Can the Paris Agreement support achieving the Sustainable Development Goals?

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Abstract

This chapter provides an ex-ante, quantitative assessment of the synergies and trade-offs between the implementation of the Paris Agreement and sustainable development. It develops a framework for comparing historical and future sustainability performance that combines a Computable General Equilibrium model for describing future global and regional baseline and policy scenarios to 2030 with empirically-estimated relationships between macroeconomic variables and sustainability indicators. Results indicate that the commitments submitted within the Paris Agreement reduce the gap toward a sustainable 2030 in all regions, but heterogeneity across regions and sustainability indicators call for complementary sustainable development polices.

Introduction

With the advent of the United Nations' 2030 Agenda and the Paris Agreement in 2015 (United Nations (UN), 2015), a growing number of studies has been exploring the synergies and trade-offs between climate policy and sustainable development. Synergies and trade-offs can go in both directions. On the one hand, the mitigation literature in the context of the new scenario framework of the Shared-Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs, O′Neill *et al.* 2017; van Vuuren *et al.* 2014) highlights how deep decarbonization (Rogelj *et al.* , 2019) can be achieved more easily under sustainable scenarios, such as the SSP1 narrative, which poses lower challenges to mitigation and adaptation. On the other hand, climate mitigation policies can generate a wide range of non-climate ancillary benefits and obstacles in achieving the Sustainable Development Goals (SDGs, Roy *et al.* 2019). Aligning mitigation policies with SDGs is key for ensuring social acceptability of the required structural transformation and for fostering the more ambitious action required to contain global warming below 1.5°C in 2100.

This chapter contributes to the emerging literature on the synergies and trade-offs between mitigation and sustainable development by evaluating the impact of the Paris Agreement implementation on a set of SDG indicators by 2030 using a Computable General Equilibrium (CGE) model. A macroeconomic framework provides a system perspective analysis, highlighting the aggregate impacts of mitigation policy on multiple sustainable development dimensions at the same time, while taking into account the general equilibrium adjustments induced by price changes. Ex-ante assessments, such as those based on simulation or numerical models, make it possible to explore the implications of mitigation policies of different ambition, broadening the evidence beyond the policies actually implemented in the past. They can examine synergies and trade-offs into the future, and provide a benchmark for policy evaluation and design while accounting for policy and socioeconomic uncertainty. This chapter develops projections of selected SDG indicators in a reference and mitigation policy scenario, contributing to expand the existing literature on mitigation pathways in the context of sustainable development. The major limitation of the few

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existing integrated assessment approaches available to date is the focus on economic and technological indicators, a choice that is driven by the limited ability of quantitative models to represent the social dimensions of sustainable development (McCollum *et al.* 2018b, von Stechow *et al.* 2016). The method presented in this chapter combines regression analysis to estimate empirically-based relationships between 16 economic, social, and environmental SDG indicators and the key socioeconomic variables represented in the CGE model. Gender inequality is the only goal left unexplored (SDG5).

The remainder of the chapter is organized as follows. Section 1 synthesizes the most recent literature on the mitigation co-benefits and side-effects on sustainable development. Section 2 describes the ex-ante approach used to assess the SDG implications of the Paris Agreement. Section 3 discusses the advantages and limitations of our methodology in sustainability assessment of policy implementation and concludes, highlighting some directions for future research concerning the co-benefits of mitigation and adaptation policies.

1 Mitigation policy and sustainable development: recent contributions from the literature

The SDGs define broad and ambitious development targets for both developed and developing countries encompassing all sustainability dimensions (economic, social, and environmental), including minimizing climate change impacts (SDG13), with the ambition of informing pathways towards inclusive green growth. The tight linkage among the economic, social, and environmental dimensions is reflected in the connections, mutually reinforcing or smothering, across different goals integrated into the broader framework. Given the multiple interactions among different SDGs, integrated approaches, such as those based on Integrated Assessment Models (IAMs) or integrated energy-economy climate models, can quantify the synergies and trade-offs between target-specific policies, such as mitigation, and all other goals, with a system perspective (von Stechow *et al.* 2016, 2015).

Despite the growing number of efforts, current integrated modelling research remains confined to sectoral studies offering a limited view on the possible co-effects and focusing on a narrow set of specific objectives. Most of the literature, recently reviewed in the IPCC Special Report 1.5, has focused on food security and hunger (SDG2), air pollution and health (SDG3), clean energy for all (SDG7), water security (SDG6). Only McCollum *et al.* (2018a) conduct a systematic review of the literature to evaluate the nature and strength of interaction between SDG7 and all other SDGs. The review relies on forward-looking, quantitative scenario studies focusing on multiple objectives. SDG7 is connected to the implementation of mitigation policies through the specific targets on access to modern energy services, increased share of renewables and improved energy intensity. Since these targets are basic requirements of any mitigation policy, McCollum *et al.* (2018a) indirectly sheds some light on the interaction between mitigation policy and SDGs. It is interesting to note that, the model-based literature reviewed in the paper is not able to identify contributions assessing social indicators (no poverty SDG1, education SDG4, gender equality SDG5, reduced inequalities SDG10). In order to provide some evidence on these dimensions, McCollum *et al.* (2018a) selects historical, empirical, or case-study papers.

The social indicators for which most evidence is found are SDG2 and SDG3. Regarding SDG3, good health and well-being, most literature focuses on reduced air pollution (Rao *et al.* 2016; Markandya *et al.* 2018) and diminished impacts of climate change and environmental degradation (Ebi *et al.* , 2018). Mitigation policy stimulates the development and the diffusion of renewable technologies that appear decisive in improving energy access especially in remote and not connected areas (McCollum *et al.* , 2018a). Regarding SDG2 (undernutrition reduction), the literature on the impacts of uncontrolled emission growth and temperature rise on agricultural production and on undernutrition prevalence is wide (Hasegawa *et al.* 2016; Nelson *et al.* 2010; Lloyd *et al.* 2011). Achieving mitigation targets helps in reducing these side effects, but at the same time can generate some trade-offs pushing a large-scale deployment of bio-energy, competition for land, and increased food prices. These are trade-offs that can be mitigated by decarbonization strategies oriented more towards demand side actions (Grubler *et al.* , 2018) or through the adoption of complementary distributional policies. The literature on the link between mitigation and poverty (SDG1) and inequality (SDG10) reduction is also quite scattered. On the one hand, as in the case of SDG2, poor people are the most exposed to climate change impacts that can be 70% higher for the bottom

40% of the population than for the average (Hallegatte & Rozenberg, 2017). Therefore, mitigation can have a pro-poor and equalising effect. On the other hand, emission cuts, by setting a price on carbon, can have regressive implications if an adequate revenue recycling scheme supporting the poorest layers of the population is not predisposed (Hassett *et al.* 2009; Metcalf 1999). The social dimension of SDG7, i.e. achieving universal energy access, can also be hindered by a mitigation policy that increases energy prices in fossil fuel-intensive countries and burdens poor households. At the same time, the efficiency improvements, especially of the renewable technologies, combined with pro-poor incentives can reduce this tarde-off (Dagnachew *et al.* 2018; Jakob & Steckel 2014). Direct effects of mitigation policy on SDG4 (quality of education) and SDG16 (preserve peace) have not been explored yet in the literature, though the literature on the link between global warming and conflicts is expanding (Hsiang *et al.* , 2011).

With respect to the economic indicators (SDGs 8, 9, 17), a broad literature on the interaction between technology and environmental externalities (Carraro *et al.* , 2010) highlights the positive impacts of climate policy on innovation and technology diffusion (SDG8, decent work and economic growth). With respect to employment opportunities the evidence is mixed. Green jobs are mostly high-skill, entail higher wages, and tend to be concentrated in high-tech areas (Vona *et al.* , 2018b). Although there are distributional implications, impacts on overall employment seem to be modest (Vona *et al.* , 2018a). Despite the multiple channels through which mitigation policy can stimulate growth (Hallegatte *et al.* , 2012), the IAM-based mitigation literature highlights the macroeconomic costs of stringent mitigation actions, mostly due to early retirement of capital, higher energy costs for producers and consumers, terms of trade effects (Paltsev & Capros, 2013). The regional distribution of impacts on economic performance can also be expected to be uneven, mostly due to terms-of-trade effects, which would penalize net exporters and work in favour of net energy importers. In developing countries prioritizing poverty-related issues, emission costs could divert funds necessary to development policies.

In addition, even mitigation with a compensatory scheme by industrialised countries can lead to a "climate finance curse", sluggish investments and technological change in energy intensive sectors and, ultimately, slower economic growth (Jakob & Steckel, 2014). Regarding SDG17, the IPCC 1.5 report highlights that the diffusion of new technologies related to decarbonization strategies requires transnational capacity building and knowledge sharing and could contribute to international partnership (Roy *et al.* , 2019). Impacts on industry, innovation, and infrastructure (SDG9) are mixed and sector-specific, with a tendency to penalize energy-intensive sectors and infrastructure. Transforming the industrial sector towards a renewable-based and more efficient system aligns with the goal of upgrading energy infrastructure and making the energy industry more sustainable (McCollum *et al.* , 2018b).

With respect to the environmental indicators, there is strong positive interaction between mitigation and SDG11, i.e. sustainable cities and infrastructure. This is driven by the multiple co-benefits of the behavioural and technological transformations mitigation policy might induce. According to Reis *et al.* (2018), meeting the 1.5°C policy target may limit spikes of pollutant concentration (except PM2.5) above the safe thresholds in all countries. Furthermore, mitigation commitments might stimulate the development of renewable energy technologies and energy-efficient urban infrastructure solutions boosting urban environmental sustainability by further improving air quality, and reducing noise and energy expenditure (McCollum *et al.* , 2018a).

A strong positive interaction, with high agreement and confidence is also found with water availability and quality (SDG6), natural resource protection (SDG12) through the reduced depletion of several natural resources, life below water (SDG14) through the reduced risk of ocean acidification, life on land (SDG 15) through reduced deforestation, though some weak trade-offs are also found especially for SDG 14 and 15 (McCollum et al. 2018). The scaling up of renewable energy would lower the water demand for energy (e.g. for cooling power plants), though some specific options (e.g. hydropower) could induce trade-offs and tougher competition for water use. A mitigation pathway that more strongly relies on bioenergy might have higher requirements in terms of water for irrigation, reducing availability for other sectors.

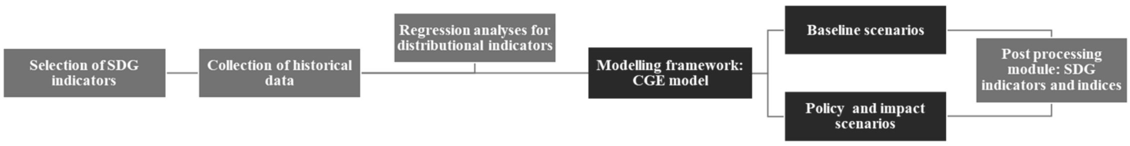
To conclude, the existing literature seems to suggest that the degree of competition between mitigation objectives and sustainable development depends on the type of transition pathway adopted. While energy supply or land and ocean mitigation options tend to entail a larger number of trade-offs and risks, demand-side measures can significantly reduce the risks associated with mitigation policies, as they tend to bring about a larger set of co-benefits. Yet, actual synergies and trade-off will be unevenly distributed across regions and nations (Roy *et al.* , 2019).

2 An ex-ante assessment of the Paris Agreement

2.1 Framework description

The Aggregated Sustainable Development goals Index (ASDI) framework developed in this chapter aims at offering a comprehensive assessment of current well-being and future sustainability based on 27 indicators related to 16 Sustainable Development Goals[1]. As describe in Figure 1, ASDI combines an empirical, regression approach based on historical data (grey) with a modelling, future-oriented framework (black) to offer an internally-consistent set-up that makes it possible to analyse future patterns of sustainability indicators and their inter-linkages.

Figure 1: ASDI framework



The **selection of the SDG indicators** was informed by the work of the UN Inter-agency Expert Group on SDG Indicators (United Nations (UN), 2017a), which listed 232 indicators to be used in assessing SDGs, and follows these guidelines: i) relevance for the SDG they refer to; ii) connection with one of the SDG Targets, iii) sufficient data coverage for each country, iv) linkage to the macroeconomic variables that are output of the model. These are the main constraints on indicator selection of any systemic and multi-approach analyses of Agenda 2030 (von Stechow *et al.* , 2016), including the ASDI framework here described. On the one side, the global perspective of the proposed modelling exercise requires the broadest coverage of indicators, dismissing some promising indicators for which sufficient data coverage is not yet available for a large number of countries. On the other side, given the goal of generating future projections of the selected sustainable indicators, we have to exclude indicators that could not be linked to any of the model variable outcomes or not showing significant a correlation with them. For this reason, at the moment, our analysis does not cover SDG5 (gender equality). We were not able to find a robust relation linking a gender-related indicator to an endogenous variable generated by the model. Table 1 lists the selected indicators and classifies them in the sustainability pillar they pertain to: economy (ECO), society (SOC) and environment (ENV). Among them, 16 are computed using model results, 7 requires regression analyses to be linked to them (SDG1, SDG2, SDG3a, SDG3b, SDG4, SDG7a, SDG10), and the remaining 4 are kept constant at historical levels (SDG14, SDG15a, SDG15c, SDG16).

The **collection of historical data** of indicators relies on several international databases (World Development Indicators (World Bank (WB), 2018), UN database (United Nations (UN), 2018), and World Income Inequality Database (WIID3.4) (United Nations (UN), 2017b)) and covers all available countries for the period 1990-2015. Historical data are used for initializing indicators in the base year of the model (2007) and for estimating the basic relationships between model's variables and indicators in the regression analysis phase.

The **regression analysis** phase makes it possible to obtain projections of those indicators not directly generated by the model: poverty headcount ratio (SDG1), under-nutrition prevalence (SDG2), physician density (SDG3a), Healthy Life Expectancy (HALE)(SDG3b), literacy rate (SDG4), Palma ratio [2] (SDG10) and electricity access (SDG7a). Using independent cross-country panel regressions (reported in Annex I), we identify the historical correlation between indicators and some socioeconomic variables[3]. The selection of the relevant explanatory variables for each indicator is based on the existing literature. Regarding SDG1, poverty prevalence has a negative correlation with unequal income distribution and a positive one with average income per capita level (Ravallion 2001, 1997; Ravallion & Chen 1997). Undernourishment prevalence (SDG2)

[1]SDG5 on geneder inequality is not explored.

[2]The Palma Ratio is 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 *et al.* , 2016).

[3]Our future sustainability scenarios are built under the assumption that the estimated relationships will hold also into the future up to 2030.

Table 1: ASDI indicators

SDG	ASDI indicator	Pillar	SDG	ASDI indicator	Pillar	SDG	ASDI indicator	Pillar
SDG1	Population below \$1.90 (PPP) per day (%)	SOC	SDG8a	Annual GDP per capita growth (%)	ECO	SDG13a	Concentration of GHG emissions from AFOLU(tCO2e/sq.km)	ENV
SDG2	Prevalence of undernourishment (%)	SOC	SDG8b	GDP per person employed (\$PPP2011)	ECO	SDG13b	Compliance to Conditional NDCs (%)	ENV
SDG3a	Physician density (per 1000 population)	SOC	SDG8c	Employment-to-population ratio (%)	ECO	SDG13c	Gap from equitable and sustainable GHG emissions per capita in 2030 (tCO2eq)	ENV
SDG3b	Healthy Life Expectancy (HALE) at birth (years)	SOC	SDG9a	Manufacturing value added (% of GDP)	ECO	SDG14	Marine protected areas (% of territorial waters)	ENV
SDG4	Youth literacy rate (% of population 15-24 years)	SOC	SDG9b	Emission intensity in industry and energy sector (kgCO2e/\$)	ENV	SDG15a	Terrestrial protected areas (% of total land area)	ENV
SDG6	Annual freshwater withdrawals (% of internal renewable water)	ENV	SDG9c	Share of domestic expenditure on Research and Development (% of GDP)	ECO	SDG15b	Forest area (% of land area)	ENV
SDG7a	Renewable electricity (% of total population)	ENV	SDG10	Palma ratio	ECO	SDG15c	Endangered and vulnerable species (% of total species)	ENV
SDG7b	Primary energy intensity (MJ/\$PPP07)	ENV	SDG11	CO2 intensity of residential and transport sectors over energy volumes (tCO2/toe)	ENV	SDG16	Corruption perception index	SOC
SDG7c	Access to electricity (% of total population)	SOC	SDG12	Material productivity (\$PPP2011/ kg)	ENV	SDG17	Government gross debt (% of GDP)	ECO

reduces when economic conditions (Headey 2013; Heltberg 2009; Fumagalli *et al.* 2013) as well as food production (Headey, 2013) improve, and when inequality reduces (Heltberg, 2009). Physician density (SDG3a) has a positive relation with total health expenditure per capita and a negative one with private health expenditure share. The healthy life expectancy (SDG3b) increases with the level of population education (Gulis, 2000), urbanisation (Bergh & Nilsson, 2010), physician density (or more in general public expenditure in health)(Kabir, 2008), electricity access (Youssef *et al.* , 2015) and drops in the case of high level of undernourishment prevalence (Black *et al.* , 2008). Regarding the literacy rate (SDG4), we consider a simple regression with education expenditure per capita and urbanisation, both fostering education attainment. The literature on electricity access (SDG7c) is wide and identifies GDP per capita (Chen *et al.* , 2007), electricity supply, urbanisation (Lahimer *et al.* , 2013), corruption control (Javadi *et al.* , 2013) as favouring factors. Inequality works in the opposite side. Among the explanatory variables of our inequality measure, i.e. Palma ratio, we included public education expenditure per capita, sectoral Value Added (VA) share in agriculture and industry, corruption control and unemployment (Ferreira & Ravallion 2009; Ferreira *et al.* 2010).

The **modelling framework** used to develop SDG projections is the ICES model, (Eboli *et al.* 2010; Delpiazzo *et al.* 2017), a global CGE model based on the GTAP model (Corong *et al.* , 2017) and running over the period 2007-2030 with recursive dynamics. The baseline scenario assumes no mitigation policies are implemented until 2030, while the mitigation policy scenario simulates the implementation of the conditional Nationally Determined Contributions (NDCs) submitted to the UNFCCC in the context of the Paris Agreement. By comparing the performance of the SDG targets in the two scenarios, the approach can quantitatively evaluates the implications of mitigation policy on sustainable development. Model features, baseline and policy scenarios assumptions are described in detail in the Annex II.

The **post-processing module** computes the values of the SDG indicators up to 2030 using the output of ICES. For the indicators not directly generated by the model, the estimated relationships from historical data with the regression analysis are used in an out-of-sample estimation procedure and combined with output variables of the model. All inidicator values are then normalised between [0,100] using a benchmarking procedure that identifies sustainable and unsustainable thresholds for each indicator relying on the SDG targets and best practices[4]. SDG indicators are then aggregated into SDG-specific indices (simple average of the underlying indicators) and into an Aggregate Sustainable Development Index (ASDI), a simple average of the SDG indices that reaches the score 100 whether all goals are met[5].

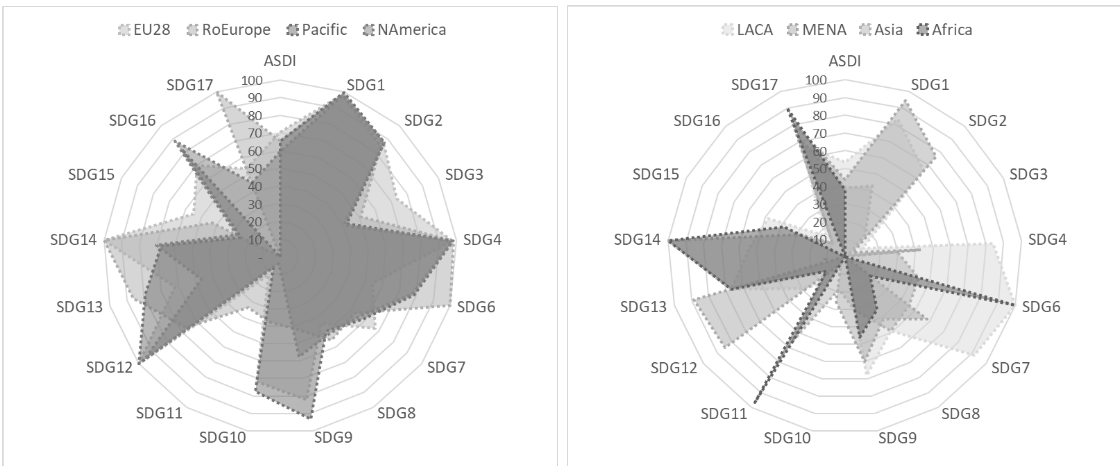
[4]A more detailed description of this step and a table with benchmarks can be found in Annex I.

[5]A more detailed description of this step can be found in Annex I.

2.2 Regional performance in achieving SDGs: a 2007 snapshot

The selected SDG indicators, normalised, and aggregated as described in the previous section and in Annex I make it possible to quantify country well-being and sustainability measured in terms of proximity to all SDGs. The approach can be applied to historical as well as to future, simulated data, enabling a comparison and measurement of changes in sustainability patterns over time and scenarios. Figure 2 synthesizes collected historical indicator values at global level and shows the performance in each SDG and overall (ASDI) of 8 regional aggregates[6]. The graph on the left shows the score of top performer regions (EU28, Rest of Europe, Pacific and North America) in 2007. All of them are still far from achieving SDGs (score of 100). The EU28 is the front-runner, with a score of 70.5, Rest of Europe and Pacific region closely follow (both at 65.4), and North America is spaced-out (59.3). On the right are four regional aggregates lagging behind in the sustainability pathway: Latina America (LACA region, 53.4) is close to the top performer group, whereas the gap widens for Middle East and North Africa (MENA region, 43.7), Asia (39.1) and Africa (37.7).

Figure 2: Aggregate Sustainable Development Index (ASDI) and SDGs scores in 2007, top (left) and bottom (right) performers. Different gray shading represents the 8 regions. Lightest gray is EU28 on the left and LACA on the right.



The two radar graphs immediately visualize the noticeable difference between the two groups of countries. The top performers (left panel) are particularly close to achieving many SDGs related to the social pillar, i.e. SDG1, SDG4, SDG10 and SDG16. The graph of bottom performers (right panel) shows a more uneven regional distribution, with few isolated spikes for SDGs mostly related to the environmental pillar, i.e. SDG14 and SDG6.

Looking more closely at regional differences, all top performers nearly meet SDG1 and SDG4, close to zero prevalence of extreme poverty and universal literacy rate, respectively. They have an average score of 87 (over 100 that represent the full sustainability) in SDG2, zero hunger, with around 2.6% of population undernourished. The score regarding reduced inequality (SDG10) and corruption perception (SDG16) is more heterogeneous: EU28 and Pacific region score around 75 on equal income distribution, and North America only 4 with a Palma ratio of inequality equal to 1.95 (i.e. close to the unsustainable level of 2). Corruption perception is low in North America and Pacific (on average 85) and really high in Rest of Europe (score 0).

Focusing on the economic indicators, top performers score uniformly around 50 in SDG8 (indicators relative to growth of GDP, level of GDP per employed and employment ratio). Sustainability of public debt (SDG17) is fully achieved in the case of Rest of Europe (100) and it is null in the case of EU28 (0 due to the high debt GDP ratio in some EU28 countries). North America and Pacific region have a score around 50. The score of SDG9, combining two economic and one environmental indicators for industry, innovation, and sustainable infrastructure, is uneven, on average 88 for EU28 and Pacific region, and 49 for North America and Rest of Europe. Despite the similar levels of manufacturing value added indicator, and some heterogeneity regarding the share of investment

[6] It is worth to remember that the score in each SDG and in ASDI index is restricted to the 27 selected indicators and not to all other dimensions encompassed by the UN Agenda 2030.

in R&D (higher in the North America and Pacific region), the score of SDG9 strongly reflects the indicator on emission intensity in energy and industry sectors, which is low both in the Rest of Europe, and North America (respectively 0 and 8.2 over 100).

Regarding the other environmental indicators, water withdraw (SDG16) is fully sustainable in Rest of Europe (100) and the least sustainable in EU28 (54). SDG7 in terms of energy intensity growth and renewable electricity share scores around 55 in top performer regions, except in EU28 where it reaches 67. On the contrary, CO_2 intensity in residential and transport (SDG11) is high for all top performers, in particular in North America (6 over 100). North American countries perform well in terms of efficient use of material, non-fossil resources (SDG12), while Rest of Europe scores worst (66.6). Marine ecosystems protection (SDG14) has also a score above average in all best performer regions, with Pacific region scoring worst (67.5). Indicators relative to the protection of terrestrial ecosystem (SDG15) have a lower performance, with the Pacific region and North America scoring worst (24.7 and 27.6, respectively). More differentiated is the result relative to SDG13, climate action, where Rest of Europe is leading with a score of 86.1, followed by Pacific (79.3) and EU28 (62). North America has the worst performance (46.3)[7].

As mentioned above, the snapshot of 2007 sustainability of the worst-performing regions is strongly heterogeneous. In Latin America (LACA) social indicator scores closely follow North America ones, with slightly higher poverty levels (SDG1, score 83.4) and lower literacy rates (SDG4, 83.8). The social indicators more problematic for this region are undernutrition prevalence (SDG2, 66.1), good health (SDG3, 11), inequality (SDG10, 0) and corruption perception (SDG16, 16). Economic indicators are close to the average (SDG8, 49.1, SDG17, 68.8 and SDG9, 68.1) and environmental SDGs range from good performances in water management, clean energy production and climate action (respectively SDG6, 100, SDG7, 91.7 and SDG13, 66.6), to average results in water and land ecosystem protection (SDG14 and SDG15), to low outcomes regarding emission intensity in residential and transport (SDG11, 16.3), efficiency in using mineral resources (SDG12, 30).

The MENA region outperforms LACA in poverty and undernutrition reduction (SDG1, 94, and SDG2, 76), and equity (SDG10, 26). However, other social indicators are at critical levels. Education (SDG4, 43.1), corruption perception (SDG16, 10.3) and in particular health (SDG3, 5.2). Economic indicators are slightly lower than those of LACA, excluding debt sustainability (SDG17) that for MENA is quite high (82.7). In the environmental sphere, particularly problematic are water management (SDG6, 0), CO2 intensity in residential and transport (SDG11, 4.2) and protection of marine ecosystem (SDG14, 0).

Comparing the performance of social SDGs in Asia and MENA region, it is worth highlighting that poverty and undernutrition prevalence are considerably higher in Asia (SDG1 43.1 and SDG2 17.1), whereas other indicators, pertaining to health, education, inequality, and corruption perception are sharing a similar low score (SDG3, 1.8, SDG4, 29.7, SDG10, 18.4 and SDG16, 10.3). Asian economic sustainability does not differ significantly from that of MENA, only SDG9 has a lower performance (30.4) due to the high emission intensity in energy and industry sector. Critical environmental SDGs are instead material efficiency (SDG12, 13.2) and terrestrial ecosystem protection (SDG15, 28.4), whereas water management, emission intensity in residential and transport, and marine areas protection is more sustainable than in MENA region.

In 2007, Africa is the region with the widest gap from achieving all SDGs. The less sustainable sphere is the social one. Poverty and undernutrition prevalence (SDG1 and SDG2), healthy life expectancy (HALE, SDG3), literacy rate (SDG4), inequality (SDG10) and corruption perception (SDG16) have a 0 score. The low level of GDP per person employed reduces SDG8 score (34.9), and the low emission intensity in industry and energy sectors lead to an average score in SDG9 (46). Two environmental SDGs have very low scores, SDG7(17.6) and SDG12 (13.2). In the case of SDG7, high growth of energy intensity and low renewable share are combined with an unsustainable level of access to electricity.

[7]SDG13 summarises three indicators: the concentration of emissions from agriculture, forestry and land sue (AFOLU), the distance from achieving NDC emissions, and the gap from equitable and sustainable GHG emissions per capita. In spite of being closer to sustainable and equitable emissions per capita than Rest of Europe and Pacific, EU28 is characterised by a higher AFOLU emissions concentration and results farther from achieving its NDC due to a more ambitious target.

2.3 Regional trend in achieving SDGs: baseline scenario

As described in Annex II, a baseline scenario without any mitigation policy in place is projected starting in 2007, reproducing historical patterns up to 2010 and, then following similar trends of those observed in the recent decades. This is the so-called "Middle of the road" narrative of the Shared Socioeconomic Pathways, SSP2 as described in (O′Neill *et al.* , 2017). The score in each SDG and in the overall sustainability indicator ASDI is computed for each simulation year and is compared with 2007 results. For the sake of clearness, results for 45 countries and macro-regions of the ASDI framework is grouped into 8 regional aggregates.

The socioeconomic dynamics and technological changes characterizing the baseline scenario (changes in population, employment, GDP growth, reduction in fossil fuel dependency, and rise in energy efficiency) are heterogeneous across regions as well as within regions, and determine convergence or divergence from achieving SDGs. Figure 3 shows the changes in sustainability indicators between 2007 and 2030 across regions. Asia, Africa and MENA are gaining most in 2030, namely 17.7, 10.7 and 9.6 percentage points (pp) with respect to 2007, instead LACA and EU28 experience a reduced sustainability (respectively -0.1 and -2.3 pp). These changes bring Rest of Europe to the top of ranking (ASDI 71), followed by EU28 (ASDI 68.2), whereas Asia shift to a middle level of sustainability (ASDI 56.8).

Asian progress is relevant in reducing poverty (SDG1), undernutrition prevalence (SDG2), inequality (SDG10), in improving health (SDG3) and education (SDG4) (respectively, 55.4, 53.7, 67.4, 19.6 and 27.5 pp with respect to 2007). This evolution is fuelled by a moderate improvement economic sustainability (SDG8, +13.7pp) due to higher levels of GDP per person employed. The drawbacks for the environment emerge in particular regarding the intensity of water use (SDG6, -43.4 pp) and climate action (SDG13, -5.2pp). In the latter case, economic growth implies higher emissions and therefore a widening gap from the NDC and equitable and sustainable emission path. The baseline scenario exhibits exogenous improvements in efficiency, reflecting historical patterns, and this trend appears in the advancements in material productivity (SDG12, +51.3pp), emission intensity in residential and transport (SDG11, +6pp) and affordable and clean energy (SDG7, +26.8pp)[8].

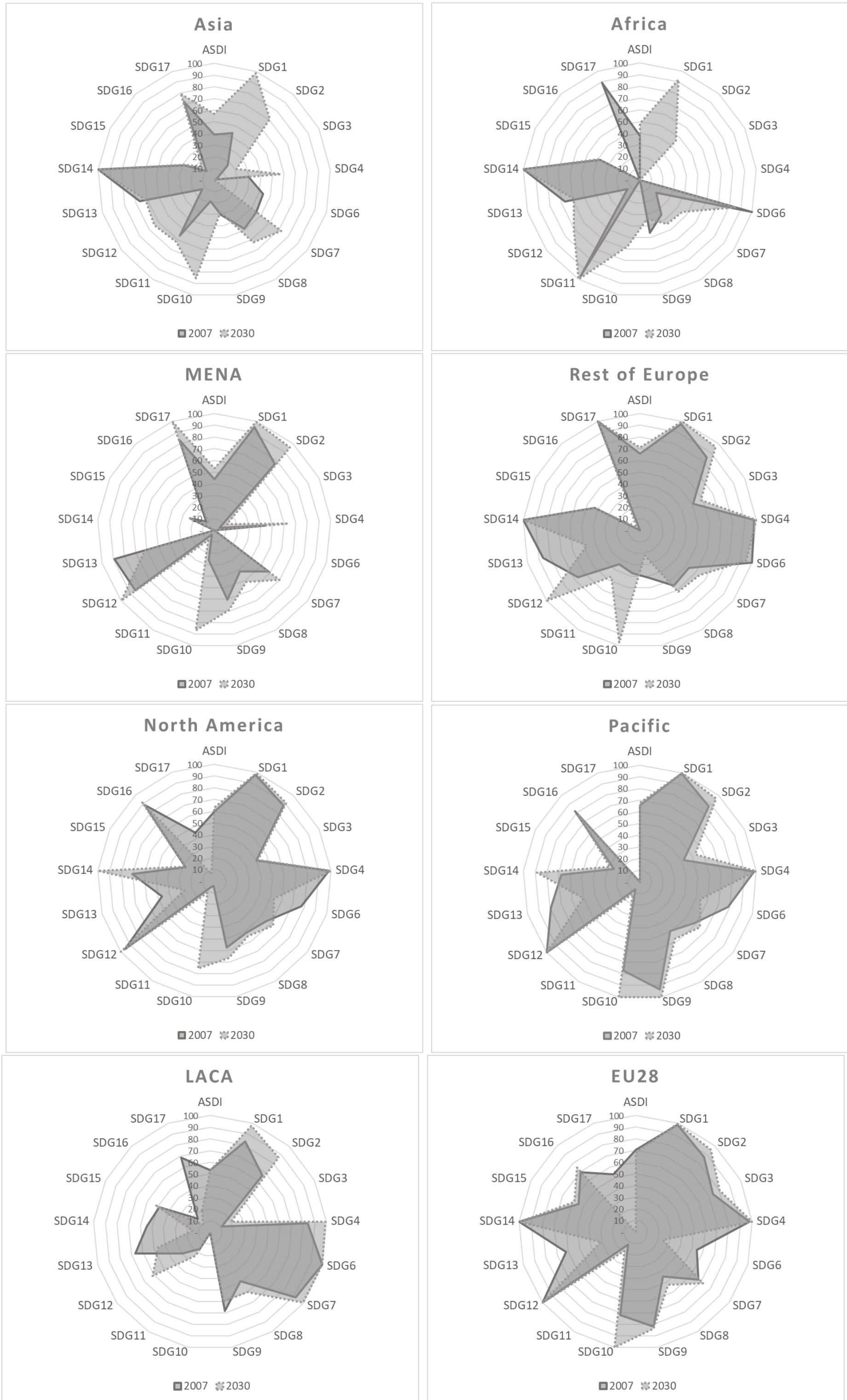
In spite of a higher sustainability level in 2030, African region remains at the bottom of the ranking (ASDI 48.4). Poverty, undernutrition prevalence, and inequality dramatically reduce with respect to 2007 (SDG1 +91.6pp, SDG2 +45.9pp and SDG10 +57.7pp), although progress is not enough in the case of health and education status (SDG3 and SDG4 still have a 0 score). Economic sustainability worsens in particular regarding the sustainability of public debt (SDG17 -89.4pp). SDG8 remains stable (+9.4pp) despite opposing changes at the indicator level (slower GDP per capita growth, but higher GDP per employed). In the environmental realm, material use productivity rises considerably (SD12 +57.8pp) as well as the sustainability of the energy system (SDG7 +26.8pp) due to the higher share of electricity produced from renewable sources and wider access to it. Also in Africa, economic and population growth undermine the sustainable use of water resources (SDG6 -14.4pp) and climate action (SDG13 -8.1pp).

As mentioned above, the EU28 and LACA regions experience a reduction in sustainability by 2030. In spite of the constant progress in the social SDGs, in particular inequality reduction (SDG10 +28.1pp) and improvements in economic growth (SDG8 +8.4pp), the sustainability of public debt deteriorates (SDG17 -53.1pp) and some environmental indicators are negatively affected by the resource-intensive socioeconomic development foreseen in the baseline scenario. The intensity of water withdraw rises (SDG6 -30.1pp) and the uncontrolled increase in emissions from agriculture and forest land, and of overall GHG emissions widen the distance from achieving the ambitious EU28's NDC (SDG13 -31.2pp).

Strong improvements in energy and material efficiency (SDG9 +9.1pp; SDG12 + 4.1pp), the strengthening of terrestrial ecosystem protection (SDG14 +29.7pp), the less ambitious NDC (SDG13 -19.6pp), the high reduction of inequality (SDG10 +71.5pp), and a lower public finance deterioration (SDG17 -38pp) mark the divergence between North America and the EU28 between 2007 and 2030. Despite these dynamics, the EU28 sustainability score in 2030 (ASDI 68.2) remains above North American one (ASDI 63.1).

[8] Asia's score in SDG7 depends on a cleaner energy system (lower growth of primary energy intensity and higher renewable electricity share), but also on the expansion of access to electricity.

Figure 3: Dynamics of ASDI and SDG scores, 2007 vs. 2030



2.4 Paris Agreement mitigation scenario

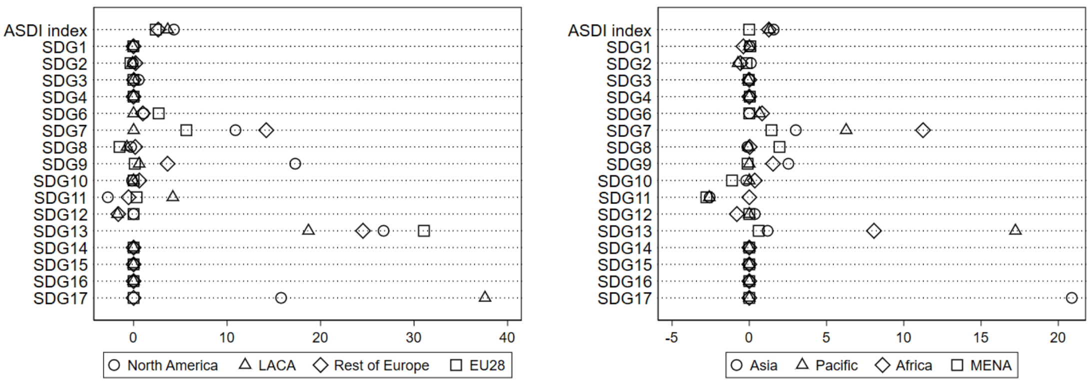
The Paris Agreement, adopted in 2015, initiated a new climate policy regime characterized by country-driven emission targets as part of their international effort to limit global warming beyond 2020, the so-called the Nationally Determined Contributions (NDCs). The NDCs describe the mitigation efforts of the UNFCCC Parties up to 2030. They are quite heterogeneous in terms of stringency, coverage, and reference level. For example, China, India and Chile have expressed their NDCs in terms of emission intensity. Most NDCs describe an unconditional and a conditional target: the former to be met autonomously, and the latter, more ambitious, requiring external financial and technical support.

In the policy scenario design, we focus on the conditional mitigation objectives stated in the NDCs (reported in Annex II) and on the reduction of CO2 emissions. Our mitigation scenario starts in 2013 and assumes that each country achieves its NDC by 2030. The EU28 implements an Emission Trading System (ETS), while all other countries are assumed to implement a unilateral domestic carbon tax. Carbon tax revenues are recycled internally to households, public saving, and investments.

Our results show that the implementation of the NDCs will lead to higher sustainability for all countries, excluding MENA region, which is essentially unaffected (see Figure 4). It is important to highlight that the change in the ASDI score induced by the mitigation policy is much smaller compared to that observed in the baseline scenario. The changes observed in the baseline scenario reflect socioeconomic and technological changes that occur between 2007 and 2030, whereas in the case of mitigation policy we only evaluate the effect of the single policy on the 2030 score.

North America experiences the highest benefit form the mitigation policy (ASDI +4.3pp with respect to 2030 baseline scenario), followed by LACA (ASDI +3.6pp), Rest of Europe (ASDI +2.6pp) and the EU28 (ASDI +2.4pp). The EU28, Africa, and Pacific observe a change lower that 2 pp, and the MENA region has a modest reduction of -0.01pp.

Figure 4: Climate policy impact on SDGs in 2030 (Percentage point change relative to the baseline)



Mitigation policy most strongly affects the environmental SDGs. SDG13, on climate action, registers a rise between +31.1pp in the EU28 and +0.6pp in the MENA region, reflecting the achievement of the NDC targets and the convergence toward more equitable, sustainable emissions per capita. The SDG13a show a general worsening because our mitigation policy focuses on CO2 and leave uncontrolled other gases emitted by Agriculture, Forestry, and Other Land use (AFOLU). In addition, we assumed that Egypt[9], part of MENA region, does not have a NDC. The country experiences a leakage effect that pushes it away form equitable and sustainable emission path.

SDG7 is the second index for the magnitude of change induced by the policy, ranging between +14.2pp in Rest of Europe and +0.01pp in the LACA region. Also in this case, the SDG score depends on combined impacts on the underlying indicators. Mitigation targets stimulate the switching towards a cleaner energy mix characterised by higher electricity share from renewables (between +25.5pp in Africa and no change in the LACA region[10]) and lower primary energy

[9]Egypt and Bolivia do not have a quantitative NDC, therefore, we assume the two countries are not implementing any mitigation policy.

[10]LACA region is fully sustainable in this dimension (score 100) also in the baseline scenario, therefore, an improvement of this indicator does not translate into a higher score.

intensity (between +21.7pp in Rest of Europe and no change in LACA region[11]). It is worth noticing that the indicator on electricity access (social dimension in SDG7) is not negatively affected by the implementation of Paris agreement, especially in those countries still far from achieving that target (no change in Asia and +0.4pp in Africa). In both cases, regional average results mask country heterogeneity. Some Asian and African countries slightly slow down their progress in electricity access (e.g. Bangladesh and Uganda), while others see an acceleration, having a energy system more flexible to renewable switching (Ghana and Ethiopia). Positive implications of the policy spread also to SDG6, inducing a more sustainable water use. In the EU28, the score change is of +2.7pp. The effects on SDG11 and SDG12 are more heterogeneous. CO2 intensity in residential and transport sectors rises in Asia, MENA, North America and Pacific (SDG11 -2.5pp), and material productivity shrinks in LACA, Rest of Europe, and Africa.

The economic SDGs show conflicting results. The carbon tax revenue improves government accounts and debt sustainability (SDG17) in LACA (37.6), Asia (20.9), and North America (+15.8pp). In the other regions the change is not perceivable because the score of the indicator remains below the unsustainable level. SDG8 is the most sensitive to the costs of mitigation policy, reflecting a slow down in GDP per capita growth in regions with ambitious climate policy (-4.5pp in Europe) and a leakage effects where the interventions are too light (+5.9pp in MENA region). The change of SDG9 ranges between +17.3pp in North America and -0.1pp in the MENA region and it is mainly due to the cut in emission intensity in the energy and industry sectors fulfilled with the mitigation targets.

Social indicators are slightly negatively affected by the costs of the mitigation policy and reflect the closure assumptions of the model. The carbon revenue is recycled partially to support household income, whereas government expenditure, a strong driver for social indicators, is left unchanged with respect to the baseline scenario. In Asia, social indicators slightly improve, on average, driven by the positive performance of India, whereas Indonesia, Bangladesh and Rest of Asia highlight the need of additional pro-poor policies to complement mitigation interventions and limit their side-effects. Africa shows a slow-down in poverty and undernutrition reduction (SDG1 -0.4pp and SDG2 -0.6pp). All countries in the region, excluding Mozambique, are negatively affected by the policy and its macroeconomic costs. As noted in (Campagnolo & Davide, 2018), inequality (SDG10) positively (negatively) reacts to ambitious (loose) mitigation targets, but the policy-induced inequality reduction is not sufficient to compensate the average GDP loss due to mitigation and decrease poverty.

3 Discussion and conclusions

This chapter develops a framework for comparing historical and future sustainability performance measured by different SDG indicators. A CGE model is used to describe future baseline and policy scenarios at global scale for some key world regions to 2030. Relationships based on historical correlation patterns are used to link the macroeconomic variables projected by the model with 16 SDG indicators to derive sustainability implications. By looking at the sustainability issue in a dynamic manner, the approach here described makes it possible to track SDG indicator values across countries and trough time, shedding light on the regional distribution of synergies and trade-offs and contributing to expand the emerging literature on systemic analysis of climate policy and sustainable development.

Results highlight that mitigation policy reduces the gap toward achieving all sustainability goals by 2030 in all regions. Yet, regional results mask a complex relationship between mitigation policies and SDGs, which is highly country-specific, making it difficult to identify clear patterns, especially for some indicators. For example, the impact on environmental goals, such as SDG7 and 13, is unequivocally positive. Economic and social indicators are characterized by a higher regional diversity. Overall, results are in line with the evidence highlighted by the existing literature, pointing at synergies especially for environmental indicators. On the contrary, social dimensions are more frequently found to show trade-offs with mitigation policies, pointing at the need for additional pro-pure policy interventions Roy *et al.* , 2019. This analysis does not find evidence for strong trade-offs, one reason being the mitigation strategy, both in terms of stringency, which is moderate, and in terms of mix, as it does not rely on negative emission technologies and expansion of bio-energy.

[11] Ibidem.

Social and economic sustainability indicators tend to deteriorate in most regions, essentially for three reasons. First, the analysis focuses on mitigation policy without considering the benefits related to the reduced climate change impacts. Including the policy benefits in terms of reduced climate impacts, which are regressive, could reverse the outcome of mitigation policies. Second, different carbon revenue recycling schemes can be designed to explicitly address the distributional issues of climate policy (Carattini *et al.* , 2019). Third, additional mechanisms of co-benefits could operate through technological change, which in this framework remains exogenous.

The goal of this chapter is to describe the methodology and illustrate how it operates under a specific socioeconomic and policy scenario.

Socioeconomic uncertainty deeply interacts with mitigation policy, and different baseline developments would affect results also with respect to the sustainability impacts of climate policy. The proposed framework can be easily adapted to handle multiple scenario combinations and to expand the set of baseline scenarios and mitigation policies.

Further refinements of the proposed framework include developing refined empirical estimates of the relationship between the SDG indicators and the model outcome variables, as well as exploring the role of uncertainty of these underlying relationships. The analysis is based on the central estimates, but confidence intervals could also be used. Widening the set of GHG considered as well as the negative emissions from land use change could decrease the cost of the policy and the trade-off with social indicators. Whereas here the focus is on the interaction of mitigation policy with sustainable development, other existing policies could further modify the results. Adding the representation of climate change impacts and adaptation measures, which are not yet widely explored in the CGE and SDG literature, highlighting further channels of trade-offs and synergies, is needed in order to complete the characterization of the interlinkages between climate policy, impacts, and sustainable development. This analysis underestimates the benefits of mitigation because all impacts connected to global warming and all benefits deriving from a contained temperature increase in 2100 are not included. The emission pathway of the proposed baseline scenario falls between the Radiative Concentration Pathways RCP6.0 and RCP8.5, but the effects of the associated temperature increase on GDP growth as well as on other drivers (e.g. labour productivity) is not included. In this cost-effective approach, GDP is affected by emissions only through mitigation costs.

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Extending our framework considering more SSPs characterised by different emission paths would allow presenting a range of results. A further development for our line of research could also embed a climate change impact assessment that characterises the two suggested references. In the current chapter, we are underestimating the benefits of mitigation, because we are neglecting all impacts connected to global warming and all benefits deriving from a contained temperature increase in 2100 (below2Â°C). To conclude, in the chapter we consider a SSP2 scenario with emission levels falling between RCP6.0 and RCP8.5. The effect of RCP on GDP growth path is limited to mitigation costs, i.e. rises going closer to RCP8.5 emission level; impacts connected to different RCPs are not part of our current framework.

Annex to the Chapter: Can the Paris Agreement support achieving the Sustainable Development Goals?

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Annex I

The current list of SDG indicators defined by the works of UN Inter-agency Expert Group on SDG Indicators (United Nations (UN), 2017) considers 232 indicators. The well-established and in use indicators are less than half of them. The final ASDI screening considers 27 indicators covering 16 SDGs (All but SDG5 - Achieve gender equality and empower all women and girls). TableAI1 lists the ASDI indicators coupled with the related SDG, the sustainability pillar of pertinence, whether they derive from a regression (regression results are reported in TableAI3), how they are computed and the main source of data.

Table AI1: ASDI indicators

SDG	**Pillar**	**Indicator**	**Est.**	**Formulation**	**Source**
SDG1	SOC	Population below \$1.90 (PPP) per day (%)	Yes	$\beta_0 + \beta_1 ln(GDP\_PPP\_pc_{t-1}) + \beta_2 Palma_{t-1}$	WDI
SDG2	SOC	Prevalence of undernourishment (%)	Yes	$\beta_0 + \beta_1 ln(GDP\_PPP\_pc_{t-1}) + \beta_2 ln(GDP\_PPP\_pc_{t-1})^2$ $+\beta_3 Palma_{t-1} + \beta_4 ln(Agri\_prod\_pc_{t-1})$	WDI-UN
SDG3a	SOC	Physician density (per 1000 population)	Yes	$ln(Physician_num_t)\beta_0 + \beta_1 ln(Pop_{t-1}) + \beta_2 ln(Health\_exp\_pc_{t-1})$ $+\beta_3 Priv\_Health\_exp\_Sh_{t-1}$	WDI
SDG3b	SOC	Healthy Life Expectancy (HALE) at birth (years)	Yes	$\beta_0 + \beta_1 ln(Physician\_dens_{t-1}) + \beta_2 ln(Edu\_exp\_pc_{t-1})$ $+\beta_3 Ely_access_{t-1} + \beta_4 Undern\_pop_{t-1} + \beta_5 Urban\_sh_{t-1}$	WDI
SDG4	SOC	Youth literacy rate (% of population 15-24 years)	Yes	$\beta_0 + \beta_1 ln(Edu\_exp\_pc_{t-1}) + \beta_2 Urban\_sh_{t-1}$	WDI
SDG6	ENV	Annual freshwater withdrawals (% of internal renewable water)	No	(Total sectoral water use)$_t$/(Renewable water)$_t$ * 100	WDI
SDG7a	ENV	Renewable electricity (% of total population)	No	(Renewable electricity output)$_t$ / (Electricity output)$_t$ * 100	IEA
SDG7b	ENV	Primary energy intensity	No	(Energy consumption)$_t$ / $(GDPPPP)_t$	IEA
SDG7c	SOC	Access to electricity (% of total population)	Yes	$\beta_0 + \beta_1 ln(GDP\_PPP\_pc_{t-1}) + \beta_2 ln(GDP\_PPP\_pc_{t-1})^2$ $+\beta_3 ln(Ely\_out\_pc_{t-1}) + \beta_4 Urban\_sh_{t-1}$ $+\beta_5 Palma_{t-1} + \beta_6 Corrupt\_control_{t-1}$	WDI
SDG8a	ECO	Annual GDP per capita growth (%)	No	Growth $(GDPPPP)_t/pop_t$	WDI
SDG8b	ECO	GDP per person employed (\$PPP2011)	No	$(GDPPPP)_t$ / (Employed population)$_t$	WDI
SDG8c	ECO	Employment-to-population ratio (%)	No	(Employed population)$_t$ / (Total population)$_t$ *100	WDI
SDG9a	ECO	Manufacturing value added (% of GDP)	No	(Manufacturing Value Added)$_t$ / $(GDPPPPpc)_t$ *100	WDI
SDG9b	ENV	Emission intensity in industry and energy sector (kgCO2e/\$)	No	(GHG emissions)$_t$ / (Value added)$_t$	WDI
SDG9c	ECO	Share of domestic expenditure on Research and Development (% of GDP)	No	(RD expenditure)$_t$ / $(GDP\_PPP)_t$ * 100	WDI
SDG10	SOC	Palma ratio	Yes	$\beta_0 + \beta_1 ln(Edu\_exp\_pc_{t-1}) + \beta_2 ln(Agri\_VA\_sh_{t-1}) +$ $\beta_3 ln(HInd\_VA\_sh_{t-1}) + \beta_4 Corrupt\_control_{t-1} +$ $\beta_5 ln(Unempl_{t-1}) + \beta_6 Con\_inc$	WDI-WIID
SDG11	ENV	CO2 intensity of residential and transport sectors over energy volumes (tCO2/toe)	No	(CO2 emissions)$_t$ / (Energy use)$_t$	IEA

SDG	Pillar	Indicator	Est.	Formulation	Source
SDG12	ENV	Material productivity ($PPP2011/ kg)	No	$(GDPPPP)_t$ / (Material domestic consumption)$_t$	WDI-SERI
SDG13a	ENV	Concentration of GHG emissions from AFOLU[1] (tCO2e/sq.km)	No	(AFOLU GHG emissions)$_t$/ (Agri. and For. land)	WDI-CAIT
SDG13b	ENV	Compliance to Conditional NDCs (%)	No	(Emission$_t$ - NDC Target$_t$) / NDC Target$_t$ * 100	WDI-CAIT
SDG13c	ENV	Gap from equitable and sustainable GHG emissions per capita in 2030 (tCO2eq)[2]	No	(GHG emissions per capita)$_t$ - (Eq. and Sust. GHG per capita)$_t$	CAIT
SDG14	ENV	Marine protected areas (% of territorial waters)	No	Constant after 2015	WDI
SDG15a	ENV	Terrestrial protected areas (% of total land area)	No	Constant after 2015	WDI
SDG15b	ENV	Forest area (% of land area)	No	(Forest land area)$_t$ /(Total land area)$_t$ * 100	WDI
SDG15c	ENV	Endangered and vulnerable species (% of total species)	No	Constant after 2015	WDI
SDG16	SOC	Corruption perception index	No	Constant after 2015	TI[3]
SDG17	ECO	Government gross debt (% of GDP)	No	(Public debt)$_t$ /(GDP PPP pc)$_t$ * 100	WDI-IMF

In order to compare country performance in different SDG indicators and to compute some aggregate measures, it is necessary to bring all indicators to a common measurement unit, the [0,100] scale (**normalization**). The normalisation is obtained using a benchmarking procedure that defines two threshold values for each indicator: unsustainable and sustainable levels. In choosing the threshold levels, we firstly looked at the 169 SDG targets, which are our preferred source whether it gives a quantitative target. When the targets are qualitative, other sources are preferred such policy targets in OECD or countries' best practices.

TableAI2 shows the threshold values used for the normalization process.

ASDI framework considers several **aggregation steps** in order to produce aggregate indices conveying more synthetic information to policymakers:

- SDG indices are the average value of indicators pertaining to each goal;
- The ASDI index is the average of scores among all SDGs.

[1]AFOLU stands for agriculture, forestry and other land use.

[2]The equitable and sustainable GHG emission per capita level in 2030 is computed as the ratio of the median GHG emission level in 2030 according to scenarios that will contain (with likelihood $> 66\%$) the temperature increase below 2°C by the end of the century , i.e. 42 GtCO2e (United Nations Environment Programme (UNEP), 2015), and the median estimate of world population in 2030.

[3]Transparency International.

Table AI2: ASDI benchmarks

SDG	Indicator	Unsustainable level	Sustainable level
SDG1	Population below $1.90 (PPP) per day (%)	40	0
SDG2	Prevalence of undernourishment (%)	20	0
SDG3a	Physician density (per 1000 population)	2	3
SDG3b	Healthy Life Expectancy (HALE) at birth (years)	60	80
SDG4	Youth literacy rate (% of population 15-24 years)	85	100
SDG6	Annual freshwater withdrawals (% of internal renewable water)	30	5
SDG7a	Renewable electricity (% of total population)	5	60
SDG7b	Primary energy intensity (MJ/$PPP07)	10	3
SDG7c	Access to electricity (% of total population)	40	100
SDG8a	Annual GDP per capita growth (%)	0	7
SDG8b	GDP per person employed ($PPP2011)	5000	50000
SDG8c	Employment-to-population ratio (%)	40	80
SDG9a	Manufacturing value added (% of GDP)	5	15
SDG9b	Emission intensity in industry and energy sector (kgCO2e/$)	2	1
SDG9c	Share of domestic expenditure on Research and Development (% of GDP)	0.5	3
SDG10	Palma ratio	2	1
SDG11	CO2 intensity of residential and transport sectors over energy volumes (tCO2/toe)	2.5	0.5
SDG12	Material productivity ($PPP2011/ kg)	0.5	2
SDG13a	Concentration of GHG emissions from AFOLU[4] (tCO2e/sq.km)	100	0
SDG13b	Compliance to Conditional NDCs (%)	0	100
SDG13c	Gap from equitable and sustainable GHG emissions per capita in 2030 (tCO2eq)[5]	15	0
SDG14	Marine protected areas (% of territorial waters)	5	20
SDG15a	Terrestrial protected areas (% of total land area)	10	50
SDG15b	Forest area (% of land area)	5	60
SDG15c	Endangered and vulnerable species (% of total species)	20	5
SDG16	Corruption perception index	30	80
SDG17	Government gross debt (% of GDP)	100	20

Table AI3: Regression table

	Palma ratio	ln(Poverty)	Access	Undernutrition	ln(Pysician number)	ln(HALE)	Literacy rate
L.ln(Education exp. pc)	-0.0990^{*}					0.0206^{***}	2.901^{**}
	(0.030)					(0.000)	(0.006)
L.ln(Agriculture VA share)	-0.186^{***}						
	(0.000)						
L.ln(Industrial VA share)	-0.0794^{*}						
	(0.023)						
L.ln(Unemployment)	0.0395						
	(0.149)						
L.ln(GDP PPP pc)		-3.172^{***}	0.794^{***}	-57.03^{***}			
		(0.000)	(0.000)	(0.000)			
L.ln(GDP PPP pc)sq			-0.0425^{***}	2.799^{***}			
			(0.000)	(0.000)			
L.Palma		0.139^{**}	-0.0124^{*}	1.215^{**}			
		(0.002)	(0.023)	(0.003)			
L.ln(Electricity output pc)			0.0295^{+}				
			(0.086)				
L.Urban population share			0.00901^{***}			0.00386^{***}	0.428^{***}
			(0.000)			(0.000)	(0.001)
L.ln(Agricultural production pc)				-4.662^{*}			
				(0.015)			
L.ln(population)					1.509^{***}		
					(0.000)		
L.ln(Health exp. pc)					0.0738^{***}		
					(0.000)		
L.ln(Private health exp. share)					-0.000788^{*}		
					(0.015)		
L.ln(Physicians)						0.0136^{**}	
						(0.009)	
L.Electricity access share						0.00131^{**}	
						(0.003)	
L.Undernutrition prevalence						-0.00223^{*}	
						(0.017)	
Corruption control	-0.0880^{*}						
	(0.024)						
L.(Corruption control)			-0.0238^{*}				
			(0.014)				
Consumption/Income	-0.0123						
	(0.703)						
Constant	39.62^{***}	28.33^{***}	-3.551^{***}	302.6^{***}	5.147^{***}	3.552^{***}	47.61^{***}
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country fixed effect	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*No*	*No*	*No*	*No*	*No*	*No*
R^2	0.242	0.837	0.526	0.462	0.398	0.618	0.225
Countries	126	126	148	140	166	135	152
Observations	755	994	1812	1764	2044	761	1893

p-values in parentheses

Robust standard errors, adjusted for clustering at the school level, are presented in parentheses.

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Annex II

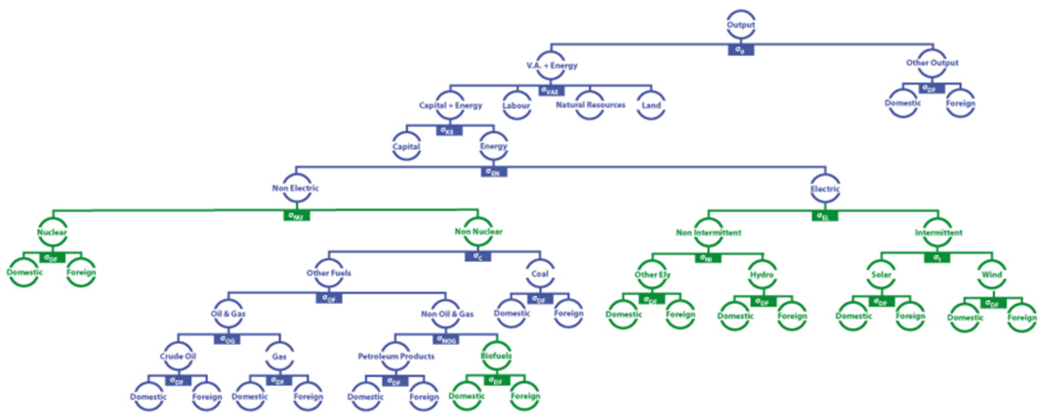
AII1 Model description

ICES is a recursive-dynamic multiregional Computable General Equilibrium (CGE) model developed to assess the impacts of climate change on the economic system and to study mitigation and adaptation policies (Eboli *et al.* , 2010). 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 & Truong, 2002), which in turn is an extension of the standard GTAP model (Corong *et al.* , 2017). 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 a number of industries n, 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 (FigureAII1) are specified via a series of nested Constant Elasticity of Substitution (CES) functions. In the first nest, a Value-Added-Energy nest ($QVAEN$) (primary factors, i.e. natural resources, land, and labour and a Capital+Energy composite), is combined with intermediates (QF), in order to generate the output. Perfect complementarity is assumed between value added and intermediates. This implies the adoption a Leontief production function. For sector i in region r final supply (output) results from the following constrained production cost minimization problem for the producer:

$$\begin{aligned} min \quad PVAEN_{i,r} * QVAEN_{i,r} + PF_{i,r} * QF_{i,r} \\ s.t. \quad Y_{i,r} = min(QVAEN_{i,r}, QF_{i,r}) \end{aligned}$$

where $PVAEN$ and PF are prices of the related production factors.

Figure AII1: ICES production tree



The second nested-level in FigureAII1 represents, on the left hand side, the value added plus energy composite ($QVAEN$). This composite stems from a CES function that combines four primary factors: land ($QLAND$), natural resources (QFE), labour (QFE) and the capital-energy bundle (QKE) using σ_{VAE} as elasticity of substitution. Primary factor demand on its turn derives from the first order conditions of the following constrained cost minimization problem for the representative firm:

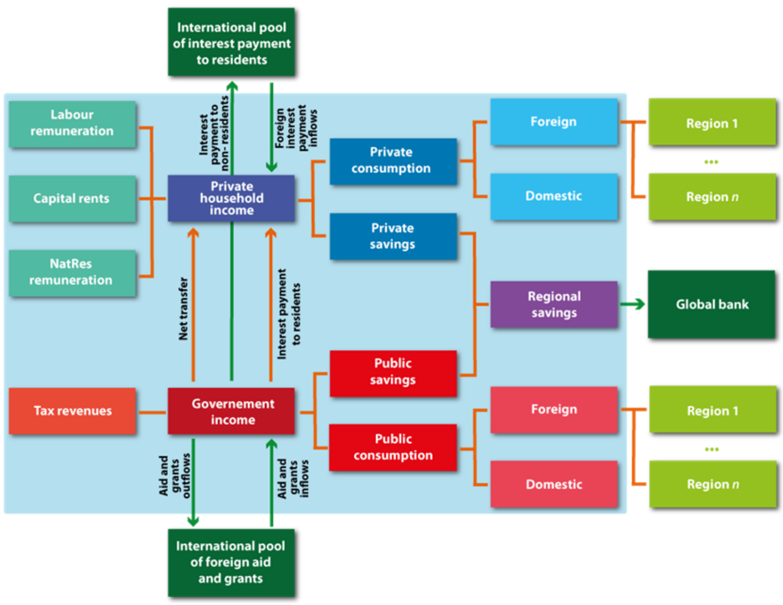
$$min \quad P^{Land}_{i,r} * LAND_{1,r} + P^{NR}_{i,r} * NR_{i,r} + P^{L}_{i,r} * L_{i,r} + P^{KE}_{i,r} * KE_{i,r}$$

$$s.t. \quad QVAEN_{i,r} = (LAND_{i,r}^{\frac{\sigma_{VAE}-1}{\sigma_{VAE}}} + NR_{i,r}^{\frac{\sigma_{VAE}-1}{\sigma_{VAE}}} + L_{i,r}^{\frac{\sigma_{VAE}-1}{\sigma_{VAE}}} + KE_{i,r}^{\frac{\sigma_{VAE}-1}{\sigma_{VAE}}})^{\frac{\sigma_{VAE}-1}{\sigma_{VAE}}}$$

On its turn, the KE bundle combines capital with a set of different energy inputs. This is peculiar to GTAP-E and ICES. In fact, energy inputs are not part of the intermediates, but are associated to capital in a specific composite. The energy bundle is modelled as an aggregate of electric and non-electric energy carriers. Electricity sector differentiates between intermittent and non-intermittent sources. Wind and solar, which are intermittent sources, are separated from non-intermittent sources: hydro power and the rest of electricity produced using fossil fuel sources (coal, oil and gas)[6] The Non-Electric bundle is a composite of nuclear and non-nuclear energy. The aggregate Non-nuclear energy combines, in a series of subsequent nests, Coal, Natural Gas, Crude Oil, Petroleum Products and Biofuels, while Nuclear corresponds to the carrier used for electricity generation. All elasticities regarding the inter-fuel substitution bundles are those from GTAP-E (Burniaux & Truong, 2002), while for the extended renewable electricity sectors we set those values considering different studies (Paltsev *et al.* 2005; Bosetti *et al.* 2006). The demand of production factors (as well as that of consumption goods), can be met by either domestic or foreign commodities which are however not perfectly substitute according to the "Armington" assumption. In general, inputs grouped together are more easily substitutable among themselves than with other elements outside the nest. For example, the substitutability across imported goods is higher than that between imported and domestic goods. Analogously, composite energy inputs are more substitutable with capital than with other factors. In ICES, two industries are treated in a special way and are not related to any country, viz. international transport and international investment production. International transport is a world industry, which produces the transportation services associated with the movement of goods between origin and destination regions, thereby determining the cost margin between f.o.b. and c.i.f. prices. Transport services are produced by means of factors submitted by all countries, in variable proportions. In a similar way, a hypothetical world bank collects savings from all regions and allocates investments in order to achieve equality in the absolute change of current rates of return.

FigureAII2 describes the main sources and uses of regional income. In each region, a representative utility maximizing household receives income, originated by the service value of national primary factors (natural resources, land, labour, and capital), that she/he owns and sells to the firms. Capital and labour are perfectly mobile domestically but immobile internationally (investment is instead internationally mobile). Land and natural resources, on the other hand, are industry-specific. The regional income is used to finance aggregate household consumption and savings.

Figure AII2: Sources and uses of regional household income



[6]ICES model further specifies renewable energy sources in electricity production, namely wind, solar and hydroelectricity, 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 8 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 & A. 2005; GTZ 2009, IEA country profiles and REN21).

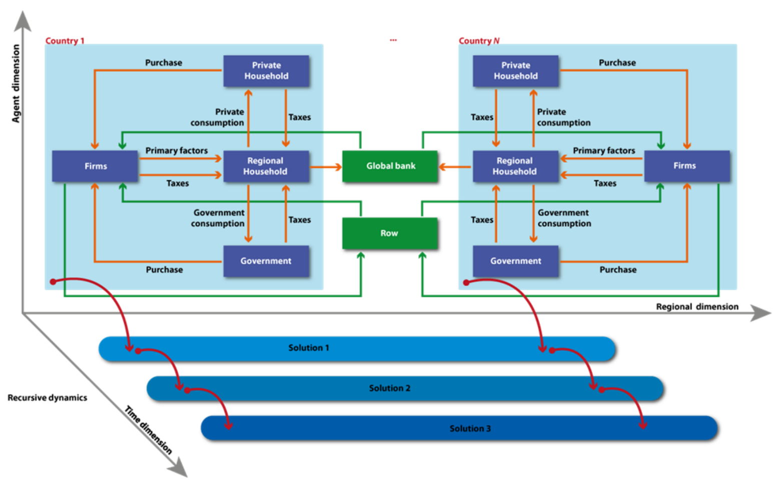
Government income equals to the total tax revenues from both private household and productive sectors, a series of international transactions among governments (foreign aid and grants) and national transfers between the government and the private (Delpiazzo *et al.* , 2017). Both the government and the 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. Both private and public sector consumption are addressed to all commodities produced by each firm/sector. Public consumption is split into a series of alternative consumption commodities according to a Cobb-Douglas specification. However, almost all public expenditure is concentrated in the specific sector of Non-market Services, including education, defence and health. Private consumption is analogously addressed towards alternative goods and services including energy commodities, that can be produced domestically or imported. The functional specification used at this level is the Constant Difference in Elasticities (CDE) form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods[7]

The recursive-dynamic feature is described in FigureAII3. Starting from the picture of the world economy in the benchmark year, by following socioeconomic (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. Capital growth is standard along exogenous growth theory models and follows:

$$Ke_r = I_r + (1 - \delta)Kb_r$$

where Ke_r is the end of period capital stock, Kb_r is the beginning of period capital stock, ÎŽ is capital depreciation and I_r is endogenous investment. Once the model is solved at a given step t, the value of Ke_r is stored in an external file and used as the beginning of period capital stock of the subsequent step t+1. 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 AII3: Recursive-dynamic feature of ICES model



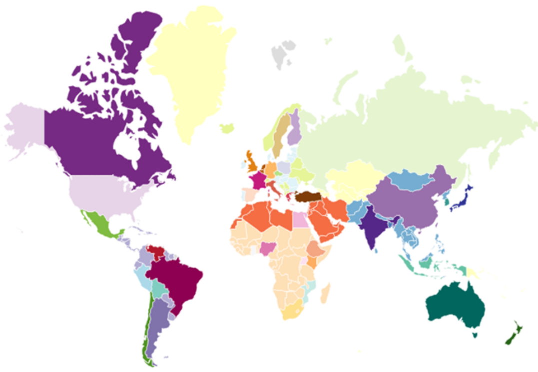
As with capital, at each simulation step the government net deficit at the end of the period is stored in an external file and adds up to next year debt.

[7]Hanoch′s constant difference elasticity (CDE) demand system (Hanoch, 1975) has the following formulation: $1 = \sum B_i U^{Y_i R_i} (\frac{P_i}{X})^{Y_i}$ where U denotes utility, P_i the price of commodity i, X the expenditure, B_i are distributional parameters, Y_i substitution parameters, and R_i expansion parameters. The CDE in principle does not allow to define explicitly direct utility, expenditure or indirect utility functions. Accordingly, also explicit demand equations could not be defined. Fortunately, in a linearized equation system such as that used in GTAP, it is possible to obtain a demand function with price and expenditure elasticities.

AII2 Regional aggregation

ICES is a Computable model: all the model behavioural equations are connected to the GTAP 8 database (Narayanan & McDougall, 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 (FigureAII4).

Figure AII4: Regional aggregation ICES model



For sake of clearness in presenting results, we further aggregate the 45 countries/regions in 8 regional aggregates following the mapping presented in TableAII1.

Table AII1: Mapping ICES regions into macro regional aggregates

Id.	Country/region	Macro region	Id.	Country/region	Macro region
1	Australia	Pacific	24	Germany	EU28
2	NewZealand	Pacific	25	Greece	EU28
3	Japan	Pacific	26	Italy	EU28
4	SouthKorea	Pacific	27	Poland	EU28
5	Bangladesh	Asia	28	Spain	EU28
6	China	Asia	29	Sweden	EU28
7	India	Asia	30	UK	EU28
8	Indonesia	Asia	31	RoEU	EU28
9	RoAsia	Asia	32	RoEurope	RoEurope
10	Canada	NAmerica	33	Russia	RoEurope
11	USA	NAmerica	34	Turkey	MENA
12	Mexico	LACA	35	Egypt	MENA
13	Argentina	LACA	36	RoMENA	MENA
14	Bolivia	LACA	37	Ethiopia	Africa
15	Brazil	LACA	38	Ghana	Africa
16	Chile	LACA	39	Kenya	Africa
17	Peru	LACA	40	Mozambique	Africa
18	Venezuela	LACA	41	Nigeria	Africa
19	RoLACA	LACA	42	Uganda	Africa
20	Benelux	EU28	43	SouthAfrica	Africa
21	Czech Republic	EU28	44	RoAfrica	Africa
22	Finland	EU28	45	RoW	RoEurope
23	France	EU28			

AII3 Reference scenario

Our reference in designing the baseline scenario is the set of possible futures envisioned by the climate change community and known as Shared Socioeconomic Pathways (SSPs) (O′Neill *et al.* , 2017). These are 5 possible futures with different mitigation/adaptation challenges and are characterized by different evolution of main socioeconomic variables. SSPs can be linked to Representative Concentration Pathways (RCPs), that envisions the GHG emission evolution and forcing and temperature rise due to specific patter of socioeconomic growth (Riahi *et al.* , 2017). SSPs provide future patterns for population, working age population and GDP at country level. Other trends for exogenous drivers such as primary factor productivity, sector-specific efficiency, total factor productivity and energy prices are then used in order to calibrate given endogenous variables, namely GDP, energy use, emissions and value-added shares to be coherent to the selected RCP.

Among Shared Socioeconomic Pathways (SSPs), we used as business as usual SSP2 "Middle of the road" scenario. The main features of this scenario are:

- similar trends of recent decades, but some progresses towards achieving development goals;
- medium population growth;

- per-capita income levels grow globally at a medium pace; slow income convergence across countries; some improvements in the intra-regional income distributions;
- reductions in resource and energy intensity, and slowly decreasing fossil fuel dependency.

Give the short time horizon of the proposed analysis, we focus on the SSP2 because it is the the pathway that more closely follows the historical development in terms of socioeconomic variables evolution (medium population and GDP growth). In calibrating the SSP2, we followed not only the socioeconomic trends reported in SSP database[8], but we also adjusted energy efficiency and fuel prices in order to obtain a global emission level in line with IAM multi-model projections (Riahi et al. 2017). Our projected emission levels are in line with IAM multi-model projections (Riahi *et al.* , 2017). The literature reports a range between 61279 and 70005 Mt CO2-equiv/yr in 2030. Our baseline global emissions are 65140 Mt CO2-equiv/yr. The projected emission range in 2100 is between 85030 and 106778 Mt CO2-equiv/yr which corresponds to a radiative forcing between 6.561 and 7.251 W/m2, and a temperature rise between 3.8 and 4.2 °C. These results place our baseline in between RCP6 and RCP8.5.

AII4 Mitigation scenario

We designed a mitigation scenario mimicking Paris Agreement functioning: all parties achieve the conditional mitigation targets stated in the NDC by 2030; for regional aggregates, we computed reference and target emission levels and calculated the required regional reduction. We relies on CAIT database for computing reference historical emission levels, whereas our baseline scenario is used when NDC uses a BAU scenario as term of comparison. Due to model limitations, we impose the GHG emission targets only to CO2 emissions. Mitigation objectives considered for each country/region are reported in TableAII2. Two countries in our aggregation do not have a clearly quantitative mitigation target, i.e. Egypt and Bolivia; therefore, in our simulation, we assume they have not a NDC.

The mitigation policy starts in 2013 and it is fully achieved by 2030. The European Union (EU28) opts for an Emission Trading System (ETS), 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. Carbon tax revenues are redistributed internally to government investment, public saving and transfers to households.

Table AII2: 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
NewZealand	-30	Emission reduction wrt 2005	RoLACA	-11	Average mission reduction wrt 2030 BAU scenario
Japan	-26	Emission reduction wrt 2013	EU28	-40	Emission reduction wrt 1990
SouthKorea	-37	Emission reduction wrt 2030 BAU scenario	RoEurope	-37.2	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 wrt 2005	RoMENA	-5	Average mission reduction wrt 2030 BAU scenario
Indonesia	-41	Emission reduction wrt 2030 BAU scenario	Ethiopia	-64	Emission reduction wrt 2030 BAU scenario
RoAsia	6	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	RoAfrica	-24.4	Average mission reduction wrt 2030 BAU scenario
Peru	-30	Emission reduction wrt 2030 BAU scenario	RoW	-11.3	Average mission reduction wrt 2030 BAU scenario

[8] `https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about`

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