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Long term socio-economic projections based on the Shared Socio-economic Pathways (SSPs)

Contents

1. Introduction

The Climate Change community has proposed in the last few years a new interdisciplinary framework to elaborate scenarios for the analysis and assessment of climate change mitigation and adaptation options. This framework works in two dimensions: one is the Representative Concentration Pathways (RCPs) with scenarios about climate forcing, the other is the so called Shared Socio-economic Pathways (SSPs), which analyses the socio economic aspects related to climate change. In particular, the SSPs consist of five storylines or narratives (SSP1 to SSP5) about a set of variables including population, technical progress and economic growth (i.e. GDP) among others (Detlef P. van Vuuren et al. 2011; O'Neill et al. 2012). A main characteristic of the SSPs is that the set of variables that are taken into account is broad enough to characterize a global socio-economic future for the decades to come and to differentiate SSPs from one another in terms of the socio-economic challenges they would present to mitigation and adaptation[1].

Socio-economic scenarios and, in particular, projections of economic growth (economic activity or GDP) and demographic development (population), are often needed to run biophysical impact models. The main purpose of this document is to explain the generation of a set of socio-economic scenarios, based on the SSPs, for the HELIX FP7 project.

The five SSPs are implemented in a macro-econometric growth model, the MaGE model (Fouré et al 2010), which has been developed at the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).The model has a solid empirical basis because most of its parameters are statistically estimated using a panel data with world country-level information and long-time series.

MaGE is a macroeconometric model of the world economy suitable for long term socio economic projections of the current century. It is based on a three-factor production function, i.e. labour, capital and energy, plus two forms of technological progress, one for the aggregate bundle of labour and capital and the other specific for energy, i.e. energy productivity.

The OECD has used the ENV-growth model (Chateau et al. 2012) to produce the SSPs. The ENV-growth model is very similar to MaGE. Firstly, both models are based on a production function that considers capital, labour and energy as the primary inputs. Secondly, technology plays a key role in the quantification of long-term economic growth pathway, assuming that there is a country leader in technological terms, and the rest of the world are followers. Thirdly, human capital is fundamental for the determination of the time evolution of GDP. Education levels of the various age groups are

[1] A detailed database for the five SSPs is available at IIASA (IIASA, 2013; updated in March 2013 https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about). This database includes projections of GDP, population and education structure coherent with the narratives of the SSPs.

driving the process of human capital accumulation, which, according to the assumptions underlying the model, increases overall productivity. Fourthly, the two models take long-term population projections from exogenous sources (United Nations). Finally, energy or natural resources are included as production factors in the supply side of the economy and their scarcity is assumed to be reflected in oil price, i.e. an exogenous variable of the model.

There are also some differences between the two models. While ENV-growth assumes an exogenous behaviour for savings rate[2], in MaGE the savings decisions by households depend on the life-cycle theory. The MaGE model also considers that the difference between the national savings and national investment depends on the degree of capital mobility (the Feldstein-Horioka theory).

The document is structured in five sections, in addition to this introduction. Section 2 describes the main features and equations of the MaGE model. Section 3 details how the SSPs have been implemented in MaGE. Section 4 shows the main results of the economic projections regarding the global economy and the major economies, while the complete table of the results is enclosed as an excel file to this report. Section 5 compares the results of the SSP analysis conducted with MaGE with already existing projections obtained with a similar growth model, section 6 finally, concludes with a discussion of the main results and possible next steps.

2. MaGE Model v.2.0

The MaGE model is fitted with United Nations and International Labour Office labour projections, and includes econometric estimations of the equations for projecting the following variables:

(i) capital accumulation,
(ii) savings rate,
(iii) relationship between savings and investment rate,
(iv) education,
(v) female participation to the labor market
(vi) technological progress (which includes energy and total factor productivity).

The model accounts for energy constraints by including energy use in the production function and by taking account of rents accruing to oil exporting countries. The model therefore proposes a novel approach to growth analysis which assumes limited possibility for energy and the capital/labour bundle to substitute each other; in other words energy is a critical factor of production and capital and labour can compensate its scarcity only to a limited extent. A model's main feature is the idea of

[2] Env-growth in fact assumes that countries converge to the US saving to gdp ratio.

convergence, which is also known as the catch-up effect. According to this hypothesis poorer countries income per capita grows faster than in advanced economies thus leading to a convergence or catch up of the first over the second in the long period. The catch up idea is applied in the present analysis for some of the most important equations of the model, i.e. saving rate, technical progress, energy productivity or education. The convergence parameters are key elements of the model and can be effectively used and adjusted to align the model to the SSPs narratives.

2.1 MaGE main equations

If we denote energy, capital and labour by $E_{i,t}$, $K_{i,t}$ and $L_{i,t}$ respectively, for country *i* at time *t*, real GDP can be written as a production function of the CES type:

$$Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)} \quad (1)$$

Eq.$Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$ (1 corresponds to a well-known economic functional form called CES, i.e. Constant Elasticity of Substitution. In Eq.$Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$ (1, $Y_{i,t}$ denotes GDP in constant 2005 US dollars. $A_{i,t}$ is the measure of Total Factor Productivity, which, in this case, is the efficiency of the combination of labour and capital, while $B_{i,t}$ is a measure of energy productivity. The parameters α and σ, which are, respectively, the share of capital in GDP and the elasticity of substitution between the labour/capital bundle with energy, are assumed to be 0.3 and 0.136; these values are in line with literature. In order to project GDP by taking energy price into account the specification of the production function (Eq.$Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$ (1) is changed by substituting E, energy, with the equation:

$$E_{i,t} = Y_{i,t}\, \frac{B_{i,t}^{\sigma-1}}{p_E^{\sigma}} \quad (2)$$

which is derived by maximizing profit max $(Y - p_E E - p_K K - p_L L)$ subject to the combination of factors, i.e. labour, energy and capital, of the production technology specified in Eq. $Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$ (1.

All the variables in Eq. $Y_{i,t} = \left[(A_{i,t}\, K_{i,t}^{\alpha}\, L_{i,t}^{1-\alpha})^{(\sigma-1)/\sigma} + (B_{i,t}\, E_{i,t})^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$ (1 must be projected in order to have projections for GDP. Starting with the capital variable, it is projected with the so called *permanent inventory process*, which takes into account an initial capital stock at time t-1, a constant depreciation rate δ and investments at time t.

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t} \tag{3}$$

In Eq. $K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t}$ (3, δ is assumed to be equal to 0.06, i.e. capital depreciates at a constant rate of 6%, the initial capital stock at time t-1 is assumed to be three times the GDP at time t-1, so the dynamics of capital accumulation depend mainly on investments and on savings.

Equations $\left(\frac{I}{Y}\right) i,t = \alpha_i + \beta_i \left(\frac{S}{Y}\right)_{i,t} + \varepsilon_{i,t}$ (4 and $\left(\frac{S}{Y}\right) i,t = \alpha_i + \beta_1 \frac{y_{i,t-1}}{y_{US,t-1}} + \beta_2 \left[\frac{y_{i,t-1}}{y_{US,t-1}}\right]^2 + \beta_3 g_{i,t-1} + \sum_{k=1}^{K} \varphi_K\, d_{i,t}^k + \sum_{k=1}^{K} \omega_k d_{i,t}^k\, g_{i,t-1} + \varepsilon_{i,t}$ (5 explain investments, expressed as investment rate, as a function of savings, i.e savings over income, a relation known as the Feldstein-Horioka, and savings as a function of a country's GDP to the US GDP, i.e. a variable for the catch up process, and a set of demographic variables including $g_{i,t-1}$ growth of population in the previous year, $d_{i,t-1}$ demographic structure of the population and the interaction between the two.

$$\left(\frac{I}{Y}\right) i,t = \alpha_i + \beta_i \left(\frac{S}{Y}\right)_{i,t} + \varepsilon_{i,t} \tag{4}$$

Savings and investments have a non-unitary relationship which relaxes the assumption of either a closed economy, where domestic savings are the only source for investments, or full capital mobility, where there are no obstacles for financial capital to move from a country to another.

$$\left(\frac{S}{Y}\right) i,t = \alpha_i + \beta_1 \frac{y_{i,t-1}}{y_{US,t-1}} + \beta_2 \left[\frac{y_{i,t-1}}{y_{US,t-1}}\right]^2 + \beta_3 g_{i,t-1} + \sum_{k=1}^{K} \varphi_K\, d_{i,t}^k + \sum_{k=1}^{K} \omega_k d_{i,t}^k\, g_{i,t-1} + \varepsilon_{i,t} \tag{5}$$

For labour, the model projects the participation rate to the labour market for both male and female. Male participation rates are projected using the ILO, i.e International Labour Organization, methodology. Female participation rates are explained as a function of the level of education, i.e. the higher the share of the population holding a secondary or tertiary degree the higher the female participation to the labour market as in Eq. $ln\left(\frac{l_{a,i,t}^F}{1-l_{a,i,t}^F}\right) = \sigma_{a,i} + \beta_a^2 h_{a,i,t}^2 + \beta_a^3 h_{a,i,t}^3 + \varepsilon_{i,t}$ (6 where $l_{a,i,t}^F$ is the female participation rate, $\sigma_{a,i}$ is the country specific intercept also known as the fixed effects and β_a^2 and β_a^3 are the parameters for age groups a that explain how education level represented by the variables $h_{a,i,t}^2$ $h_{a,i,t}^3$ induce a higher female participation rate

$$ln\left(\frac{l_{a,i,t}^F}{1-l_{a,i,t}^F}\right) = \sigma_{a,i} + \beta_a^2 h_{a,i,t}^2 + \beta_a^3 h_{a,i,t}^3 + \varepsilon_{i,t} \tag{6}$$

Apart from the female participation to the labour market, "human capital" is a key component of MaGE and in particular is one of the main variables explaining growth in productivity. The education levels of the population are used as proxies for human capital development and are explained as a catch up process where countries converge following a logistic trend to the country that shows the highest shares of secondary and tertiary education levels.

The last two remaining variables are A and B which are respectively total factor productivity, which can also be seen as a generic variable for technical progress, and energy productivity. The growth process of these two variables is explained by equations $\Delta ln(A_{i,t}) = \alpha_{0,i} + \alpha_1 a_{i,t-1} + \alpha_2 h_{i,t-1}^3 + \alpha_3 a_{i,t-1}(h_{i,t-1}^2 + h_{i,t-1}^3) + \varepsilon_{i,t}$ (7 and $\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B_{i,t-1}^*}{B_{t-1}}\right) + \mu_2 ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t}$ (8.

$$\Delta ln(A_{i,t}) = \alpha_{0,i} + \alpha_1 a_{i,t-1} + \alpha_2 h_{i,t-1}^3 + \alpha_3 a_{i,t-1}(h_{i,t-1}^2 + h_{i,t-1}^3) + \varepsilon_{i,t} \quad (7)$$

Eq. $\Delta ln(A_{i,t}) = \alpha_{0,i} + \alpha_1 a_{i,t-1} + \alpha_2 h_{i,t-1}^3 + \alpha_3 a_{i,t-1}(h_{i,t-1}^2 + h_{i,t-1}^3) + \varepsilon_{i,t}$ (7 is used to project the growth of A which represents a measure of technical progress, i.e. augmenting the productivity of labour and capital. Country specific growth rates of A are modelled as dependent on a pure catch up effect, a pure tertiary and secondary education effect and an interaction between catch-up and education. The variable $a_{i,t-1}$ is in fact the distance of country *i* to the productivity frontier in year *t-1* $ln\left(\frac{A_{i,t-1}}{A_{t-1}^*}\right)$ where A_{t-1}^* is the frontier, which is calculated as the average of the top five countries. The variable $h_{i,t-1}^3$ is the share of population in country *i* holding a tertiary degree, while the last term in the right hand side of Eq. $\Delta ln(A_{i,t}) = \alpha_{0,i} + \alpha_1 a_{i,t-1} + \alpha_2 h_{i,t-1}^3 + \alpha_3 a_{i,t-1}(h_{i,t-1}^2 + h_{i,t-1}^3) + \varepsilon_{i,t}$ (7 is the effect of the interaction between catch-up process and the level of education.

Energy productivity (B in the production function) growth is also modelled as a catch-up effect with two determinants: distance to energy productivity frontier and distance to the economic development frontier. The following equation is estimated:

$$\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B_{i,t-1}^*}{B_{t-1}}\right) + \mu_2 ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t} \quad (8)$$

Where $B_{i,t-1}^*$ denotes the energy productivity frontier in country i at time t-1. The energy productivity frontier is the mean of the four most energy productive countries: UK, Japan, Germany, and France. The economic development frontier is instead proxied with per capita income in USA, which is the variable y_{US} in Eq. $\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B^*_{i,t-1}}{B_{t-1}}\right) + \mu_2\, ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t}$

(8)

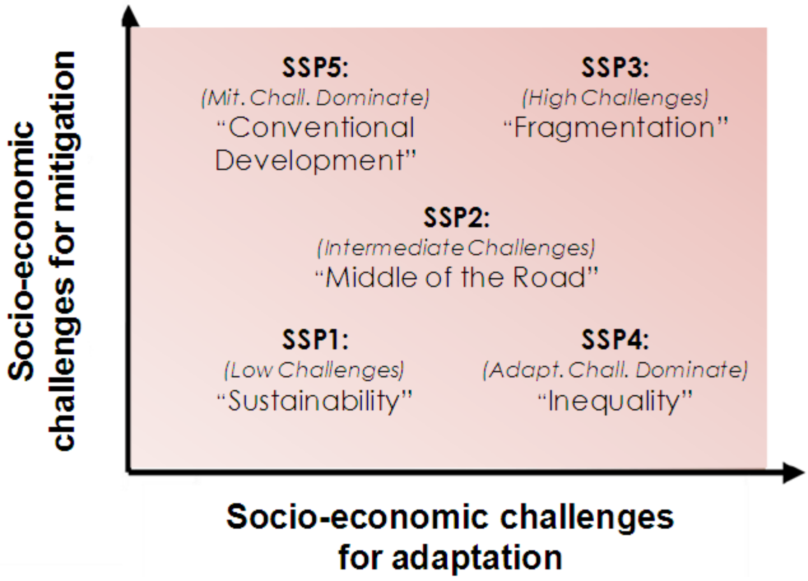
Population and education is projected using the IIASA projections (Lutz W et al. 2008, KC S and Lutz W 2014) of the working age population to 2050 (medium fertility variant). The results of the estimation are summarized in Table 5 at page 32 of the CEPII technical working paper (http://www.cepii.fr/anglaisgraph/workpap/pdf/2012/wp2012-03.pdf).

3. SSP scenario implementation in MaGE

3.1 SSPs scenarios

Figure 1 gives a synthetic representation of the five SSP and how they cover the domains of adaptation and mitigation.

Figure 1. The SSPs



Source: O'Neill et al. (2012)

SSP1 or "Sustainability" scenario corresponds to a scenario where the world is on a good track to achieve sustainability and the millennium development goals. At the same time resource intensity and fossil fuel dependency are decreasing, global and within countries inequality is also decreasing along with a globalized economy and a rapid technological change. SSP2 or "Middle of the road" is characterized by continuation of the socio economic trends of the last decade. This scenario is characterized by little progress toward decreasing fossil fuel dependency and sustainability. Also inequality and the millennium development remain far from being achieved. SSP3 called also "Fragmentation" portrays a world separated into regions with little international cooperation; low investments in technology development and low level of education all slowing down economic growth. There is an overall failure in achieving global development goals, and resource intensity as well as fossil fuel dependency remain high. SSP4 or "Inequality" envisions a world with high within and across countries wealth inequalities. Adaptation capacity is highly jeopardized due to ineffective Institutions, controlled by small elite, while mitigation challenges are low due to low economic growth rates and consequent low reference emissions. SSP5 or "Conventional Development" maintains the emphasis on economic growth as the solution to social and economic problems. The result is an economic system that poses serious challenges to the global mitigation efforts as highly dependent on fossil fuels. On the other hand easy climate adaptation results from the achievement of the human development goals.

The SSPs scenario specification proposed in this paper is based on two articles. The main contents of the SSP scenarios are derived from O'Neil et al. (2012) whereas the specific quantification for the scenarios on institutions is based on the estimation results proposed in a paper from Chanda and Dalgaard (2008).

3.1 Defining the scope of our scenarios

Narratives provided in O'Neil and al. (2012), and in particular the summary tables provided in appendix III of their paper, are a good starting point to derive our quantification. Analysing the narratives using the lens provided by MaGE raises two main issues:

- Some elements in the narratives are out of the scope of the MaGE model.
- Some elements are not directly configurable in MaGE because they are endogenous variables that are outcomes of other variables on which scenarios are drawn.

In this section, we will consider all the narratives from O'Neil et al (2012) and separate them into those that we will include in our growth scenarios and those we cannot deal with. The complete narratives and scenarios from O'Neil et al. (2012) are provided in the Appendix 2 of this paper. The narratives included directly in MaGE scenarios are:

- Demographics: Fertility, Mortality, Education.
- Policies and institutions: Institutions
- Technology: Development, energy intensity
- Environment: Fossil constraints

So we propose the following implementation of SSP scenarios (details on what we understand as "institutions" and the corresponding quantification is provided below in the following section):

	SSP1 Sustainability	SSP2 Middle of the Road	SSP3 Fragmentation	SSP4 Inequality	SSP5 Conventional
Demographics	Provided by IIASA				
Education	Provided by IIASA				
Institutions	--	--	*All*: Decreasing institution efficiency through TFP	*OECD*: Increasing institution efficiency through TFP + convergence	*All*: Increasing institution efficiency through TFP

				to the most energy efficient countries *Other*: Decreasing institution efficiency through TFP	*OECD*: CV to most energy-efficient countries *Other*: CV to OECD level of institutions
Technological development	x2 technological frontier growth, i.e. B* in Eq. 7 doubles by 2100	--	x½ technological frontier growth, i.e. B* in Eq. 7 grows by 1.5 by 2100	x2 technological frontier growth, i.e. B* in Eq. 7 doubles by 2100	x2 technological frontier growth, i.e. B* in Eq. 7 doubles by 2100
Energy intensity	--	--	--	--	+50% energy productivity in 2050
Fossil constraints	--	--	--	High energy price	Low energy price

Table 1 : implementation of the SSP scenarios in MaGE

Regarding SSP4 "Inequality", we are not able to implement within-country inequalities therefore our scenarios will only focus on cross-country differences. Moreover, the following narrative cannot be modelled as scenarios in MaGE, because they are either outcomes of the model or they are out of the scope of the model itself:

- Demographics
    - Population growth: outcome of fertility, mortality and migrations (outcome of the model).
    - Demographics: Urbanization level, Urbanization type (outside the scope).
- Economy and lifestyles:
    - GDP per cap: outcome of all other variables.
    - Within-country inequality, Consumption, Diet (outside the scope).
- Policies and Institutions: International cooperation, Environmental policy, policy orientation
- Technology
    - Carbon intensity: Results from scenarios on energy prices and energy productivity.
    - Energy technical change
    - Technological transfers: Comes from education and institutions scenarios.
- Environment: Environment, Land use.

3.2 Our implementation proposal: focus on institution scenarios

Institutions appear in different ways in MaGE. This is convenient because we can implement scenarios more precisely, but the drawback is that the definition of "efficient" institutions – as well as the quantification of their impact – is not easy.

According to Aron (2000), institutions interfere in the accumulation of all production factors, and in particular in productivity improvements – both regarding innovation and catch-up – and in capital accumulation. The author also considers that the impact of institutions is too often limited to productivity improvements. As far as we know, proper quantitative estimates of the impact of institutions have only been conducted on TFP (Chanda and Dalgaard, 2008). This implies that, for other variables of interest, we use a rather normative way of defining "efficient" and "inefficient" institutions.

Institutions in MaGE

In MaGE equations, institutions appear at two different levels. First they appear in the fixed effects (FE), i.e. the intercepts of the equations that can be seen as "reference period average" when it comes to projections (see MaGE working paper). The other form in which institutions are reflected is in the difference of parameters for some of the equations which are estimated for two separate groups of countries depending on whether they belong or not to the OECD. The equations for which we are able to implement institution scenarios are growth of TFP (Eq. 7), female participation (Eq.

$$ln\left(\frac{l^F_{a,i,t}}{1-l^F_{a,i,t}}\right) = \sigma_{a,i} + \beta^2_a h^2_{a,i,t} + \beta^3_a h^3_{a,i,t} + \varepsilon_{i,t} \qquad (6),$$

growth in energy productivity (Eq. $\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B^*_{i,t-1}}{B_{t-1}}\right) + \mu_2\, ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t}$

(8) and Feldstein-Horioka or savings-investment relationship

(Eq.$\left(\frac{I}{Y}\right) i,t = \alpha_i + \beta_i \left(\frac{S}{Y}\right)_{i,t} + \varepsilon_{i,t}$

(4).

So, for instance, better institutions only in the OECD countries, as for instance in SSP4, would increase both the "reference period average", i.e. the intercept, and also the speed of convergence to the energy productivity frontier, i.e. parameter μ_1 in Eq. $\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B^*_{i,t-1}}{B_{t-1}}\right) + \mu_2\, ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t}$ (8, for the OECD equation while it would leave as they are the parameters of the equation estimated for non OECD countries. Following the same principle, an adjustment of the equations' parameters to reflect the uences of better institutions is applied to the equations for growth of TFP (Eq.$\Delta ln(A_{i,t}) = \alpha_{0,i} +$ $\alpha 1\ ai,t-1+\alpha 2hi,t-13+\alpha 3ai,t-1hi,t-12+hi,t-13+\varepsilon i,t$ (7), savings rate $IYi,t=\alpha i+\ \beta i\ SYi,t+\ \varepsilon i,t$ (4),

female participation (Eq.$ln\left(\frac{l^F_{a,i,t}}{1-l^F_{a,i,t}}\right) = \sigma_{a,i} + \beta^2_a h^2_{a,i,t} + \beta^3_a h^3_{a,i,t} + \varepsilon_{i,t}$

(6), energy productivity (Eq.$\Delta ln(B_{i,t}) = \mu_1 ln\left(\frac{B^*_{i,t-1}}{B_{t-1}}\right) + \mu_2\, ln\left(\frac{y_{i,t-1}}{y_{US,t-1}}\right) + \varepsilon_{i,t}$

(8) and Feldstein-Horioka or savings-

$IY_{i,t}=\alpha_i+\beta_i SY_{i,t}+\varepsilon_{i,t}$ (4).

Error! Reference source not found. summarizes how change in Institution is implemented in MaGE for the five SSPs scenarios.

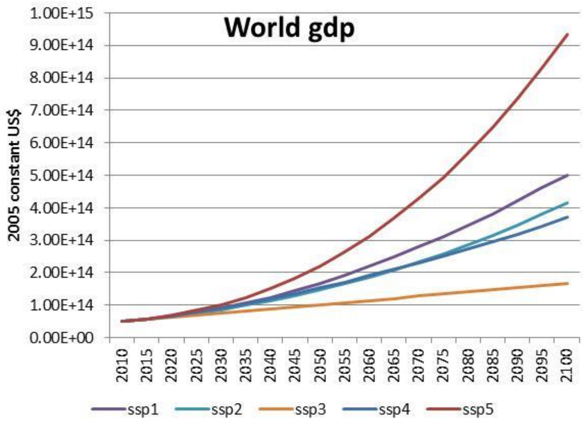
Relation	**Presence of institutions**	**SSP3 "Ineffective"**	**SSP4 "Effective for elite"**	**SSP5 "Effective"**
TFP	Intercept	-30% TFP level in 2100	OECD: +50% Other: -30%	+50% all
Energy productivity	Intercept + estimation groups	--	OECD: CV to best performing (Austria, Ireland, Italy, Norway) Other : Status quo	OECD: CV to best performing (Austria, Ireland, Italy, Norway) Other: CV to best performing
Savings rate	FE	--	--	Non-OECD: CV to OECD
Female participation	FE	--	--	Non-OECD: CV to OECD
Feldstein-Horioka	FE + estimation groups	--	--	Non-OECD: CV to OECD

The detailed methodology is in the Appendix of this paper.

4. Results

4.1 Global GDP scenarios

The following graphs (Figure 3) give an overview of the trend of world GDP per capita and a measure of between country income distribution at world level.



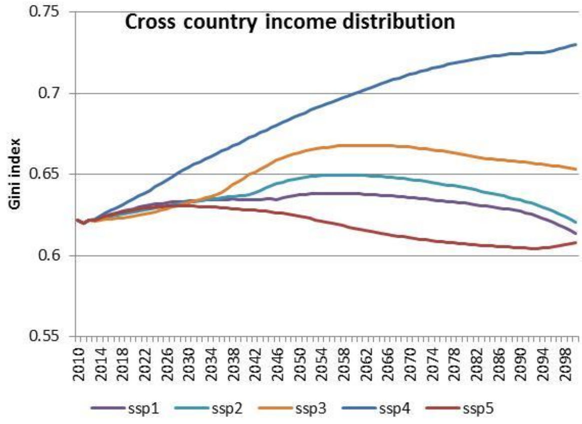


Figure 3: world GDP projections and Gini coefficients

The graph on the right side of Fig. 3 depicts the Gini coefficients for the analysed time series. The Gini coefficient is a measure of income inequality. It can vary between 0, which correspond to perfectly equal income distribution to 1, which on the contrary indicates totally unequal income distribution. The Gini coefficients give a measure of between countries income inequality; the macroeconometric model used for the analysis is not yet able to give a measure of the within country, i.e. at the household level, income inequality. Income inequality at world level is declining in all the SSPs except SSP4 and partly in SSP3 where world income remain rather unequally distributed.

4.2 GDP projections for the largest world economies

The following pictures show the GDP projections for the five SSP scenarios plus the reference for six important economic regions, China, Brazil, EU, USA, Russia and India. The GDP projections are expressed in billions of US 2005 dollars at market exchange rates. We avoid the conversion of the results in Purchasing Power Parities because the PPP conversion factors are only available for one year and the assumption of constant PPP conversion factor up to 2100 would be too strong not taking in to account the inflation dynamics.

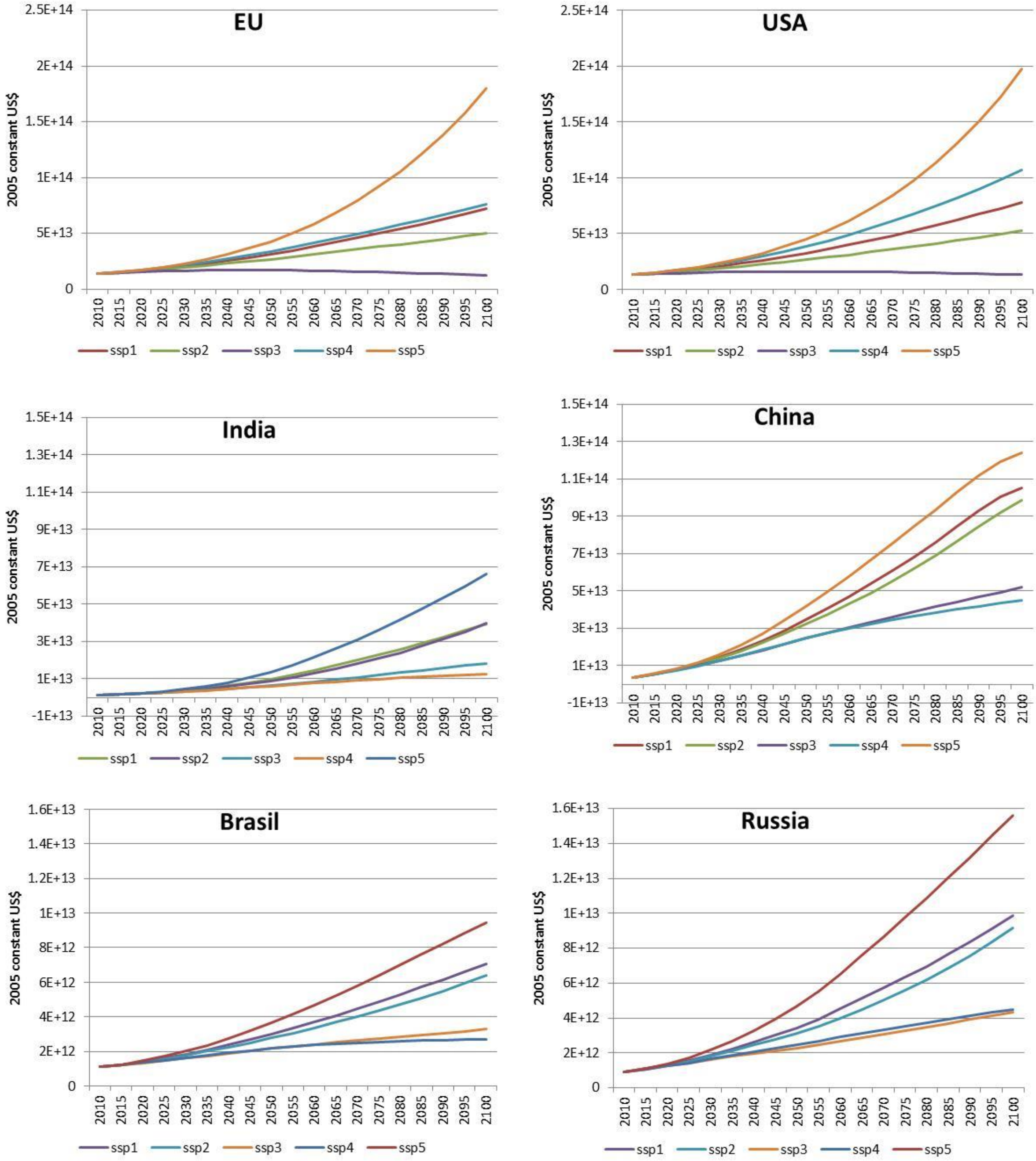


Figure 1: GDP projections for China, EU and USA, Brazil, India and Russia

The first three graphs show the projections for China, the EU and USA. For China the GDP projected for 2100 ranges from the 45 trillions of US $ of the SSP4 up to the 124 trillions of SSP5, in this last case a 30 fold increase compared to the GDP in 2010. For the USA the range of projected GDP is much larger; projections range from the 13 trillions of SSP3 to the 197 trillions of SSP5. Compared to the 30-fold increase in China, US GDP in 2100 is 13 fold the GDP in 2010. A similar large difference is found for the GDP projections of EU which cover a range between 13 and 179 trillions of US$ with an overall increase that spans from around 1 to 11 fold increases.

Brazil, Russia and India have lower GDP levels and for Brazil and Russia the model projects also relatively low growth prospects. Brazil has a GDP that goes from 2 to 8 trillions and in 2100 will be 8 times higher than in 2010 at most. For Russia, both projected GDP and growth prospects are higher, up to 14 trillions, i.e. a 15-fold increase compared to GDP level in 2010. Projections for India are substantially higher with a GDP ranging from 12 to 59 trillions and growth prospects that go from 9 to 48 fold increase.

By looking at the scenarios, SSP5 or "Conventional development" is the one with highest GDP growth prospects. This scenario is in fact characterised by low energy price, countries are still heavily dependent on fossil fuels, but the social costs of ghg emissions are not internalised. Conventional growth paradigms are enforced and these are assumed to imply very high increases in productivity.

Contrary to what is projected for SSP5, the results for the other scenarios are rather mixed. For instance the SSP4 assumptions corresponds to a highly unequal world and in fact these assumptions promote growth in advanced economies, i.e. US and EU, while is the worst for the BRICs. Energy price are assumed to be high in this scenario and contrary to EU and USA where this is compensated by high increases of productivity, in the BRICs this goes along with slow-moving productivity increases.

SSP3 is also characterised by very low GDP level for both advanced and emerging economies. For USA and EU there is almost no GDP increase, mainly due to decreasing productivity. Slightly better GDP prospects are evaluated for the BRICs where productivity decreases less.

SSP1 and SSP2 narratives give quite comparable results for the BRICs, where a higher emphasis on sustainability issues, i.e. SSP1, do not seem to affect GDP growth prospects. A slightly different result is obtained for USA and EU where the high relevance of sustainability issues in the political agenda do affect the GDP growth rates, also because while the narrative assume a rapid technical progress, it maintains constant the capacity of the countries to catch up.

5. Comparison with existing SSPs projections: OECD

The following graphs compare the projections for the SSPs obtained with MaGE and those of Env-growth the OECD growth model. The comparison is limited to the two main economic actors in global economy, i.e. China and USA, plus a comparison at the global level.

The two sets of projections follow a very similar pattern in the short/medium term; in most cases the GDP projected until 2040 or 2050, in same case even up to 2060, is the same for both models.

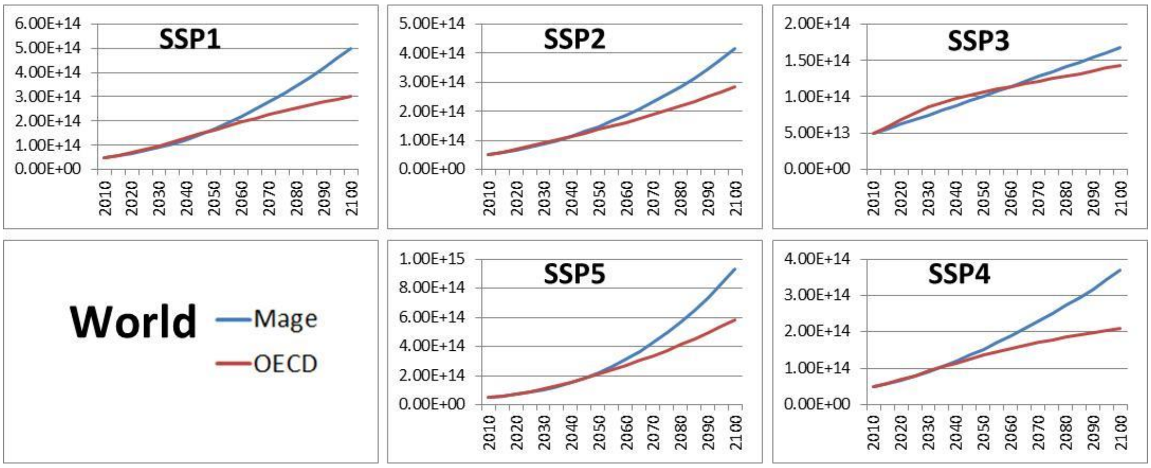


Figure 2 Comparison MaGE vs Env-growth at world level

At the global level in addition to resulting in the same projections in the medium term, the two models do not deviate too much also in the long term, i.e. up to 2100. This is especially true for SSP3, while for the other SSPs the differences stay in a range of +17 to +75% MaGE higher than Env-growt. Similar differences are found for the US economy. In all the SSPs, except SSP3, the two models give very similar results in the medium term and differences more or less in the same range as for the global aggregated results. SSP3 presents projections which are completely different both in the short, medium and long term; moreover it is one of the few cases where Env-growth yields projections higher than MaGE. A different quantification of the TFP, i.e. technical progress, dynamics could possibly explain the results for SSP3.

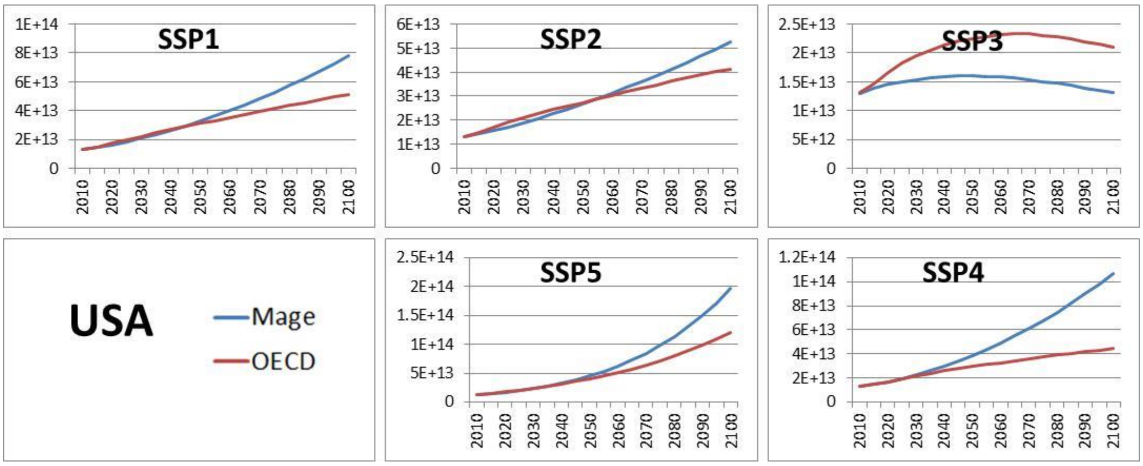


Figure 3: Comparison MaGE vs Env-growth USA

The results for China share the same patterns as for the other analysed regions, except that the differences in the longer period become much higher: from more than two times to more than 4 times higher.

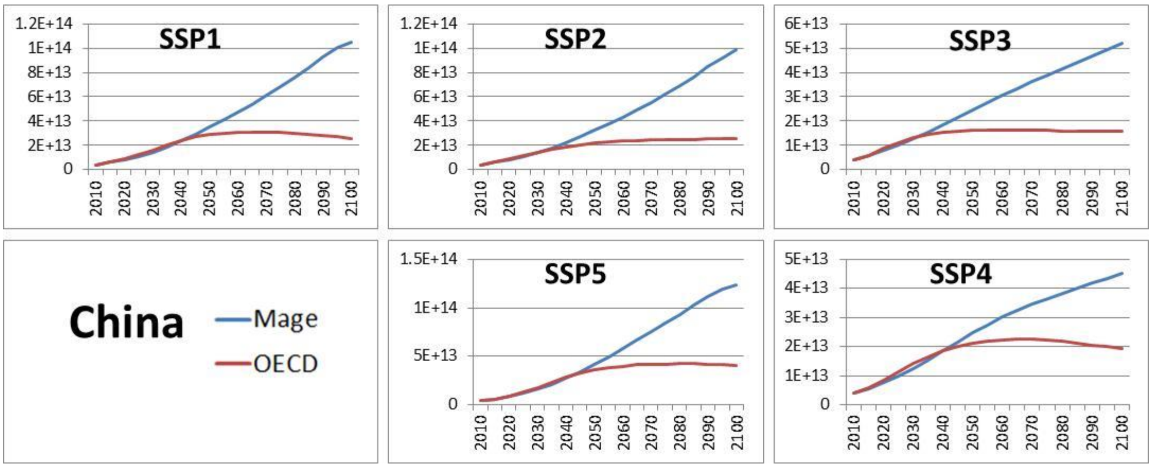


Figure 4: Comparison MaGE vs Env-growth for China

For China, the larger large discrepancies might depend on the dynamic of saving/investment and capital accumulation, which work under different assumptions in the two models.

6. Final conclusions

In these report the narratives behind the SSP scenarios have been translated in to quantitative socio economic projections at the 2100 horizon. One main conclusion is that the projections do not support the hypothesis of a trade-off between sustainability and potential of growth.

Theo achieve development goals, a lower resource intensity and fossil fuel dependency, can possibly coexist and lead to high prospects in terms of economic growth at world level.

In contrast, a highly unequal world across countries whereby 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, will imply growth prospects very limited at the global level, while aggravating the problem of allocation of resources towards alleviating the impact of environmental degradation. Possible next steps for the present analysis are mainly related to improvements of the model. The inclusion of urbanization or migration as additional variables of the model would certainly provide with a tool more suitable for the analysis of SSP scenarios.

Acknowledgement

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Appendix 1: Narratives according to O'Neil et al. (2012)

a. Narratives included

SSP	SSP1 Sustainability			SSP2 Middle of the Road			SSP3 Fragmentation			SSP4 Inequality			SSP5 Conventional		
Income group	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Demographics															
Fertility	Low		Medium	Medium			High		Medium	High	Low/medium		Low/medium	Low	Replacement
Mortality	Low			Medium			High			High	Medium		Low		
Migration	Medium			Medium			Low			Low			High		
Education	High			Medium			Low			Low/uneq.	Medium/uneq.		High		
Policies and institutions															
Institutions							Ineffective			Effective for elite*			Effective		
Technology															
Development	Rapid			Medium			Slow			Rapid for large corporations*			Rapid		
Energy intensity										Unclear			High		
Environment and natural resources															
Fossil constraints										Perception (and possibly reality) of strong constraints			None for coal and gas, possible for oil		

* Only within-country differences can be implemented

b. Narratives that are outcomes of MaGE

SSP	SSP1 Sustainability			SSP2 Middle of the Road			SSP3 Fragmentation			SSP4 Inequality			SSP5 Conventional		
Income group	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Demographics															
Population growth	Relatively low			Medium			Relatively high			Mixed			Peak and decline		
Economy															
GDP per cap growth	Medium		Fast	Medium		Slow	Slow			Low	Medium	Medium/high	High		
Across-regions inequality	Convergence, but retaining diversity									High			Convergence to high levels		
Technology															
Carbon intensity										Ambiguous (baseline/scenario)			High		
Transfer	Rapid			Medium?			Slow			Little transfer within countries to poorer populations			Rapid		

* Only within-country differences can be observed.

a. Narratives not included

SSP	SSP1 Sustainability	SSP2 Middle of the Road	SSP3 Fragmentation	SSP4 Inequality	SSP5 Conventional
Economy					
International trade			Barriers to trade	Unclear / not specified	High, with regional specialization in production
Environment and natural resources					
Agriculture productivity				High for large-scale farms, low for small-scale.*	Rapid
Sector structure	Rapid service sector growth				Limited shift towards services, high demand for manufactured products

Appendix 2: Impact of institutions on TFO

We consider TFP as a global and diffuse impact of institutions. TFP scenarios are detailed below in a separate paragraph. Regarding other relationships, we can only play with the convergence towards "more efficient" institutions, defined here by the OECD average both for fixed effects and other coefficients (when there are estimation groups). The quantification of the Impacts of institutions on TFP is based on a paper by Chanda and Dalgaard (2008) which estimated the following relation:

$$\log TFP_i = \beta_0 + \beta_1 INSTITUTIONS_i + \beta_2 OPENNESS_i + \beta_3 GEOGRAPHY_i + \epsilon_i \quad (9)$$

Where INSTITUTIONS is measured – in their central case – by the GADP ("Government Anti-Diversionary Policy") index. The empirical estimation of the above equation proves a positive impact of institutions on TFP. Despite being based on a slightly imprecise inference process the estimation of Chanda and Dalgaard (2008) can be anyway used to find out an order of magnitude for variation in TFP due to institutional efficiency; therefore we will anyway use their estimates.

The estimated relation ($\log TFP_i = \beta_0 + \beta_1 INSTITUTIONS_i + \beta_2 OPENNESS_i + \beta_3 GEOGRAPHY_i + \epsilon_i$ (9) allows us to measure the impact of a variation in institutions – for instance by an amount of σ between two periods 0 and 1, everything else being kept constant:

$$\log TFP_i^1 = \log TFP_i^0 + \beta_1 \times \sigma$$

And in levels:

$TFP_i^1 = TFP_i^0 \times e^{\beta_1 \sigma}$ (3)

Chanda and Dalgaard (2008) find the following results, when they include all the geographical controls:

$$0.88\ (OLS) \leq \beta_1 \leq 1.87\ (2SLS)$$

We assume that the variation of institutions we consider corresponds to a standard error of the GADP index distribution ($\sigma = \pm 0.21$). Using relation (3) yields:

$$\begin{cases} +20\% \leq \Delta TFP \leq +48\%\ if\ \sigma = 0.21 \\ -32\% \leq \Delta TFP \leq -17\%\ if\ \sigma = -0.21 \end{cases}$$

Then, our scenarios correspond roughly to +50% TFP for more efficient institutions, and -30% TFP for inefficient institutions.