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Report

Assessing Ghana's Position in Achieving the SDGs and the Implications of the Paris Agreement

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Abstract

Ghana's current wellbeing and future sustainability are assessed with respect to the 17 Sustainable Development Goals (SDGs) using the innovative APPS (Assessment, Projection and Policy of Sustainable Development Goals) methodology. The APPS framework highlighted recent progresses in Ghana's wellbeing, in particular between 2000 and 2010, driven by remarkable socioeconomic improvements. Considering a business-as-usual scenario, APPS projections confirm a rising sustainability performance up to 2030. A policy scenario, envisioning the compliance with the emission reduction targets of the Paris agreement, can slightly increase Ghana's sustainability. However, in 2030 Ghana will still be far from achieving many SDGs; further efforts will be needed to improve population health and education, to reduce inequality and promote environmental protection, not overlooking the binding constraint of a rising public debt.

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01 Introduction

The purpose of this work is to assess Ghana's progresses in wellbeing and future sustainability as defined by the aspirational goals that the 2030 Agenda for Sustainable Development (UN, 2015) set on September 2015. These are the 17 Sustainable Development Goals (SDGs) to be achieved worldwide by 2030 by means of a global strategy. The dimensions considered by SDGs are overarching and go from poverty reduction in all its forms, to sustainable economic growth, environment preservation, and climate mitigation commitments. Each SDG is then structured into Targets: 169 targets proposed by the United Nations Open Working Group. Furthermore, in July 2017, UN adopted a framework of indicators to pointy monitor the progresses in implementing 2030 Agenda for Sustainable Development (UN IEAG, 2017).

Our wellbeing and sustainability assessment is informed by these indicators and targets and stems from an analytical quantitative framework, "APPS" (Assessment, Projection and Policy of Sustainable Development Goals) involving empirical and modelling approaches in a multi-step procedure. Innovative of this kind of exercise, supported by the use of projections from a macroeconomic general equilibrium model, is the possibility to examine ex ante country sustainability performances, and not only ex-post like many exercises in this context (Sachs et al., 2017), and to capture systematically complementarities and trade off across the different goals/targets.

The study is divided into two research steps. The **wellbeing assessment** (Section 2) relies on historical data of some SDG-representative indicators. It assesses Ghana's current gap from achieving SDGs and highlights Country's progresses on this matter in the recent decades. The **sustainability assessment** (Section 3) offers an ex-ante scenario-specific overview of what will be the Ghana's gap from achieving SDGs in 2030. Two situations are considered: the first examines 2030 perspective for sustainability in a "business as usual" scenario based upon the "middle of the road" Shared Social economic Pathway n. 2 - SSP2 (O'Neill et al., 2017), the second contrasts this business as usual scenario with an international global effort to contain GHG emissions in accordance with the prescription of the 2015 Paris agreement.

02

Ghana’s wellbeing assessment

2.1 APPS framework for wellbeing assessment

As recommended by UN, indicators are valid tools to measure countries’ progresses over time and compliance with SDG Targets. For this purpose, APPS framework selects 27 indicators covering 16 SDGs (All but SDG5 – Achieve gender equality and empower all women and girls). The indicator selection process, the data sources and details on the APPS framework are extensively described in Appendix I. Table 1 lists the APPS indicators coupled with the related SDG and specific target they measure.

Data for the 27 indicators were collected for the period 1990-2015 and considers 108 countries.

Following the purpose of computing aggregate measures of current wellbeing, we employed a normalisation procedure to bring all countries in the same measure unit [0,100]. Normalised indicators are then aggregated according to their affinity to each SDG offering a measure of Ghana’s performance in each SDG. The overall wellbeing, reported by the APPS Index, is the average Country’s performance across SDGs. Our framework also produces some collateral aggregate indicators analysing the performance by sustainability pillar.

Table 1. *APPS indicators and SDG targets.*

UN SDG	APPS Indicator	SDG Target	Sustainability pillars
1 NO POVERTY	Poverty headcount ratio at $1.90 a day (PPP2011) (% of population)	1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day	Society
2 ZERO HUNGER	Prevalence of undernourishment (% of population)	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	Society
3 GOOD HEALTH AND WELL-BEING	Physician density (per 1,000 people)	3.c Substantially increase health financing and the recruitment, development, training and retention of the health workforce in developing countries, especially in least developed countries and small island developing States.	Society
	Healthy Life Expectancy (HALE) at birth (years)	n/a	Society
4 QUALITY EDUCATION	Youth literacy rate (% of population 15-24 years)	4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy	Society
5 GENDER EQUALITY	n/a	n/a	Society

UN SDG	APPS Indicator	SDG Target	Sustainability pillars
6 CLEAN WATER AND SANITATION	Annual freshwater withdrawals, total (% of internal renewable water)	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	Environment
7 AFFORDABLE AND CLEAN ENERGY	Access to electricity (% of total population)	7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	Society
	Renewable electricity (% in total electricity output)	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	Environment
	Primary energy intensity (MJ / $PPP2011)	7.3 By 2030, double the global rate of improvement in energy efficiency	Environment
8 DECENT WORK AND ECONOMIC GROWTH	GDP per capita annual growth (%)	8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries	Economy
	GDP per person employed ($PPP2011)	8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value	Economy
	Employment-to-population ratio (%)	n/a	Economy
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Manufacturing value added (% of GDP)	9.2 Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries	Economy
	Total energy and industry-related GHG emissions over sectoral value added (kg of CO_2e / $PPP2011)	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.	Environment
	Research and Development (R&D) expenditure (% of GDP)		Economy
10 REDUCED INEQUALITIES	Palma ratio	10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average	Society
11 SUSTAINABLE CITIES AND COMMUNITIES	CO_2 intensity of residential and transport sectors (t of CO_2 / t of oil equivalent energy use)	n/a	Environment

UN SDG	APPS Indicator	SDG Target	Sustainability pillars
	Material productivity ($PPP2011/ kg)	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	Environment
	Net GHG emissions from agriculture, forestry and other land use (AFOLU) sectors per square metre of forest and agricultural land (t of CO_2e / sq. m)	n/a	Environment
	Compliance to Conditional INDCs	13.2, Integrate climate change measures into national policies, strategies and planning	Environment
	Gap from equitable and sustainable GHG emissions per capita in 2030 (t CO_2eq) *		Environment
	Marine protected areas (% of territorial waters)	14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information	Environment
	Terrestrial protected areas (% of total land area)	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Environment
	Forest area (% of land area)	15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Environment
	Endangered and vulnerable (animals and plants) species (% of total species)	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity, and, by 2020, protect and prevent the extinction of threatened species	Environment
	Corruption Perception Index	16.5 Substantially reduce corruption and bribery in all their forms	Society
	Central government gross debt (% of GDP)	17.4 Assist developing countries in attaining long-term debt sustainability through coordinated policies aimed at fostering debt financing, debt relief and debt restructuring, as appropriate, and address the external debt of highly indebted poor countries to reduce debt distress	Economy

* *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 $GtCO_2$ e (UNEP, 2015), and the median estimate of world population in 2030 (UN, 2015).*

2.2 Ghana's wellbeing assessment in the past two decades

According to historical records, Ghana's pathway towards higher wellbeing levels has appeared erratic in the past 2 decades (Figure 1). The APPS index, synthetizing SDG indicators distance from 2030 targets, had a score of 36 in 1990. This result is attributable to average performance in the economic pillar (39.1), medium high performance in the environmental pillar (59.4) and low performance of the social indicators (5.8).

In 2000, the APPS Index score measured a considerable reduction of wellbeing: despite a moderate improvement of social indicators (up to 8.3) and a stable environmental performance (59.7), the economic sphere experienced a substantive drop passing from a score of 39.1 to 22.5.

The results for 2010 show a clear improvement in wellbeing (up to 41.2) leaded by a consistent rise of social pillar (from a score of 8.3 to 27.6), a recovered economic pillar (36.3) and a stable environmental performance.

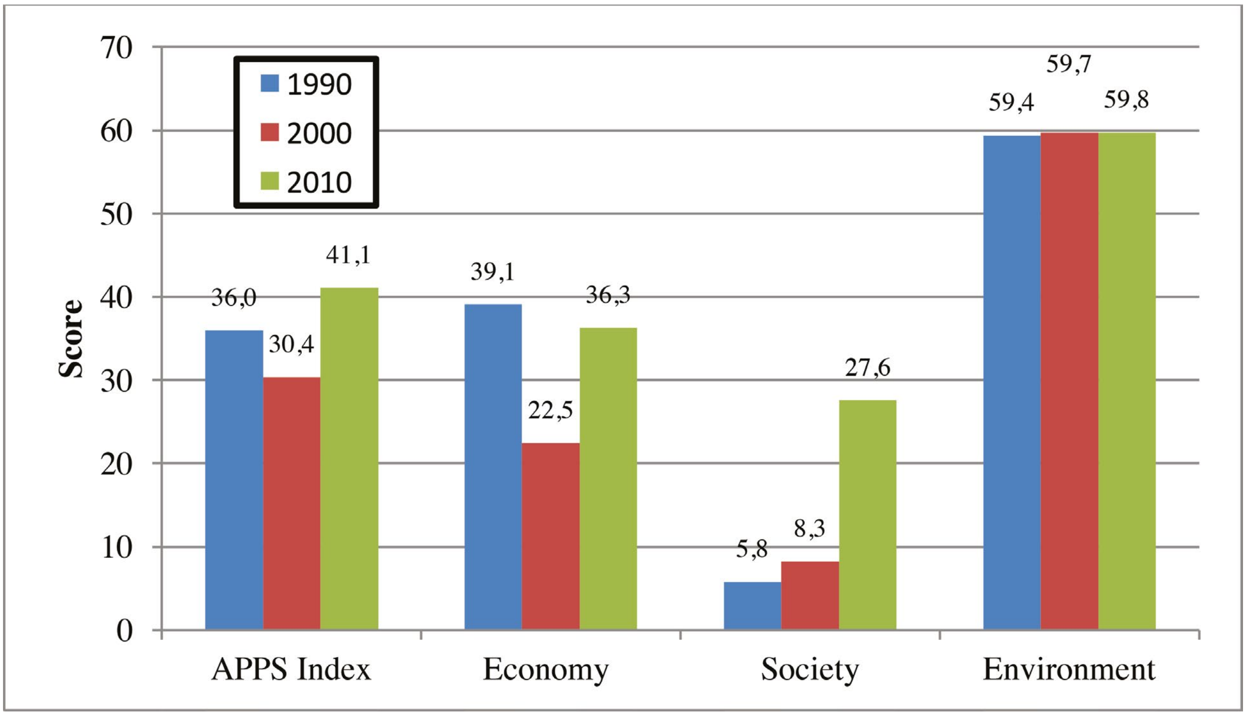

Figure 1. *Ghana's performance in APPS Index and indices by pillar in 1990, 2000 and 2010.*

Basically the evolution of APPS Index highlights a slowdown of sustainable development around year 2000 and a huge progress achieved between 2000 and 2010. Digging into Ghana's performance in each SDG index is thus useful to understand the roots of this evolution. This is done in Figure 2 reporting the performance in the APPS Index, and in the 16 SDGs[1]. The detailed analysis follows.

Ghana wellbeing in 1990

In 1990, the performance in **social indicators** was generally not sustainable (normalized score 0): poverty prevalence was at 47.4% (SDG 1),

1 *The scores in each SDG results from aggregating normalised values of indicators pertaining to that specific SDG. See Table 1 for the correspondences between indicators and SDGs.*

and undernutrition prevalence at 47.3% (SDG 2), 50 years was country average healthy life expectancy at birth (SDG3), only 70% of young population was able to read (SDG 4), and 23% of population had access to electricity (SDG 7). The society was quite unequal, with the income of the richest 10% of the population equal to 1.7 times that of poorest 40% (SDG 10), and affected by high level of corruption: the Corruption Perception Index had a low score of 3.3 (SDG 16).

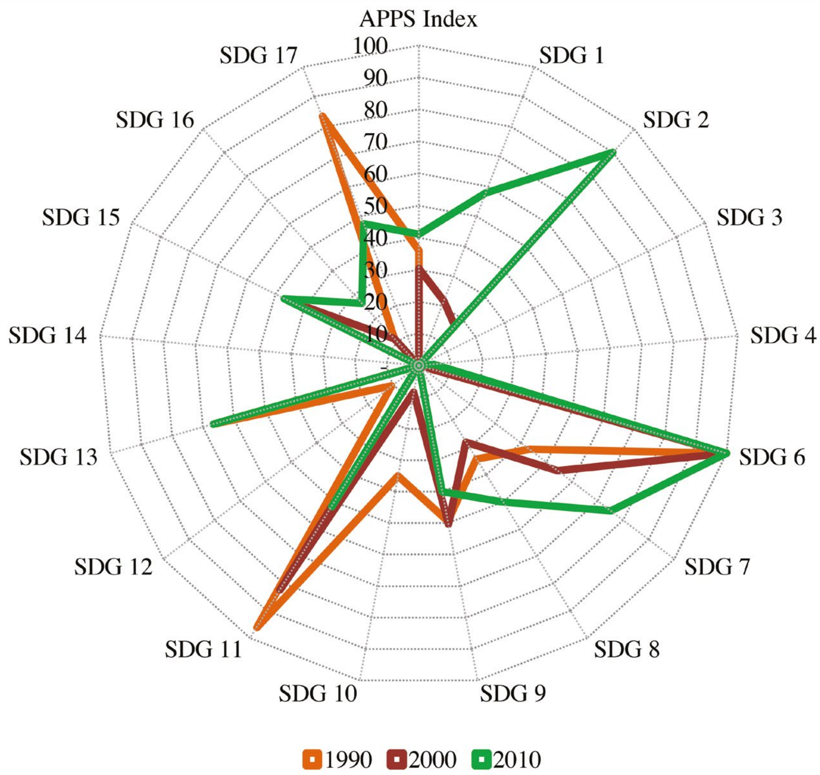

Figure 2. *Ghana's performance in APPS Index and SDGs in 1990, 2000 and 2010 (normalised scores).*

The **economic pillar** score was close to the average featuring a moderate 2.4% annual growth of GDP per capita and high employment-to-population ratio (67.5%), compensating low income per person employed (2912 $PPP2011) (SDG8). The other element contributing to the economic pillar performance was the low debt-to-GDP ratio: 28.3% (SDG17). The SDG 9, concerning status and perspective of industrial sector, had an average score due to a relevant manufacturing sector and low investments in R&D (0.2% of GDP).

As anticipated above, the **environmental indicators** had high scores in 1990: low water intensity with 3.3% of fresh water withdrawals (SDG 6), medium high primary energy intensity with 7.88 Mtoe/million$PPP (SDG 7) offset by a totally green electricity sector, i.e. 100% of electricity coming from renewables (SDG 7). Also the economy was not emission intensive: low emission intensity in energy and industry-related sectors, i.e. 0.9 kg of CO_2e / $PPP2011 (SDG 9), and low CO_2 intensity of residential and transport sectors, i.e. 0.6 t of CO_2 / toe (SDG 11). Material intensity (SDG 12) and marine areas protection (SDG14) were the most problematic dimensions for environmental sustainability: 0.7 $PPP2011/ kg was the productivity of extracted minerals and no marine areas were protected. Instead, in both SDG 13 and SDG 15, the low performance in one indicator (respectively high net GHG emissions in the AFOLU sector, and low proportion of terrestrial protected areas) was compensated by high scores in other indicators pertaining to these SDGs; regarding SDG 13, emission levels were below NDC target and per capita emissions well below the sustainable and equitable emission levels. In SDG15, the above average forest area coverage (38%) and the low percentage of endangered animals (10.4%) lead to a close-to-the average performance.

Slow-down of wellbeing progresses between 1990 and 2000

The drop in wellbeing observed between 1990 and 2000 (-15.6%) was due to a worsening of economic performance (-42.5%); in particular annual GDP growth rate halved compared to 1990 (SDG8) and debt-to-GDP ratio, reaching the 78% level, became unsustainable (SDG 17).

The improvements in **social wellbeing** in 2000 (+42.5% w.r.t. 1990) were perceivable especially in SDG 1 (poverty prevalence drops to 31% of the population), SDG 2 (undernutrition prevalence drastically reduces to 17.5%), SDG 7 (44% of population have access to electricity). Among social indicators, only inequality measure worsened with Palma ratio reaching a value of 1.9 (SDG 10).

In general, the **environmental performance** remained unchanged at aggregate level. Small negatively alterations were registered in SDG 11 and 12, namely CO_2 emission intensity of residential and transport sectors increased (0.85 t of CO_2 / toe) and material productivity reduced (0.4 $PPP2011/ kg). However, more protected terrestrial areas and wider forest extension slightly improved the score of SDG 15.

The recovery between 2000 and 2010

The rise of wellbeing observed in the period 2010 (+35.3% w.r.t. 2000) was the result of a recovered economic pillar (+61.6%) and a quickly progressing social one (+234.4%).

In this decade, **social indicators** leapt: extreme poverty prevalence (SDG 1) nearly halved reaching 16.9%, malnutrition prevalence (SDG 2) more than halved getting closer to developed country levels (6.5%), literacy rate (SDG 4) rose to 85.7%, access to electricity reached 65.1%, and Corruption Perception Index measured a less corrupted society. Due to normalisation procedure, it was no possible to detect the improvement of healthy life expectancy indicator that remained above the unsustainable level despite passing from 50 years to 53.3 years. The Palma ratio, measuring within-country income dispersion, was the exception among social indicator worsening up to 2005 (with a level of 2.2), reducing in the following years.

The recovery of **economic pillar** was led by the performance in SDG 8, namely a higher annual GDP per capita growth (5.2 % in 2010), more employment (70.2% employment to population ratio). Also SDG 17, the debt-to-GDP ratio, contributed to this result dropping from 111.9% in 2000 to 46.3% in 2010. The downsides of this recovery were in SDG 9, in particular a lower contribution of manufacturing to GDP creation and still insufficient investments in R&D.

The environmental degradation linked to a faster economic growth is not perceivable looking at the overall result of the **environmental pillar**, but emerges from a closer look by SDG. The CO_2 emission intensity of residential and transport sectors (SDG 11) increased to 1.5 t of CO_2 / toe and as well the emission intensity in energy and industrial sectors (SDG 9) rose to 0.9 kgCO_2/$PPP11.

03 Ghana's future sustainability

3.1 APPS framework for sustainability assessment

The APPS framework allows the assessment of sustainability into the future, i.e. the compliance of Ghana's "business-as-usual" scenario with 2030 SDG targets and the measurement of the gap to achieve them over time. In addition, APPS can be used to evaluate the ramification of a specific policy on the future sustainability, tracking its impact on the targeted SDG and the spillovers on all other SDGs.

Maintaining the same set of indicators used in the wellbeing assessment (Section 2) and a more aggregated regional detail (Appendix II), historical records of SDG indicators and empirical analyses are combined with a Computable General Equilibrium (CGE) model in order to produce SDG indicator projections up to 2030 in a reference scenario. Using a macroeconomic model allows taking into account, albeit in a simplified way, the systemic feature of the economy, the environment and the human society. In the present exercise, this interconnection within and between pillars is not static, but analysed in a dynamic context (see Section 3.2 for the description of reference scenario). The majority of APPS indicators stem directly from the CGE model output (economic or environmental variables); however, for few social indicators a post-processing procedure is required. The post-processing consists in computing the empirical relations between SDG indicators and some relevant macroeconomic variables in the past (1990-2015) across countries and, using these coefficients in out of sample estimations with CGE outputs as explanatory variables. For more details see APPENDIX II. The same methodology is also applied for the macroeconomic output of policy exercises. In this report, we envision the enforcement of the Paris agreement and specifically of "Nationally Determined Contributions" (NDCs) on emission reduction (Section 3.4).

Following the same methodology used in wellbeing assessment (Section 2 and APPENDIX I), the so computed indicators for the period 2007-2030 and for reference and policy scenarios are then normalized and aggregated to obtain some synthetic measures of future sustainability (Section 3.3 and Section 3.5).

3.2 Reference scenario

The APPS framework uses as a reference source for future scenarios those developed by the climate change community and known as Shared Socioeconomic Pathways (SSPs) (O'Neill et al 2015). They are connected to different mitigation/adaptation challenges and, in a broader sense, to sustainable pathways of future economic development. Scenarios are based upon specific assumptions on both exogenous and endogenous variables at the national/regional level. SSPs provide future patterns for population as well as labour force and cropland area. 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.

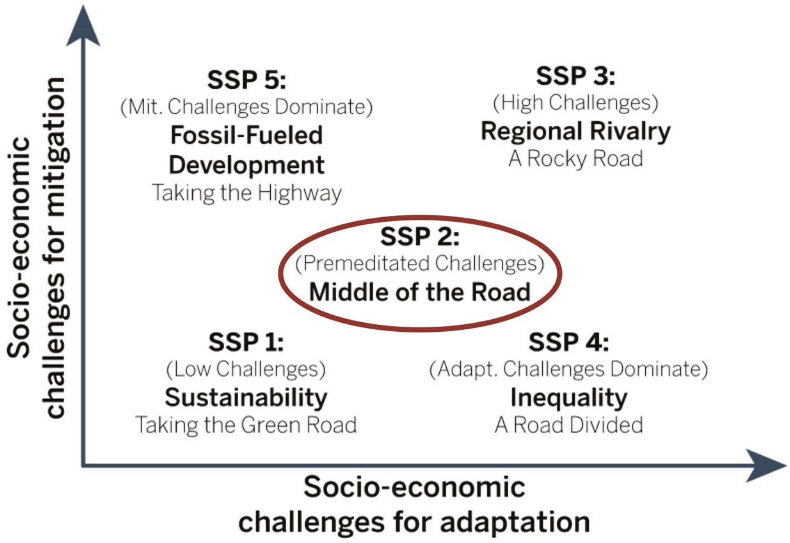

Figure 3. *Shared Socioeconomic Pathways matrix (O'Neill et al 2017).*

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 at a medium pace on the global average; slow income convergence; some improvements in the intra-regional income distributions;
- reductions in resource and energy intensity, and slowly decreasing fossil fuel dependency.

In our reference scenario, the growth of GDP, population and employment reproduces historical trends up to 2014 (WDI 2016) and then mimic SSP2 growth rates (OECD projections). Figure 4 and Figure 5 give an overview of annual GDP and population growth rates between 2000 and 2030 for the 45 APPS countries/macro-regions. Population trend relies on WDI database (WB 2017) up to 2014 and then to SSP2 growth rates (IIASA-WiC projections).

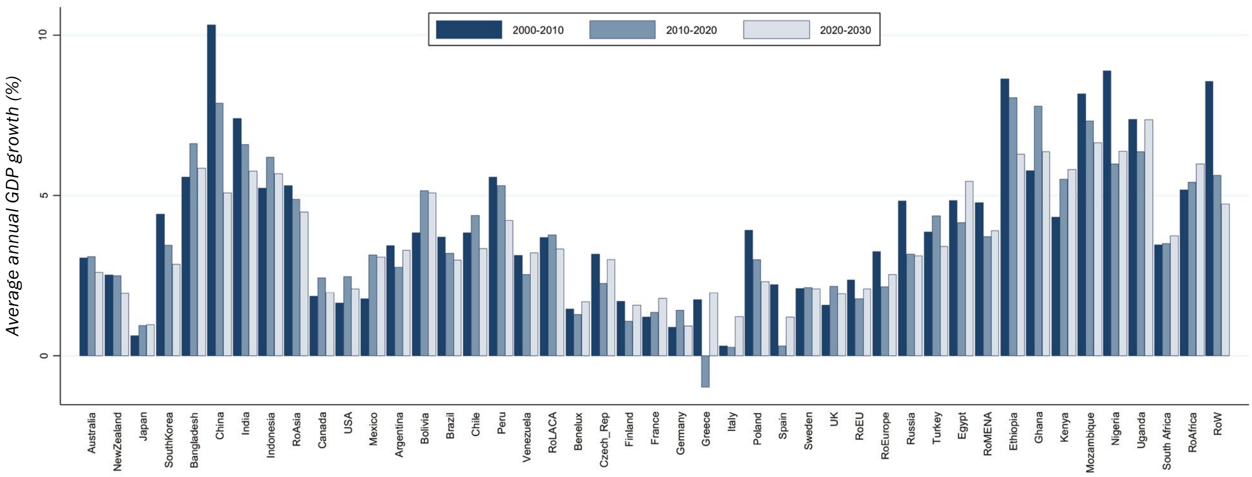

Figure 4. *Average annual GDP growth in the SSP2 scenario*

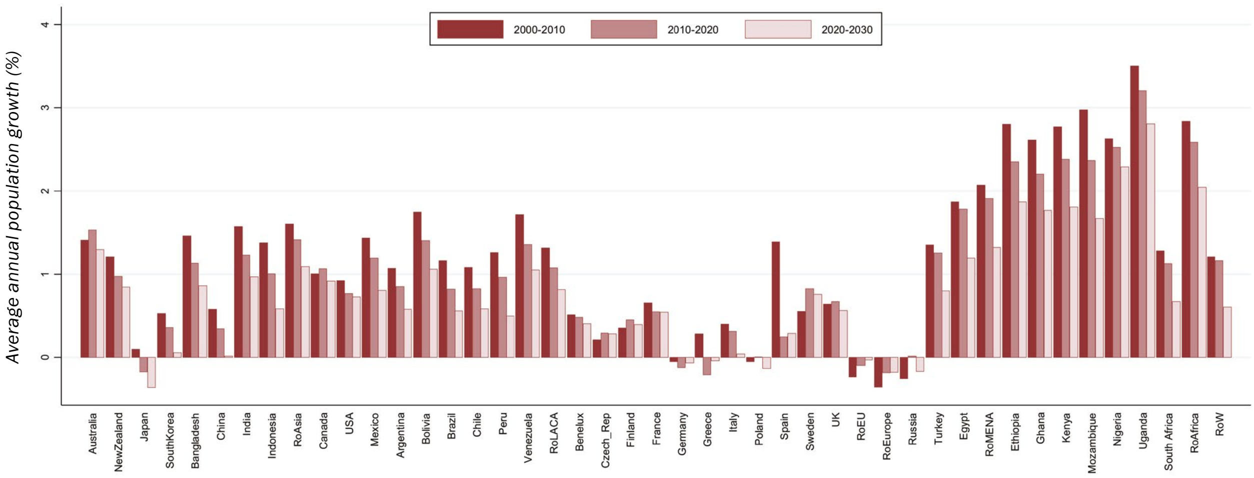

Figure 5. *Average annual population growth in the SSP2 scenario*

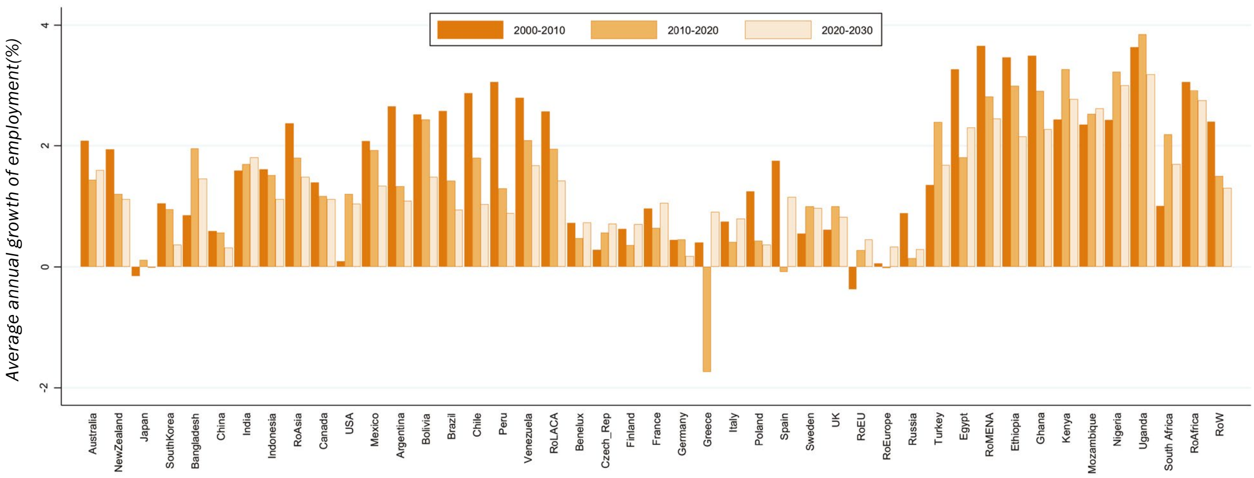

Figure 6. *Average growth of employed population in the SSP2 scenario*

The evolution of employed population (Figure 6) in the reference scenario stems from the historical data (up to 2014) and specific assumption about SSP2 storyline: participation rates converging to 70% in the long run and unemployment to a structural level of 2% (IIASA, 2016).

Under SSP2 scenario, global GHG emissions will be 62000 million tons of CO_2eq in 2030 (Figure 7) reaching presumably between 85030 and 105535 million tons of CO_2eq in 2100 (IIASA, 2016). This emission scenario lies between RCP 6 and RCP 8.5 and is associated with an alleged temperature rise in the range 3.7 - 4.2°C in 2100.

Ghana will contribute marginally to global GHGs in 2030 (3.4% of GHG emissions of Sub-Saharan Africa excluding South Africa).

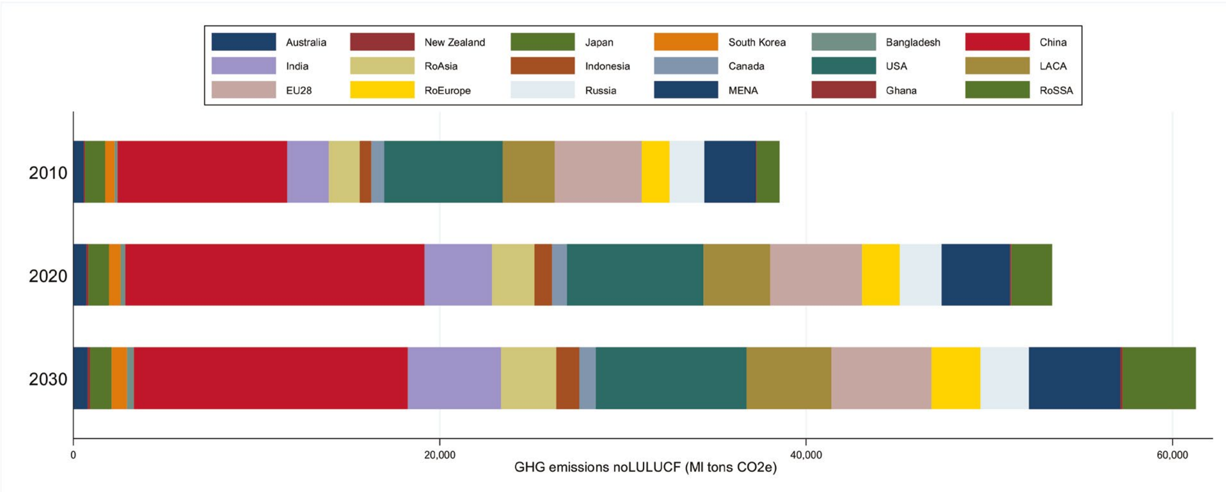

Figure 7. *GHG emissions in the SSP2 scenario*

3.3 Ghana's sustainability assessment in SSP2 scenario

Under SSP2 scenario, Ghana experience a rise of sustainability in 2030 compared to 2015 with APPS Index score passing from a value of 43.3 to 50.2 (Table 2). The Country falls at the 35th rank out of 45 country/regional aggregates (losing two positions in 2030 respect to 2015); notwithstanding Ghana is the first Sub-Saharan country in our ranking.

Ranking 2030	Countries	APPS Index 2030	Δ Ranking	APPS Index 2015	Ranking 2015	Ranking 2030	Countries	APPS Index 2030	Δ Ranking	APPS Index 2015	Ranking 2015
1	Sweden	85,4	0	85,3	1	24	Spain	56,8	-1	55,3	23
2	Finland	74,7	1	73,3	3	25	RoLACA	56,3	-1	54,4	24
3	NewZealand	72,5	1	70,9	4	26	Greece	55,6	0	52,4	26
4	Germany	72,4	-2	74,1	2	27	RoMENA	54,0	4	48,1	31
5	Australia	71,6	3	69,0	8	28	Peru	53,9	2	49,5	30
6	Canada	71,3	3	66,9	9	29	Bolivia	53,2	3	47,3	32
7	UK	70,8	0	69,2	7	30	Turkey	53,1	-1	49,8	29
8	RoEU	69,7	-2	69,5	6	31	Egypt	52,9	4	41,8	35
9	France	69,3	-4	70,1	5	32	Mexico	52,5	-5	51,8	27
10	RoEurope	68,7	0	66,0	10	33	RoW	52,5	-8	52,6	25
11	Benelux	67,2	0	66,0	11	34	Bangladesh	52,4	4	39,6	38
12	Japan	65,0	0	65,9	12	35	Ghana	50,2	-2	43,3	33
13	Russia	64,9	0	63,0	13	36	India	50,0	4	34,5	40
14	Venezuela	63,7	5	59,8	19	37	China	49,0	-3	42,7	34
15	Italy	63,5	2	62,5	17	38	RoAsia	46,0	-1	39,8	37
16	Indonesia	63,2	12	50,9	28	39	SouthAfrica	44,2	0	39,5	39
17	Czech_Rep	63,0	-3	62,8	14	40	Nigeria	44,0	-4	41,7	36
18	Poland	62,4	-2	62,6	16	41	Ethiopia	42,4	1	34,1	42
19	USA	62,1	2	58,7	21	42	RoAfrica	41,1	1	30,8	43
20	Brazil	60,9	-2	59,9	18	43	Uganda	40,4	2	28,6	45
21	Argentina	60,2	1	57,3	22	44	Mozambique	37,1	-3	34,3	41
22	SouthKorea	59,6	-7	62,8	15	45	Kenya	32,2	-1	29,2	44
23	Chile	59,6	-3	59,7	20						

Table 2. *APPS index ranking and score in 2015 and in 2030*

Keeping the trend observed in the 2000-2010 decade, the social pillar (+59.1%) is the major contributor to the increase of Ghana sustainability (Figure 8); the economic pillar (+13.5%) will also improve, but together with an evident worsening of the environmental sphere (-17.6%).

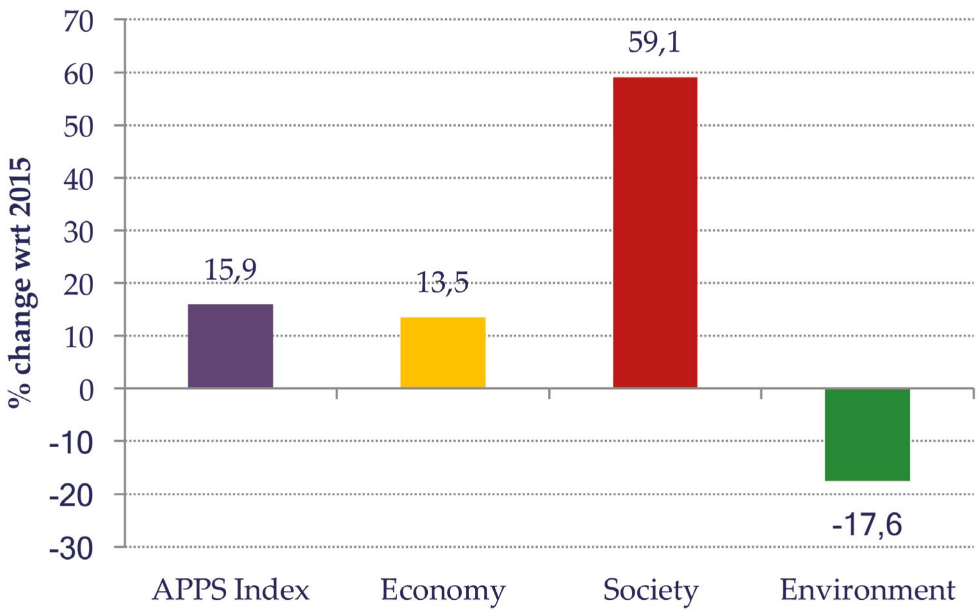

Figure 8. *Ghana performance in APPS Index and indices by pillar in 2030 w.r.t. 2015*

Figure 9 disentangling specific components of the sustainability performance highlight a strong improvement of **social indicators**: poverty (SDG 1), and undernutrition prevalence (SDG 2) decrease reaching the levels of 0.9% and 2.6% respectively. The speed of reduction is similar to the one observed in the 2000-2010 decade. Also Palma ratio, a measure of income inequality (SDG10), shrinks mimicking the downward trend observed in historical time series after 2005 and passes from 1.8 in 2015 to 1.5 in 2030. The spread of access to electricity continue in our SSP2 reference scenario reaching 87.2% in 2030.

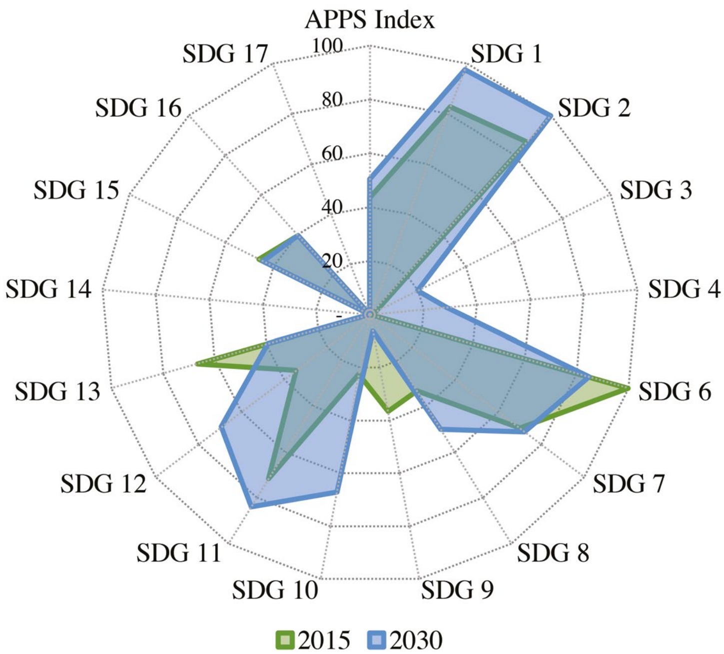

Figure 9: *Ghana performance in SDGs in 2015 and 2030.*

Other two social indices, SDG 3 and SDG 4, which were and are currently below unsustainability level, will show in 2030 perceivable improvements: literacy rate will rise up to 89.3% and the healthy life expectancy will advance up to 59.6 years.

The performance in SDG8, annual GDP growth rate of 3.7% and GDP per employed up to 18000 $PPP2011, is driving the rise of the **economic pillar** score. However, not all economic indicators are performing better under the business as usual scenario. Keeping constant the current fiscal policy up to 2030 the debt-to-GDP ratio (SDG 17) increases. Indeed, economic growth and the related increase of tax revenues are not sufficient to support public expenditure and transfers to the rest of the economic system. This rise of debt-to-GDP ratio is already foretold by historical trend since 2010; the model projections emphasise this trend. This outcome is not immediately evident in Figure 9 due to the normalisation procedure: the debt-to-GDP ratio in 2015 is anyway below the unsustainable level (score 0) and remains so also in 2030.

Regarding the **environmental pillar**, several trade-offs emerge. On one side, the stronger growth and welfare determine more intensive water use (SDG 6), the rise of emission intensity in energy and industry sectors (SDG 9) up to 1.81 kgCO_2/$PPP11, higher primary energy intensity (7.35 Mtoe/million$PPP2011), partially offset by a greener energy mix (65% of electricity from renewables) in SDG 7, and widening of gap from meeting NDC target in 2030 (SDG 13). These downsides are partially compensated by higher material productivity (SDG12) and lower CO_2 intensity in residential and transport sector (SDG11).

3.4 The mitigation policy scenario

The policy scenario analyses the implications of the "Paris Agreement" for Ghana's sustainability pathway. The Paris agreement, adopted by UNFCCC during the 21st Conference of Parties (COP 21) in December 2015, aims to strengthen the global response to climate change through a new regime of country-driven emission reduction and adaptation plans. These are the "Nationally Determined Contributions" (NDCs), which are plans each country autonomously determines to deal with climate change from 2020 on. Countries expressed their mitigation efforts heterogeneously; developed countries in general quantified them as an economy-wide emission reduction with respect to a reference year. Instead, developing countries set an emission intensity target or link their emission reduction target to a Business As Usual (BAU) scenario. Two types of mitigation targets exist: unconditional and a conditional. The former has to be achieved with internal funds and capabilities, and the latter, envisioning a more ambitious mitigation effort, is conditioned to external financial and technical supports.

In its NDC, Ghana set an unconditional target of GHG emission reduction by 15% relative to a business-as-usual (BAU) scenario emission. The conditional target considers that a total emission cut of 45% with respect to the BAU levels can be achieved by 2030 with this external support.

The designed mitigation scenario focuses on the conditional objectives stated in the NDCs. The current exercise focuses only on CO_2 emissions. For countries committing to an emission reduction with respect to a specific year, we use CAIT database (WRI 2016) as reference, whereas emissions resulting from SSP2 reference scenario are used when the reduction is relative to the BAU scenario.

Table 3 displays mitigations targets for countries and regional aggregates.

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)	-9	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	Rest of MENA (RoMENA)	-9	Average mission reduction wrt 2030 BAU scenario
Indonesia	-41	Emission reduction wrt 2030 BAU scenario	Ethiopia	-64	Emission reduction wrt 2030 BAU scenario
Rest of Asia (RoAsia)	-21	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 CO_2–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)	-35	Average mission reduction wrt 2030 BAU scenario

Table 3. *Mitigation Targets*

The mitigation scenario starts in 2017 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 revenues from carbon tax entering into the government budget are not altering government current expenditure, investments and transfers observed in the reference scenario, but goes directly to reduce government deficit.

3.5 Implications of mitigation scenario on Ghana's sustainability

Ranking 2030 NDC_ Policy	Countries	APPS Index 2030 NDC_ Policy	Δ Ranking	APPS Index 2030 baseline	Ranking 2030 baseline	Ranking 2030 NDC_ Policy	Countries	APPS Index 2030 NDC_ Policy	Δ Ranking	APPS Index 2030 baseline	Ranking 2030 baseline
1	Sweden	86,5	0	85,4	1	24	Spain	58,4	0	56,8	24
2	Finland	76,2	0	74,7	2	25	RoLACA	57,7	0	56,3	25
3	NewZealand	75,3	0	72,5	3	26	Greece	56,3	0	55,6	26
4	Australia	74,2	1	71,6	5	27	RoW	56,1	6	52,5	33
5	Canada	74,0	1	71,3	6	28	Peru	55,3	0	53,9	28
6	Germany	73,2	-2	72,4	4	29	Ghana	55,0	6	50,2	35
7	UK	72,7	0	70,8	7	30	Bangladesh	54,8	4	52,4	34
8	RoEU	71,6	0	69,7	8	31	RoMENA	54,7	-4	54,0	27
9	Indonesia	70,4	7	63,2	16	32	Mexico	54,7	0	52,5	32
10	France	70,4	-1	69,3	9	33	Turkey	54,1	-3	53,1	30
11	RoEurope	70,1	-1	68,7	10	34	Egypt	53,0	-3	52,9	31
12	Brazil	70,0	8	60,9	20	35	Nigeria	52,4	5	44,0	40
13	Benelux	68,8	-2	67,2	11	36	Bolivia	51,2	-7	53,2	29
14	Russia	65,9	-1	64,9	13	37	China	50,8	0	49,0	37
15	Czech_Rep	65,7	2	63,0	17	38	India	50,0	-2	50,0	36
16	Japan	65,6	-4	65,0	12	39	SouthAfrica	47,9	0	44,2	39
17	Venezuela	65,0	-3	63,7	14	40	Ethiopia	47,4	1	42,4	41
18	USA	64,9	1	62,1	19	41	RoAsia	46,8	-3	46,0	38
19	Italy	64,5	-4	63,5	15	42	RoAfrica	42,3	0	41,1	42
20	Poland	64,4	-2	62,4	18	43	Uganda	41,1	0	40,4	43
21	Argentina	61,8	0	60,2	21	44	Mozambique	37,3	0	37,1	44
22	SouthKorea	61,6	0	59,6	22	45	Kenya	36,4	0	32,2	45
23	Chile	60,3	0	59,6	23						

Table 4. *APPS index ranking and score in 2030, mitigation vs. reference scenario*

Meeting emission reduction targets stated in NDC increases Ghana's sustainability: APPS Index score in 2030 increases from 50.2 in the reference scenario to 55 in the mitigation scenario (Table 4). Ghana also gains 6 positions in the sustainability ranking leaping over Bolivia, Turkey, Egypt, Mexico, and Bangladesh.

The policy determines a beneficial effect on all pillars (Figure 10). The environmental dimension, directly targeted by the policy, increases by 29.7% compared to the reference scenario; the economic pillar follows with a 2.8% rise. The policy impact on the social indicators is moderate (1.5%).

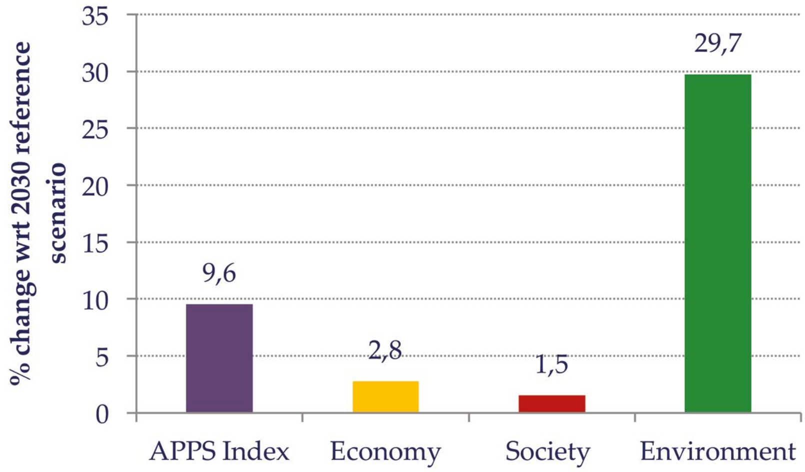

Figure 10. *Ghana performance in APPS Index and indices by pillar in 2030, mitigation vs. reference scenario*

Figure 11 shows that improvements in SDG 7, SDG 9, SDG 11, and SDG 13 are responsible for the higher sustainability performance under the mitigation scenario. Regarding SDG 7, the carbon price fuels the use of renewable energy sources: renewable electricity share goes up to 88.5% and primary energy consumption reduces to 6.1 Mtoe/million$PPP2011. The mitigation scenario has a positive impact also to the third indicator part of SDG 7, i.e. access to electricity (social pillar). The percentage of population with access to electricity passes from 87.2% of reference scenario to 89.6% witnessing that carbon pricing is not necessary hindering the reduction of energy poverty.

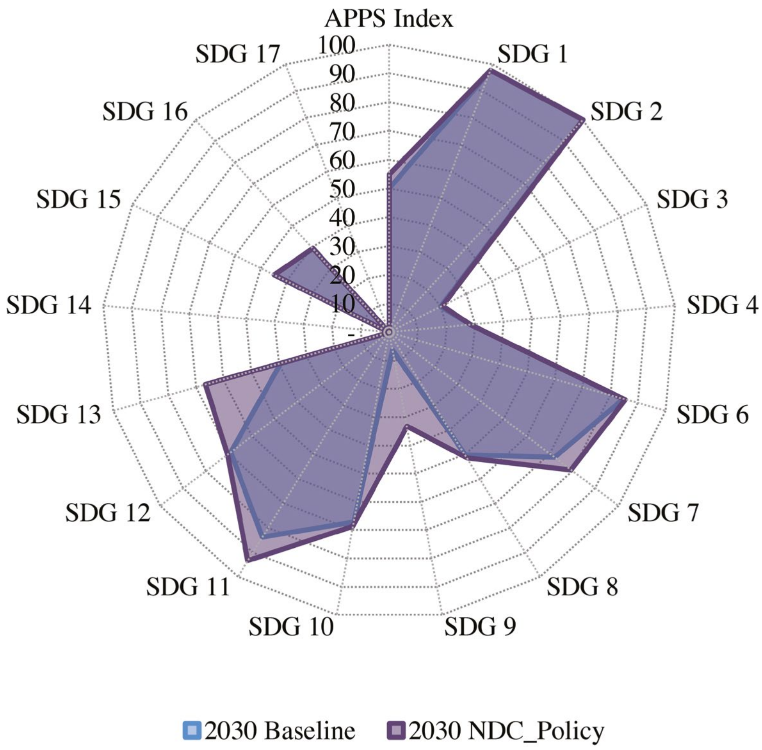

Figure 11. *Ghana performance in SDGs in 2030, mitigation vs. reference scenario*

The drastic contraction of emission intensity in energy and industry sectors (from 1.8 kgCO_2/$PPP11 of the reference to 0.9 kgCO_2/$PPP11 in the mitigation scenario) determines the higher score of SDG 9. Likewise, the decrease of CO_2 intensity in residential and transport sectors (from 0.8 t of CO_2 /toe in the reference to 0.6 t of CO_2 /toe in the mitigation scenario) pull upwards SDG 11 performance. Under the mitigation scenario Ghana achieves full sustainability in the indicator measuring the Compliance to Conditional INDCs. The overall performance in SDG 13[2], although rising, obtains a score of 66.7 because the indicator on GHG emissions from AFOLU which, although improving, remains below the unsustainable threshold.

The higher score in the **economic pillar** is mainly due to SDG 8 and, in particular, to a slightly higher average GDP per capita growth (4% in 2030) and GDP per employed (18301 $PPP2011) under mitigation scenario. This result stems from additional taxation revenues that lower fiscal deficit and public debt. In fact, the debt-to-GDP ratio is more than halved under mitigation scenario (w.r.t. reference scenario); however, it remains beyond the unsustainable level and in the normalisation procedure it obtains a score of 0.

The scale of Figure 11 does not allow noticing the impact of mitigation policy on **social indicators**. Figure 12 offers a closer look on the performance of social SDG indicators in the mitigation scenario compared to the reference scenario. The effect on poverty prevalence (SDG 1) is positive and negligible; the performance of the indicator was already close to full sustainability in 2030 reference scenario (97.7). Also, the SDG 2 on malnutrition prevalence remains unchanged because the 2030 reference scenario already achieves the full sustainable level.

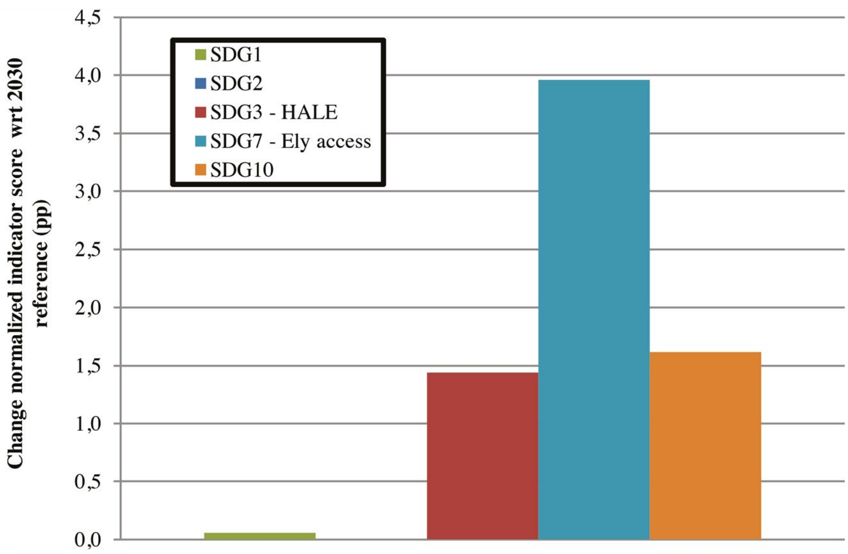

Figure 12. *Change in percentage points of Ghana performance in social SDG indicators in 2030, mitigation vs. reference scenario*

2 *The other indicator considered in SDG 13 is the one measuring the distance of per capita emissions from the equitable and sustainable level. Ghana's emissions per capita are lower than this threshold and, therefore, the Country obtains a score of 100 in this indicator.*

A marginal improvement (1.4 pp w.r.t the reference scenario) characterise the indicator on Healthy Adjusted Life Expectancy (HALE) at birth; this corresponds roughly to 2 additional months under mitigation scenario compared to reference one. The Palma ratio (SDG 10) registers a reduction of inequality by 1.6 pp. Furthermore, as mentioned above, one of the most interesting results is the positive impact of emission reduction scenario on access to electricity (SDG 7); this indicator registers a 4 pp increase in the score, the highest among social indicators, and seems to contradict the opinion that mitigation policy may hinder developing countries progresses in improving people's living standards.

04 Conclusions

Ghana's pathway towards higher wellbeing levels is certainly positive, but has appeared erratic in the past 2 decades. In 1990, the low level of wellbeing (APPS Index 36) was mainly attributable to a low performance of the social indicators and an average one in the economic and environmental pillar. In 2000, despite a small, but determinant, improvement of social indicators and a stable environmental pillar, the economic sphere worsened provoking a slow-down of progresses in wellbeing (APPS Index 30.4). The turning point, occurred between 2000 and 2010, determined a consistent rise of wellbeing (APPS Index 41.2) leaded by remarkable progresses in the social indicators and a recovered economic pillar.

In our reference scenario, Ghana will continue this path toward higher sustainability (APPS Index 50.2) being the first African country in our ranking. Main drivers are again the higher score of social (+59.1%) and of economic (+13.5%) indicators. The drawback of socioeconomic development is the worsening of environmental sphere (-17.6%) despite some mild optimistic assumptions on energy intensity of the reference scenario.

The analysed policy scenario, envisioning the compliance with the emission reduction targets (NDCs) subscribed under the Paris agreement, determines an increase of Ghana sustainability (APPS Index 55). The higher sustainability of environmental pillar is the driving force of this change, but, from a closer look, all pillars benefit in the mitigation scenario. It is worth to notice that, according to our results, engaging in GHG emission reduction will not harm Ghana's future economic and social development. An interesting example of this can be found in SDG 7, where percentage of population with access to electricity actually rises under mitigation scenario compared to the reference one.

However, enforcing NDCs is not sufficient to achieve full sustainability in SDG 13 because additional policies targeting directly emissions from agriculture and land use change are needed. Furthermore, SDG 13 is just one of the SDGs contributing to the environmental pillar performance. SDG 6, SDG 7 and SDG 12 have an above average score in 2030, but it is important to consider the implication of any policy on intensity of water resource use (SDG 6), energy intensity and renewable shares (SDG 7) and material productivity (SDG 12). Ghana should also increase its investment in protecting marine and terrestrial areas, endangered animal and plant species, and expand the forest area (SDG 14 and SDG 15). Looking at the economic sustainability, the GDP per person employed is the element limiting SDG 8 score; this indicator is a rough measure of poverty in a country because it does not account for income distribution. However, the increase of GDP per person employed, driven by higher income in middle and lower deciles, would help achieving at the same time SDG 8 and SDG 10 (Palma ratio). Policies for this purpose should rely on more progressive taxation schemes trying not to be a burden for government spending. In fact, the debt-to-GDP ratio (SDG 17), being at an unsustainable level, is an important issue for Ghana, which for sake of development will have to increase investments in the social sphere. The social pillar showed huge progresses in the last decade, but in 2030, despite quite optimistic assumption of the reference scenario, SDG 3 (Healthy Adjusted Life Expectancy), SDG 4 (youth literacy rate), SDG 10 (Palma ratio) and SDG16 (Corruption perception) will be still far from the aspirational targets of Agenda 2030. More efforts will be needed to improve the health status and the education of population, to reduce the unequal resource distribution and the perception of society corruption. Public investment will certainly have a key role in addressing these matters, but leveraging private investment and focusing on efficiency of funding will be fundamental to contain public debt (SDG 17).

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The main contributors to this report are Lorenza Campagnolo - researcher of FEEM's *Climate Change: Economic Impacts and Adaptation (EIA)* research program - and Francesco Bosello, EIA program coordinator.

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APPENDIX I: APPS framework

APPS (Assessment, Projection and Policy of Sustainable Development Goals) framework aims at offering a comprehensive assessment of current well-being and future sustainability based upon 27 indicators related to the 17 Sustainable Development Goals.

The snapshot of **current well-being** concerns 139 countries; it relies on historical data collected from main international databases for the 27 selected indicators. For 108 counties it is also possible to track indicator evolution in the period 1990-2015.

The APPS framework can also give an assessment of future sustainability shedding some lights on the evolution of SDG indicators up to 2030, under different socio-economic and policy scenarios. On this purpose, historical records of SDG indicators and empirical analyses are combined with a Computable General Equilibrium (CGE) model.

The multi-step APPS methodological framework is synthetized in Figure 1; the green arrows highlight the 5 steps characterising the well-being assessment as well as essential elements in the sustainability assessment: selection of SDG indicators, data collection from international databases, computation of indicator values, identification of threshold levels to normalize indicators to a common metrics, and aggregation procedure to provide synthetic indices. Three further elements, red arrows, are specific for the evaluation of future sustainability: macro-economic framework, construction of reference scenarios, and corrective policies reducing gaps from SDG targets.

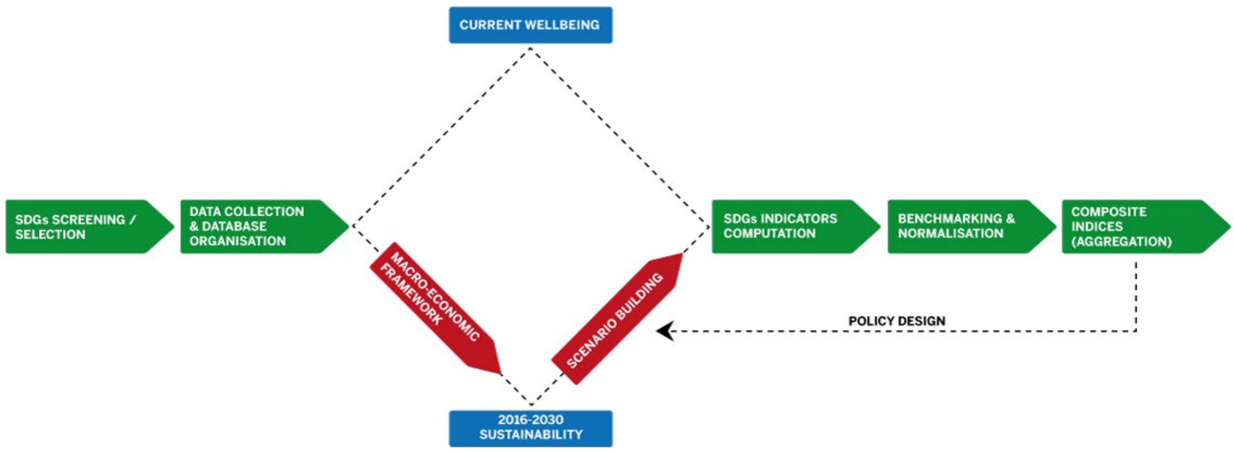

Figure AI 1: *APPS framework*

Screening and selection of indicators

The Inter-Agency and Expert Group received from UN the mandate to define the SDG indicator framework, and produced in July 2017 a list of 232 indicators (UN, 2017).

APPS indicator screening started from this list, and their selection was guided by specific requirements: **relevance** in measuring the SDG they refer to and **connection** with a specific quantitative SDG Target. Furthermore, APPS indicators need to have good **country coverage** because the well-being assessment is worldwide and the comparability of the results of aggregation procedure requires excluding countries with missing values for at least one of APPS indicators. In addition, APPS indicators are at **country level**; the presence of a macro-economic model in our framework and the world coverage forces us to disregard more disaggregated indicators (gender, cohort, location-specific).

Furthermore, the most stringent constraint in selecting APPS indicators comes from the sustainability assessment: drawing the future path of SDG indicators depends on identifying their determinants (empirical analysis on the historical data and evidences from the literature), and, at the same time, depicting the future evolution of these determinants. A macro-economic model can offer a coherent scenario-dependent representation of the future, therefore linking SDG indicators to macro-economic variables from a model can shed some light on the possible future evolution of these indicators. The lack of any **empirical evidence connecting an SDG indicator with one or more endogenous variable in our model** determined its exclusion from APPS set of indicators.

Data Collection& database organisation

Data for all the indicators identified in the previous step have been gathered from international databases: World Development Indicators, Millennium Development Goals Database, World Health Organization, UN Educational, Scientific and Cultural Organization, International Monetary Fund, CAIT (WRI Climate Data Explorer), International Energy Agency, UN Food and Agriculture Organization, and GMWD SERI/WU Global Material Flows Database.

The analysis is run at world level for the period 1990-2015; given the numerous missing data, we used linear interpolation in order to obtain countries' time series for the 27 indicators considered. Furthermore, in order to compute aggregate indicators, it is necessary to exclude from the analysis countries with missing data in one or more considered indicators. The final panel considers 108 countries. It exist also a last-available-year cross-section for 139 countries.

Benchmarking, Normalization

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.

Indicators can be classified into two main categories according to their: a) positive direction (i.e. the higher the score of a country, the higher the country's performance); b) negative direction (i.e. the higher the score of a country, the lower the country's performance). As a consequence, the **normalization procedure** required for transforming the raw data into a common [0,1] scale is different and specific for the two cases. For indicators belonging to the a) category, country performance is unsustainable whenever its score is below a critical threshold value $\underline{x}$, whereas it is defined as sustainable whenever its score is above the threshold value $\overline{x}$.

Indicators belonging to the b) category have the opposite normalization process. In both cases, a linear interpolation between these two threshold values allows evaluating the intermediates scores.

The step functions used for the normalization are the following:

$$f_a(x) = \begin{cases} 1 \ iff \ x \geq \overline{x} \\ 0 \ iff \ \ x \leq \underline{x} \\ \dfrac{(x - \underline{x})}{(\overline{x} - \underline{x})} \ iff \ \underline{x} \ \leq x \leq \overline{x} \end{cases}$$

$$f_b(x) = \begin{cases} 1 \ iff \ x \leq \overline{x} \\ 0 \ iff \ \ x \geq \underline{x} \\ \dfrac{(x - \overline{x})}{(\overline{x} - \underline{x})} \ iff \ \ \overline{x} \leq x \leq \underline{x} \end{cases}$$

The **benchmarking procedure** consists in defining the threshold values,$\underline{x}$ and $\overline{x}$, for each indicator described above and is the same in the well-being and sustainability assessment. 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, as it happens in many cases, other sources were preferred such policy targets in OECD (target in EU of 3% R&D expenditure) or best practices.

Table shows the threshold values used, respectively, for the normalization process of APPS indicators both in well-being and sustainability assessments.

Table AI 1. *APPS indicators, normalization type and benchmarks.*

Indicator	Type	Lower bound	Upper bound
ECONOMY			
GDP per capita growth (%)	a	0	7
GDP per person employed ($PPP2011)	a	5000	50000
Public debt as share of GDP (%)	b	70	20
Employment-to-population ratio (%)	a	40	80
Manufacturing value added (MVA) as percent of GDP (%)	a	5	15
Gross domestic expenditure on R&D as share of GDP (%)	a	0.5	3
SOCIETY			
Population below $1.90 (PPP) per day (%)	b	40	0
Population undernourished (%)	b	20	5
Physician density (per 1000 population)	a	2	3
Healthy Life Expectancy (HALE) at birth (years)	a	54	68
Literacy rate of 15-24 years old, both sexes (%)	a	85	100
Access to electricity (% of total population)	a	40	100
Palma ratio	b	2	1.2
Corruption Perception Index	a	2.7	8

Indicator	Type	Lower bound	Upper bound
ENVIRONMENT			
Proportion of total water resources used (%)	b	30	5
Share of electricity from renewables (%)	b	5	60
Rate of primary energy intensity (Mtoe/million$PPP11)	b	10	3
Total energy and industry-related GHG emissions over value added ($kgCO_2$/$PPP11)	b	2	1
CO_2 intensity of residential and transport sectors over energy volumes(t of CO_2 / toe)	b	2.5	0.5
Net GHG emissions in the AFOLU sector over total surface (t of CO_2e / sq. km)	b	100	0
Gap from equitable and sustainable GHG emissions per capita (t CO_2eq)	b	15	0
Proportion of terrestrial protected areas (%)	a	10	50
Proportion of marine protected areas (%)	a	5	20
Forest area (%)	a	5	60
Share of endangered and vulnerable (animals & plants) species (% of total species)	b	20	5
Direct Material Consumption over GDP (%)	a	0.5	2

APPS indices and ranking

The normalisation procedure allows producing aggregate indices and conveying more synthetic information to policymakers:

- SDG indices are the average value of indicator characterizing each goal;
- The APPS index is the average of scores in each SDG;
- Indices by pillar are the average of SDG indices related to each sustainability pillar (Economy, Society and Environment) (Figure AI 2 and last column in Table 1).

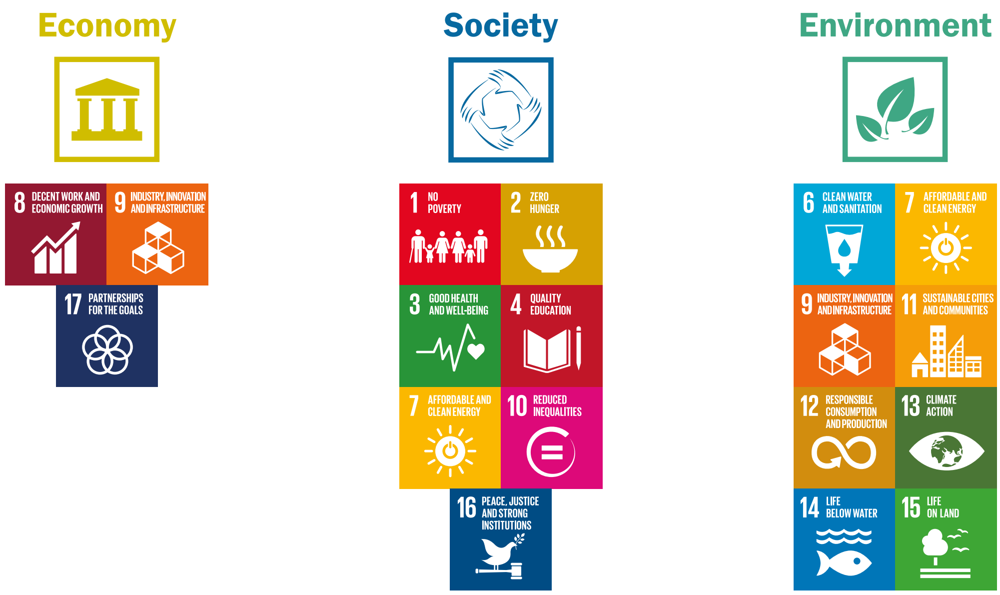

Figure AI 2. *APPS sustainability pillar indices*

APPENDIX II: Macro-economic framework for sustainability assessment

The core of the APPS' methodology for assessing future sustainability is a macro-economic model extended with social and environmental indicators. The model allows producing internally coherent future scenarios of main socio-economic variables for all countries. In many cases, the output of the model is directly used to compute the future trend of indicators. For 7 indicators (Table AII 1, in bold letters), we use the historical data collected for the well-being assessment and run independent regressions linking the past trend of our indicators to the past evolution of some macroeconomic explanatory variables (for more details, Table AII 1). The so derived coefficients are employed in an out-of-sample estimation and combined with the macroeconomic model projections of the same explanatory variables.

ICES model description

The indicators are calculated using the outputs of the **Intertemporal Computable Equilibrium System (ICES) model** (Eboli et al. 2010). ICES is a recursive-dynamic CGE model with World coverage based on the GTAP-E model (Burniaux and Truong 2002) and GTAP 7 database[3] (Narayanan and Walmsley 2008).

As in every model, there are several simplifications made in the CGE framework in order to represent the underlying phenomena in the most parsimonious way, and all results are conditioned by those assumptions. However, these simplifications allow modelling the most important elements of a complex environment in a controlled and coherent way.

Nonetheless, it is of crucial importance to acknowledge the limitations of this approach when analysing its results. The main simplifying assumptions of our CGE framework are the existence of perfect competition that clears all markets along with a full employment of production factors. In addition, the future scenarios rely on external projections of key exogenous variables driving also its results. Despite these elements are considered limitations when comparing the modelling framework to the actual world, they provide the basis for a solid and consistent scenario analysis.

In the model, the economy of each country is characterised by n industries, a representative household and government. Industries minimize production costs and have nested Constant Elasticity of Substitution production functions that combine primary factors (natural resources, land, and labour), a capital&energy composite, and intermediates in order to generate the output. The "Armington assumption" introduces some frictions on the substitutability of inputs imported from different countries.

A regional household in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally;

3 *GTAP 7 database considers 113 macro-regions and 57 production sectors for the year 2007; for APPS project the world is aggregates it in 45 macro-regions and 20 production sectors.*

instead land and natural resources are industry-specific. Income of different agents is used to finance three classes of expenditure: private household consumption, public consumption and savings; the utility of private household consumption has a Constant Difference of Elasticities functional form.

A fictitious world bank collects savings from all regions and allocates investments in order to equalise the current rates of return.

Dynamics inside the ICES model are driven essentially by two sources: one endogenous and one exogenous. The first involves capital accumulation and foreign debt evolution governed by endogenous investment decisions. On the other hand, we make several exogenous assumptions concerning trends of population stock, labour stock, labour, land and total factor productivity over time in order to obtain a reference scenario in line with main economic indicators.

The **benchmark year** for indicators calibration is 2007, and the **time horizon** for the assessment is 2015-2030.

While the assessment of current well-being is provided for the 139 countries, projecting future sustainability requires some aggregation for the sake of computation. There are **45 countries/regions** considered in the model simulations. The countries singled out are selected on the basis of their relevance for sustainability (high concern for social and environmental issues) as well as population size (covering 70% of World population). Each socio-economic system is then divided into 22 sectors providing commodities/services, chosen according to their contribution to sustainable development indicators.

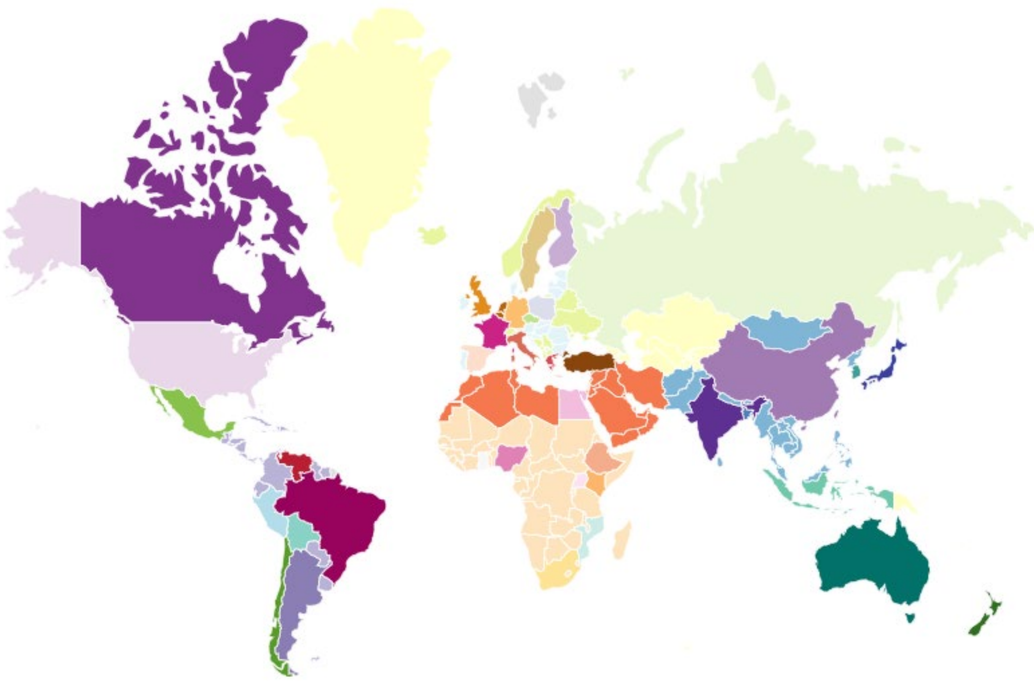

Figure AII 1. *APPS regional aggregation*

Extensions of ICES model

In order to perform a sustainability analysis, we extended ICES to consider a more detailed sectoral aggregation and to better capture the behaviour of public sector. The new sectors are: Research and Development (R&D), Education, Health, and Renewable Energy Sources (RES). All of them were split from the original GTAP 7 sectors according to the available international statistics which represent the world economy in the year 2007.

For the **R&D** sector, we used the indicator "R&D expenditure as percentage of GDP" from the World Development Indicators - WDI (World Bank 2016) and the "share of R&D financed by Government, Firms, Foreign Investment and Other National" from the OECD Main Science and Technology Indicators (OECD 2016) for attributing R&D to the different economic agents.

A similar approach has been used for **Education and Health** sectors. Data on overall expenditure on health and education have been obtained from the WDI database (World Bank 2016).

In order to regard separately the **RES**, namely wind, solar and hydro-electricity, they were split 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). The explicit consideration of the RES sector implied some modelling changes: the production function of electricity sector considers a new nest allowing the inter-electricity substitution between RES and traditional fossil electricity.

Furthermore, starting from the ICES core model, we develop a model extension (ICES-XPS) to specifically consider the **public actor** (Delpiazzo et al. 2017). Indeed, in the original ICES model the government is part of a regional household but it hasn't its own budget and its representation is limited to only consuming a fraction of regional disposable income. In this extension, instead, we split the regional household into the two main actors in the economy, i.e. the private household and the government. The government revenues now derive from: taxes paid by private household and productive sectors, international transactions among governments (foreign aid and grants) and transactions between the government and the private household (net social transfers, interest payment on public debt to residents), and flows among governments and foreign private households (interest payment on public debt to non-residents). The government can use these revenues for public expenditure in goods and services, savings or for reducing public debt.

Indicator computation

For evaluating future sustainability, APPS indicator values around 2007 are collected for each country and introduced into the modelling framework. Their future trends are linked to the dynamics of macro-economic variables in the model. This way, indicator future paths are strongly rooted in the broader context of socio-economic-environmental reference scenarios.

The Table AI 1 describes the modelling behaviour of APPS Indicators.

APPS Indicator	Modelling Behaviour
Poverty headcount ratio at $1.90 a day (PPP2011) (% of population)	GDPPPP per capita and Palma ratio (regression)
Prevalence of undernourishment (% of population)	GDPPPP per capita, Palma ratio, urban population, agricultural production per capita and industrial VA share (regression)
Physician density (per 1000 population)	Private and public education expenditure (regression)
Healthy Life Expectancy (HALE) at birth (years)	Physician density, education expenditure per capita and electricity access (regression)
Youth literacy rate (% of population 15-24 years)	Public education expenditure per capita (regression)
Annual freshwater withdrawals, total (% of internal renewable water)	Domestic demand of water by agents: households, industry, agriculture (endogenous)
Access to electricity (% of total population)	GDPPPP per capita, electricity output, urbanisation and Palma ratio (regression)
Renewable electricity (% in total electricity output)	Supply of Electricity from Renewables and Total Electricity (endogenous)
Primary energy intensity (MJ / $PPP2011)	Total Primary Energy Supply and Real GDP (endogenous)
GDP per capita growth (%)	GDP (endogenous) and Population (exogenous)
GDP per person employed ($PPP2011)	GDP (endogenous) and Employed Population (exogenous)
Employment-to-population ratio (%)	Exogenous
Manufacturing value added (% of GDP)	Value Added in Manufacturing and GDP (endogenous)
Total energy and industry-related GHG emissions over sectoral value added (t of CO_2e / $PPP2011)	Industrial Emissions and Value Added in the Industrial sector (endogenous)
Palma ratio	Sectoral VA, public education expenditure per capita, unemployment and corruption control (regression)
CO_2 intensity of residential and transport sectors (t of CO_2 / t of oil equivalent energy use)	Demand of Fossil Fuels and Emissions in Residential and Transport sectors (endogenous)
Material productivity ($PPP2011/ kg)	Material (mining) Use in Heavy Industry sector and GDP (endogenous)
Net GHG emissions from agriculture, forestry and other land use (AFOLU) sectors per square metre of forest and agricultural land (t of CO_2e / sq. m)	Emission in agriculture (endogenous), other emissions (exogenous)
Compliance to Conditional INDCs*	GHG Emissions (endogenous)
Gap from equitable and sustainable GHG emissions per capita in 2030 (t CO_2eq)**	GHG Emissions (endogenous)
Marine protected areas (% of territorial waters)	Exogenous
Terrestrial protected areas (% of total land area)	Exogenous
Forest area (% of land area)	Land use in the Forestry sector (endogenous)
Endangered and vulnerable (animals and plants) species (% of total species)	Exogenous
Corruption Perception Index	Exogenous
General government gross debt (% of GDP)	GDP and government debt (endogenous)
Research and development (R&D) expenditure (% of GDP)	R&D Value Added and GDP (endogenous)

Table AII 1. *APPS indicators and dependent variables from ICES model*

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