Supplementary note for the SSP data sets

Contents

SSP Storylines

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 IAV and 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, 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 therefore low 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.

SSP Population Projections – Assumptions and Methods

Samir KC and Wolfgang Lutz

This section describes how the five SSP Storylines have been converted into projections of national populations by age, sex and level of educational attainment based on alternative assumptions about future fertility, mortality, migration and education transition assumptions.

The starting year for these alternative scenario projections is 2010. The estimated total population size as well as the age and sex structure for each country in this year is taken from the UN estimates and projections (the 2010 assessment). Age- and sex- specific proportions in the different educational attainment categories are taken from the IIASA data base of human capital reconstruction and projections. The empirical information for this further breakdown of the population into four attainment categories (never in school, some primary education, completed junior secondary and completed first level tertiary) comes primarily from censuses, national registers, and sample surveys such as DHS (Demographic and Health Surveys). These are also the primary empirical sources for education differentials in vital rates around the year 2010. For countries for which no such empirical information is available assumptions had to be made as indicated in the notes.

The method used for carrying out projections by age, sex and educational attainment level is a generalization of the standard cohort-component method of population projections. This standard method is based on the fact that the age group a in year t will be a+x in year t+x (it is the same birth cohort, i.e. group of people born in the same year) after adjusting for the effects of mortality and migration and applying fertility rates to derive the number of births (the three components of population change). In the multi-dimensional (multi-state) generalization the population is further sub-divided into clearly defined sub-populations (provinces of a country or in this application different educational attainment categories) which can have different fertility, mortality and migration patterns as well as transitions from one state to another. In the application of the model to educational attainment the model is simplified by the fact that most education transitions are concentrated in younger age groups and that these transitions can only go in the direction of higher education levels. This system of a population which is sub-divided into different education categories can then be projected into the future based on a set of assumed age- and sex-specific education transition rates as well as age-, sex- and education-specific fertility, mortality and migration rates. Alternative assumptions up to the year 2100 on all these model parameters will be bundled in five scenarios as described in the following.

For defining these scenarios we distinguish among three groups of countries:

High Fertility Countries (HiFert): Countries with current level of fertility less than 2.9 children per woman (2005-2010).

Low Fertility Countries (LoFert): Countries with current level of fertility less than or equal to 2.9 not belonging to Rich OECD countries (see below)

High Income-OECD Countries (Rich-OECD): As per the definition of World Bank.

In terms of education scenarios we refer to the four scenarios as defined in the IIASA/VID education projections:

The fast track (FT) scenario is extremely ambitious; it assumes that all countries expand their school systems at the fastest possible rate, which would be comparable with best performers in the past such as Singapore and South Korea .

The global education trend (GET) scenario is more moderately optimistic and assumes that countries will follow the average path of school expansion that other countries already somewhat further advanced in this process have experienced.

The constant enrollment rate (CER) scenario assumes that countries only keep the proportions of cohorts attending school constant at current levels.

The most pessimistic scenario, ***constant enrollment numbers (CEN)***, assumes that no more schools at all are being built and that the absolute number of students is kept constant, which under conditions of population growth means declining enrollment rates.

(For a description of the methodology of projection and detailed explanations, please read: http://www.demographic-research.org/volumes/vol22/15/22-15.pdf . For a review article in "Science" see: http://www.sciencemag.org/content/333/6042/587).

As to the possible future fertility trends we bundle the assumptions into three cases, labeled high, medium and low fertility. Table 1 shows how these three different fertility scenarios are being used as building blocks for the SSPs for the three different country groupings.

Medium Fertility (1.75): Total fertility rate (TFR) will converge to a value of 1.75 children per woman (period rate) in the very long run by 2200. We choose a value 1.75 of the TFR as a medium ultimate fertility level based on low-fertility meta experts meeting (conducted in Vienna, Dec 2011) and the online survey of experts . Medium trajectories of TFR were also derived from the same survey and meetings, except for poor SSA countries + Egypt where there are still serious open questions about the current conditions and the process of expert-based assumption making had not yet come to a conclusion by the time the SSPs needed to be finished. For this reason we chose to use here the UN's Medium Variant up until the second half of the century and then apply the very long run convergence as described above.

High Fertility (2.1): Total fertility rate will converge to a value of 2.1 in the long run. In all cases, i.e. for all countries and points in time the TFR for High Fertility scenario is simply assumed to be 20% higher than in the medium fertility scenario.

Low Fertility (1.4): TFR is assumed to converge to a value of 1.4 in the long run. In all cases, TFRs for Low Fertility are 20% lower than in the medium fertility scenario.

Education Differentials: Differential fertility by level of education were obtained from the literature (survey reports) and in some case self-estimated. Over time the differentials are assumed to converge to a value of 1.3 representing the ratio of TFR between the No Educated and Tertiary by the time TFR reaches 1.8 children per woman. For countries with the relative ratios already below 1.3, we keep it constant at the lower level.

For the mortality parameters we also bundled the alternative assumptions into three scenarios (high, medium and low mortality). Here we needed to differentiate between child and adult mortality because for children (up to age 15) the mortality level is assumed to depend on their mothers' education rather than their own.

Medium Mortality: This is same as in the UN's *Medium Variant*.

High Mortality: Increase in life expectancy at birth is assumed to be 1 year per decade lower than the UN's Medium variant. For High Fertility countries in sub-Saharan Africa, we assumed it to be 2 years lower because of the serious developmental and food security problems, high vulnerability to climate change and possible feed-backs from excessive population growth.

Low Mortality: The increase in life expectancy at birth is assumed to be 1 year per decade higher than the in UN's *Medium Variant*. Maximum Life expectancy at birth that can be reached is chosen to be the same as the maximum assumed by the UN in the *Medium Variant*, which is around 95 for women and around 90 for Men.

Education Mortality Differentials: For men and women aged ***15+:*** Differential mortality is introduced by assumed 5 years difference in life expectancy at age 15 between the "no education" category and the tertiary educated population. The difference between "no education" and "primary" is assumed to be 1 year and for the other two differences 2 years each. These are the differentials used on IIASA's past projections.

For children up to age 15 the differential mortality is introduced through mother's education. We assume that the differentials in terms of relative ratio of mortality rates with respect to the secondary category to be 2.5, 1.75, 1, 0.75 (mostly based on DHS reports).

Finally, for migration also three alternative scenarios were specified:

Medium Migration: This follows the UN migration assumptions (the UN has only one migration variant). The age and sex distribution of net migrants are estimated from the UN's Medium Variant using the residual method (i.e. referring to the changes in national populations that cannot be explained by the given fertility and mortality assumptions).

High Migration: Net migration is assumed to be double than in the Medium Migration scenario. A restriction was imposed such that not more than 25% of a cohort (by sex) can migrate, this was observed in few countries with very low population size and we found that in these countries the population size is more sensitive to migration assumptions than fertility or mortality (e.g. Hong Kong). Under this scenario the migration volume is gradually increased in three 5-yearly time steps until it is double.

Low Migration: Under this scenario we simply assume zero net migration. This does not necessarily mean closed borders but rather that the number of in- and out-migrants are roughly comparable. Again, here a gradual decline in three 5-yearly time steps is assumed.

Education Differentials: Differential Migration by level of education is introduced differently for countries with negative and positive net migration according to the UN's assumptions for Medium Variant. If more people are leaving the country than entering, the net migrants are assumed to be distributed randomly (i.e., proportional to the sending country).These net migrants (by age, sex and education) are pooled together and the age- and sex-specific education distribution of the pool is used as the education distribution for countries with a net gain in migration.

Table 1 below gives the allocation of these different fertility, mortality, migration and education scenarios for the five SSPs as it has been discussed and finalized in the series of meetings and teleconferences. This allocation is rather self explanatory and is also part of the overall story line descriptions of the SSPs. The only point that may seem surprising to non-demographers and that requires some clarification is with respect to the fertility assumptions in low fertility countries: While during the early stages of demographic transition there is generally no doubt that higher socio-economic development is associated with lower fertility this strong relationship becomes unclear at the end of demographic transition. Once societies are already used to fully controlling their level of fertility economic boom actually tends to be associated with higher fertility (a positive income effect) and bust with lower fertility. This is the reason why for the rich OECD countries fertility is assumed to be “medium” under the moderately prosperous SSP1, “low” under the depressed SSP3 and “high” under the economic boom SSP5.

Table 1: Main assumptions for the SSP population projections

	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	Country Groupings														
SSP Element	*HiFert*	*LoFert*	*Rich-OECD*	*HiFert*	*LoFert*	*Rich-OECD*	*HiFert*	*LoFert*	*Rich-OECD*	*HiFert*	*LoFert*	*Rich-OECD*	*HiFert*	*LoFert*	*Rich-OECD*
Demographics															
Population															
Fertility	Low	Low	Med	Med	Med	Med	High	High	Low	High	Low	Low	Low	Low	High
Mortality	Low	Low	Low	Med	Med	Med	High	High	High	High	Med	Med	Low	Low	Low
Migration	Med	Med	Med	Med	Med	Med	Low	Low	Low	Med	Med	Med	High	High	High
Education	High (FT)	High (FT)	High (FT)	Med (GET)	Med (GET)	Med (GET)	Low (CER)	Low (CER)	Low (CER)	V.Low (CEN)	Low (CER)	Med (GET)	High (FT)	High (FT)	High (FT)

SSP Urbanization Projections – Assumptions and Methods

Leiwen Jiang and Brian O'Neill

Each SSP assumes either a fast, central, or slow urbanization pathway for each country of the world. The methodology for producing these three alternative pathways is described below. Here, we describe the reasoning behind the choice of pathway for each SSP. Choices are made for each of three country groups defined by income (i.e., the same country groupings used for the GDP projections, discussed below).

SSP1 (Sustainability): Sustainable development is an organizing principle in this pathway, so environmentally friendly living arrangements and human settlement design define the nature of future urbanization processes. This leads to fast urbanization in all countries both because urban centers are attractive to the rural population, and because urbanization is encouraged for environmental reasons. Slower population growth, together with rapid technological change and medium to fast economic growth, enables countries to support well-planned urban development. Cities provide employment opportunities, adequate infrastructure, and convenient services for their residents, therefore attracting in-migrants from rural areas. In addition, in order to reduce impacts on the natural environment, resource-efficient and energy-saving compact cities are promoted by governments and societies, and population concentration in these cities is encouraged.

SSP2 (Middle of the Road): This pathway assumes an extension of current trends in urbanization in all parts of the world, along with similar middle of the road assumptions about population growth, technological change, and economic growth. High income countries continue their practices in urban development; developing countries generally follow the historical urbanization experiences of the more developed countries. All countries follow the central urbanization pathway, with various forms and patterns depending on their current practices and their stages of urbanization.

SSP3 (Fragmentation): In this SSP, urbanization follows the slow pathway due to slow economic growth, limited international migration, and poor urban planning that make cities unattractive destinations. In the high income countries, low population growth (especially aging), slow economic growth and technological changes, combined with low international migration, reduce the incentives for urban expansion. In the developing regions, population grows rapidly, particularly in rural areas, but migration to the cities is nonetheless limited due to slow economic growth and technological progress leading to underdeveloped urban manufacturing and service sectors in this region. Furthermore, unfavorable economic conditions in the high income countries do not offer employment opportunities for the growing labor-age population in the developing countries, which contributes to small flows of rural-to-urban and international migration. Urban planning and infrastructure construction is underdeveloped and also limits the capacity of the cities. The large and continuously increasing rural populations combined with low agricultural productivity generate heavy pressure on arable land and cause significant land use change and environmental degradation. The vicious circle of rapid population growth, slow socioeconomic development, and environmental degradation further limit the mobility of the poor rural population, and consequently urban development.

SSP4 (Inequality): In this divided world, the cities with relatively high standards of living are attractive to internal and international migrants. However, because of aging in the high income regions (driven by low fertility), internal rural-to-urban migration will be moderate, contributing to a moderate speed of urban growth. As a result, the high income countries will follow a central urbanization pathway. In the medium income countries, with favorable population age structures and medium economic growth (driven in particular by multinational corporations), cities become the manufacturing centers and engines of economic growth, inducing fast urbanization. In the low income countries, rapidly growing rural populations live on shrinking areas of arable land due to both high population pressure and expansion of large scale mechanized farming by international agricultural firms. This pressure induces large migration flows to the cities, contributing to fast urbanization, although urban areas do not provide many opportunities for the poor. Instead, urban construction aims at providing convenience and amenity for the elites, leaving poor housing and infrastructure for the rest and leading to massive expansion of slums and squatter settlements.

SSP5 (Conventional Development): Based on rapid technological progress in using and exploring energy and other resources and fast economic growth, the world becomes increasingly capable of building human settlements through large scale engineering projects. The cities of extensive man-made environments with rather comfortable living conditions attract and are able to accommodate a large proportion of individuals of the relatively slow growing populations, although urban sprawl is common in many parts of the world. Moreover, the large scale of resource extraction, in particular the large scale of mechanized farming, makes the areas outside the urban less attractive and livable, contributing to migration to urban areas. Therefore, fast urbanization occurs in all countries under this scenario.

Table 2: Main assumptions for the SSP urbanization projections

	SSP 1			**SSP 2**			**SSP 3**			**SSP 4**			**SSP 5**		
	Country groupings for high, middle, and low income														
SSP Element	***High***	***Middle***	***Low***	***High***	***Middle***	***Low***	***High***	***Middle***	***Low***	***High***	***Middle***	***Low***	***High***	***Middle***	***Low***
Urbanization	Fast	Fast	Fast	Central	Central	Central	Slow	Slow	Slow	Central	Fast	Fast	Fast	Fast	Fast

Methodology

The urbanization projections were developed at NCAR using an approach that produces three scenarios (fast, central, and slow) for each country of the world with population greater than 1 million and land area greater than 1000 km^2 in 2010. Projections extend from 2010 to 2100 and consist of projected percent urban population for each country. In order to produce numbers of people in urban and rural areas, these projections need to be combined with the population projection for each country. Urbanization projections for each SSP were created by selecting one of the three urbanization projections for each country according to the qualitative, region-specific assumptions regarding urbanization that are part of the SSPs.

The NCAR methodology extends and modifies the method used in the UN World Urbanization Prospects (UN 2010). In the UN urbanization projection model, the urbanization level for each country (i.e., the proportion of the total population that is urban) is projected as a function of the difference between the urban and rural growth rates. A linear relationship between this growth rate difference and the urbanization level itself is defined based on historical data. More specifically, the urbanization level (PU_t) can be defined in terms of the urban-rural ratio (URR_t, the ratio of urban population to rural population),

$$PU_t = \frac{URR_t}{1+URR_t}.$$

Changes in URR_t and therefore in the urbanization level can be modeled as a function of the difference between the urban and rural population growth rates, urr_t, where the growth rate difference is itself a function of the urbanization level:

$$URR_{t+1} = URR_t * e^{urr_t}$$

$$urr_t = f(PUt)$$

where f is the linear, empirical relation derived from the data. Countries are assumed to converge to this global relationship over a 20-year transition period.

The NCAR model adopts the UN's approach of assuming a linear relationship between urban-rural population growth difference and urbanization level, but modifies the UN methodology by defining it separately for each country (rather than using a single global norm) and for fast, central, and slow urbanization scenarios (rather than a single scenario). Relationships between the urban-rural population growth difference and urbanization level for each country and scenario are defined based on a set of reference countries that are drawn from historical data (UN World Urbanization Prospects 2009 Revision). Data from small island or city countries whose land areas are smaller than 1000 km^2 and populations in 2010 less than 1 million persons are discarded, leaving 151 countries with urbanization records for the period of 1950-2010 as the core data set.

In order to select reference countries for a particular target country and scenario, we take three steps. First, we choose from the database all countries that have ever achieved an urbanization level within 5 percentage points of the level in the target country. This step collects countries that were similar to the target country in terms of urbanization level at some time in the past. Second, we eliminate from this sample the 25% of countries whose urbanization growth rates over the decade prior to reaching the target urbanization level differ the most from the target country's growth rate. This step ensures that reference countries were similar to the target country at a certain point in time not only in terms of urbanization level, but also in terms of how fast they were urbanizing at that time. Third, we divide the remaining sample into three different groups: the 25% of countries with the highest urbanization levels 30 years after they reached the target level, the 25% of countries with the lowest urbanization levels at that point, and the 50% of the sample in between. These three groups serve as the reference countries for the fast, slow, and central projections, respectively, for the target country.

However, this set of reference countries is not sufficient to support a projection over a 100-year period, given the relatively short (60-year) historical record. For example, a country currently at a low urbanization level may go through several different regimes of growth: slow increases in urbanization, a fast takeoff period, and then a slowing as it converges to a long term level. Using a single set of reference countries over a limited time period will frequently not be able to capture well these multiple regimes. We therefore adopt a two-stage projection approach to generate additional reference countries for use in the model.

Using data on urbanization level and urban-rural growth rate differences from the initial set of reference countries, we project the target country's urbanization level forward to 2040. We then use the projected 2040 level, and recent growth rate, to repeat the reference country selection process and derive a second set of reference countries to characterize urbanization after 2040. This creates nine possible combinations of reference countries across stages 1 and 2 (fast, central, and slow in stage 1, and then in each case fast, central and slow in stage 2). However, we define our three scenarios of interest as the fast-fast, central-central, and slow-slow combinations over the two stages. Data from these combinations of reference countries are used to define country-specific linear relationships between the urban-rural growth rate difference and the urbanization level, which are in turn used to generate the urbanization projections according to the equations above. One exception to the production of three scenarios for each country is that, because there is little uncertainty in future changes in urbanization among countries that have already achieved very high urbanization levels, we produce only one urbanization scenarios for countries that have already reached an urbanization level of 80% or more.

References:

UN 2010: United Nations (2010) *World Urbanization Prospects. The 2009 Revision* (United Nations Publication, New York).

SSP GDP Projections – Assumptions and Methods

The economic projections for the SSPs concentrate on projecting Gross Domestic Product (GDP) and per capita income (GDP per capita) for each of the SSPs. Three modeling teams have made projections for GDP and GDP per capita; the specific assumptions for each will be explained in detail below. All three models share a basic assumption that macroeconomic growth is driven by a combination of (i) increases in primary inputs (labour and capital, and for OECD also natural resources), (ii) labour-augmenting (human capital) efficiency improvements, and (iii) total factor productivity (tfp) improvements. The degree to which growth is determined by these factors differs, however, across the models. The IIASA model tends to place a larger weight on growth induced by human capital increases (in turn driven by educational improvements), which ceteris paribus implies relatively high growth rates in the coming decades and lower growth rates in the longer run. The PIK model generally places more emphasis on the long run growth rate of tfp. The OECD model has the distinctive feature that it calibrates growth rates until 2016 to projections made by OECD, IMF and World Bank, and then transitions to a model that is similar to that of PIK. The combination of the three models nicely illustrates the uncertainty in making GDP projections, where not only the average growth rate is uncertain, but also the growth dynamics.

All three teams have, however, harmonized the interpretation of the SSP storylines for the main drivers of economic growth. Specifically, the models use as basis for their interpretation of the SSPs (i) the speed of economic growth at the frontier (i.e. for the most advanced countries), and (ii) the speed of convergence of countries towards the frontier. Table 3 summarizes these assumptions.

Table 3: Main assumptions for the SSP GDP projections

SSP Element	**SSP1**	**SSP2**	**SSP3**	**SSP4***	**SSP5**
TFP growth at frontier	Medium high	Medium	Low	Medium	High
Speed of Convergence	High	Medium	Low	LI: Low MI: Low HI: Medium	High

* In SSP4, the speed of convergence differs across country groupings with different income levels. LI: low income countries, MI: middle income countries, HI: high income countries

Assumptions in SSP4 are differentiated between income country groups, namely low income (LI) countries, middle income (MI) countries, and high income (HI) countries. High income countries are based on the World Bank classification of countries (http://data.worldbank.org/about/country-classifications; 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/cap *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 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.

Note that all groups express the economic projections in 2005 USD, using Purchasing Power Parities (PPPs). However, different datasets and methodologies may be used by the groups to identify the associated PPP exchange rates. The projections in PPP exchange rates can be translated into projections using market exchange rates (MERs). The difference between both units stems from the fact that goods are differently valued in different economies, and not all goods are internationally traded. The growth of an economy is characterized by the growth of its GDP measured in constant price in national currency. MER projections are appropriate for valuing e.g. international trade between economies, whereas projections in PPPs are usually deemed superior for comparing the relative size of different economies.

If modelers or analysts prefer to use MER data (e.g. based on data requirements and/or the assessment of international trade), data can be converted. Currently two methods are used by different research groups:

a) Freezing the historic PPP to MER ratio and converting the PPP scenarios into MER based on this ratio. Static conversion rates between PPP exchange rates and MERs based on historical data are readily available. This generates MER trajectories that grow at a rate identical to the MER projections. The latter implies that a simple global aggregate of the MER GDP will grow slower than the global aggregate PPP GDP, if the underrated countries grow faster.
b) The second method is develop scenarios using a dynamic PPP to MER ratio, reflecting the currency appreciation with increasing convergence between countries in the long run. This choice will gradually reduce the relative size imbalance between economies over time. However, it also implies that the national GDP projections in MER grow faster than the size of the economy.

As there is no consensus on the preferred method, nor on the method how to derive “dynamic” MER-PPP conversion rates, MER conversion rates for the future are not supplied in the database.

GDP Projections by OECD

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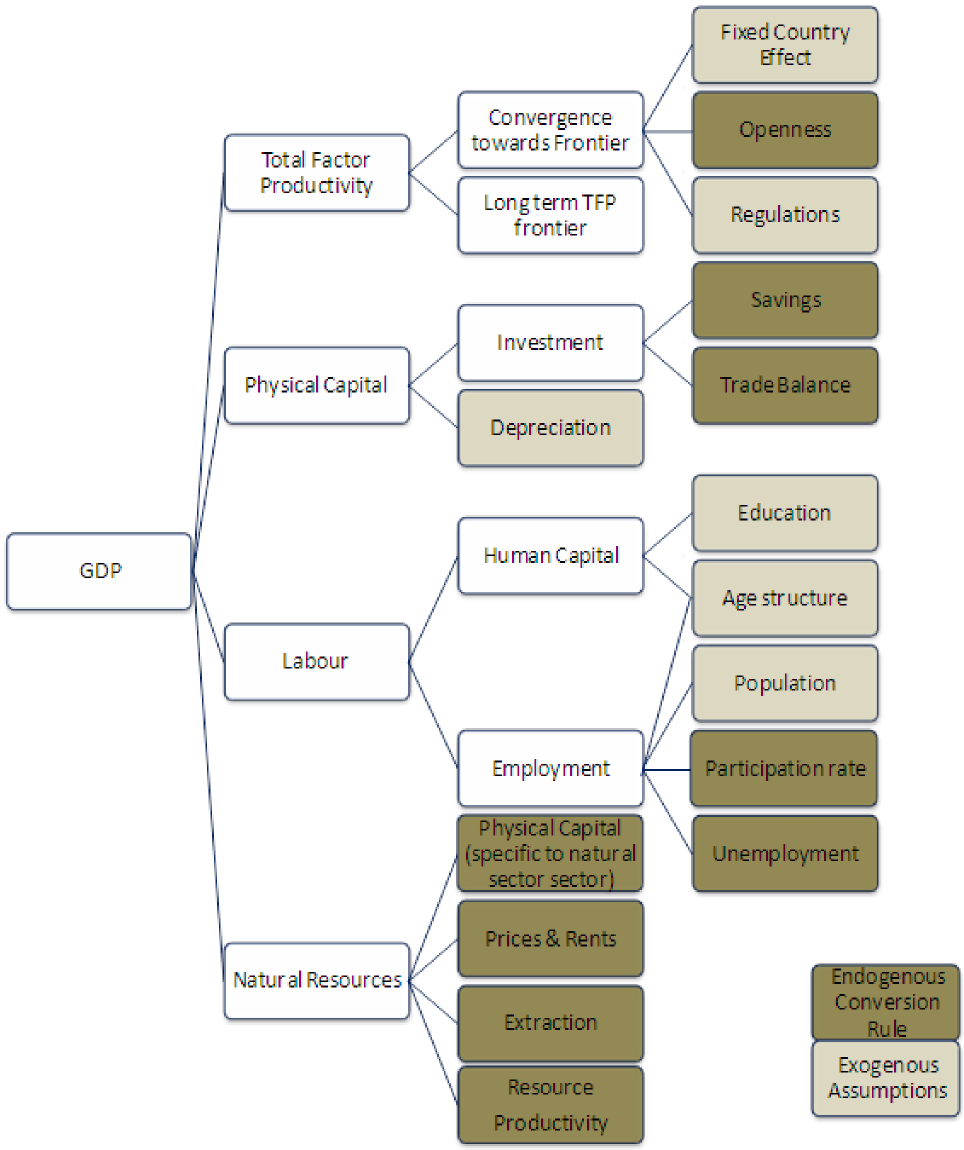
General setup of the methodology

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) with two sectors. 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. Finally, the model has been adapted to project different growth patterns according to the various SSP storylines. This note focuses on the main model characteristics and on the SSP-specific assumptions. A full description of the methodology can be found in Chateau et al. (2012).

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, which is driven by education and determines labour productivity; (iv) energy demand and natural resources (oil and gas) extraction patterns for exporting countries; 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.

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



Projections of GDP levels are determined for 176 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 OECD GDP projections are expressed in 2005 USD PPP, based on data from OECD and World Bank, which use the Atlas method for calculating PPPs. Historical conversion rates from PPP exchange rates to market exchange rates (MERs) from OECD and World Bank are available in the database. The OECD does not provide dynamic conversion rates between PPPs and MERs.

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.

Specific assumptions on total factor productivity

Conventionally, 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. 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 driven by two factors: (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), market regulations and international trade openness. The key concept of the latter component is that countries that are more open (interpreted as a larger share of imports and exports in GDP) will have easier access to advanced technologies and learning. Greater country openness boosts domestic productivity. The SSP storylines suggest that openness is relatively low in SSPs 3 and 4, and high in SSP5.*Specific assumptions on human capital*

Detailed education projections by gender and age are taken directly from IIASA. 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.

Specific assumptions on employment

Population projections are taken directly from IIASA. 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, 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.

Specific assumptions on physical capital

Capital inputs follow the standard capital accumulation formulation with a fixed depreciation rate. The investment rate per unit of GDP slowly converges to a balanced growth path level, depending on the structural parameters of the production function.

Specific assumptions on energy and natural resources

Energy resources come into play as productive inputs for energy consumers and as additional revenues from specific oil and gas sectors for producing countries. The domestic level of energy productivity is calibrated to match historical improvement rates and gradually converges to an efficiency frontier that reflects state-of-the-art standards in energy appliances. The contribution of energy resources to the economic output 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. The SSP-specific assumptions on energy prices and extraction rates are based on the energy-related storylines of the SSPs.

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GDP Projections by PIK

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GDP scenarios are derived for 32 world regions. GDP is measured in PPP 2005 USD.

Basic methodology

The basic approach is an extension of the method used by PricewaterhouseCoopers (Hawksworth, J. (2006). GDP (Variable Y) is derived from a **Cobb-Douglas production function**, i.e. it is formulated as a function of the production factors capital (Variable K) and labor (Variable L) which are combined by total factor productivity (Parameter T) and the output elasticities (Parameter α) on capital and labor. The elasticity parameters correspond to the factor income shares which for the capital income are related to regional capital intensities.

$Y = T\, K^{\alpha}\, L^{(1-\alpha)}$,

with $\alpha = r\, K/Y$ determined by the rental rate of capital r and capital intensity K/Y in a given region.

Labor input

Basis for labor input are IIASA's recent population projections. Effective labor force is the number of people in working age (15-64) (Variable $N(15\text{-}64)$) plus aged 65 and older (*Variable* $N(65+)$) multiplied by the respective labor participation rates (Variable *LPR*). Regional labor participation rates of the working age population are assumed to converge in the long run with different speed and to different levels for each SSP scenario. A low long-term level of labor participation of 60% is assumed in SSP3, a high level of 80% for SSP5. The labor participation rate in SSP1 converges to a lower level (70%) than in SSP5 based on the assumptionthat leasure time is valued higher. Participation rates also converge to 70% in SSP2, and to 75% in SSP4 for all high- and mid-income countries. The labor participation rates stay close to their current value for low-income countries in SSP4. The labor participation rate of the 65 year plus age cohort is not varied across SSPs but general convergence to levels between 8-20% (depending on the region) from the currently widely differing regional levels is assumed.

The effective labor force is transformed into a quality adjusted input of labor using projections of the mean years of schooling (MYS) of the population following a methodology by Hall and Jones (1998). The MYS projections are directly deduced from the IIASA population and education projections and vary with SSPs (see Section on population scenarios)..

$L = h(MYS)\, [LPR(15\text{-}64)\, N(15\text{-}64) + LPR(65+)\, N(65+)]$ with human capital index

$h(MYS) = exp(0.134 \min(MYS,4) + 0.101 \min(\max(MYS-4,0),4) + 0.068 \max(MYS-8,0))$

Capital input

Capital is accumulated based on assumptions on the development of regional capital intensities, related capital output elasticies r and a common depreciation rate of 5% per year. Starting from the historically given values, capital intensities are assumed to converge at different speed and towards different values for the different SSPs. In SSP1 and SSP5 capital intensities converge comparatively fast to medium and high values, respectively. There is rather slow convergence towards a medium and low value in SSP2 and SSP3, respectively and almost no change in current capital intensities in SSP4.

For a given development of labor input L, total factor productivity T, capital intensities K/Y (and associated income shares of capital α), the growth rate of capital (g_K) evolves as follows

$g_K = (g_T + g_{K/Y})/(1-\alpha) + g_L$

Initial capital stock is derived based on the perpetual inventory method and investment data from PWT 7.0 data base.

Total factor productivity (TFP)

Total factor productivity captures the residual technological progress after factoring out the human capital component (which is included in the quality adjusted labor input). TFP growth is derived from two components: a technology frontier growing at a constant rate and a convergence process of the technology followers to the frontier. Current values for regional TFPs and their growth rate are estimated from historic GDP, capital and labor input data using a weighted average (with putting more weight on growth rates that are closer to the present). The transition from this historical trend to the long-term trend depends on the growth rate of the technological leader (USA) and the catch-up process in the different regions. In the high growth scenario SSP5 we assume a TFP growth rate of the technology leader of 1.1%,0.8%, 0.7%, 0.6% and 0.3% for SSP5, SSP1, SSP2, SSP4, and SSP3, respectively.

The convergence process is differentiated for the three groups OECD, other high-income and mid-income countries, and low-income countries. Fast convergence is assumed for OECD across all SSPs. SSP1 and SSP5 are characterized by fast convergence of all country groups. SSP2 and SSP3 are characterized by medium and slow convergence, respectively, of non-OECD country groups. SSP4 is a mixed case with medium convergence for the high/mid-income country group and slow convergence for the low-income group.

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GDP projections by IIASA

Jesus Crespo Cuaresma

The GDP growth projection model used is based on a simple aggregate production function with heterogeneous labor input (differentiated by educational attainment –primary, secondary, tertiary - and age group – younger and older labor force),

$$Y_t = A_t F(K_t, L_{10t}, L_{20t}, L_{11t}, L_{21t}, L_{12t}, L_{22t}, L_{13t}, L_{23t}),$$

where Y_t is total output, A_t is total factor productivity, K_t denotes the capital stock and L_{ij} corresponds to the labor force in age group *i* (*i*=1,2 denoting younger and older labor force) with educational attainment *j* (from *j*=0 – no education – to *j*=3 – some tertiary education level attained).

This specification implies that the growth rate of total output depends on the growth rate of each one of the factors of production (total factor productivity, the capital stock and each one of the population groups by age group and education level). In addition, in the spirit of the Nelson-Phelps paradigm (see Nelson and Phelps, 1966, Benhabib and Spiegel, 1994, and Lutz et al. 2008), we assume that the growth rate of total factor productivity depends on:

- the distance to the technology frontier, as approximated by the average income per capita level of the country
- the ratio of population with higher (secondary and tertiary) educational attainment levels to total population, which is used to proxy for the technology innovation potential
- the interaction between income per capita and the ratio of population with higher educational attainment levels to total population, which accounts for technology adoption as a driver of income convergence

This modeling strategy implies that education plays a role in terms of directly increasing labor productivity through acquired skills (an effect which is related to the fact that human capital is an input of the production function) and of enabling the creation and adoption of new technologies, thus increasing economic growth by affecting the growth rate of total factor productivity. This leads to econometric specifications where the growth rate of population as well as its composition in terms of age structure and educational characteristics have an effect of economic growth.

The econometric model resulting from such a specification is given by

$$g_{Y,t} = \delta \log \frac{Y_t}{L_t} + \sum_{j=0}^{3} \varphi_j \frac{L_{1jt}+L_{2jt}}{L_t} + \sum_{j=0}^{3} \theta_j \frac{L_{1jt}+L_{2jt}}{L_t} \log \frac{Y_t}{L_t} + \alpha\, g_{Kt} + \sum_{j=1}^{2} \sum_{k=0}^{3} \beta_{jk}\, g_{L_{jkt}},$$

where g_X is the growth rate of variable *X* over the given period and all variables which are not growth rates are measured at the initial year of the considered period. We consider a panel at 5-year non-overlapping intervals covering all countries for which data exist and spanning the period 1970-2010. The panel structure implies that we are able to include fixed country-specific effects (a country-specific intercept) and fixed period effects (which we interpret as overall movements in the technology frontier that are independent of those caused by the variables of the model). This model is estimated and a simplified specification is chosen after a general-to-specific model selection procedure where we reduce the number of explanatory variables based on their statistical significance.

Human capital dynamics as implied by projections of population by age and educational attainment are used as the main driving factor of economic growth in the prediction horizon. This implies that this economic growth model together with the IIASA's population projections provide a coherent framework in which to assess quantitatively the dynamics of human capital and their effect on economic performance (as measured by income per capita) in long projection horizons.

In addition to the differences in income growth implied by differences in the dynamics of human capital, we define each one of the scenarios in terms of assumptions concerning the corresponding SSP narratives. These assumptions are imposed on:

- the growth rate of physical capital,
- the future shifts of the technology frontier that are independent of those whose source is improvements in educational attainment,
- changes in other variables which are not included in the model but are important determinants of growth (institutional changes, international trade trends …) and in our specification are captured through the country-specific fixed effects.

Since the country-specific fixed effects have an important effect on the long-run equilibrium income growth rates, our assumptions concerning their development are essential to materialize our views concerning future income convergence patterns across countries. In particular, patterns concerning long-run income convergence (or lack thereof) are calibrated by assuming convergent (or divergent) dynamics in these fixed effects over the prediction period.

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