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Research Report

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Long term socio-economic scenarios for Representative Concentration Pathways defining alternative CO2 emission trajectories

Jean Fouré & Lionel Fontagné

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CEPII
113, rue de Grenelle
75007 Paris
+33 1 53 68 55 00

www.cepii.fr
Press contact: presse@cepii.fr

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About the team

Lionel Fontagné[*#]

Jean Fouré[*]

Mouez Fodha, administrative officer[@]

[*] CEPII

[#] University Paris 1 Panthéon-Sorbonne

[@] CIREM

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Lionel Fontagné Jean Fouré

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1. Introduction

Building on an initiative by the Intergovernmental Panel on Climate Change (IPCC), researchers of the climate change field have been conducting since 2010 an interdisciplinary exercise in order to identify the key elements that would impact the potential magnitude and cost of climate change mitigation over the 21st century. The outcome of these working groups has been the elaboration of five potential scenarios – denominated as Shared Socioeconomic Pathways (SSP) – meant to be a common basis for climate policy analyses.

Since the publication of the narratives describing the five SSP scenarios, different teams have contributed by producing quantitative evaluation. Among them, two of particular interests are the projections of population and education by the International Institute for Applied Systems Analysis – IIASA (see KC et al., 2010), as well as the GDP projections produced by the OECD (2012).

Besides, recent work conducted at CEPII have lead to the elaboration of a set of tools to deal with long-term trade and development issues – the MaGE and MIRAGE models - which seemed natural candidates for an evaluation of the SSP scenarios. The present report aims to contribute to the SSP modeling effort by employing the tools developed at CEPII. Interestingly, the current exercise is encompassing the evolution of institutions, trade aspects and sector-specific assumptions. We finally derive a quantitative evaluation of the five scenarios. Sectoral evolutions at the country level are derived consistently from the combination of a long term growth model (MaGE) and an energy-oriented version of the Computable General Equilibrium (CGE) model nicknamed MIRAGE.

2. Methodological framework

In this section, we present the methodological framework relying on two models, MaGE and MIRAGE, as well as the definition of our 5 scenarios.

a. MaGE model

MaGE is a growth model used in projection at the country level. Growth projections for the 166 countries included in our sample are obtained with the 2.3 version in the model (Fouré *et al.* (2012, 2013). Based on a three-factor (capital, labor, energy) and two-productivity (capital-labor and energy-specific) production function, MaGE is a supply-side oriented macroeconomic growth model, defined at country level. It was built in three steps: production factor and productivity data were collected for the 1980-2012 period drawing on World Bank, United Nations and International Labor Organization data; behavioral relations for factor accumulation and productivity growth were estimated; and these relations were used to project GDP.

Supply is modeled as a CES production function of energy and a Cobb-Douglas bundle of capital and labor. We recover energy-specific productivity from the profit-maximization program of the representative firm, while TFP of the capital-labor bundle is computed as a Solow residual.

Behavioral relations are estimated for the education level, female participation to the labor force, capital accumulation and the two forms of productivity. For the labor force we start from UN population projections, split across 5-year age groups. For each of these age groups, we estimate education and then deduce labor force participation in the following way: while male labor force participation follows the logistic relation determined by the International Labor

Organization projections (and therefore does not depend on education), female participation is assumed to change with education level (more education means less participation for the study-age women, while it enhances participation afterwards). Educational attainment, defined as the percentage of each age group having attained a secondary or tertiary diploma, is assumed to follow a catch-up process to the leaders. The catching-up has different speeds, depending on the region and age-group, while the leader levels for each age-group and educational level are composites of the different leader countries (*i.e.* Austria, Japan, the United States, Switzerland, France, Norway, New-Zealand and Russia, depending on the education level and time period). These best-practice targets are assumed to continue to grow at their historical pace.

Investment in MaGE is a function of savings. It is modeled as a non-unitary error-correction relationship that differentiates long-term correlation between saving and investment and annual adjustments around this trend. Saving is a function of economic growth and the age structure of the population, consistent with the life-cycle hypothesis. Capital accumulates in MaGE according to a permanent-inventory process with a constant depreciation rate. Because of the significant differences we found between OECD and non-OECD members, both the investment and saving relationships are estimated separately for the two country groups. The closure rule in MaGE imposes consistency between saving and investment at the global level.

Capital-labor TFP and energy efficiency are driven by catch-up to the best-performing countries. TFP catch up is conditional on, and driven by, the educational level: while tertiary education fuels innovation (autonomous productivity improvements), secondary education is a prerequisite for imitation (catching-up). Energy efficiency catch up depends both on the distance to the technological frontier in energy use, and on the level of development, to reflect differences in sectoral structure across countries.[1]

b. MIRAGE model

The multi-sectoral CGE model MIRAGE has a recursive sequential dynamic set-up that is consistent with the output of MaGE aggregate growth models. We rely here on the version of it dedicated to long-term and energy-related issues, nicknamed MIRAGE-e (Fontagné et.al, 2013). Projections from MaGE are used to construct a dynamic baseline for MIRAGE-e (Decreux and Valin, 2007). MIRAGE-e relies on the same exogenous variables (population, energy prices) that are embodied in the macroeconomic models, but takes as additional exogenous variables the results from the macroeconomic projections, notably GDP, saving rates, current accounts, labor force, human capital formation and energy efficiency. Moreover, the distribution of human capital in the population is used to set the number of skilled and unskilled workers in MIRAGE-e, which distinguishes these two categories of labor, with the assumption that skilled workers correspond to people having obtained a tertiary level diploma. The global closure of MIRAGE-e is ensured by imposing that the share of each country/region in the global current account imbalance varies yearly according to the macro projections.

[1] At early stages of development, economies rely largely on agricultural production, which is not very energy-intensive, while industrialization leads to an intensification of energy use and the later change towards services reverses the trend. Conditioning the energy-efficiency catch-up to the level of development allow to represent this stylized fact at the macro level.

Supply in MIRAGE-e

On the supply side, each sector in MIRAGE-e is modeled as a representative firm, which combines value-added and intermediate consumption in fixed shares. Value-added is a bundle of imperfectly substitutable primary factors (capital, skilled and unskilled labor, land and natural resources) and energy. Firms' demand for production factors is organized as a CES aggregation of land, natural resources, unskilled labor, and a bundle of the remaining factors. This bundle is a nested CES aggregate of skilled labor, and another bundle of capital and energy. Finally, energy is a CES aggregate of energy sources (except for non-electricity energy production sectors, for which the share of each energy input is fixed). Energy consumption of the representative firm comprises five energy goods (electricity, coal, oil, gas and refined petroleum), which are aggregated in a single bundle that mainly substitutes for capital.

MIRAGE-e assumes full employment of primary factors, whose growth rates are set exogenously, based on the macro projections on a yearly step, as detailed below.

Population, participation in the labor market and human capital evolve in each country (or region of the world economy) according to the demographics embedded in the macro projections. This determines the labor force as well as its skill composition (skilled/unskilled).[2] Skilled and unskilled labor is perfectly mobile across sectors, but immobile between countries.

Natural resources are sector specific, while land is mobile between agricultural sectors. Natural resources for the mining sector and land for agricultural sectors are set at their 2004 levels: prices adjust demand to this fixed supply. In the baseline, natural resources for fossil fuel production sectors adjust to match the exogenous price target we impose (from the International Energy Agency, 2012) for coal, oil and gas, and according to the energy demand projected by the model. By contrast, in the simulations, changes in demand for fossil energy sources influence their price, while natural resources are fixed at their baseline level.

Installed capital is assumed to be immobile (sector-specific), while investments are allocated across sectors according to their rates of return. The overall stock of capital evolves by combining capital formation and a constant depreciation rate of capital of 6% that is the same as in the long-term growth models. Gross investment is determined by the combination of saving (the saving rate from the growth model, applied to the national income) and the current account. Finally, while total investment is saving-driven, its allocation is determined by the rate of return on investment in the various activities. For simplicity, and because we lack reliable data on foreign direct investment at country of origin, host and sectoral levels, international capital flows only appear through the current account imbalances, and are not explicitly modeled.

Demand in MIRAGE-e

On the demand side, a representative consumer from each country/region maximizes instantaneous utility under a budget constraint and saves a part of its income, determined by saving rates projected in our first-step exercise. Expenditure is allocated to commodities and services according to a LES-CES (Linear Expenditure System – Constant Elasticity of Substitution) function. This implies that, above a minimum consumption of goods produced by each sector, consumption choices among goods produced by different sectors are made

[2] In MIRAGE, contrary to MaGE, no gender distinction is made.

according to a CES. This representation of preferences is well suited to our purpose as it is flexible enough to deal with countries at different levels of development.

Within each sector, goods are differentiated by their origin. A nested CES function allows for a particular status for domestic products according to the usual Armington hypothesis (Armington, 1969): consumers' and firms' choices are biased towards domestic production, and therefore domestic and foreign goods are imperfectly substitutable, using a CES specification. We use Armington elasticities provided by the GTAP database (Global Trade Analysis Project) and estimated by Hertel *et al*. (2007). Total demand is built from final consumption, intermediate consumption and investment in capital goods.

Efficiency in the use of primary factors and intermediate inputs is based on the combination of four mechanisms. First, agricultural productivity is projected separately, as detailed in Fontagné *et al.* (2013). Second, energy efficiency computed from the aggregate growth models is imposed on MIRAGE-e (it enters the capital-energy bundle). Third, a 2 percentage point growth difference between TFP in manufactures and services is assumed (as in van den Mensbrugghe, 2005). Fourth, given the agricultural productivity and the relation between productivity in manufacturing and services, MIRAGE-e recovers endogenously country-specific TFP from the exogenous GDP and production factors. Notice that TFP thus recovered from the baseline projections is subsequently set as exogenous in the alternative scenarios. Therefore, GDP becomes endogenous in such scenarios.

Dynamics in MIRAGE-e is implemented in a sequentially recursive way. That is, the equilibrium can be solved successively for each period, given the exogenous variations of GDP, savings, current accounts, active population and skill level coming from the growth models, as described above. For baseline projections, the time span is 93 years, the starting point being 2007.

MIRAGE-e was calibrated on the GTAP dataset version 8.1, with 2007 as a base year. As shown in Table 1, our data aggregation singles out all energy industries and combines other industries into main representative subsectors within the agriculture, manufacturing and services aggregates. For the regional aggregation, we retain the main trade groups and also isolate the main emerging economies. We aggregate the rest of the world on a geographical basis.

Table 1. Sector and country aggregation in MIRAGE-e

Country aggregation	Sector aggregation
Europe	**Primary**
European Union (EU28)	Vegetal agriculture
European Free Trade Association (EFTA)	Animal agriculture
Other Europe	Coal
Americas	Oil
United States of America (USA)	Gas
Other North America Free Trade Agreement (NAFTA)	Minerals
Mercosur	**Secondary**
Other Latin America	Food
Asia-Oceania	Clothing
Oceania	Petroleum
China & Honk-Kong	Chemistry
Japan	Metals
Association of Southeast Asian Nations (ASEAN)	Vehicles and equipment
India	Electronic
Other developed Asia	Other Manufacturing
Other developing Asia	**Tertiary**
Africa	Electricity
Middle-East and North Africa	Transport
Other Africa	Finance, insurance and business
	Other Services

Source: authors

Tariff data at the HS6 level corresponds to the ad valorem equivalents from the MAcMap database (Guimbard *et al.*, 2012) and are aggregated to match our regional and sectoral decomposition using the trade-weighted method. Finally, we include international transaction costs and non-tariff measures (NTM) in goods, modeled as an iceberg trade cost. Data for trade costs associated with delays were calibrated using a database provided by Minor and Tsigas (2008), who adopt the methodology in Hummels and Schaur (2012).

The way in which MaGE and MIRAGE-e are related is summarized in Figure 1 in Section 3, which shows the different variables that the models exchange and the point at which assumptions are introduced (see Section 3 for details). We developed 5 scenarios based on the Shared Socio-economic Pathways (SSP), plus five sensitivity analysis scenarios. Details on assumptions underlying these simulations are described in the next sections.

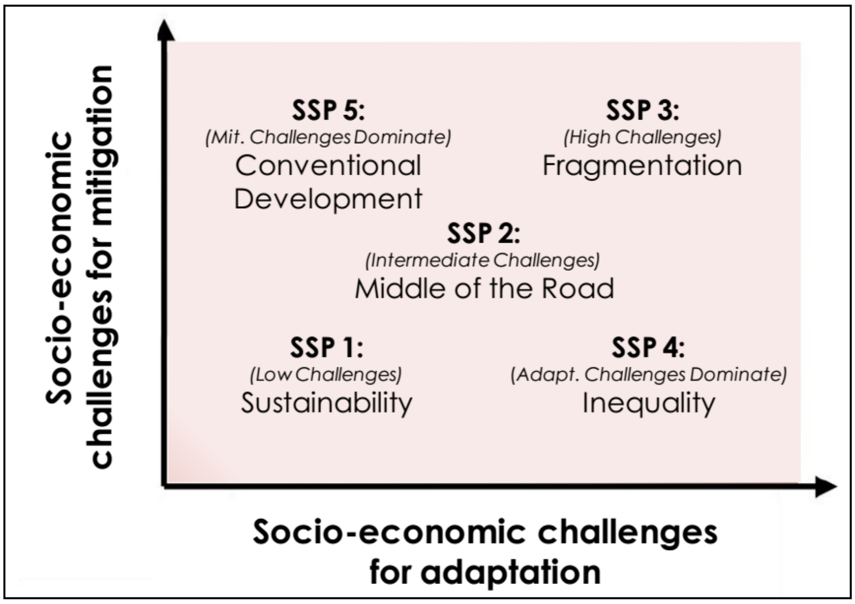
3. Interpreting the SSP pathways

Following the initiative by the International Panel on Climate Change (IPCC), launched in 2007, researchers from various fields have gathered to elaborate five scenarios representing the potential contexts in which the world could have to deal with climate change and CO_2 mitigation. The outcome of these meetings is summarized in O'Neill et al. (2012), on which we will build our own interpretation of the narratives provided.

a. Background and narratives

The 5 scenarios are articulated around two base directions: the socio-economic challenges for mitigation, and the socio-economic challenges for adaptation. Each of the scenarios includes a different mix of these challenges, as summarized in Figure 1.

Figure 1 – Graphical representation of the five SSP scenarios



Source: O'Neil et al. (2012)

The following paragraphs describe in more detail the 5 scenarios. These descriptions are taken from 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 contributing to this are: a rapid development of low-income countries, a reduction of inequality (globally and within economies), a 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.

SSP2 – Middle of the Road

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, and 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.

SSP3 – Fragmentation

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.

SSP4 – Inequality

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.

SSP5 – Conventional Development

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.

b. Scope of MaGE and MIRAGE models

Of course, the complexity of these narratives cannot be perfectly represented in a macroeconomic model. Our set of tools can however build much differentiated scenarios upon these narratives. The first step in our interpreting the SSP narrative is identifying the scope of the mentioned variables, and the way it can enter in our models.

Building on the appendices from O'Neill et al. (2012), we separate the different variables between (i) those on which we can build exogenous scenarios in MaGE, (ii) those on which we can build exogenous scenarios in MIRAGE, (iii) those that are in fact outcomes of our models and (iv) the variables that are out of the scope of our models. The three first categories are presented in Table 2.

Table 2 – From SSP narratives to MaGE-MIRAGE scenarios

Topic	MaGE scenario	MIRAGE scenario	Outcomes
Demographics	Fertility Mortality Migration Education		Population growth
Economy		Sector structure International trade	Growth Across-regions inequality
Policies and institutions	Institutions		
Technology	Techno. development Energy intensity		Carbon intensity Techno. transfers
Environment & Natural resources	Fossil constraints	Agricultural productivity Sector structure	

Source: authors

Along with these scenarios that we implement, some elements of the narratives cannot be included in our two models. These are urbanization, within-country inequality, international cooperation, environmental policy, energy technology change (towards renewable energy) and land use. Consumption structure is partially endogenous in MIRAGE.

c. Quantifying the assumptions

We develop several strategies, depending on the issue, in order to best represent our understanding of the SSP narratives and use all the capabilities of our models. The general summary of the variables we retained are presented in Table A1 in appendix.

Demographics and education

Out approach regarding demographics is hybrid, since all the dimensions cannot be directly encompassed using MaGE. Furthermore, other institutions have published detailed demographic scenarios, in particular the IIASA. These IIASA scenarios already include variation in mortality, fertility and migration, whereas MaGE can only deal with some migrations flows. We therefore chose to rely on IIASA projections for population.

Regarding education, two options were available: use IIASA projections or develop scenarios directly in MaGE. On the one hand, MaGE projections would have been more flexible, but on the other hand, IIASA include the impact of education on fertility. We then chose IIASA projections to keep a maximum consistency.

Finally, total population has to be converted into active population. On this matter, MaGE provides the best framework by including variation in female participation to the labor force due to increases in education level.

Institutions

The economic literature has studied institutions and their impact for long. For instance, Aron (2000) documents that institutions interfere in the accumulation of all production factors, and in particular by productivity improvements – both regarding innovation and catch-up to the technological frontier – and in capital accumulation. Quite often, as the author suggests, institutions are limited to productivity improvements, neglecting all other aspects. We will try to depart from this common assumption.

Although not explicitly specified, institutions differentials appear in MaGE in two ways. First of all, they are embodied in the fixed effects that are estimated in our econometric relationships (TFP, savings rate, female participation to the labor force and savings-investment relation). Second, institutions also appear in the Feldstein-Horioka relation, because we conduct two separate estimations on two different country groups (OECD countries vs. non-OECD countries). As a consequence, the estimated coefficients embody institutional differences between OECD members and other countries. Scenarios of institutional convergence can then be derived from these two ways.

However, quantifying the magnitude of the impact of institutions on our variables of interest is subject to judgment: to our knowledge the literature has not investigated the quantitative impact of institutions on other variables than TFP. Therefore, productivity improvements due to improvements in institutions efficiency will be derived from estimates from the literature – as described below – while we will have a simple normative definition of efficient institutions regarding other variables (savings rate, female participation and savings-investment relationship).

The link between productivity improvements and institutional environment has been quantified By Chanda and Delgaard (2008). The impact of institutions – measured by the Governement Anti-Diversionary Policy (GADP) index – on the level of TFP is tackled using several estimation strategies (Ordinary Least Squares – OLS – and 2-Stage Least Squares – 2SLS – with instrumental variables). Endogeneity issues were finally not convincingly addressed and the results provide only orders of magnitude of the actual impact of institutions on TFP. Appendix B details how we converted these estimated coefficients into TFP level scenarios.

Regarding other relations that are impacted by institutional convergence, we will arbitrarily consider then institutions in OECD countries are more efficient than in non-OECD countries, and as a consequence, convergence towards more efficient institutions will only impact non-OECD countries, making them converge by 2100 to the average OECD institutions (both the fixed effects and other estimated coefficients converge).

Technology

First of all, SSP narratives include scenarios on the technological frontier. This TFP frontier is present in MaGE, and is represented by the TFP level of Ireland and Denmark (these two countries share the leadership over our estimation period). Other countries converge towards the technological frontier conditionally on their education level. In projection, the baseline assumption in MaGE is that the TFP frontier continues to grow at its 1995-2008 average pace (around 1.5% annual growth). The amount of additional TFP for leader countries in SSP scenarios is however not easily determined, so we will consider scenarios where the TFP leader level of TFP growth is +/-50% of the baseline growth rate.

The second issue about technology scenarios is energy productivity. We will consider a 50% increase in energy productivity by 2100.

Fossil constraints

Fossil constraints in MaGE are materialized by oil price, whose trajectory binds the amount of energy use given the current level of energy-specific productivity. In MIRAGE, we can further differentiate the type of energy, and consider different prices for coal, oil and gas. The central scenario in both models corresponds to the medium projections of the International Energy Agency (IEA), taken from the World Energy Outlook (IEA, 2012). Accordingly, high and low fossil resource prices scenarios will be derived from their counterparts in IEA projections.

Sector structure and international trade

MaGE does not encompass the sector structure of the economy, but MIRAGE does. The shift in structure is driven by relative (final and intermediate demand), hence relative prices and productivity differential. In our central case, agricultural productivity is exogenous (following the projections documented in Fontagné et al., 2013) while we constraint services productivity growth being 2 percentage points lower than industrial TFP. The national average TFP level is computed given these constraints, plus the need to match MaGE projections in terms of GDP. Accordingly, scenarios will build on this productivity structure.

As for scenarios, a more productive agriculture will correspond to a 0.2% additional annual productivity growth, corresponding roughly to the average productivity growth in crops sector. In addition, productivity growth in services will be 0.45% greater (or 0.4% lower), in order to match the orders of magnitude of productivity variations given by Chanda and Delgaard (2008) – i.e. +50% or -30% by 2100). The case of Japan and the EFTA is particular, since imposing a 0.4% lower annual growth in services for these countries - they are very services-intensive, but with a low overall productivity growth - would lead to unrealistic results. Therefore, we assume that the TFP in services is only 0.2% lower in SSP5 scenario.

International trade is mainly influenced by tariff and other transaction costs faced by exporters, as well as by energy prices through transport, as documented in Fontagné and Fouré (2013). We will focus on the two first determinants, since energy prices scenarios are derived separately, taking the assumptions elaborated in Fontagné and Fouré (2013). Namely, we will consider (i) a world trade war by 2100 resulting in a return to post-Tokyo round tariffs (in 1976) plus an increase in transaction costs by 20% ; or (ii) a global liberalization resulting in a 50% decrease in tariffs plus 20% decrease in transaction costs.

Summary

Table 3 summarizes the assumptions made to represent at best the five SSP narrative scenarios.

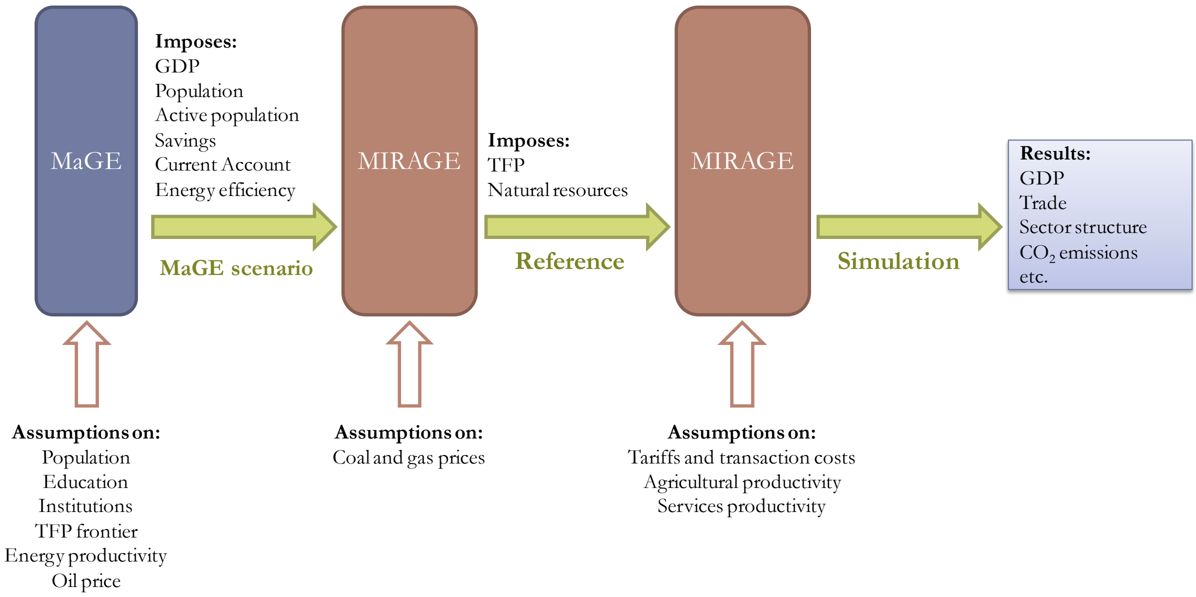
Table 3 – MaGE and MIRAGE assumptions

	SSP1 Sustainability	SSP2 Middle of the Road	SSP3 Fragmentation	SSP4 Inequality	SSP5 Conventional	Model
Population	Provided by IIASA					MaGE
Education	Provided by IIASA					MaGE
Institutions	--	--	-30% TFP	OECD: +50% TFP Non-OECD: -30%	+50% TFP Non-OECD: convergence of FE and coefficients	MaGE
TFP frontier	+50% frontier growth	--	-50% frontier growth	+50% frontier growth	+50% frontier growth	MaGE
Energy productivity	--	--	--	--	+50% energy productivity	MaGE
Fossil resource prices	--	--	--	High energy price	Low energy price	MaGE MIRAGE
Agricultural productivity	--	--	--	OECD: 0.2% additional growth	0.2% additional growth	MIRAGE
Services productivity	0.45% additional growth	--	--	--	0.4% less growth	MIRAGE
Tariffs	--	--	Return to post-Tokyo round tariffs	--	-50% tariff	MIRAGE
Transaction costs	--	--	+20%	--	-20%	MIRAGE

Source: authors

The way these assumptions are introduced are summarized in Figure 2. It is important to note that, for instance, each SSP scenario will contain two different GDP trajectories: the first one is the output of the MaGE model, and the second corresponding to the same trajectory to which we add the impact of sector-specific assumptions (sectoral productivity, tariffs or transaction costs).

Figure 2 – Complete articulation of the models and assumptions



Source: authors

4. Results

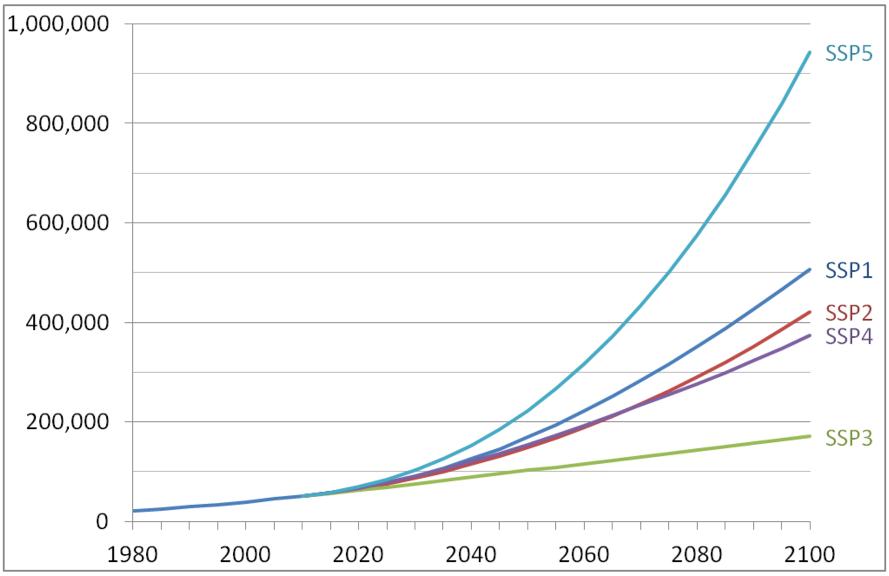
We present in the following the main results of this exercise; detailed results are provided in a database format.

a. SSP scenarios in MaGE

The first striking result is the extremely large range of possible worlds opened by the combination of the above-mentioned assumptions. Figure 3 shows the amount of variation in world GDP between the SSP scenarios. They range from a multiplication by 4 (SSP3) to 20 (SSP5) between 2007 and 2100. Clearly, the "conventional development" scenario would impose an extremely high toll on environment and natural resources. In contrast, a "fragmented" world would limit the economic size of the world economy, but without bringing the resources to alleviate environmental problems. The "sustainability" confirms here attractiveness: while limiting the costs of adaptation and mitigation, it offers a good comprise in terms of growth and thus in terms of resources potentially mobilized to address environmental issues: it is always easier to adjust in a reasonably well-growing economic environment.

GDP

Figure 3 – World GDP in volume (billion constant 2005 USD)



Source: authors' calculations, using MaGE

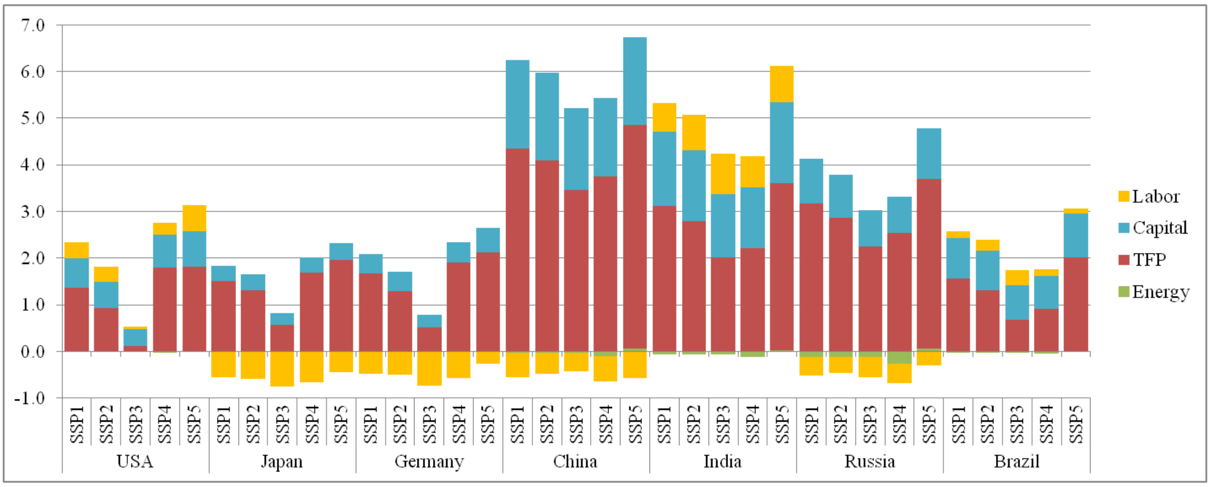
Growth decomposition

The next step is to decompose the envisaged economic growth, and to identify the main drivers of the evolutions at stake in the various scenarios. Such decomposition of annual growth rates is proposed in Figure 4.

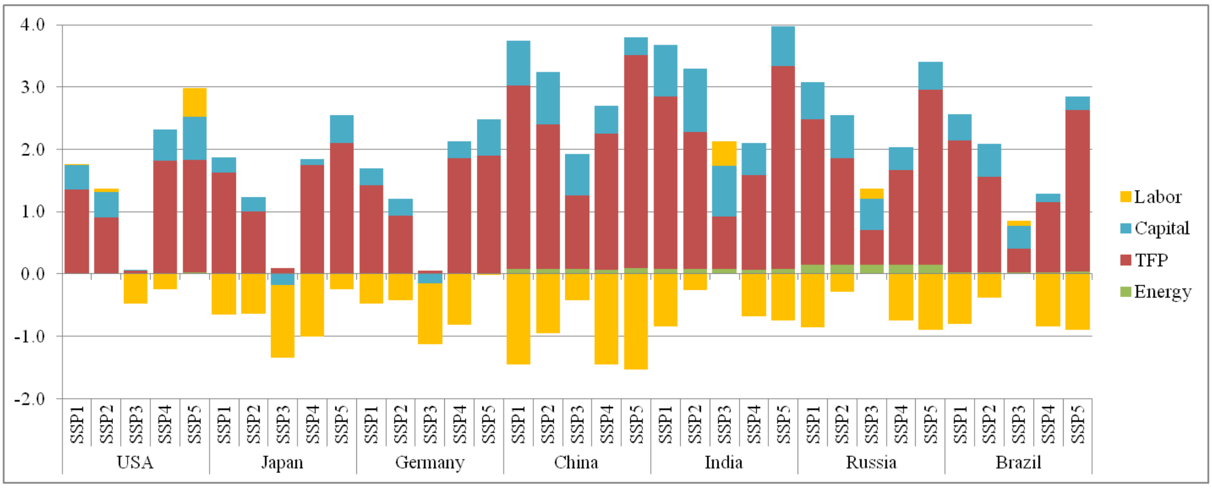
The first, expected, outcome is the toll on growth exerted by demography in a series of large countries at the 2050 horizon: Japan, Germany, China, and Russia. Brazil, the United States and even India could be also affected – depending on the scenarios – by the end of the century.

Figure 4 – Average annual non-oil GDP growth rate decomposition

(i) 2010-2050



(ii) 2050-2100



Source: authors' calculations, using MaGE

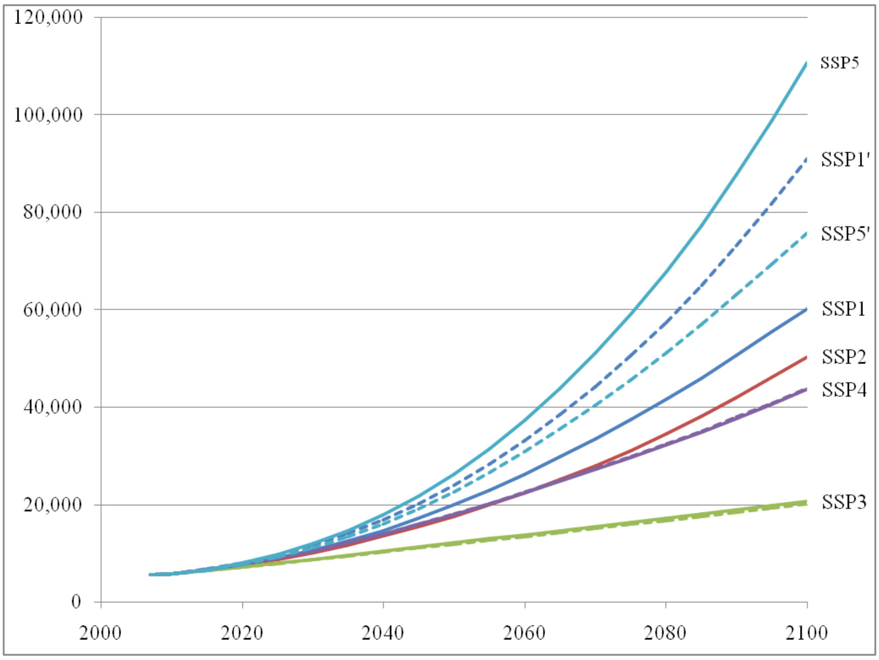
The second observation is that the main driver of GDP growth is TFP, and the more so after 2050 where investment will play a lesser role. As a consequence, scenarios on productivity growth will have the largest impacts. In most developed countries, such as Japan, the USA or Germany, the majority of TFP growth comes from the frontier growth (since these countries are not far from the frontier). For instance, in the "fragmentation" scenario, technological progress at the frontier is almost fully compensated by inefficient institutions. On the contrary, in developing countries, only part of TFP growth vanishes due to institutions.

b. SSP scenarios in MIRAGE

The next step is to combine results delivered by MaGE and MIRAGE. As referred to above, MIRAGE not only provides a sectoral breakdown of MaGE results. This is also the proper tool to be used to address changes in protectionism or in transaction costs in general. In Figure 5, we observe that the combination of the two models is providing important results. For instance, the outcome of the "conventional development" scenario is very different when additional assumptions imposed to MIRAGE are taken into account (namely reduced productivity gains in services and reduced tariffs and transaction costs for goods). The growth prospects for the world economy are much reduced. When MIRAGE and MaGE assumptions are combined, on the contrary, the "sustainability" scenario demonstrates all its potential: what is referred to as SSP1' in Figure 5 offers now the best growth prospect to the world economy. In other words, there is no trade-off between sustainability and growth prospects.

GDP

Figure 5 – World GDP in volume, including assumptions on trade and sector productivity, 2007-2100



Note: Plain lines denote MaGE output, whereas dotted lines denote MIRAGE output, which include the impact of sector-specific trade and productivity assumptions.
Source: authors' calculations, using MaGE and MIRAGE

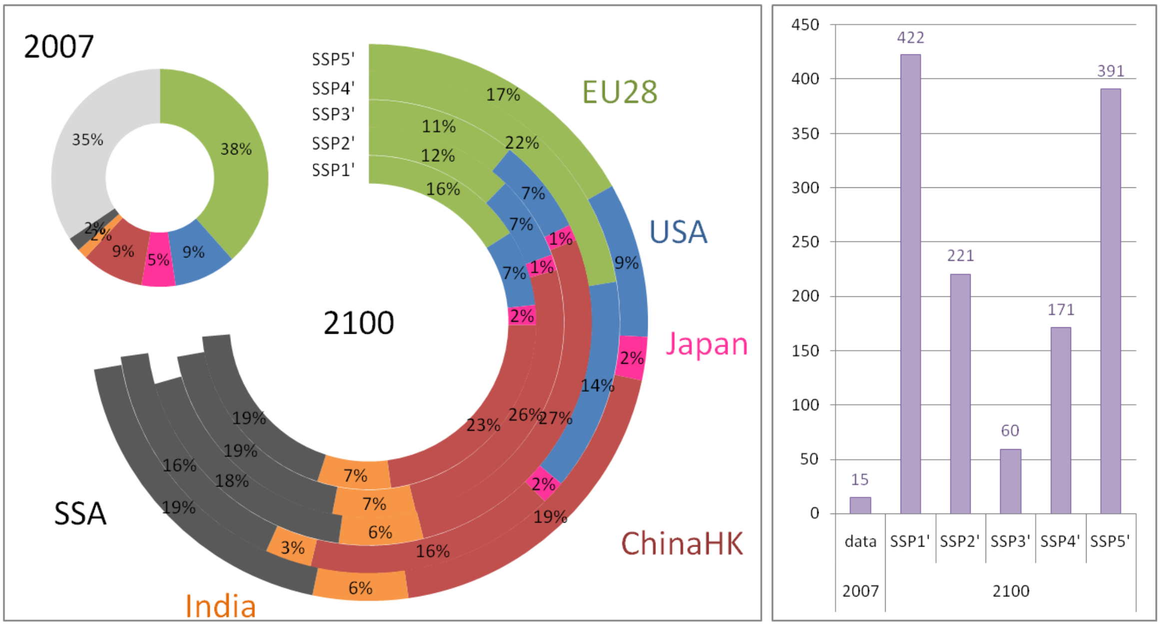
Figure 5 stresses that properly modeling sector structure – and trade to a lesser extent – remains crucial when encompassing potential future trends. Indeed, an increased TFP growth in services (scenario SSP 1') could be instrumental to future growth, even if absence of institutions convergence or favorable energy-related environment changes (compared to scenario SSP5').

Trade

Regarding trade patterns, the first important result is the very large range of possible outcomes. In terms of the global volume of trade, trade would be multiplied by a factor 4 to 28, depending of the scenarios, as a result of trade to GDP elasticity.

In any case, Sub-Saharan Africa, along with China and India would increase their participation to international trade, whereas developed countries such as the EU, the USA and Japan would represent in 2100 a lower share in world trade (Figure 6). However, Scenario SSP4 ("inequality") is particularly different from the others, due to the very asymmetrical assumptions it implies (inequality between developed and developing countries): in this context, developed countries would still concentrate around 40 percent of world trade, against between 19 and 28 percent in other scenarios.

Figure 6 – World total exports and share by region, 2007 and 2100, thousands billion 2007 USD, incl. intra-EU trade



Source: authors' calculations, using MaGE and MIRAGE

c. Sensitivity analysis

Projected patterns of the world economy are very sensitive to assumptions translating rather qualitative statements of the SSP scenarios into quantitative changes in the models used. We now perform a robustness analysis and compare our understanding of the qualitative scenarios with what the OECD did.

Assumptions for sensitivity scenarios

In order to test for the sensitivity of our assumptions, we try to compare our implementation of the five SSP scenarios with assumptions made by the OECD in their own evaluation of the very same scenarios (OECD, 2012). We reproduce in Table 4 OECD assumptions that we will implement in MaGE.

Table 4 – OECD assumptions on SSP scenarios

	SSP1	SSP2	SSP3	SSP4	SSP5
TFP					
TFP frontier growth	Medium high 1%	Medium 1.1%	Low 0.6%	Medium 1.2%	High 1.6%
CV speed	High	Medium	Low	LI: Medium low MI: medium HI: medium	Very high
Openness	*Medium*	*Medium*	*Low*	*LI: Low* *MI: Medium* *HI: Medium*	*High*
Natural resources					
Resources	*Conv: Medium* *Unconv: Low*	*Medium*	*Conv: Medium* *Unconv: High*	*Low*	*Oil: Low* *Gas: High*
Fossil price	Low	Medium	High	Oil: High Gas: Medium	High
Demographics					
Population	Provided by IIASA				
Education					

Note: Italics denote the two topics of OECD scenarios that cannot be implemented in MaGE.
Source: authors based on OECD (2012) and IEA (2012)

Regarding TFP convergence speed, we use directly the coefficients and specification from OECD, on a country by country basis, whereas we for energy price, we rely on scenarios by IEA (2012).

The OECD model for TFP is very different from MaGE original modeling. Namely, TFP converge on a country by country basis towards a long-term TFP target $A_{r,t}^{LT}$ at a varying speed $\rho_{r,t}$, with the following specification:

$$A_{r,t} = A_{r,t-1}\left(\frac{A_{r,t}^{LT}}{A_{r,t-1}}\right)^{\rho_{r,t}}$$

We use the $\rho_{r,t}$ from OECD, but approximate the long term level by the average of leaders considered in the source paper over.[3] The speed of TFP growth for these countries is set to the frontier growth value presented in Table 4. Finally, TFP trajectory is smoothed – using spline interpolation – between 2013 and 2025 when these 5 scenarios are implemented, because the switch to OECD methodology lead to an important shock of TFP growth in year 2013, which MIRAGE cannot handle (in particular, its impact on current account trajectories).

The main differences between our set of scenarios and OECD's reside in the capabilities of the different models. On the one hand, the OECD model encompasses an impact of trade openness on productivity (positive externalities) and differentiates conventional and unconventional fuels. The combination of MaGE and MIRAGE does not handle any of these two aspects. More specifically, our understanding is that the relation between trade and productivity cannot be properly assessed in a CGE not fitting heterogeneous firms. On the other hand, we are able to deal with institutions and sector-specific assumptions, contrary to OECD (2012).

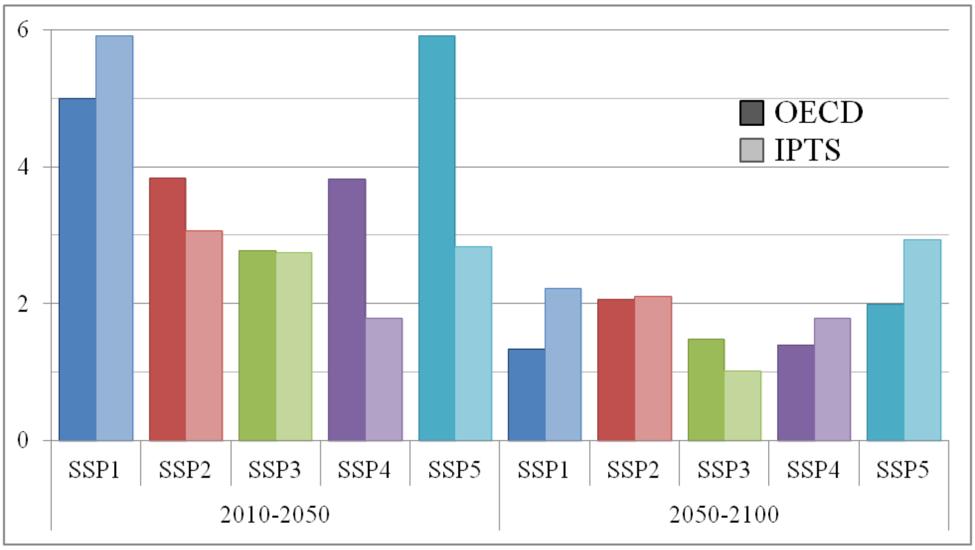
[3] These leaders are Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, Netherlands, Norway, Spain, Sweden, United Kingdom and the United States of America.

Key results

In Figure 7, we compare the outcome of our scenarios (here labeled "IPTS") with the one of OECD scenarios. The dark bar holds for OECD scenarios (as modeled with MaGE-MIRAGE). We consider two horizons, before and after 2050.

The largest differences between our approach and the OECD are for the first 40 years of the exercise. As for the first sub-period, the way the OECD is translating the SSP scenarios into a modeling exercise points to the "superiority", in terms of overall growth of the "conventional development" scenario. In contrast, in our approach, this scenario is very much dominated by the "sustainability" scenario. The second difference is for the "inequality" scenario, which is much worse than "middle of the road" for us, and equivalent for the OECD.

Figure 7 – World GDP average annual growth rate in the 10 scenarios, 2010-2050 and 2050-2100



5. Concluding remarks

We translated in these report SSP scenarios into quantitative outcomes at the 2050 and 2100 horizon combining MaGE and MIRAGE. Overall, we find no trade-off between sustainability and potential of growth.

Sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency, will lead to the highest prospects in terms of economic growth at world level. This means that a rapid development of low-income countries, a reduction of inequality (globally and within economies), a rapid technology development, and a high level of awareness regarding environmental degradation, will also generate the economic resources making it easier to tackle the sizeable issues the world economy will be facing in the next decades.

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 not deliver. Growth prospects will remain limited at the global level, aggravating the problem of allocation of resources towards alleviating the impact of environmental degradation.

This "no-trade off" conclusion is an important contribution to the debate on the SSPs.

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7. Appendices

A. Summary of SSP narratives by variable

Table A1 presents a summary of the narratives we tried to reproduce, following O'Neil et al (2012).

Table A1 – Narratives by variable

SSP	**SSP1 Sustainability**			**SSP2 Middle of the Road**			**SSP3 Fragmentation**			**SSP4 Inequality**			**SSP5 Conventional**			**MODEL**
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	MaGE
Mortality	Low			Medium			High			High	Medium		Low			MaGE
Migration	Medium			Medium			Low			Low			High			MaGE
Education	High			Medium			Low			Low/uneq.	Medium/uneq.		High			MaGE
Policies and institutions																
Institutions							Ineffective			Effective for elite			Effective			MaGE
Technology																
Development	Rapid			Medium			Slow			Rapid for large corporations			Rapid			MaGE
Energy intensity										Unclear			High			MaGE
Environment and natural resources																
Fossil constraints										Perception (and possibly reality) of strong constraints			None for coal and gas, possible for oil			MaGE/ MIRAGE
Economy																
International trade							Barriers to trade			Unclear / not specified			High, with regional specialization in production			MIRAGE
Environment and natural resources																
Agriculture productivity										High for large-scale farms, low for small-scale.*			Rapid			MIRAGE
Sector structure	Rapid service sector growth												Limited shift towards services, high demand for manufactured products			MIRAGE

B. Institutions and TFP level

Chanda and Dalgaard (2008) estimate the following relationship:

$$\log TFP_i = \beta_0 + \beta_1 INSTITUTIONS_i + \beta_2 OPENNESS_i + \beta_3 GEOGRAPHY_i + \epsilon_i \tag{1}$$

Where $INSTITUTIONS_i$ is measured – in their central case – by the GADP ("Government Anti-Diversionary Policy") index. The estimated relationship (1) 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:

$$\log TFP_i^1 = \log TFP_i^0 + \beta_1 \times \sigma \tag{2}$$

And in levels:

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

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 will correspond to +50% TFP for more efficient institutions, and −30% TFP for inefficient institutions.