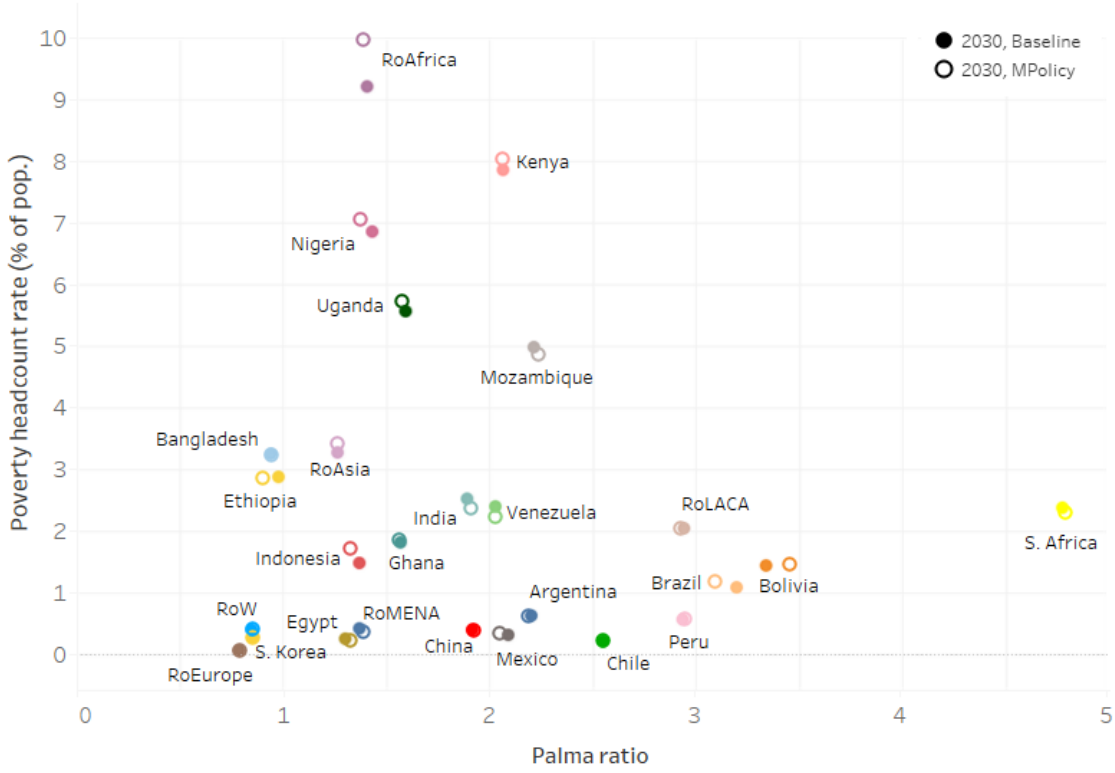


Figure 7 Palma ratio and poverty prevalence in 2030, MPOLICY and SSP2 baseline scenario

The countries gaining from the climate policy because of a non-stringent NDC show higher inequality than in the baseline scenario. Bolivia is a clear example of this pattern, with an increase of approximately 4% in the Palma ratio. The contraction of the industrial sector, highly dependent on more costly imported energy, is behind this result.

The outcome in terms of poverty prevalence reduction with respect to the 2030 baseline scenario, is mixed and depends on how the composition of both income and inequality is affected by the policy.

Worldwide poverty prevalence increases by 2% (nearly 3 million people) compared to the baseline scenario(Figure 7). The mitigation policy accelerates poverty reduction in RoMENA (-10%), Egypt (-9%), Venezuela (-7%), India (-6%), South Africa (-3%) and Mozambique (-2%). In these countries, the slight rise in inequality is more than compensated by economic gain coming from a non-stringent climate policy. Ethiopia is the only country in which the reduction of inequality (-8%) due to the policy more than compensates the cost of mitigation (-0.6%) and determines a slight reduction of poverty prevalence compared to the baseline scenario (-0.5%).

Three countries show a substantial rise in poverty prevalence: Indonesia (15%), Brazil (9%) and RoAfrica (8%), where the economic costs of mitigation policy are not compensated by the inequality reduction.

It is worth remembering that this assessment considers only the possible abatement cost for the society without accounting for the climate policy benefits, such as the consequent reduction of climate change-related damage. According to the recent literature, climate change impacts will have strong distributional and poverty implications (Dennig et al. 2015); therefore not accounting for them implies an overestimation of mitigation costs.

Furthermore, our results rely on assumptions about economic growth and the carbon intensity of the selected baseline scenario. However, the comparative outcome of the mitigation policy with respect to the baseline scenario in terms of poverty and inequality should not be altered by a lower GDP growth or carbon intensity. Moreover, a sensitivity analysis on scenario assumptions could be an interesting topic for future research.

8. Poverty and inequality under the mitigation scenario with the Green Climate Fund

In order to recreate a more realistic scenario of the COP21's aftermath, we design a further recycling rule of carbon revenues, according to which the developed countries, committed to an emission reduction objective in their NDCs, devote a part of their revenues to an international fund aimed at supporting the developing countries' climate action (MPOLICY+GCF scenario). Following the actual allocation rules adopted by the Green Climate Fund's Board so far, we design

the fund in order to achieve an “equal balance between adaptation and mitigation” actions, as well as a “geographic balance and a reasonable and fair allocation across a broad range of countries” (GCF, 2014). Since, for the moment, we consider only the support to mitigation actions, our fund will reach $50 billion (US$2007) in 2020 (50% of the pledged $100 billion a year by 2020) and then remains constant. The funds are then distributed across beneficiary countries proportionally to their population share (Figure 8). Assuming an equal percentage contribution among the donors, to reach the planned amount, they donate 7% of their carbon revenues up to 2020 and then slightly reduce them progressively. The major contributors to this fund are the EU28, providing 41% of the total amount, and the United States, with 28%.

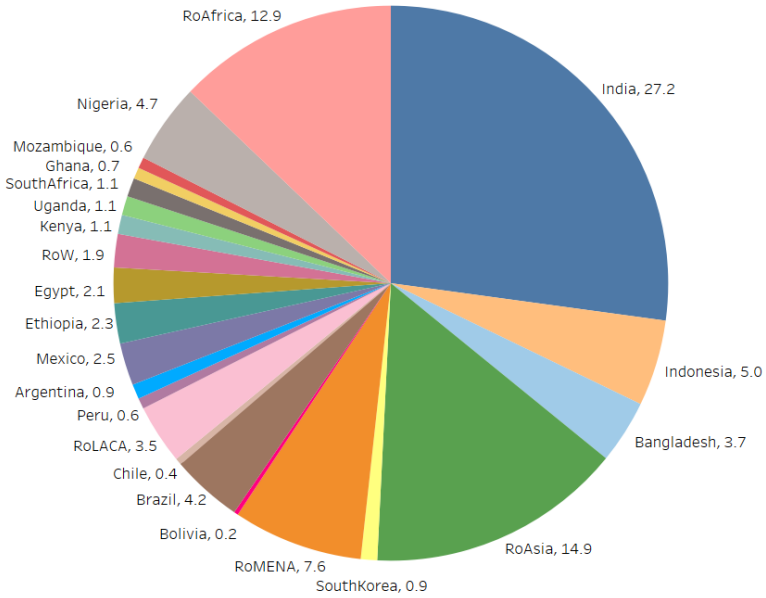


Figure 8 Developing fund recipients

In the MPOLICY+GCF scenario, the developing countries receive the funds and use them to subsidise clean electricity and R&D sectors. This recycling scheme determines a small drop of inequality (0.2% globally) by 2030 compared to the MPOLICY scenario. The results are quite heterogeneous at the country level (Figure 9) and appear unrelated to the share of funds received, but rather to the magnitude of the funds with respect to the country’s economy. Ethiopia, which obtains only 2.5% of the GCF’s funds (corresponding to 1.3% of its GDP in 2030), experiences the highest inequality reduction (9.3% with respect to the 2030 MPOLICY scenario), which follows a

35% increase of VA share generated in the industrial sector and a 1% rise in the expenditure share for public education. In Bolivia, the small fraction of international money that flows into the country (i.e. 0.3% of its GDP) determines a 0.7% reduction in inequality, due to the rise in production in the Clean Electricity and R&D sectors. In Nigeria and Mozambique, the Palma ratio shows the highest upsurge, increasing respectively by 0.5 and 0.6% compared to the MPOLICY scenario. The similarities in the policy effects occur despite disparities in the magnitude of funds flowing into the two countries, respectively 5% and 0.7% of the total amount (equal to 0.3% and 0.7% of their GDP in 2030), as different mechanisms determine this outcome: GCF funds lead to a contraction in the industrial sector share in Nigeria, given that the majority of subsidies are directed to the R&D sector (services), and a shrinkage in the agricultural sector share in Mozambique.

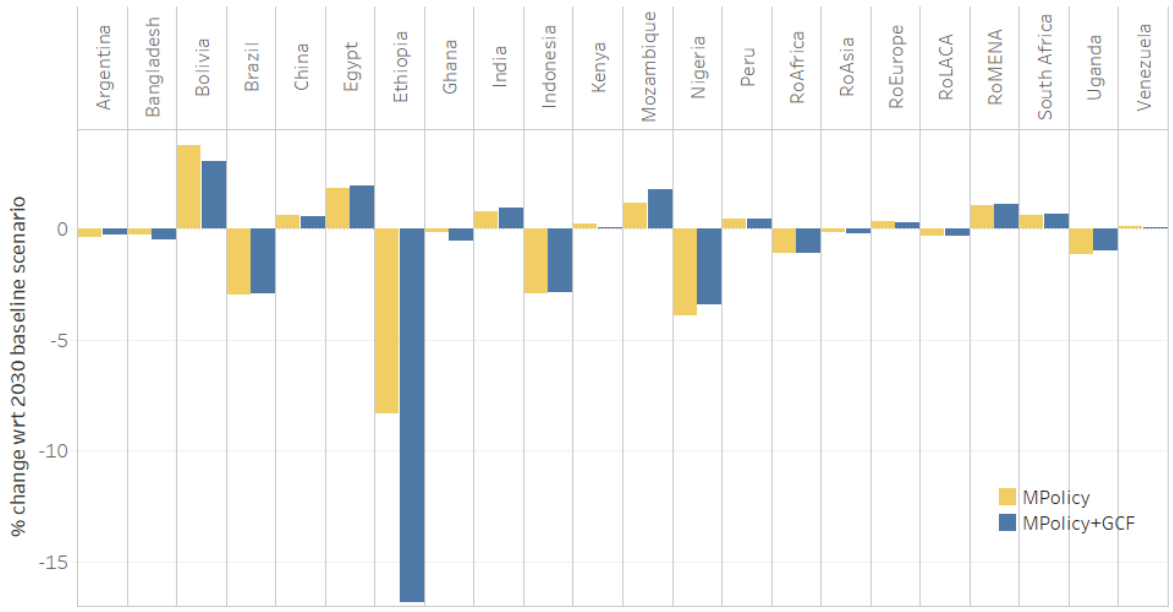


Figure 9 Palma ratio in MPOLICY and MPOLICY+GCF scenarios, %change w.r.t 2030 SSP2 baseline scenario

The MPOLICY+ GCF scenario has an impact on poverty prevalence, altering both the inequality measure and the average per capita income. By 2030, poverty worldwide slightly decreases (-185 thousand poor people) compared to the MPOLICY scenario, with highly heterogeneous outcomes across regions.

The main driver of this impact is the change in per capita GDP that the policy determines. Countries receiving the highest shares from the GCF experience a GDP increase compared to the MPOLICY scenario, which, joined to irrelevant changes in inequality, reduces poverty prevalence in Indonesia (-0.6%), RoAfrica (-0.48%), RoAsia (-0.35%), Brazil (-0.12%) and India (-0.02%).

Conversely, in Bangladesh, Uganda, Ghana and Ethiopia the influx of international funds causes a rise in poverty compared to the MPOLICY scenario (respectively by 1.82, 0.88, 0.73 and 0.44%). Behind this result is a regressive effect of subsidies on the GDP passing through the trade balance. The support to Clean Electricity and R&D determines a flow of labor and capital towards these sectors that is detrimental to other production sectors (in particular light industry), which see a reduction in output. This also determines a contraction in exports not compensated by a rise in the exportation of Clean Electricity and R&D, whose traded production is limited.

Mozambique and Egypt show an interesting pattern: in spite of a limited influx from the GCF (0.7% and 2.2% of the fund), they experience a substantial drop in poverty prevalence compared to the MPOLICY scenario, namely -2.6% and -1%. For both countries, the rise in per capita income more than compensates a small increase in inequality. The subsidy, especially to Clean Electricity, has a progressive impact on these two economies, stimulating heavy industry production, which is the leading export sector and, therefore, determining an improvement in the trade balance.

Despite the moderate decrease worldwide of poverty prevalence linked to the introduction of the GCF scheme compared to MPOLICY alone, its magnitude remains above the baseline level in 2030 (around 3 million people more than in the baseline scenario).

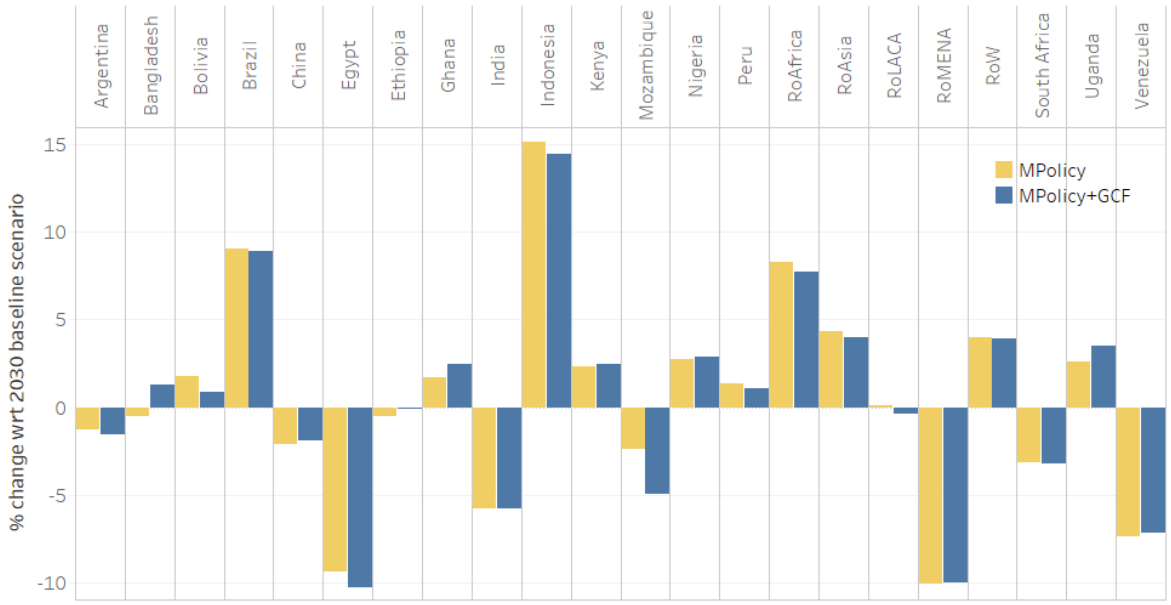


Figure 10 Poverty headcount rate in MPOLICY and MPOLICY+GCF scenarios, %change wrt 2030 SSP2 baseline scenario

9. Conclusions

Two types of conclusions can be derived from our analysis. First, from a methodological point of view, our study shows that linking empirical social SDG indicators to a CGE model, as in the case of the "Poverty headcount ratio" and the "Palma ratio," makes possible a coherent assessment of future trends of these indicators under different scenarios and policy interventions.

Second, the output of our analysis makes an important contribution to the literature on the linkages between climate change policy and sustainable development, and makes it possible to formulate policy recommendations that inform the ongoing debate on the implementation of the Paris Agreement and the Green Climate Fund.

In particular, if we consider the full implementation of the emission reduction contributions stated in the NDCs, and take into account only the cost side of mitigation policy, the Paris Agreement is projected to slow down poverty reduction compared to the reference scenario. Despite the heterogeneity of results, the effect is stronger for countries that proposed a relatively more stringent mitigation component in their NDC, whereas countries with a loose mitigation target are likely to

experience lower policy costs and a consequent competitive advantage. However, the aggregate effect of current NDCs on poverty headcounts is not so broad, accounting for an increase of 2% globally in 2030 compared to the baseline scenario. Conversely, countries with relatively more stringent mitigation policies show a decline in inequality compared to the baseline scenario levels. This would suggest potential synergies between climate change interventions and the income increase in the poorest strata of the population.

By introducing the possibility of distributing a portion of carbon revenues through a Green Climate Fund to support developing countries we can infer some implications for both the donor and the recipient countries. Specifically, by assuming an equal share of proceeds from the ETS or carbon tax among developed countries, the maximum amount of revenues they are required to donate to reach the pledged funds is 7% in 2020, after which the burden starts to decrease. In most developing countries that receive international financial support in the form of sector-specific subsidies, it accelerates poverty reduction efforts compared to the mitigation scenario with internal recycling of revenues. In big recipient countries, the funds lead to a GDP increase and a consequent reduction in poverty prevalence. However, some of the least developed countries show a regressive effect of subsidies to Clean Electricity and R&D, which, by attracting resources, are detrimental to other production sectors, which in turn experience a reduction of output and a contraction of exports. Mozambique and Egypt show interesting results: in spite of a limited influx from the Fund, they experience a consistent drop in poverty prevalence due to the subsidy, especially to Clean Electricity, which stimulates one of the leading export sectors, i.e. heavy industry, and, therefore, determines an improvement in the trade balance. Worldwide, in the MPOLICY+GCF scenario poverty slightly decreases (-185 thousand poor people) even though the magnitude does not manage to offset the increase experienced in the MPOLICY scenario.

Overall, we observe that the relative magnitude of funds flowing into beneficiary countries is a crucial factor in making the international climate transfers a pro-poor instrument, as it is more likely to observe a reduction in poverty in countries that receive a higher amount of funds proportional to the size of their economy. Therefore, the allocation scheme matters for determining the final outcome on poverty prevalence.

However, it is worth emphasizing that its major purpose is to spread good practices and technologies for mitigation and adaptation, and it should therefore be considered as additional to traditional funds for tackling other sustainable development targets. Nevertheless, our results would suggest the need to prioritize policies that jointly address climate change mitigation and socio-economic development. In addition, our results make a strong case for the creation of a new effective mechanism that will contribute to mitigating greenhouse gas emissions and supporting sustainable development, as stated in Article 6.4 of the Paris Agreement.

Crucially, it should be recalled here that these results probably overestimate the negative effect of mitigation on poverty and inequality because our framework does not consider the benefits connected to reduced climate change impacts, which will be addressed in future research. As a consequence, these results must be judged with caution: although it is reasonable to think that climate policy per se and its cost will imply a slight increase in poverty prevalence, if we also take into account the benefits of avoided climate-induced impacts, we very likely will find a reversal of the results in favour of a poverty reduction in both mitigation scenarios.

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Appendix I

ICES is a recursive- dynamic multiregional Computable General Equilibrium (CGE) model developed to assess impacts of climate change on the economic system and to study mitigation and adaptation policies. The model's general equilibrium structure allows for the analysis of market flows within a single economy and international flows with the rest of the world. This implies going beyond the "simple" quantification of direct costs, to offer an economic evaluation of second and higher-order effects within specific scenarios either of climate change, climate policies or different trade and public-policy reforms in the vein of conventional CGE theory.

The core structure of ICES derives from the GTAP-E model (Burniaux and Troung, 2002), which in turn is an extension of the standard GTAP model (Hertel, 1997). The General Equilibrium framework makes it possible to characterise economic interactions of agents and markets within each country (production and consumption) and across countries (international trade).

Within each country the economy is characterised by n industries, a representative household and the government. Industries are modelled as representative cost-minimizing firms, taking input prices as given. In turn, output prices are given by average production costs. The production functions (Figure A1) are specified via a series of nested Constant Elasticity of Substitution (CES) functions that combine primary factors (natural resources, land, and labour), a Capital+Energy composite, and intermediates, in order to generate the output. To all intermediates apply the ″Armington assumption″ that introduces some frictions on the substitutability of inputs imported from different countries.

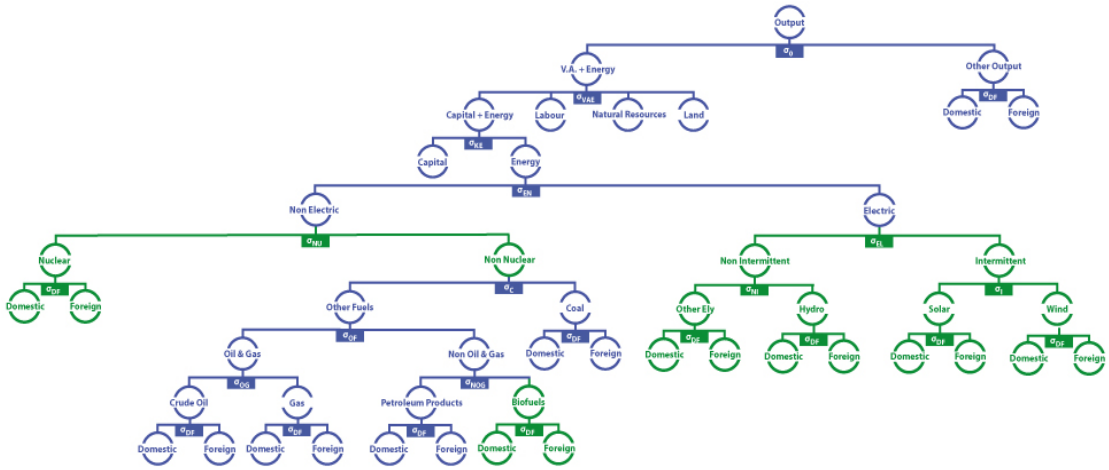

Figure A1 - ICES production tree

As well as in GTAP-E model, the specification of Energy nest is detailed considering electricity and several fossil fuels (coal, oil, gas and petroleum products). ICES model further specifies renewable energy sources in electricity production, namely wind, solar and hydro-electricity, splitting them from the original electricity sector. The data collection refers to physical energy production in Mtoe (Million tons of oil equivalent) from different energy vectors and for each GTAP 7 country/region. The data source is Extended Energy Balances (both OECD and Non-OECD countries) provided by the International Energy Agency (IEA). We complemented the production in physical terms with price information (OECD/IEA 2005; Ragwitz et al. 2007; GTZ 2009; IEA country profiles and REN21).

Figure A2 describes the main sources and uses of regional income. In each region, income is detained by private household and government income; for the former agent, income corresponds to the service value of national primary factors (natural resources, land, labour, and capital), for the latter one, it equals to the total tax revenues from both private household and productive sectors, a series of international transactions among governments (foreign aid and grants) and national transfers between the government and the private (Delpiazzo et al., 2017). Both the government and the private household consume and save a fraction of their income according to a Cobb-Douglas function. The government income not spent is saved, and the sum of public and private

savings determines the regional disposable saving, which enters the Global Bank as in the core ICES.

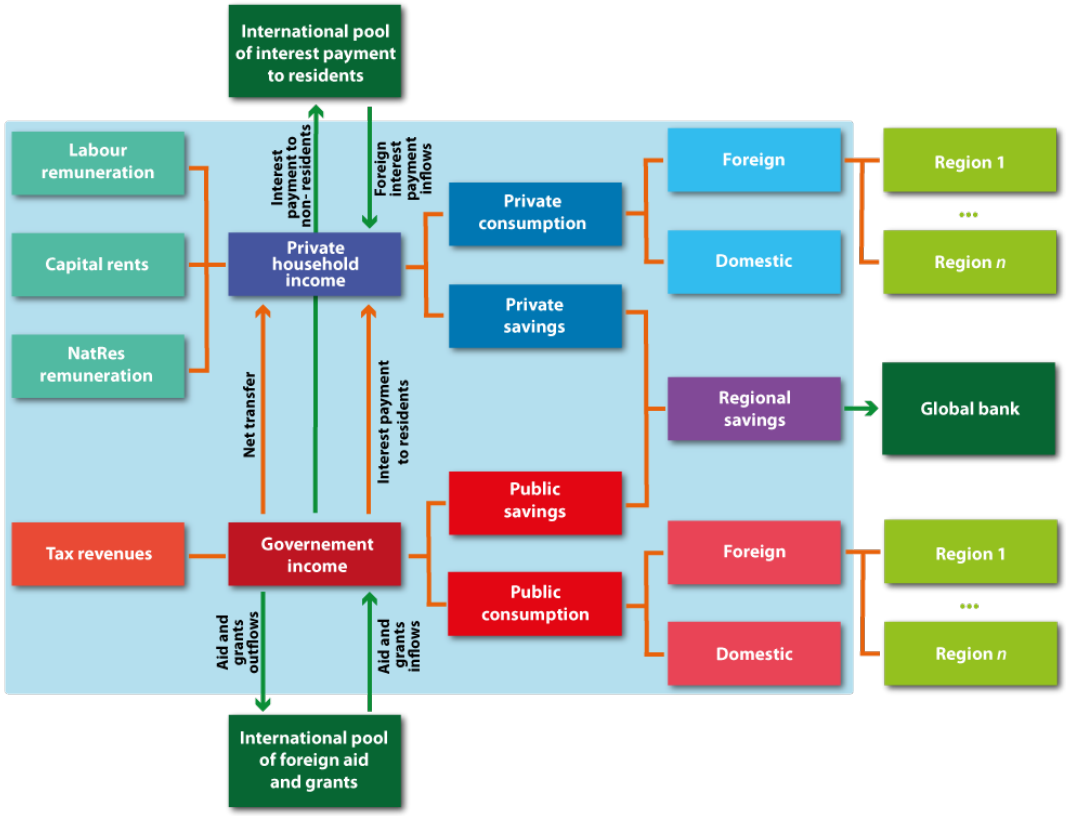

Figure A2 - Sources and uses of regional household income

The recursive-dynamic feature is described in Figure A3. Starting from the picture of the world economy in the benchmark year, by following socio-economic (e.g. population, primary factors stocks and productivity) as well as policy-driven changes occurring in the economic system, agents adjust their decisions in terms of input mix (firms), consumption basket (households) and savings. The model finds a new general (worldwide and economy-wide) equilibrium in each period, while all periods are interconnected by the accumulation process of physical capital stock, net of its depreciation. The matching between savings and investments only holds at the world level; a fictitious world bank collects savings from all regions and allocates investments following the rule of highest capital returns.

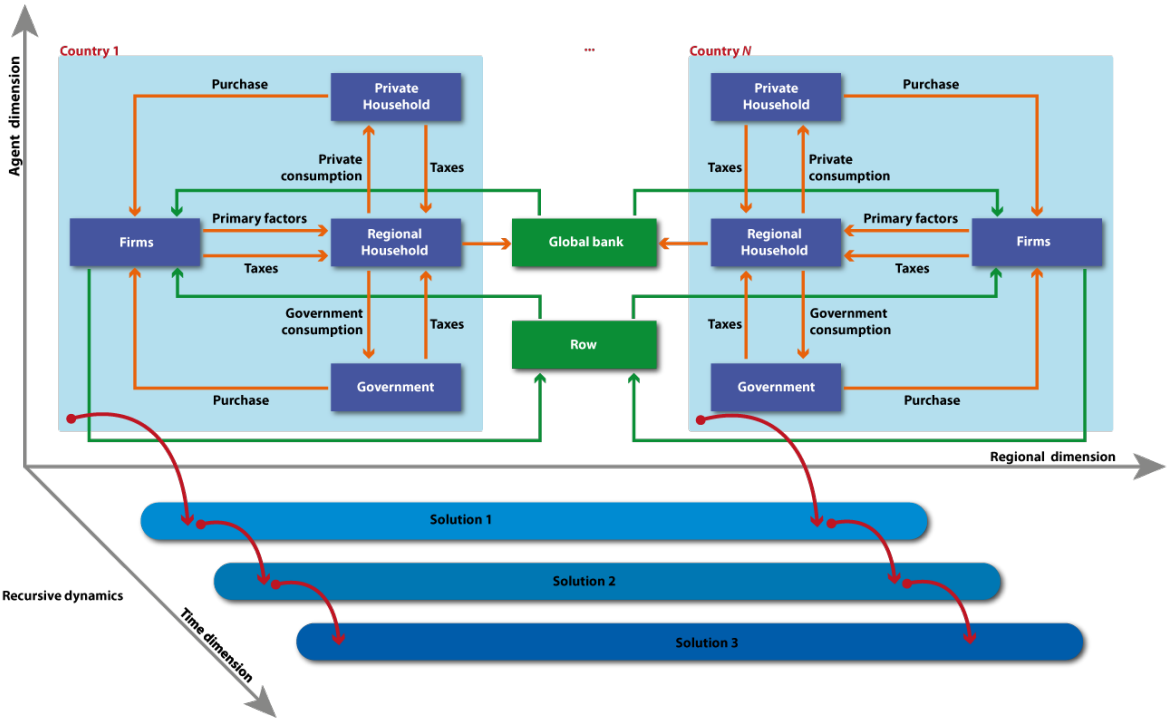

Figure A3 - Recursive-dynamic feature of ICES model

Regional and sectoral aggregation

ICES is a Computable model: all the model behavioural equations are connected to the GTAP 8 database (Narayanan et al., 2012), which collects national social accounting matrices from all over the world and provides a snapshot of all economic flows in the benchmark year. Being based on the GTAP database, ICES has worldwide coverage. In this analysis, we consider 45 countries/regions (Figure A4 and Table A1).

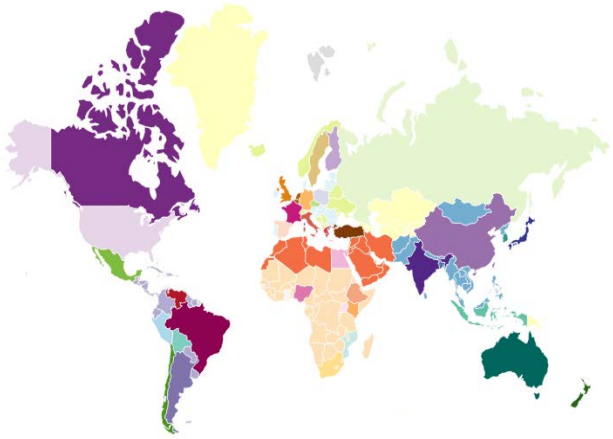

Figure A4 – Regional aggregation ICES model

Countries /macro-regions					
1	Australia	16	Chile	31	RoEU
2	NewZealand	17	Peru	32	RoEurope
3	Japan	18	Venezuela	33	Russia
4	SouthKorea	19	RoLACA	34	Turkey
5	Bangladesh	20	Benelux	35	Egypt
6	China	21	Czech_Rep	36	RoMENA
7	India	22	Finland	37	Ethiopia
8	Indonesia	23	France	38	Ghana
9	RoAsia	24	Germany	39	Kenya
10	Canada	25	Greece	40	Mozambique
11	USA	26	Italy	41	Nigeria
12	Mexico	27	Poland	42	Uganda
13	Argentina	28	Spain	43	SouthAfrica
14	Bolivia	29	Sweden	44	RoAfrica
15	Brazil	30	UK	45	RoW

Table A 1: ICES countries /macro-regions

Each socio-economic system is then divided into 22 sectors (Table A2).

Sectors			
1	Agriculture	12	Fossil Electricity
2	Livestock	13	Clean Electricity
3	Processed Food	14	Heavy Industries
4	Forestry	15	Light Industries
5	Fishing	16	Transport
6	Other Mining	17	Water
7	Coal	18	R&D
8	Oil	19	Market Services
9	Gas	20	Health
10	Oil Products	21	Education
11	Nuclear Fuel	22	Public Services

Table A2: ICES sectors

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