Long-term economic growth and environmental pressure: reference scenarios for future global projections

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Abstract

Future projections of the impact of international climate change (and other) policies are usually presented against a "business as usual" baseline or a reference scenario. As a wide range of possible factors can affect the economic growth projections, it is useful to depict a range of possible developments. This paper presents a set of global representative scenarios that may provide alternative perspectives on future socio-economic developments and compare these scenarios in terms of their respective economic and environmental consequences. The scenarios are based on the Shared Socioeconomic Pathways (SSP) storylines developed by the Integrated Assessment Modelling Consortium (O'Neill et al., 2012). The different scenarios (i.e. SSP representations) are then framed in terms of how they affect different elements that influence growth, such as demographics, education and technology convergence. Given the long-term nature of some of the major environmental challenges, including climate change, the time horizon is 2100.

This paper typically assumes a convergence process, though placing special emphasis on the drivers of GDP growth over the projection period rather than projecting convergence only on income levels. Based on this, long-term projections are made for key drivers of per capita economic growth (e.g. total factor productivity and human capital). Together with population growth, these drivers are then used to project GDP pathways for more than 175 countries, representing 98.5% of global GDP in 2010.

Keywords: growth, convergence, climate

JEL classifications: O41, O44, Q34, Q43

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1 INTRODUCTION

Future projections of the impact of international climate change (and other) policies are usually presented against a “business as usual” baseline or a reference scenario. But a wide range of possible factors can affect the economic growth projections. It is therefore useful to depict a picture of possible developments. This paper presents a set of global representative scenarios that may provide alternative perspectives on future socio-economic developments and compare these scenarios in terms of their respective economic and environmental consequences. The scenarios are based on the Shared Socioeconomic Pathways (SSP) storylines developed by the Integrated Assessment Modelling Consortium (O’Neill et al., 2012). The SSPs are part of a new scenario framework for the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The scenario process and SSPs framework are described in Moss et al. (2010), and van Vuuren et al. (2012). The framework combines climate forcing (as represented by the Representative Forcing Pathways) and socio-economic conditions on the other. Together, these describe a framework for assessing scenarios on climate change mitigation, adaptation and residual impacts.

Baseline economic scenarios underlying global environmental economic projections typically assume that globally, income levels will gradually converge towards those of most developed economies. This paper takes a similar approach, though placing special emphasis on the drivers of GDP growth over the projection period rather than projecting convergence only on income levels. Given the importance of natural resource exploitation for GDP is certain countries, specific attention is paid to the development of income from natural resources, especially natural gas and crude oil.

The purpose of this paper is to introduce a detailed methodology for making consistent long-term economic projections for most countries in the world. The methodology is based on the ENV-Growth model, which starts by mimicking short-term economic projections of the OECD and IMF up to 2016, and then projects a gradual process of convergence towards a balanced growth path along the lines of an augmented-Solow growth model (so called *conditional-convergence* hypothesis, Barro&Sala-i-Martin, 2004). The model assume that country income levels will gradually converge towards those of most developed economies, and places special emphasis on a detailed set of the drivers of GDP growth over the projection period rather than projecting convergence only on income levels. Based on this, long-term projections are made for key drivers of per capita economic growth. the speed of convergence speed depends on the driver and the scenario. Together with population growth, these drivers are then used to project future paths for GDP of more than 175 countries, representing 98.5% of global GDP in 2010.

This methodology is then applied to construct illustrative pathways of per capita income levels for each of the SSP scenarios. The different SSP scenarios are framed in terms of the challenges they present for climate change adaptation and mitigation and characterised by their storylines. Detailed attention is given here to how these storylines affect different elements that influence growth, most notably demographic trends, education levels, the speed of convergence of income of less developed countries, technological progress, trade openness and the long term savings and investment profile.

The paper is structured as follows. Section 2 describes the ENV-Growth model that is used for making the projections. Section 3 discusses the interpretation of the different SSP storylines and the consequences for the drivers of economics growth. Section 4 presents the resulting income projections for the SSP scenarios. Section 5 concludes.

2 THE ENV-GROWTH MODEL

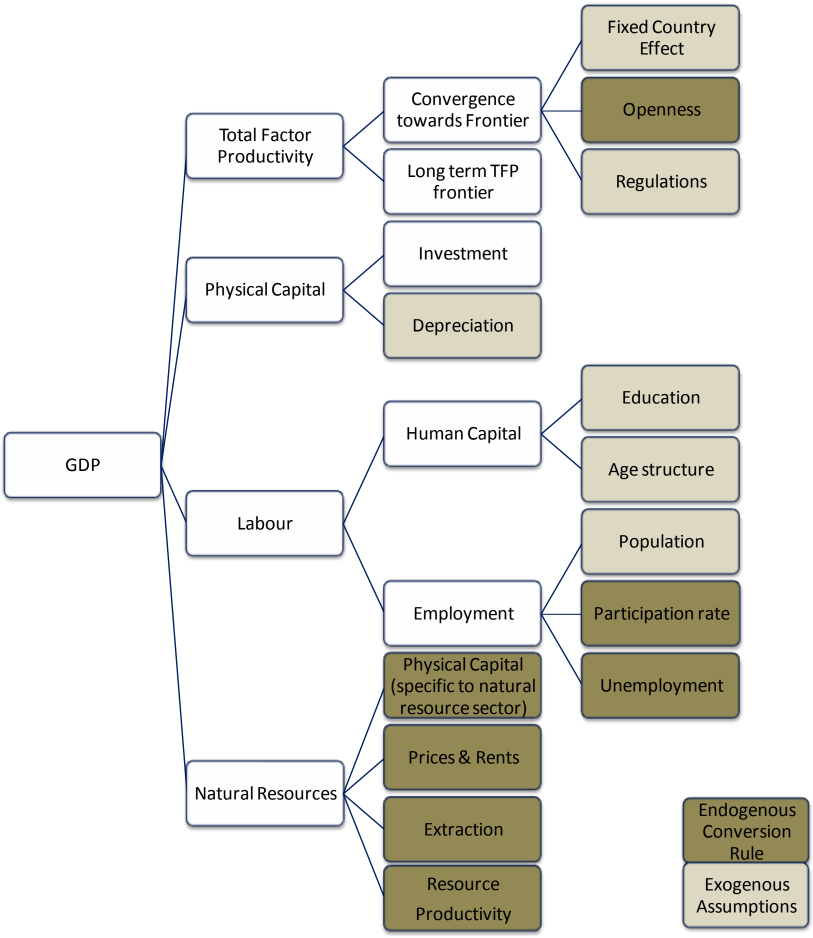
2.1 Modelling framework

The OECD modelling framework for projecting future global and country-specific GDP levels is based on the assumption that income levels of different countries will gradually converge towards those of most developed economies (Barro and Sala-i-Martin, 2004). Future GDP projections are then conducted using an augmented Solow growth model (Mankiw et al., 1992). The OECD model, ENV-Growth, places special emphasis on the drivers of GDP growth over the projection period rather than projecting convergence directly on income levels.

The core of the model is based on the methodology developed by the OECD Economics Department (Duval and De la Maisonneuve, 2010; OECD, 2012), which develops a "conditional growth" framework to make long-term GDP projections and applies it to OECD countries with a 2050 time horizon. The ENV-Growth model applies this methodology to a longer timeframe, until the end of the century, and to a larger set of countries, including non-OECD countries. The model has also been enhanced to include fossil-fuel energy both as a production input as in Fouré et al. (2012) and as resource revenues for oil and gas producing countries.

The model is based on long-term projections of five key drivers of economic growth: (i) physical capital; (ii) employment, in turn driven by population, age structure, participation and unemployment scenarios; (iii) human capital or labour efficiency, driven by education; (iv) energy demand, energy efficiency and natural resources (oil and gas) extraction patterns; and (v) total factor productivity (TFP). Gradual convergence of regions towards the best performing countries is projected at a speed of 1-5 percent, depending on the driver. Figure 1 graphically represents the methodology; the some model equations are presented in the Annex.

Figure 1. Schematic overview of the OECD ENV-Growth model



As in Solow's (1956) seminal work, the continuous improvement in TFP leads to more effective production as more output can be created with the same combination of primary factors (capital, labour and natural resources). The ENV-Growth model features additional input-specific factor productivity for labour and energy demand. More specifically, human capital developments capture the education-driven increases in labour productivity, while autonomous energy efficiency increases the productivity of energy inputs.

TFP growth is a combination of two elements: (i) countries gradually converge towards their long-term TFP frontier; (ii) the long-term TFP frontier itself grows over time. As the long term TFP frontier is country-specific, all countries will observe some convergence to their own frontier. In that sense, there is no group of "frontier countries" that have already achieved full convergence. More technologically advanced countries are however closer to their frontier and therefore grow less rapidly than countries that are further from the frontier.

The conditional convergence hypothesis underlying the dynamic process in this model implies, *ceteris paribus*, that countries that are farther from the frontier converge faster. Moreover, as suggested by OECD (2012), the speed of convergence towards the frontier is also influenced by fixed country effects (reflecting a wide variety of specific factors), product-market regulations and international trade openness. The key concept of the latter component is that countries that are more open will have easier access to advanced technologies and learning. Greater country openness boosts domestic productivity.

Energy resources come into play as productive inputs for energy consumers (gains in energy efficiency as a driver of economic growth) and as additional revenues from specific oil and gas sectors for producing countries (value added generated from extracting resources). The contribution of energy resources to GDP of producing countries (World Bank, 2011) is derived from country-specific resource depletion modules. These sub-models describe the interplay between oil and gas reserves and resources, together with parameters reflecting the time evolution of marginal production costs, and are used to project prices and production levels.

2.2 Model calibration

Projections of GDP levels are determined for 177 countries, representing 98.5% of global GDP in 2010. The projections replicate short-term economic projections of the World Bank (2011), OECD (2011) and the IMF (2011) up to 2016. The model then follows a gradual process of convergence towards a balanced growth path along the lines of the Solow growth model.

The first step of the calibration process was to compile an historical database for all the countries considered. The strategy was to rely on the World Bank world development indicators database (December, 2011 release) from 1960-2010 for non-OECD countries, and on the OECD Economic Outlook database (December 2011) for OECD countries for the period 1960-2013 (thus including short-run OECD projections). All variables in real value terms (GDP, government expenditures, etcetera…) are brought onto a common metric by expressing them in 2005 USD in PPP terms (last available year of the world bank ICP program).

For the countries where IMF projections (from World Economic Outlook database – September 2011) are available for the period 2010-2016 data and historical trends are extrapolated to make projections starting in 2017.

Historical energy demands in Mtoe were extracted from IEA Extended Energy Balance (2011) while their projections up to 2016 rely on IEA World Energy Outlook (2011). The labour force database (participation rates and employment rates by cohort and gender) was built upon the use of ILO(2011) active population prospects (up to 2020) and OECD Labour Force Statistics and Projections, 2011),.

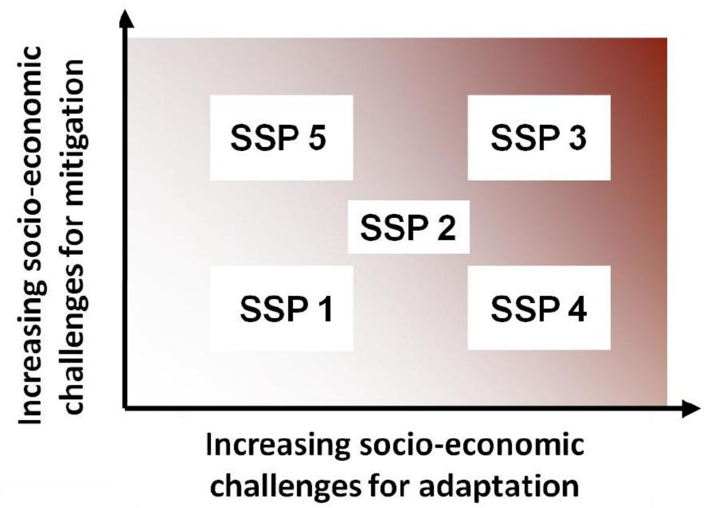
Physical capital stock were built-up from investment series through the perpetual inventory method, assuming a 5% annual depreciation rate. The Historical total factor productivity (TFP) and Autonomous Energy Efficiency (AEE) where derived by inverting GDP law of motions and Energy demands equations, as in Fouré et al. (2012) .

Scenarios can be differentiated by the elements influencing growth, including demographic trends, education levels, the speed of convergence of income of less developed countries, technological progress, trade openness and long term savings and investment.

3 INTERPRETATION OF THE ECONOMIC DIMENSION OF THE SSP STORYLINES

The different SSP storylines are described in O'Neill et al. (2012), and summarised in Annex II. These storylines revolve around two axes: challenges to mitigation and challenges to adaptation, as illustrated in Figure 2.

Figure 2. Schematic representation of the SSPs



Source: O'Neill et al. (2012).

The narratives for these 5 scenarios contain some information on the economic projections consistent with these SSPs. For instance, in SSP1 per capita income growth is assumed to be "medium" for low and middle income countries, and "fast" for high income countries. Given the model set-up explained in the previous section, these narratives are translated into assumptions for specific model inputs.

The scenario-specific assumptions are illustrated in Table 1. Assumptions related to TFP drivers in SSP4 are differentiated between income country groups, namely low-income (LI) countries, Middle-Income (MI) countries, and High-Income (HI) countries.[1]

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[1] High income countries are based on the World Bank classification of countries (http://data.worldbank.org/about/countryclassifications; for 2010, the threshold for the high income group is 12,275 USD/capita). Middle income countries combine all World Bank upper-middle income countries, and those lower-middle income countries that have (i) at least 2,500 USD/cap income in 2010 (excluding the poorest countries in this group), plus (ii) at least 2% growth projected for 2010-2015 (excluding stagnant countries), and (iii) income above 4,000 USD p.c. or growth above 4% (i.e. identify the high achievers in the group in terms of either income or growth). Low income countries are all other lower-middle income

Table 1. SSP scenario-specific assumptions for key growth drivers

	SSP1	SSP2	SSP3	SSP4	SSP5
TFP-related drivers					
TFP frontier growth	Medium high	Medium	Low	Medium	High
Convergence speed	High	Medium	Low	LI: Medium low MI: Medium HI: Medium	Very high
Openness	Medium	Medium	Low	LI: Low MI: Medium HI: Medium	High
Natural resource-related drivers					
Prices	Low	Medium	High	Oil: High Gas: Medium	High
Resources[1]	Conv: Medium Unconv: Low	Medium	Conv:Medium Unconv: High	Low	Oil: Low; Gas: High
Demographic drivers[2]					
Population growth	Low - Medium	Medium	Low - High	Low - High	Low - High
Education	High	Medium	Low	Very low - Medium	High

Notes:

1. "Conv" stands for conventional; "Unconv" stands for unconventional.

2. Demographic projections are summarised from Lutz and KC (2012).

Population projections are taken directly from IIASA (see Lutz and KC, 2012). Total employment results from the combination of time-dependent participation rates, which are specific for each age cohort, and projected unemployment levels. Age and gender participation rates are taken from the International Labour Organisation projections up to 2020 (ILO, 2011). Then the convergence process applies to participation rates by cohorts and gender, based on various relevant variables such as ratio of dependency and education levels. Unemployment levels are assumed to converge very slowly to a structural level of 2%. For most countries, this convergence process is still ongoing by the end of the century.

Detailed *education* projections by gender and age are also taken directly from IIASA (Lutz and KC, 2012). These are converted into a human capital index using mean years of schooling as an intermediate variable, following the formulation of Hall and Jones (1999) as well as estimates from Morisson and Murtin (2010). Increases in human capital effectively reflect labour productivity increases.

Capital inputs follow the standard capital accumulation formulation with a fixed depreciation rate of 5% per year. The investment rate per unit of GDP slowly converges to a balanced growth path level, depending

countries plus all low income countries from the World Bank classification. This classification on countries, and especially the thresholds for the middle income country group, is chosen to highlight the elements in the SSP storylines that differentiate between developing countries that have good opportunities to catch up to higher income countries, and countries that are in a more challenging situation.

on the structural parameters of the production function. A possible future extension of the methodology would be to endogenize the saving-investment current account dynamics as done by Fouré et al. (2012) or by OECD Economics Departement (2012). However, if the saving-investment relationship were fully endogenized one cannot control the capital accumulation process in a way that is consistent with the narrative stories underlying the 5 SSP scenarios without explicitly defining the drivers of changes in savings behaviour. Therefore, the current version of the model only models investments, and not savings.

Energy resources are included through two channels. First, the domestic level of energy productivity (gains in energy efficiency that contribute to economic growth) is calibrated to match historical improvement rates and gradually converges to an efficiency frontier that reflects state-of-the-art standards in energy appliances. For the projection the law of motion of AEE as estimated by Fouré et al. (2012) is used, which assumes a U-shaped relation between economic development and energy productivity.

Secondly, country-specific resource depletion modules are calibrated for oil and gas using SSP-specific assumptions on energy prices and extraction rates. These assumptions are based on the energy-related storylines of the SSPs and summarised in Table 1.

Following the OECD Economic Department methodology *TFP growth* is based on an empirical specification underlying TFP convergence process draws on recent work by Bourlès et al. (2010) and Bouis et al. (2011). It accounts for the effect of international spillovers and competitive policies by explicitly allowing productivity to depend on product market regulations.

One driver of the convergence process, and future productivity, is the development of *openness*. The amount of trade between countries is likely to be increasing in domestic and trading partners' income (or income per capita) reflecting that as countries becomes wealthier they trade more. Conversely, all else equal, larger countries are likely to trade less as they have access to a larger domestic market. Transportation costs and other costs or barriers to trade potentially reduce the amount of trade (*e.g.* Leamer and Levinsohn, 1995). Thus, the model assumes that the speed of convergence towards the long-run TFP frontier to depend on openness.

Physical capital stock were built-up from investment series through the perpetual inventory method, assuming a 5% annual depreciation rate. The historical total factor productivity (TFP) and Autonomous Energy Efficiency (AEE) where derived by inverting the law of motion for GDP and energy demands equations, as in Fouré et al. (2012).

4 RESULTING INCOME PROJECTIONS

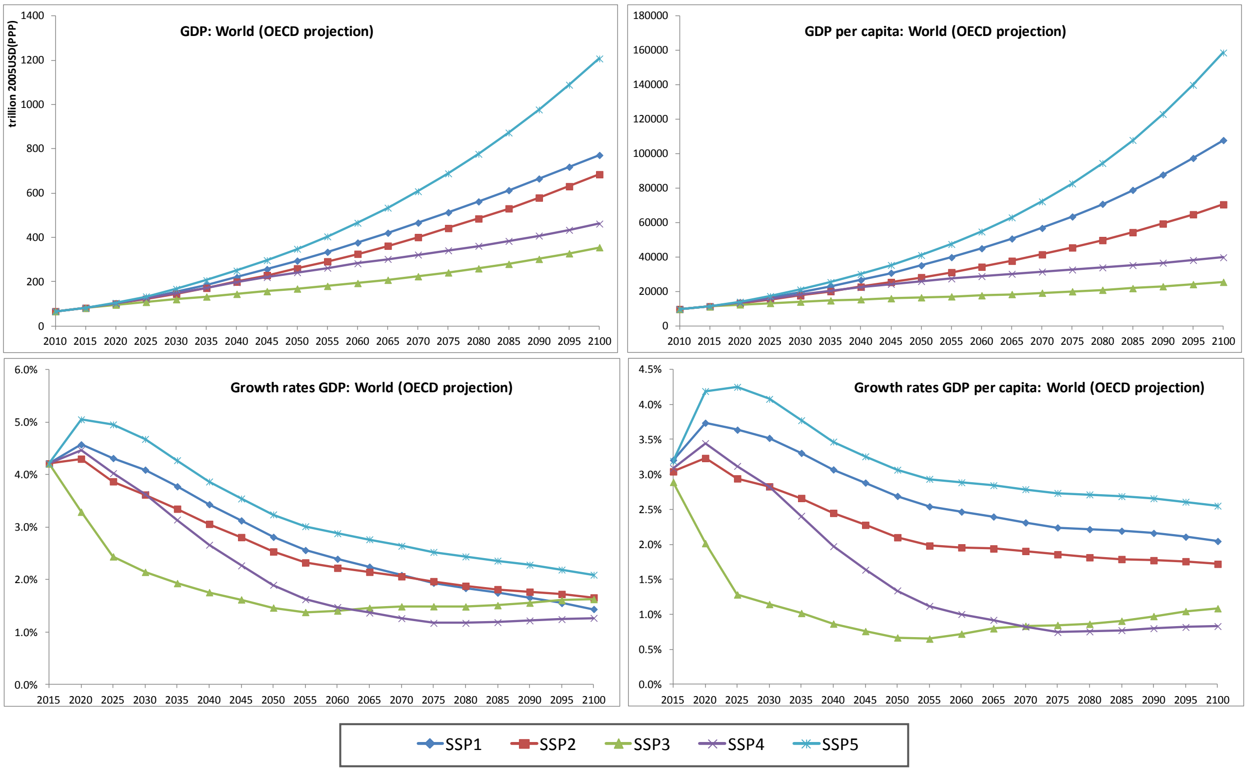
4.1 A comparison of the SSPs

While the purpose of the SSP scenarios is in itself not to cover the full spectrum of plausible economic projections, global GDP levels by the end of the century vary substantially across SSPs, as shown in Figure

3.[2] The range of global GDP levels at the end of the century varies from just over 355 trillion USD to more than 1200 trillion USD, with SSP3 at the bottom of the range, and SSP5 at the bottom. This pattern is similar for per capita income levels, even though the population projections vary across scenarios.

SSP5, with its focus on development, not surprisingly has the highest income projections, with global GDP increasing more than 18-fold between 2010 and 2100, and per capita income increasing 16-fold. This is induced by growth rates of per capita income that remain well above 2% per annum throughout the century. SSPs 3 and 4, which represent the scenarios with lowest international co-operation, are at the bottom of the range. They both see marked reductions in global growth to around 1% per annum; the drop in global growth occurs almost immediately in SSP3, and around mid-century in SSP4. SSP 3 in particular shows very low growth in income (less han a three-fold increase over the century), following the assumptions on low growth rates of the economic drivers. SSPs 1 and 2 have intermediate growth rates. SSP1 is higher at global level mostly as it is based on quicker convergence. Further, given the higher population projections in SSP2, per capita income levels diverge between SSPs 1 and 2 more than absolute GDP levels.

Figure 3. Global GDP (bln 2005USD) and income levels (2005USD) for the 5 SSPs and associated annual growth rates (%/year)



[2] Remember: GDP and income (per capita GDP) levels are presented in 2005USD using PPPs; growth rates are average annual growth rates over a 5-year period.

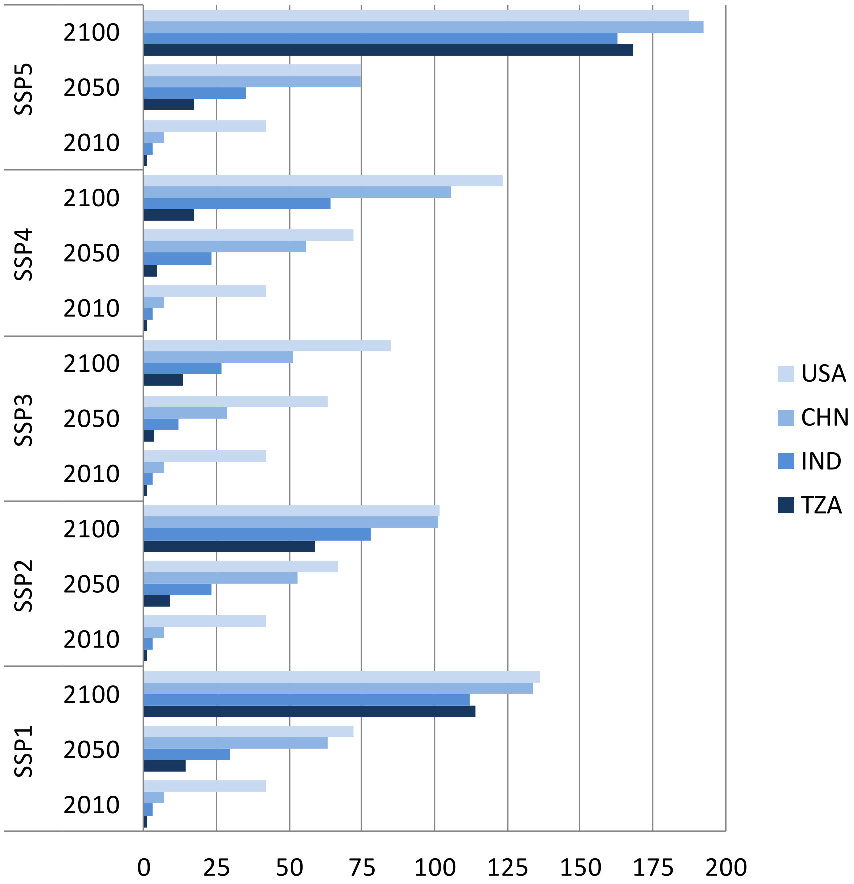
Although results at global level show a certain ranking between the different SSPs, the same ranking does not hold for all countries. Figure 4, panel A illustrates the income levels in the different SSPs for a few selected countries: USA, India, China and Tanzania. While SSPs 1 and 5 are respectively at the bottom and top of the range for all countries considered, there are substantial differences in the other SSPs. In particular, SSPs 2 is higher than SSP 4 in advanced economies such as the USA but lower in countries at lower stages of development such as India and Tanzania. The two SSPs are very similar in the case of China. The figure also illustrates that income convergence is a slow process. In most SSPs, by 2050, per capita GDP in India remains about half of China per capita GDP, which is itself roughly half of the US level. By 2100, per capita GDP convergence is particularly striking in SSP1 and SSP5 for India and Tanzania, which largely catch up with China and the USA (and the USA income level in itself is much higher than in 2010 and 2050). The inequalities remain much sharper in SSP3 and SSP4.

The graphs in Figure 4, panel B illustrate how the timing of income growth also differs across countries. In some countries, such as China, income grows quickly at the beginning of the century and then slows down. In other countries, such as India, income grows almost exponentially in the development-oriented scenarios, esp. SSP5. For the SSPs with at least medium convergence speed (SSPs 1, 2 and 5), the income growth rates follow a typical convergence pattern. Advanced economies such as the USA follow a relatively stable growth path, with annual growth declining somewhat in the coming decades due primarily to aging of society (which among others leads to lower overall participation rates and hence less employment). Emerging economies such as China and India grow much faster at the beginning of the century, but over time their growth rates diminish as their state of technology (i.e. TFP levels) get closer to the high-income countries. For China the decline in the growth rates is accelerated by the age structure of their society: unlike India they do not have a large pool of young people that will sustain economic development in the coming decades. For the less developed countries, including Tanzania, the process of convergence is still in its infancy: capital inflows into the economy is still scarce (although the short-term forecast is that capital grows with around 7% per annum in this decade), and returns to capital investments are high. This triggers increasing growth rates and a gradual catch-up in productivity (tfp), which eventually declines again as capital becomes more abundant and tfp levels converge.[3] Thus, a typical hump-shaped overall growth pathway emerges for most developing countries.

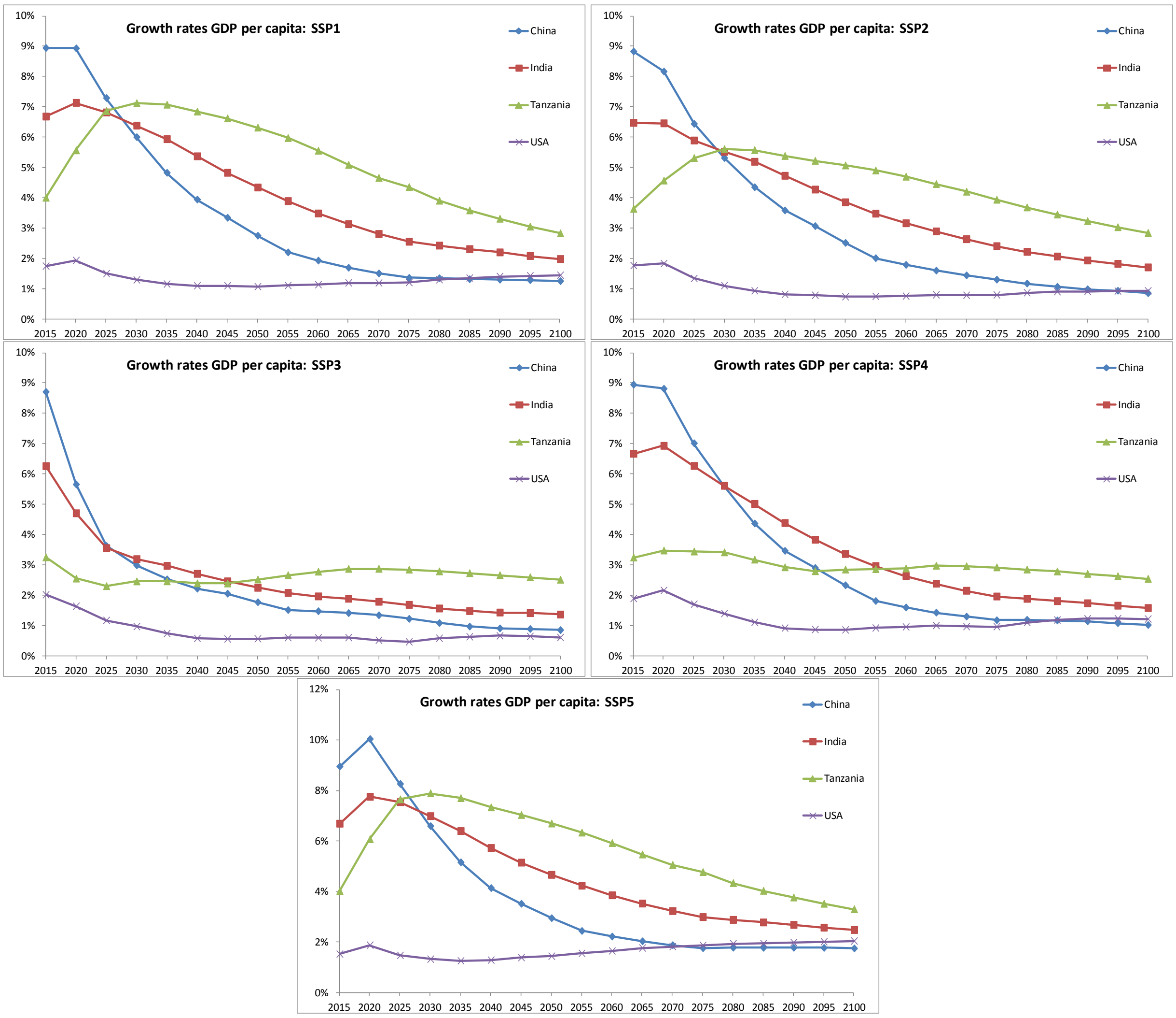
[3] The fact that the income growth rates is projected to peak at around 7% in most developing countries highlights the extraordinary nature of the current economic boom in China.

Figure 4. Income levels in selected countries across the 5 SSPs (2005USD)

A. Income levels



B. Growth rates



4.2 Income convergence

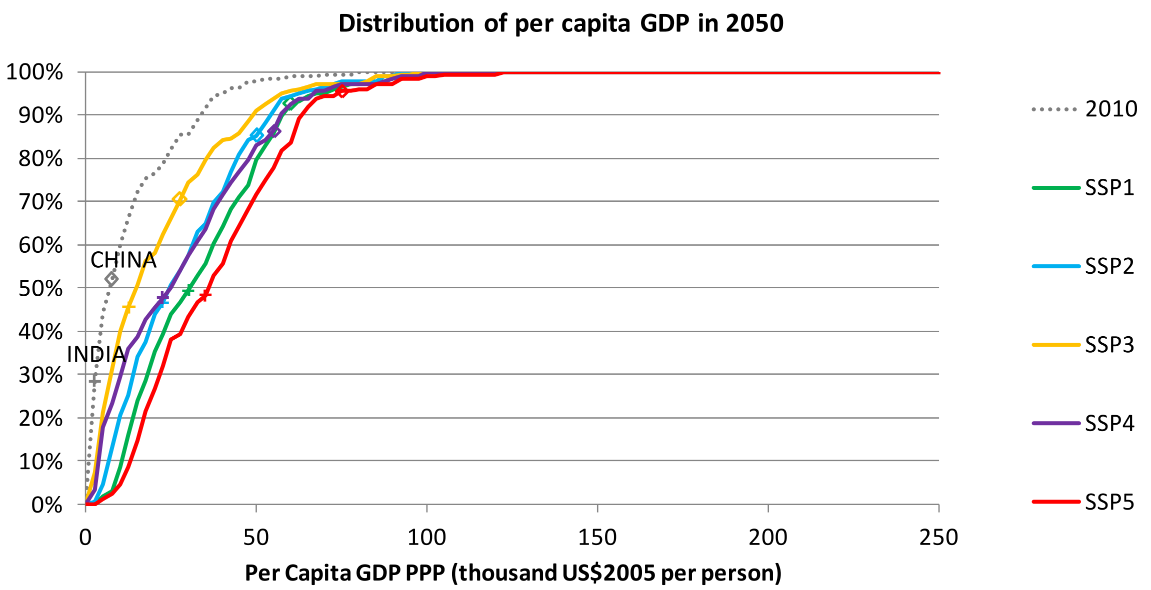
The SSPs lead to very different results in terms of convergence. Figure 5 illustrates the distribution of per capita income in 2010, 2050 and 2100, and indicates the positions of China and India in these distributions. The steep line for 2010 indicates a high degree of income inequality, with income levels in the majority of countries below 7,500 USD. By 2050 (panel A), the various SSPs exhibit limited discrepancies in the general distribution of per capita income; the median per capita income lies between 15 and 35 thousand USD.

Although the chart shows relatively similar distributions of income across scenarios, the relative position of countries for a given scenario changes significantly. For example, Chinese per capita income in SSP3 is close to 30 thousand USD and is positioned right before the third quartile of the distribution, while other scenarios induce much faster growth in China and places the country amongst the 10% highest income countries in the world. India grows much faster in the first half of the century and sees average per capita income reaching medium income level by 2050 in most scenarios.

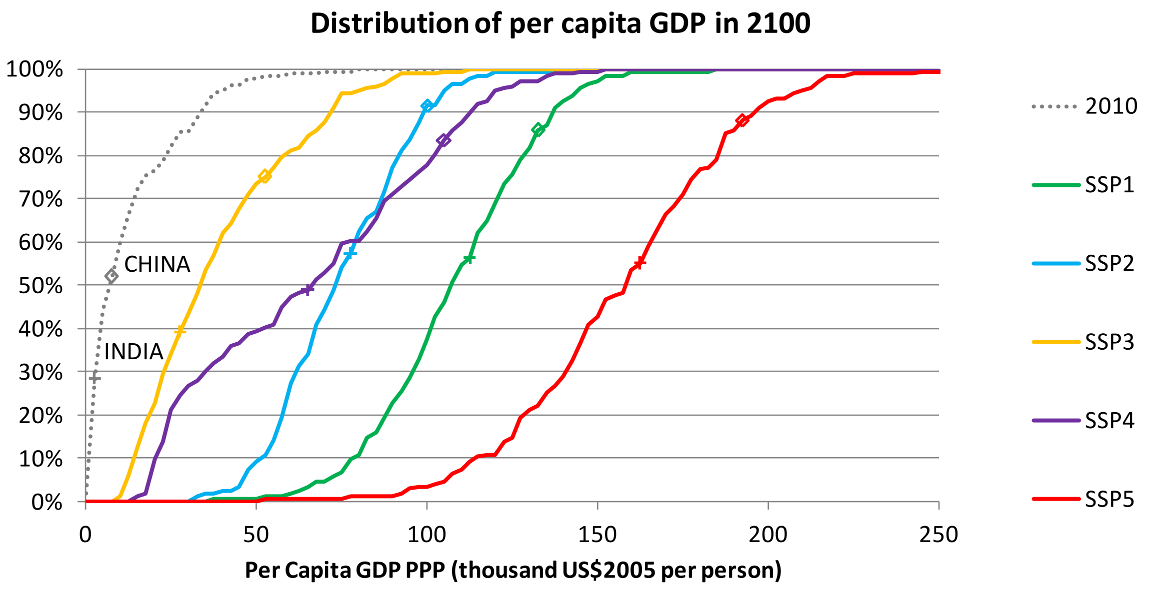
The key determinants of the SSP storylines produce more significant changes later in the century. The resulting spread in income distribution across countries is a lot wider in 2100 (panel B) than in 2050 (panel A). By 2100, in all scenarios but SSP3, per capita income levels of more than half of the countries covered by the analysis will exceeded by far the current level of USA income, i.e. about 45 thousand USD. By looking at the sizeable gap between first and third quartiles (i.e. the relatively rich and poor) of the SSP4 distribution and how it crosses SSP2, the figure clear shows how inequitable the world is in the SSP4 storyline. The other SSPs show less variance, and more relative convergence in per capita income levels in 2100 across countries.

Figure 5. Distribution of income levels

A. Year 2050



B. Year 2100



Another way to look at income convergence at world level is to consider income inequality indicators. The population-weighted income inequality across countries (not within countries), better known as the Gini coefficient, measures the degree of inequality as an index, with 0 indicating a perfectly equal distribution and higher values indicating higher degrees of inequality. As shown in Table 2, global income inequality (currently equal to 0.64 for the sample of countries considered and for the USD2005PPP exchange rates) reduces particularly in SSPs 1, 2 and 5, reaching the values of 0.12, 0.15 and 0.11, respectively, by the end of the century. In SSPs 3 and 4, international income inequality differences are much more persistent, with inequality coefficients of 0.43 and 0.54, respectively. This is not suprising given that these two scenarios are based on storylines reflecting a persistent inequality and a lower economic convergence.

An alternative is the ratio of the highest income over the lowest income. For 2010, this ratio equals 249. This ratio declines drastically in all SSPs, though more so in SSPs 1, 2 and 5. SSP3, in which all countries have relatively low incomes, is the scenario for which the high/low ratio remains highest. This result differs when looking at the income inequality indicator, for which SSP4 has the lowest value. While the income inequality indicator is based on a group of countries, the high/low income ratio is more sensitive to the specific values of the lowest and highest income countries.

Table 2. Selected indicators for income convergence in the SSPs

	2010	2100				
		SSP1	SSP2	SSP3	SSP4	SS5
Highest income (thousands USD)	78	182	134	108	150	276
Lowest income (thousands USD)	0.3	34	28	6	11	48
Income inequality	0.64	0.12	0.15	0.43	0.54	0.11

Ratio high/low	249	5	5	18	14	6

4.3 Drivers of growth

To better understand the differences in results between the SSPs, Figure 6 illustrates the drivers of growth for selected countries. The results show that capital is a main driver of growth, together with increases in tfp. Labour supply and human capital plays an important role especially in the context of a low income countries like Tanzania, and countries with relatively young populations such as India.[4] It is also fundamental to consider the reliance on natural resources. In China there is a decreasing reliance on natural resources, especially in SSP1, which reflects a more sustainable future development, although the overall impact on economic growth is not large. Population growth plays a dual role in these projections: on the one hand can it increase labour supply levels (although with aging populations and age-specific participation rates labour supply trends do not strictly follow population trends), and on the other hand will it imply that total income has to be divided over more individuals. The "Population" bars in the graph reflect the second role.

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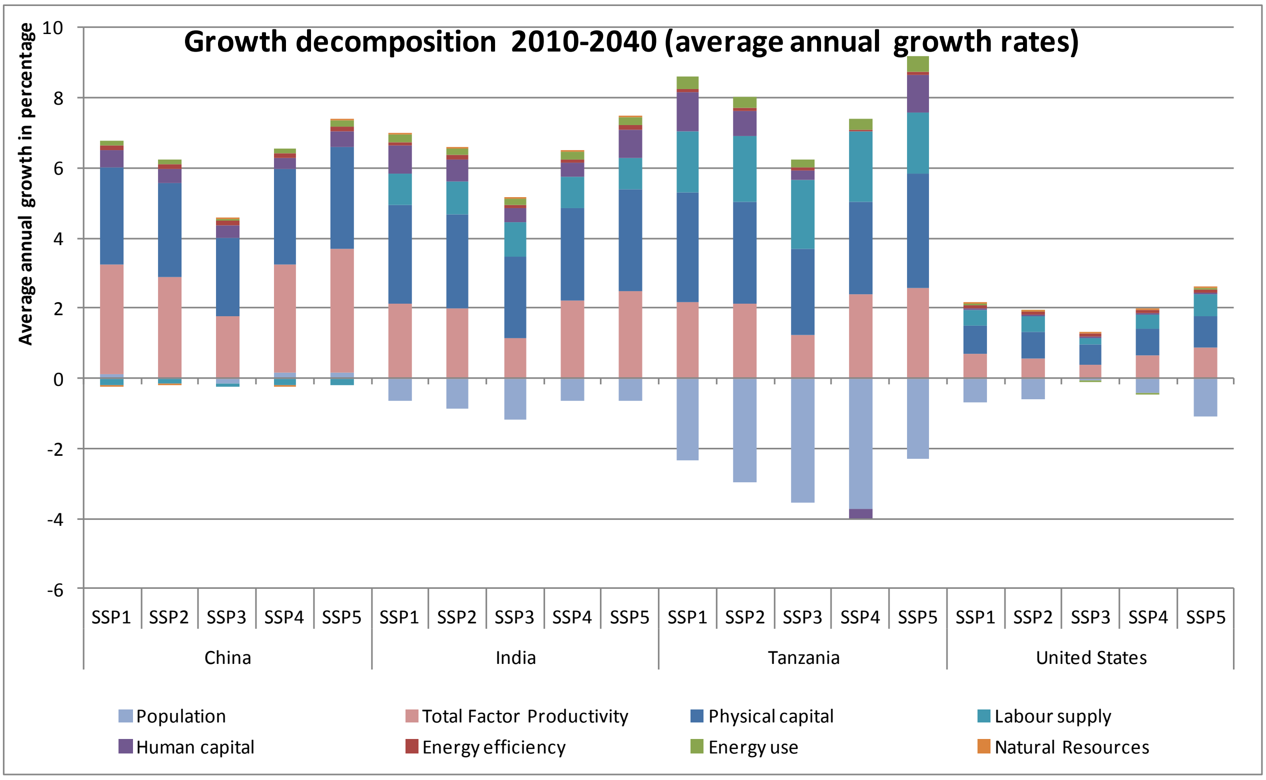
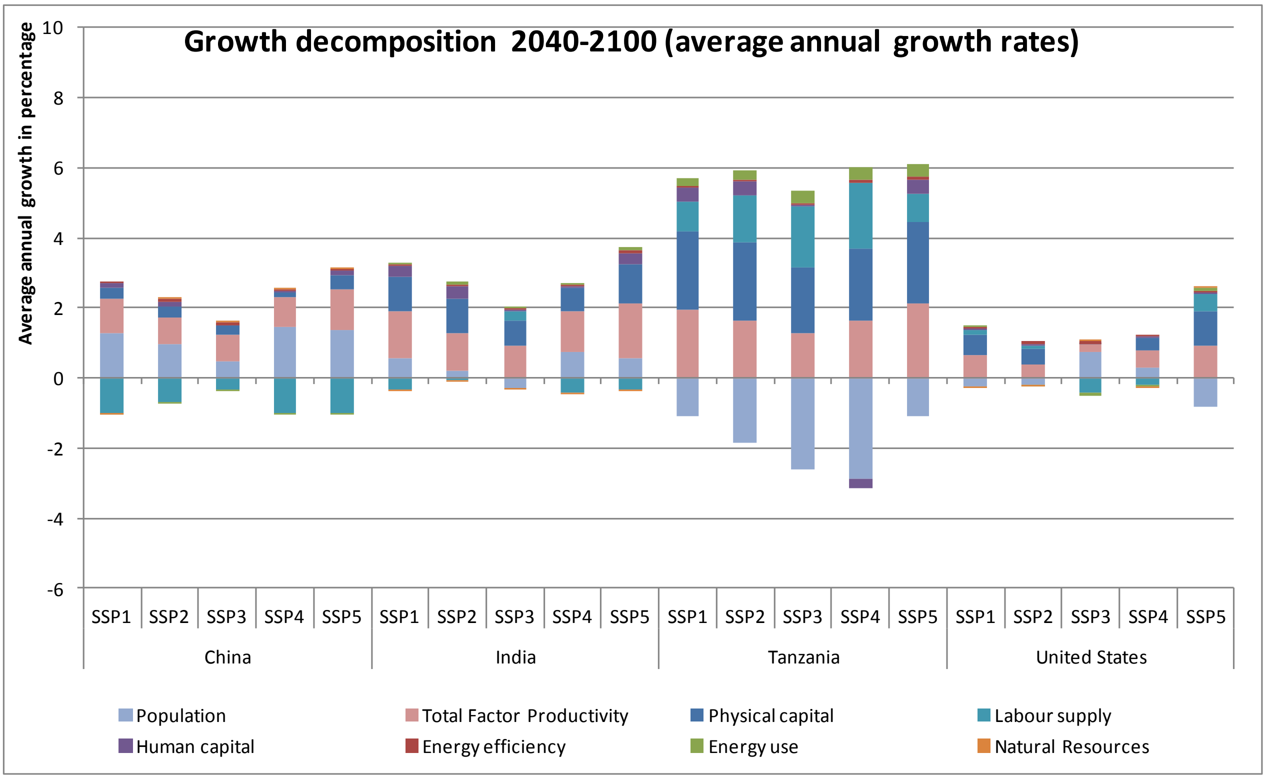
[4] The Constant Enrollment Numbers assumption for education in low income countries adopted in SSP4 imply that a decreasing share of the population has access to proper schooling, and hence human capital levels are falling over time in this scenario.

Figure 6. Drivers of growth in selected countries for the five SSPs (annual growth rates)

A. Short and medium term (2010-2040)

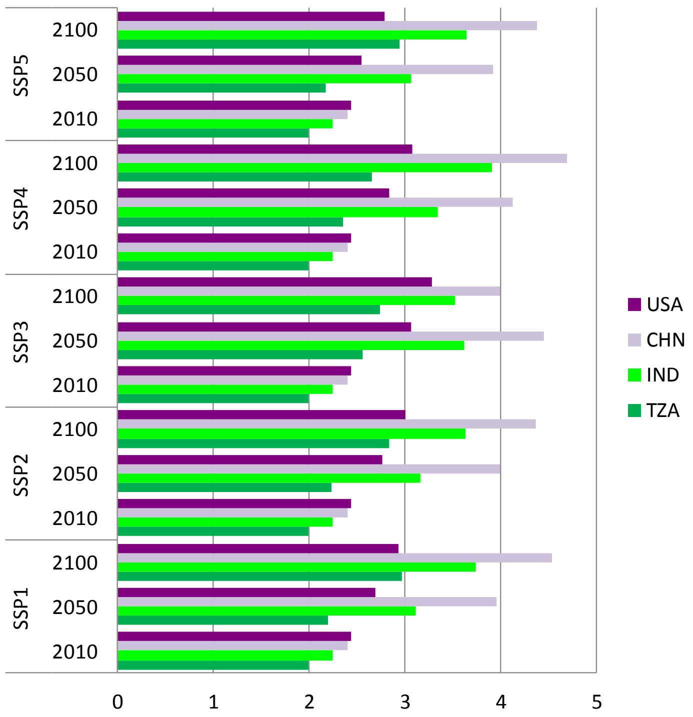


B. Long-term (2040-2100)



Finally, Figure 7 shows capital intensity of the economies. In all countries, capital intensities increase over time, reflecting that none of the economies are fully on a balanced growth path yet. India, and especially China, overtake the USA in capital intensity, to support their high growth rates. Tanzania also boosts its capital intensity, but as it starts from a much lower level it remains the least capital intensive of this set of countries.

Figure 7. Capital intensity in selected countries for the five SSPs



5 CONCLUSIONS

This paper introduced a detailed methodology for making consistent long-term economic projections for most countries in the world. The ENV-Growth model, based on a gradual process of conditional convergence towards a balanced growth path, has been presented as a tool to project different future scenarios to be used as a reference for future projections of the impact of international climate change (and other) policies. The methodology has been applied to construct illustrative pathways of per capita income levels for the five each of the SSP scenarios. The different SSP scenarios are framed in terms of how they affect different elements that influence growth, most notably demographic trends, education levels, the speed of convergence of income of less developed countries, technological progress, trade openness and the long term savings and investment profile.

[To be completed]

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ANNEX I. EQUATIONS IN THE ENV-GROWTH MODEL

In the model, GDP (Y) is calculated as a function of capital (K), labour (a combination of human capital h and the labour force L), energy (E) and the value added of the natural resource exploitation sector (VA^{NR}):[5]

(1) $$Y_{r,t} = \left[\alpha_{VA} \left(A_{r,t} \cdot \left(K_{r,t}\right)^{\alpha_{r,t}} \cdot \left(h_{r,t} \cdot L_{r,t}\right)^{1-\alpha_{r,t}} \right)^{\frac{\sigma_E - 1}{\sigma_E}} + (1-\alpha_{VA}) \cdot \left(\lambda^E_{r,t} \cdot E_{r,t}\right)^{\frac{\sigma_E - 1}{\sigma_E}} \right]^{\frac{\sigma_E}{\sigma_E - 1}} + VA^{NR}_{r,t} - P^E_{r,t} \cdot E_{r,t}$$

Total factor productivity (A) depends on the existing TFP levels and on the long-term TFP frontier:

(2) $$A_{r,t} = A_{r,t-1} \cdot \left[\frac{A^{LT}_{r,t}}{A_{r,t-1}} \right]^{\rho_{r,t}}$$

The convergence rate (ρ) in turn is a function of the openness of the economy (Open):

(3) $$\rho_{r,t} = \frac{\rho^0 + \rho^{open} \cdot \left(Open_{r,t} - c^{open\_\rho}\right)}{1 + \rho^0 + \rho^{open} \cdot \left(Open_{r,t} - c^{open\_\rho}\right)}$$

(4) $$open_{r,t} = fe^{open}_{r,t} \cdot \left(open_{r,t-1}\right)^{c^{open}}$$

(5) $$A^{LT}_{r,t} = Exp\left\{ fe^{TFP}_{r,t} + e0 + g \cdot (t - t0) + a^{pmr} \cdot \left(pmr_{r,t} - c^{pmr}\right) \right\}$$

Capital input (K) equals the sum of the discounted cumulated capital and the new capital investment (I):

(6) $$K_{r,t} = \left(1 - \delta_r\right) \cdot K_{r,t-1} + I_{r,t-1}$$

(7) $$\frac{I_{r,t}}{Y_{r,t}} = \gamma^I_r \cdot \frac{I_{r,t-1}}{Y_{r,t-1}} + \left(1 - \gamma^I_r\right) \cdot i\_y^{LT}_{r,t}, \qquad with \qquad i\_y^{LT}_{r,t} \equiv \left(g^Y_r + \delta\right) \cdot \frac{\alpha_{r,t}}{MPC^{LT}_r}$$

(8) $$\alpha_{r,t} = \gamma^\alpha_r \cdot \alpha_{r,t-1} + \left(1 - \gamma^\alpha_r\right) \cdot \alpha^{struct}_r$$

Human capital (h) is calculated as:

(9) $$h_{r,t} = \overline{h_{r,t}}$$

Labour input (L) is a function of the unemployment rate (unr), the labour participation rate (pr) by age and gender (respectively indexed with a and g) and the population (Pop):

(10) $$L_{r,t} = \left(1 - unr_{r,t}\right) \cdot \sum_{a>15,g} pr_{a,g,r,t} \cdot Pop_{a,g,r,t}$$

[5] The natural resource exploitation sector includes oil and gas extraction.

(11) $unr_{r,t} = \gamma_r^{unr} \cdot unr_{r,t-1} + \left(1-\gamma_r^{unr}\right) \cdot unr_{r,t}^{struct}$

Total value added of the natural resource exploitation sectors depends on the prices of natural resources (PNR), the natural resource-specific capital inputs (KNR) and extraction levels (NR) for each type of resource (indexed by j):

(12) $$VA_{r,t}^{NR} = \sum_j P_{j,r,t}^{NR} \cdot \left[(1-\alpha_j^{NR}) \cdot K_{j,r,t}^{NR\;\frac{\sigma_j^{NR}-1}{\sigma_j^{NR}}} + \alpha_j^{NR} \cdot NR_{j,r,t}^{\frac{\sigma_j^{NR}-1}{\sigma_j^{NR}}} \right]^{\frac{\sigma_j^{NR}}{\sigma_j^{NR}-1}}$$

TFP dynamics is governed by an error-correction model estimated by OECD economic Department (2012):

(13) $$\begin{aligned} \Delta a_{i,t} &= \rho_{i,t}^{a}(a_{i,t}^{*} - a_{i,t-1}) \\ a_{i,t}^{*} &= \partial_i + g_t + PMR_{i,t}\beta \\ \rho_{i,t}^{a} &= h(O_{i,t}) \end{aligned}$$

where ait = log Ait, and i, and t indicates country and time; a* is the long-run TFP level which is given an exogenous long-term growth rate g common to all countries which corresponds to the pace of the world technological frontier. Contrarily to Economic Department procedure here the country specific time dummies δt are not estimated but calibrated in order to imply a smooth transition process between IMF medium term projection (up to 2013) and the long-run structural growth path described in the model.

Product market regulation (PMR) affects the level of MFP, while openness *O* affects the country-specific speed of convergence ρ towards the technological frontier. Over the long run, the level of MFP differs across countries, but the growth rate of productivity is the same, provided policies and other institutional settings are kept constant. Panel regressions are reported in OECD(2012).

Future openness is modelled as a reduced-form equation depending on domestic income, income of trading partners, population, competitiveness of countries (*e.g.* real exchange rate) and policy barriers to trade (*e.g.* PMR barriers to trade).

$$o_{i,t} = \alpha + \delta_1 o_{i,t-1} + \delta_2 y_{i,t-1} + \delta_3 y^{*}{}_{i,t-1} + \delta_4 pop_{i,t-1} + \delta_5 REER_{i,t-1} + \delta_6 T_{i,t-1} + \eta_i + d_t + \varepsilon_{i,t}$$

where *o, y*, y^*, *pop*, *REER* and *T* refer to log of openness (exports plus imports as a share of GDP), log of domestic income, log of trade weighed income of trading partners, log of population, log of real effective exchange rate and PMR trade regulations. *i* denotes country, *t* year, η country-fixed effects and d_t time fixed effects. To allow for non-linear or threshold effects of income and population on openness, the impact of these variables is allowed to differ, respectively, between high and low income countries and large and small countries in terms of population.

ANNEX II. BRIEF DESCRIPTION OF THE SSP STORYLINES[6]

The SSP storylines served as the starting point for the development of the quantitative SSP elements. Each storyline provides a brief narrative of the main characteristics of the future development path of an SSP. The storylines were identified at the joint Impacts, Adaptation and Vulnerability (IAV) and Integrated Assessment Models (IAM) workshop in Boulder, November 2011. A brief summary of the storylines are provided here for comprehensiveness. For further details and extended descriptions of the storylines, see O'Neill et al. (2012).

SSP1 - Sustainability

This is a world making relatively good progress towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. Elements that contribute to this are a rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, and a high level of awareness regarding environmental degradation. Rapid economic growth in low-income countries reduces the number of people below the poverty line. The world is characterized by an open, globalized economy, with relatively rapid technological change directed toward environmentally friendly processes, including clean energy technologies and yield-enhancing technologies for land. Consumption is oriented towards low material growth and energy intensity, with a relatively low level of consumption of animal products. Investments in high levels of education coincide with low population growth. Concurrently, governance and institutions facilitate achieving development goals and problem solving. The Millennium Development Goals are achieved within the next decade or two, resulting in educated populations with access to safe water, improved sanitation and medical care. Other factors that reduce vulnerability to climate and other global changes include, for example, the successful implementation of stringent policies to control air pollutants and rapid shifts toward universal access to clean and modern energy in the developing world.

SSP 2 - Middle of the Road (or Dynamics as Usual, or Current Trends Continue, or Continuation, or Muddling Through)

In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades,

[6] Copied from the supporting note on the SSP database, available at https--secure.iiasa.ac.at-web/apps/ene/SspDb.

leaving populations without access to safe water, improved sanitation, medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

SSP 3 - Fragmentation (or Fragmented World)

The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns such as air pollution. Countries focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Little international cooperation and low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and economic trends. Growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by high population growth, use of local energy resources and slow technological change in the energy sector. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security, including barriers to trade.

SSP 4 - Inequality (or Unequal World, or Divided World)

This pathway envisions a highly unequal world both within and across countries. A relatively small, rich global elite is responsible for much of the emissions, while a larger, poorer group contributes little to emissions and is vulnerable to impacts of climate change, in industrialized as well as in developing countries. In this world, global energy corporations use investments in R&D as hedging strategy against potential resource scarcity or climate policy, developing (and applying) low-cost alternative technologies. Mitigation challenges are thereforelow due to some combination of low reference emissions and/or high latent capacity to mitigate. Governance and globalization are effective for and controlled by the elite, but are ineffective for most of the population. Challenges to adaptation are high due to relatively low income and low human capital among the poorer population, and ineffective institutions.

SSP 5: Conventional Development (or Conventional Development First)

This world stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self interest. The preference for rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high GHG emissions and challenges to mitigation. Lower socio-environmental challenges to adaptation result from attainment of human development goals, robust economic growth, highly engineered infrastructure with redundancy to minimize disruptions from extreme events, and highly managed ecosystems.SS