Journal of Global Economic Analysis, Volume 5 (2020), No. 1, pp. 28-62.

Macroeconomic Drivers of Baseline Scenarios in Dynamic CGE Models: Review and Guidelines

BY JEAN FOURÉ[a], ANGEL AGUIAR[b], RUBEN BIBAS[c], JEAN CHATEAU[d], SHINICHIRO FUJIMORI[e], JULIEN LEFEVRE[f], MARIAN LEIMBACH[g], LUIS REY-LOS-SANTOS[h] AND HUGO VALIN[i]

For dynamic computable general equilibrium (CGE) modeling, long-term baseline construction is key and depends on the applied methods and the sources of projections considered. For dynamic CGE models, baseline assumptions and base data are both important determinants of results. This paper reviews the assumptions made by 24 modeling teams on baseline macroeconomic drivers, understood as factor accumulation and gross domestic product (GDP) growth. We critically review the various methods, identifying state-of-the-art practices and propose simple guidelines, particularly focusing on consistency between data sources and models, which is intended to help dynamic CGE modelers build their own baselines.

JEL codes: C53, C68, O40, E20.

---

[a] French Centre d'Etudes Prospectives et d'Informations Internationales, TSA 10726, 75334 Paris Cedex 07, France (e-mail: jean.foure@cepii.fr).

[b] Center for Global Trade Analysis, Purdue University West Lafayette, Indiana 47907 (e-mail: aaguiar@purdue.edu).

[c] Organisation for Economic Cooperation and Development, 2 rue André-Pascal, 75775 Paris, France (e-mail: ruben.bibas@oecd.org).

[d] Organisation for Economic Cooperation and Development, 2 rue André-Pascal, 75775 Paris, France (e-mail: jean.chateau@oecd.org).

[e] Kyoto University, 361, C1-3, Kyoto University Katsura Campus, Nishikyo-ku, Kyoto-city, 615-8540 Japan, (e-mail: sfujimori@athehost.env.kyoto-u.ac.jp).

[f] Centre International de Recherche sur l'Environnement et le Développement, Campus du Jardin Tropical, 45 bis, avenue de la Belle Gabrielle, 94736 Nogentsur-Marne Cedex, France (e-mail: jlefevre@centre-cired.fr).

[g] Potsdam Institute for Climate Impact Research , Telegraphenberg A 56
P.O. Box 60 12 03, D-14412 Potsdam, Germany (e-mail: leimbach@pik-potsdam.de).

[h] European Commission, Joint Research Centre (JRC), Directorate C. 6 for Economics of Climate Change, Energy and Transport, C/ Inca Garcilaso 3, Seville, 41092 (e-mail: luis.rey-los-santos@ec.europa.eu).

[i] IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria (e-mail: valin@iiasa.ac.at)

Keywords: Dynamic baselines; Shared socioeconomic pathways; GDP projections; Factor accumulation.

1. Introduction, issues and objectives

The goal of a baseline scenario in global Computable General Equilibrium (CGE) modelling is to properly "reshape" the state of the initial data year to a potential future situation in the medium- to long-run. In this paper, we will consider macroeconomic drivers, understood as the relative economic shape of countries – measured by Gross Domestic Product (GDP) – and the accumulation of factors – namely, labor, capital, natural resources and land. Our definition voluntarily excludes the allocation of economic activity between sectors and the efficiency in the use of primary factors, because these issues are covered in Chateau et al. (2020) of this same special issue of the Journal of Global Economic Analysis. Similarly, we will not consider demand-side trajectories, covered in Ho et al. (2020) also in this special issue.

The relative size of each economy in the baseline may impact substantially the results of any policy simulation. This will imply potential higher market penetration for products from a bigger country. More importantly, a change in the sign of trade balance in the baseline might change the sign of simulated policy outcomes. Similarly, any climate change mitigation must depend on economic activity too, and any absolute emission reduction such as many of the Nationally Determined Contributions of the Paris Agreement will be harder to achieve if the economy grows faster, leading to higher carbon pricing.

In addition, baseline exercises aim to address the uncertainty around the future. By exploring the continuation of current trends, or instead, by considering alternative scenarios, they allow us to identify policies that might have a positive outcome given our expectation of the future, or discover unexpected requirements for a policy to succeed.

Fortunately, in the past few years, there has been a tremendous effort to increase the documentation, standardization and availability of such dynamic trajectories, and especially the Shared Socioeconomic Pathways (SSP) discussed in this paper. For the purpose of this paper, we reviewed 24 dynamic CGE models (see Dellink et al., 2020) that participated in the GTAP-OECD workshop "Shaping long-term baselines with CGE models", held in Paris in January 2018, and their key features on macroeconomic baselines. This paper will go through all these features. They are summarized in Appendix Table A1 regarding sources for GDP and population trajectories, and in Appendix Table A2 regarding assumptions on factor accumulation.

The review reveals that the practices differ between the different teams, and there is not always a straightforward best-practice that can be identified. Furthermore, the description of the macroeconomic baseline, and in particular factor accumulation, is not always very detailed in the model's documentation, and to the best of our knowledge has not yet obtained the critical review it deserves.

Therefore, the objectives of this paper are twofold. First, we attempt to extensively document all the issues around macroeconomic baselines and point out the different alternatives set up by the different modelling teams. Second, we try to analyze these methodologies critically and propose recommendations, both technical – What are the best practices in the implementation of macroeconomic baselines? What is achievable at a low cost? – and in terms of research agenda – What are the current bottlenecks? Which direction could be prioritized to foster better baselines in the future?

To do so, given the wide coverage of our scope, we have chosen a thematic organization, where we will first focus on primary factor inputs (Section 2). Section 3 will cover the way aggregate productivity is introduced in CGE models with a particular focus on GDP trajectories, while Section 4 will try to summarize key recommendations and potential directions for future research.

2. Factor inputs in baselines

Contrary to GDP projections, which are rather well documented and standardized in the reviewed models (see Section 3), the accumulation of primary factors in the baseline is not well documented and differs extensively due to the various objectives of the different teams. Nevertheless, the baseline trajectories for these factors are key for two reasons. First, some of them (demographics, capital accumulation, and education) are directly linked to GDP trajectories as they are among the main drivers of GDP growth at the national level. Second, the assumptions on factor accumulation across time shape the specialization patterns of the different regions in the world. Although we do not cover especially this specialization issue in this paper (see Chateau et al., 2020 for more detailed information), we want to stress that the capital intensity, skill-intensity, and land availability impact significantly the relative comparative advantages of the different regions. For instance, an increase in the supply of skilled labor in one country will imply a drop in its price, hence increasing competitiveness in skill-intensive sectors compared to other countries. In the remainder of this section, we will consider the different factors present in the GTAP Data Base (Aguiar et al., 2019) one by one (labor, capital, land, natural resources). A full review of the different approaches in the reviewed models is provided in Appendix Table A2.

2.1 Population, labor and migration

Most of the CGE models reviewed in this paper build their long-term baselines based on exogenous demographic assumptions. The detailed source for each of the models reviewed is provided in Appendix Table A1. Broadly speaking, population growth rates are obtained from exogenous data sources, labor force is based on working age population and labor supply growth is driven by labor force growth. Some models differentiate between labor skills and use exogenous data on education profiles to target growth of skilled and unskilled workers.

Several papers have documented the potential impacts population projections could have on dynamic baselines. Fontagné et al. (2015) analyze how the macroeconomic inputs that influence education, savings behavior and female participation to the labor force, may affect trade pattern in the medium run. This paper shows that demographic determinants may influence such trade patterns more than trade policies themselves.

Tyers and Shi (2007) integrate a demographic model into a dynamic CGE model to show the importance of demographics on the global economy. Different demographic assumptions affect economic growth, saving rates, capital accumulation, land and natural resource rents.

Walmsley et al. (2017) examined the impact of increased migration on the East and South East Asian economies using a dynamic CGE model that accounts for international migration flows. The policy scenario allowed for endogenous migration across countries in response to changes in real wages, which was contrasted against a baseline where domestic and foreign labor grew at the same rate.

2.1.1 Data sources

In principle, there is a broad consensus on the use of exogenous demographic data, which facilitates the comparison between models. However, the differences between data sources may affect the results. Three main data sources have been identified: UN Population Division (UN, 2017 and 2019), IIASA SSP (KC and Lutz, 2017) and ILO (ILO, 2017). Table 1 summarizes the characteristics of each source. ILO projections present the most detailed labor statistics. In contrast to the other two, it reports data on labor force, employment rates, employment by sectors and skills. The main drawback is the limited time dimension. While UN Population Division and IIASA SSP project their variables until 2100, ILO projections report values until 2030 for population data and until 2022 for employment. Given that most dynamic CGE baselines extend beyond 2030, the use of the ILO projections may require additional assumptions. UN Population Division and IIASA SSP do not report labor force projections. Thus, baselines must be built based on additional assumptions. In general, labor force growth is equated to the growth of working age population, usually defined (e.g. at the OECD or World Bank) as people aged 15 to 64. Alternatively, the EconMap projections (Fouré et al., 2013) propose a combination of both sources: first, the ILO projection model is extended to 2100 and complemented with a female participation projection model for each age group. The corresponding activity rate is then applied to UN or IIASA projections depending on the scenario. OECD (2019) adopts a similar approach within its ENV-Growth model, but projects instead employment rates by five-year age groups and gender on the basis of an assumption of long-run convergence to these specific employment rates towards OECD standards.

Table 1. Characteristics of available population projections

Source	Last year	Frequency	Population	Population by age group	Labor force	Labor supply (employment)
EconMap	2100	1 year	yes[c]	yes[c]	yes	no
ENV-Growth	2060	1 year	yes[d]	yes[d]	yes	yes
IIASA SSP	2100	5 years	yes	yes	no	no
ILO	2030	1 year	yes[a]	yes[a]	yes	yes[b]
UN Population Division	2100	1 year	yes	yes	no	no

Notes: [a] Based on UN estimates 2017. [b] Until 2022. [c] Based on UN estimates 2015 or IIASA. [d] Based on IIASA.

Source: Author construction.

2.1.2 Comparison of demographical projections

Figure 1 shows the estimated world population using the three primary data sources. We observe differences not only between data sources but also between versions. The UN Population Division has changed population projections over time for the medium variant scenario. The UN 2017 and 2019 estimates foresee higher population growth rates than the UN 2010 estimates. Thus, by 2100, the 2010 version estimated world population to be lower than the 2017 and 2019 version by 1 billion people. There are also differences between the UN Population Division 2010 medium variant scenario and the IIASA SSP2 scenario, which represents the middle-of-the-road scenario made available in 2011. According to these two sources, by 2050, the UN 2010 estimates a population with 600 million more people than the IIASA SSP2 scenario. The IIASA SSP2 scenario then projects a decline of global population from 2070 onwards. On the other hand, the UN 2010 estimates that global population steadily grows until 2100. In the medium term both datasets project similar growth rates of working age population (UN, IIASA) or labor force (ILO, EconMap). These values are also similar to the labor force growth rates reported by ILO (Figure 2). In the longer run, large differences may appear between the different working-age population growth projections, but also in the potential differences between working-age population and labor force.

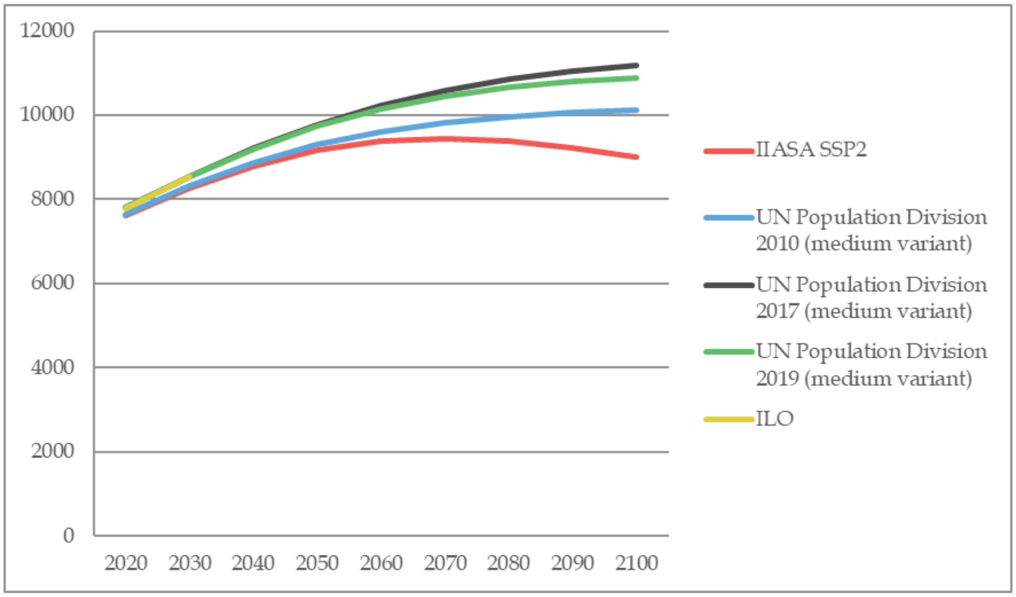

Figure 1. World population projections, 2020-2100 (million)

Source: Author calculations.

As mentioned above, the use of different data sources and/or versions may have significant effects on the results, and several studies have investigated these effects. Teams either change or update their labor input projections (Fouré et al., 2013 or OECD, 2019) or their model considers a demographic component (Tyers and Shi, 2007 and Walmsley et al., 2017).

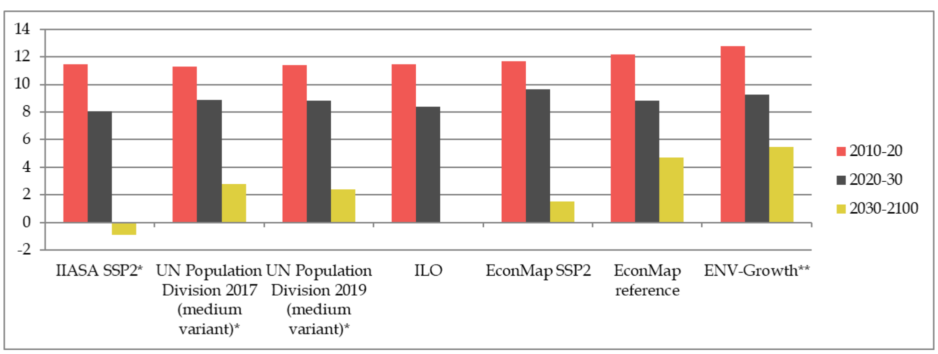

Figure 2. 10-year average growth rate of labor force or working-age population, 2010-2100 (percentage points)

Notes: * These sources only report working-age population. Other sources report economically active population. ** This source only extends to 2060, hence the third column corresponds to 2030-2060.

Source: Author calculations.

The divergence between working-age population and labor force projections in the long-run strongly suggests that working-age population projections should not be used as a proxy for labor force, especially when considering longer time horizons.

Beyond population projections, four models (GDyn, ICES, MIRAGE-e and ENV-Linkages) allow differentiation of population projections by skill level. In these models, the growth rate of population is differentiated between educational level (mostly skilled versus unskilled population), and are taken from external projections. Although differentiating population growth by skill level is a key factor in countries baseline specialization (see, e.g. Fontagné et al., 2017), the differentiation by skill level is subject to a methodological caveat: most of the literature on skill growth, used to build projections, is based on educational attainment data, whereas the standard classification in CGE analysis is based on occupations. In addition, the most recent releases of GTAP data only include few differences between sectors in skill intensity due to the lack of available data. Therefore, this is an area where more research is needed in order to be able to tackle properly skills in baseline exercises, such that (i) education projections can be consistent with occupation-based data and (ii) build data to feed the GTAP Data Base that include more heterogeneity in skill intensity between sectors to allow a proper projection of comparative advantages.

2.2 From savings to capital formation

In CGE models, decisions need to be made with respect to the relationship between total savings and total investment. These are important assumptions that can influence the results of the simulation. Dixon and Rimmer (2002) categorize four camps, which are synthesized in Table 2.

Table 2. Savings and investment closure categories

	Savings	Investment	Employment
The neoclassicals	Assumed propensity to save	Endogenous	Full employment (or Fixed)
The Johansen school	Endogenous	Assumed investment pattern	Full employment (or Fixed)
The General-Theory-Keynesians	Endogenous	Endogenous	Endogenous (allows for unemployment), which led to adjustment of income/savings
The neo-Keynesians	Endogenous	Endogenous	Fixed. Adjustment through value of marginal product and real wages.

Source: Dixon and Rimmer (2002)

The consensus in CGE models is that aggregate savings and investment rates in the long run at the national level mainly respond to macroeconomic forces like monetary policy and demographics. These determinants are out of the scope of CGE models in general (use of a single currency, exogeneity of demographics). Simple rules have often been used in CGE models. However, these rules have been too simple in some cases, for instance when assuming that savings equal investment at the national level, hence neglecting changes in current account imbalances. This section will go through capital formation, from savings to investment, and discuss in turn the consequences in terms of current account balances.

2.2.1 Savings

In the different models reviewed, two main strategies co-exist: the majority of models consider savings as exogenous, while some others have endogenous determination of savings.

For instance, in the GTAP models, the regional households allocate their income according to a Cobb-Douglas (CD) per capita utility function specified over three sources of utility: private expenditures, government expenditures, and savings. The CD functional form implies that the average propensity to save is fixed and savings become a fixed proportion of income in each region.

There is however no consensus yet on how the propensity to save may behave. While McDougall (2002) determines that the propensity to save is almost constant and could be considered fixed over time, Fouré et al. (2013) show that the determinants of savings identified in the macroeconomic literature (for instance population structure and GDP per capita growth) can lead to substantial changes in the propensity to save, especially in fast developing countries. For this reason, in the MIRAGE-e model (Fontagné et al., 2013), the savings rate is also exogenous, but follows a trajectory coming from the EconMap projections (Fouré et al., 2013). In the OECD ENV-Growth model determinants of savings are also estimated in a way similar to Fouré et al. (2013), but using OECD own regressions, where demographics and past GDP growth determine the level of savings, and together with investment schedule, current accounts projections are residually determined by the closure rules. Starting from the premise that saving rates projections are uncertain, the choice of the OECD CGE model differs from the one of Fontagné et al. (2013). In the OECD CGE model, investment ratios are calibrated in the baseline, letting the marginal propensity to save in the utility function to be endogenous.

In forward-looking models, saving rates are determined by the trade-off between utility from present consumption and utility from future consumption. In recursive dynamics, the utility function represents utility from present consumption and it does not factor in future consumption. Investment adjusts to meet the level of savings. The alternative of anchoring investment and letting savings rate adjust does not seem convenient in a dynamic setting, because it is less robust theoretically and empirically according to the macroeconomic literature, which points the causality in the reverse direction (savings determine investment, while savings are determined by macroeconomic determinants such as population structure and economic activity).

Models that follow Dervis, de Melo, and Robinson (1982) also specify macro rules to describe the current account and government fiscal balances. These additional macro-closure decisions, address components of national savings. Foreign savings inflows can be exogenous, while the exchange rate is endogenous, or vice versa. Similarly, government savings can be exogenous by allowing government spending to be endogenous, or vice versa.

The dynamic extension of the GTAP model, GDyn, first inherited the treatment of savings from the standard GTAP model. One unwelcome implication is that rising income over time and fixed propensity to save causes an implausible accumulation of foreign assets in countries like Japan where saving exceeds investment. If in addition, a country exhibits high income growth, like in China, such country would end up owning a large part of the world's wealth (Golub and McDougall, 2012). This model behavior is unlike real world observations, where saving and investment are highly correlated across countries and net foreign positions are small (Feldstein and Horioka, 1980). Golub and McDougall (2012) offer an alternative savings specification that has no particular theoretical foundation, but is motivated by the stylized fact that in the real world, gross foreign assets and liabilities do not diverge as much as in standard GDyn. Saving rate in each region is endogenous and a function of the ratio of wealth to income.

Tyers et al. (2005) also modify the fixed propensity to save assumption in GDyn by introducing endogenous age-gender specific propensities to save, which depends on real disposable income and the real interest rate. These group-specific saving rates then determine regional saving rates in each period.

To contrast, in the forward-looking G-Cubed CGE model by McKibbin and Wilcoxen (1999), household behavior is derived from an intertemporal utility subject to a lifetime budget constraint. Golub and McDougall (2012) report that in G-Cubed only a portion of consumption and saving are determined by these intertemporally optimizing consumers, the rest being determined by after-tax current income and fixed marginal propensity to save. "Because at least part of the supply of savings in G-Cubed is determined by the tradeoff between utility from present consumption and utility from future consumption, current saving is implausibly sensitive to remote future events." (Golub and McDougall, 2012).

2.2.2 Foreign savings or current account

This section deals briefly with current accounts, while further details are provided in Bekkers et al. (2020), which is also in this special issue of JGEA. Models that assume the identity of savings (S) and investments (I) imply that current accounts (CA) are zero and exports (X) and imports (M) compensate each other. More generally (i.e. when savings are different from investment), the following relation holds on a macro level:

$$S - I = X - M = CA \quad (1)$$

A current account surplus or deficit is linked to a capital flow. Countries that export more than they import generate revenues that are not expended domestically, but which are saved and flow abroad in order to finance the import surplus of their counterparts. Speller, Thwaites and Wright (2011) highlight the sharp increase of net international capital flows between 2002 and 2007, with global current account imbalances doubling from 3% to 6% of world GDP.

CGE models that consider current account imbalances follow two major alternatives (closure rules). Both will have an impact on savings and investment. The first alternative is to set the current account exogenously, either following the historical trend based on econometric estimations (see for instance Chinn and Prasad, 2003) or following projections from a linked macro-model. Linked macro-models (like in ENV-Linkages or MIRAGE-e) simulate country-specific savings and investment subject to globally balanced current accounts. The econometric based approach seems to be robust only for a limited time horizon as it may expand current account differences between countries. A simpler variation of this alternative is to fix the current account as a share of world GDP or to make the current accounts converge to zero, but these two alternatives are not supported by data or macroeconomic theory.

A second alternative derives the current accounts endogenously given the propensities to save (or the time preferences in an intertemporal setting), and other factors that drive trade flows (endowments, productivity differentials). Still, a closure rule is needed. A common approach is to presume a level of net foreign assets (i.e. current accounts accumulated over time) for the final year of the model's time horizon (or at a later time horizon than the one used to present results, as it is often the case in Integrated Assessment Models). Most often this level is either set to the current level or is assumed to level off. In both cases, intermediate current account deficits and implied levels of indebtedness can be large, but can also be restricted by assumptions on capital market imperfections (Alfaro, Kalemi-Ozcan, Volosovych, 2008) like debt constraints or risk premia on foreign investments. Furthermore, as a persistent high debt level is considered to be unsustainable (Aizenman and Sun, 2010; Chen, 2011), imposing restrictions on borrowing and lending can help in models that cover a longer time horizon. Another approach is that used in the GDyn model, where the current account equation also includes foreign income payments and receipts, which are part of the framework that models international capital mobility (Ianchovichina and McDougall, 2012). Aguiar (2009) further extended GDyn to include remittances in and out in the current account equation.

Our conclusion on savings rate and current account projections is therefore that any simplistic approach (constant savings rate, or convergence of current account to zero) should be avoided. Only assumptions backed by the macroeconomic literature should be considered. On the current account, Bekkers et al. (2020) provide additional insights.

2.3 Natural resources

Beside labor and capital, some economic sectors also depend on other key endowments that we group here under the category of "Natural resources" (geophysical and biological). These resources are present for the primary sectors (land for agriculture and forestry, fish stock for fisheries, fossil fuel for the energy sector, other extractive materials for construction and industry, and water for the water services). As an illustration, the 12 primary agricultural sectors in the GTAP Data Base depend on a land endowment, whereas forestry, fisheries, primary energy and raw material extractive industry all are endowed with natural resources. Water is not represented by default as a factor in GTAP but some specific extension to the model and database have been developed over time (not covered here, see Haqiqi et al., 2016).

2.3.1 Fossil Fuels

Fossil fuels (oil, coal and natural gas) represent around 80% of total world primary energy supply and thus these resources are key macroeconomic drivers of baseline scenarios beyond labor and capital. Good representation of fossil fuel supply in baseline scenarios is especially important to anchor alternative energy and low-carbon transition scenarios that aim to reduce the use of these resources.

In most dynamic CGE models, fossil fuel primary production is broken down in a few economic sectors (usually oil, coal and natural gas sectors) with sector-specific immobile resources. The resource input usually enters the top production nest and is combined with capital, labor and other inputs to produce sectoral output; see Faehn et al. (2020).

The models reviewed in this paper follow two main approaches for fossil fuel resource supply: i) the bulk of models (10 models) calibrate resource inputs and resource supply curves (through shift parameters) to match fossil fuel price trajectory or other variables, but ii) several models (4-5 models) represent endogenous resource depletion and availability. Almost no models rely on exogenous or fixed resource inputs.

The calibration approach makes it possible to control key variables such as fossil fuel prices taken from external energy scenarios (for example International Energy Agency, or IEA, scenarios).[1] The calibration can optionally target regional

[1] For instance, in MIRAGE model baseline, resource inputs are calibrated to match average coal, oil and natural gas world prices taken from World Energy Outlook 2016.

prices beyond world prices (such as in AIM-CGE). Resource inputs are more rarely calibrated on capital or GDP growth (MAGNET) or to match energy supply targets (ENGAGE and ENV-Linkages). In both cases, the calibration approach could introduce inconsistencies if the model's baseline does not match the price projections assumptions. If this is the case, these inconsistencies have to be checked by the modelling team.

The calibration approach is the most common, but not necessarily the best practice as it has several drawbacks. Fossil fuel demand depends heavily on economic activity and may not be consistent with the targeted fossil fuel prices in CGE baselines if economic assumptions and resulting fossil fuel demand are inconsistent with that of the external energy scenario used. A more general consistency issue is that fossil fuel prices scenarios are usually based on energy models with different economic paradigms than CGE models. In addition, this calibration of resource stocks approach prevents the simultaneous variation of stocks and energy prices in the model as a result of a policy change.

Several models include endogenous resource supply through resource depletion models. In general, simple recursive resource supply functions are introduced and account for resource depletion between two time periods due to fossil fuel production levels during the former period, starting from a given base year resource stock (Chen et al., 2017). However, a few CGE models include more complex resource depletion models; see Faehn et al. (2020). For instance, Imaclim-R combines advanced dynamic oil resource supply functions (reflecting both depletion and accessibility of heterogeneous oil reserves categories at regional scale) and regional extraction cost curves linked to different categories of reserves (Waisman et al., 2012). Other models build on external coupling to capture endogenous resource depletion (TEA model linked to a specific energy model), but this is beyond the scope of this paper (see Delzeit et al., 2020). The required data for fossil fuels reserves come from various sources including (Rogner, 1997; USGS, 2012; WEC, 2013).

The endogenous approach seems promising but can have some limitations as well. First, the required data for fossil fuel reserves are usually scattered and may not be consistent across sources when available. Second, too simple resource supply specifications combined with standard economic behavior (like price-taking behavior) may lead to unrealistic fossil fuel market outputs and prices. Accounting for strategic interactions at play on oil markets (for instance with OPEC) may for instance be needed to control market behavior. Some models venture into this direction like Imaclim-R, which optionally models specific economic behaviors of "swing producers" that can influence world oil prices, departing from standard price-taking assumption (Waisman et al., 2012).

2.3.2 Land

Land input is a key factor for agricultural and forestry activities. Traditional modelling of land transformation fits well for substitution across land uses in a static framework, but often fails to capture land use change trends required by long term baseline scenarios. Land use changes over time lead to conversion of natural land into productive land through primary forest and other natural vegetation clearing. Different approaches have been developed to allow for expansion of currently used land into other land cover types, through land supply curves. The land supply representation significantly varies across models for those models that represent it. Many models do not explicitly describe how land supply is implemented. Here we distinguish three different methodologies (see more details in Schmitz et al., 2014):

1) Implicit land supply managed through the land transformation nesting including grassland and forest land cover types.
2) Explicit land supply curve based on a full representation of available land based on biophysical assessment and constrained by total terrestrial land area.
3) Arable land expansion by exogenous assumptions.

The first approach is the simplest in the sense that it relies on the initial nested representation of land rents from the GTAP economic accounts and uses the substitution mechanisms within existing rent, without expansion of the total land rent. It is the approach followed for instance by GDyn, FARM or AIM/CGE. The second approach relies on exogenously specified supply curves through stylized assumptions or the use of biophysical information. For instance, the TEA model relies on a single elasticity of expansion to represent increase in productive land (Cunha et al., 2020). The MIRAGE-Biof model follows the same approach, but distributes the expansion into different land cover types to differentiate land use change impacts (Laborde and Valin, 2012). Another land supply curve example is that of MAGNET and ENV-Linkages models, for which land supply is derived from the productivity of land as estimated by the integrated assessment model IMAGE. The third approach is represented by some exogenous trends on land use that are applied to the total land stock. This approach is followed for the dynamic trajectory in the MIRAGE-Biof model.

With the increasing research on climate change mitigation, large land use changes are one of the key elements to explore the bioenergy availability and CO_2 emissions or sequestration. Future efforts are to be expected from dynamic CGE modeling teams to improve the representation of the linkages between land use sectors factor uses, and biophysical land impacts.

3.3.3 Fishery and other mineral resources

There are limited models that represent other natural resources such as fisheries or other mineral resources beyond the level of detail provided by the GTAP Data Base. The typical approach is to consider that the natural resource endowment is fixed (or strongly inelastic, with a very small supply elasticity). For future scenarios, mostly the endowment is exogenously changed or no specific dynamics are considered. For instance, MAGNET (Thünen) assumes 0.25 times the capital growth rate for the natural resources. So far, only few studies related to other resources have been carried out and there should be much room to improve other resource representations.

3. Baseline methodology: GDP trajectories

In a *CGE* model, the magnitude of potential effects simulated are determined by the relative economic size of the different regions in the world. In addition, the longer the time horizon, the larger the potential changes in the geographical allocation of wealth. As a consequence, the most important factor to consider in a baseline exercise is the trajectory of aggregate productivity, whether it is explicitly included in the CGE model or it is endogenously recovered from an external GDP projection. After discussing the different methodologies applied by the models reviewed, this section will focus on how GDP projections are built and how the different sources compare.

3.1 Review of existing approaches

As shown in Appendix Table A1, there exist two distinct methodologies to shape medium- to long-term projections of economic growth among the models reviewed for this article.

The most common approach is to rely on external projections for GDP growth, which are provided by several sources discussed below. In this case, a baseline trajectory is built within the CGE model with the aim to calibrate a productivity trajectory under the constraint that GDP grows at the rates projected by the projection source. However, there is a large diversity between models on the production factors affected by such productivity improvements, which can be labor-only (9 models), all factors – usually labor, capital, land and natural resources (7 models) or labor, natural resources and intermediate consumption (1 model). It is important to note that such exogenous GDP assumptions are only used for baseline calibration: all the models reviewed release this constraint when they implement policy simulations.

There is no absolute superiority of one alternative over the other (labor-augmenting or all-factor-augmenting productivity), even in the macroeconomic theory, where both alternatives cohabit (see Section 2.2.1). However, the projected GDP growth by the different sources already imply specific assumptions on this issue. For instance, OECD projections are built using labor-augmenting productivity (Dellink et al., 2017), while EconMap use capital-labor-augmenting productivity (Fouré et al., 2013). It might seem appealing for CGE models to follow the same assumptions as the underlying growth model, but there is no specific reason to do so. The structure of CGE and macroeconomic models are very different, and using an external GDP projection in a very different productivity structure might be a good way to challenge its plausibility.

Three of the reviewed CGE models (GDyn, IGEM and MESSAGE) also implement an alternative approach where the GDP trajectory is endogenously determined within the CGE model, or in other words to design/calibrate law of motion for factor efficiency improvements and let the GDP be determined endogenously together with factor accumulation assumptions.

There is no consensus regarding the choice between the two approaches (endogenous vs. exogenous GDP in the baseline exercise) because the projections have to be crafted. It should be noted that it is by far easier to rely on existing projections than to build them and since they are available, it helps to compare CGE model outcomes when they rely on a common GDP growth trajectory. Yet, when the GDP trajectories are endogenous in the CGE, the level of control and consistency within the baseline exercise is better, although it makes it difficult to compare against baselines from other models because the GDP trajectories are a function of model parameterization.

An advanced hybrid approach has therefore been developed and is used by two teams in OECD and CEPII (respectively ENV-Linkages – Chateau et al. (2014) and MIRAGE-e – Fontagné et al., 2013), where the projections are indeed built externally from the CGE but by a sister macro-economic growth model (respectively ENV-Growth – Dellink et al. (2017) – and MaGE – Fouré et al., 2013). Consistency between the two corresponding models is sought to be maximized. In particular, in these cases, the macroeconomic model and the CGE model share in the baseline the same assumptions in terms of population, skill level growth, energy price trajectories, and current account balances.

3.2 Building GDP trajectories

Whatever the pursued approach, some insights on how GDP projections are built are useful to understand the mechanics behind baseline exercises. Several approaches of baseline design exist. Extrapolating linear trends is simple but indeed misses any economic rationale; it may lead to major errors in the representation of how the world economy evolves in the future. Alternatively, one can rely on macroeconomic projections. Using the concept of balanced growth path or other theoretically founded frameworks allows to maintain consistency, but at the cost of less details. Finally, relying on experts' appraisal as in Dixon and Rimmer (1998) is an option. While it faces the risk of inconsistency due to the absence of an encompassing framework, it allows to deal with issues and determinants beyond usual economic variables. The last two options are highly flexible, and the reliance on a macroeconomic model have the advantage of being easy to set-up based on the vast literature in macroeconomics, and can encompass a wide range of issues based on this literature, as for instance, endogenous current accounts, forward-looking behavior or conditional convergence.

Of particular interest is the initiative of the Intergovernmental Panel on Climate Change (IPCC): five different stylized baseline scenarios, SSPs, have been developed using a multidisciplinary approach (O'Neill et al, 2017). Macroeconomic growth models will be the focus of this section, but some conclusions may also apply to CGE models with endogenous baseline trajectories.

3.2.1 Building a GDP trajectory

Solow's (1957) seminal attempt to decompose economic growth between factor accumulation (capital and labor) and a residual interpreted as technology improvements, is indeed simplifying though estimating such aggregate production functions remains the most workable framework to quantitatively analyze long term trends in economic growth, and by far the most common in the literature. In a nutshell, this approach starts from a rather simple macroeconomic aggregate production function, with basic components: Y is real potential GDP, K is the stock of capital, L the labor force and A the residual, understood as the technological component, the Total Factor Productivity (or TFP).

Labor and capital are at the heart of long-term growth analysis (Solow, 1957; Wilson and Purushothaman, 2006; Duval and de la Maisonneuve, 2010), and the stability of their shares in value added explains the success of the aggregate Cobb-Douglas production function. Building on these works, several other factors have also been considered key to long-term growth projections, like human capital (Duval and de la Maisonneuve, 2010), primary energy consumption (Fouré et al., 2013) or natural resources (Dellink et al., 2017), as illustrated in Table 3.

Table 3. Macroeconomic projection models

Source	Duval and de la Maisonneuve, 2010	Fouré et al., 2013	Wilson and Purushothaman (2006)
Production function	$Y = K^{\alpha}(AhL)^{1-\alpha}$	$Y = \left[(AK^{\alpha}L^{1-\alpha})^{\frac{\sigma-1}{\sigma}} + (BE)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$	$Y = AK^{\alpha}L^{1-\alpha}$
Additional factors	h: human capital	E: primary energy consumption B: energy-specific productivity	

Source: Authors construction.

While all these components can be observed in historical data, the projection of GDP consists in making assumptions on the future accumulation of factors and productivity. The latter component may well be the most important: in the Solow framework, it is the only growth component that matters in the long-run. We also know since Wang and Yao (2003) that human capital and the residual growth were contributing more to GDP growth than factor accumulation. The strategies to derive projections are different for each production factor and productivity. More details on these strategies can be found in the references to macroeconomic models.

Beside these theoretically-oriented growth models, Crespo Cuaresma (2017) proposes a different approach, where the GDP growth rate results from a panel estimation with lagged GDP per capita, labor force by age group and education level and growth of capital as explanatory variables.

Several institutions have published GDP projections, with varying assumptions, time horizon and regional coverage. In terms of time horizon, medium-term projections are those before 2050 and long-term projections by 2100. Medium-term projections are often released as one potential trajectory, based on estimations and representing a "business as usual" scenario. For the long-run however, because uncertainty grows as the time horizon advances, several scenarios are provided. Some of them are constructed explicitly as scenarios that deviate from "business as usual". In particular, our attention will focus on the SSPs.

3.2.2 Units for GDP: PPP are better than MER

When looking at long-term issues in developing economies, measuring income (with GDP) in purchasing power parities (PPP)[2] is more appropriate than using market exchange rates (MER). Indeed, growth rates for developing countries measured over a given period are likely to differ according to the measure used (PPP or variable MER). In macroeconomic projections, where convergence of income levels is postulated to occur by a certain date, the difference between the two measures will impact the growth rates. That is, since MER is starting from a lower level of measured income, to achieve convergence by a certain date, the MER-measure of income will have to grow faster. In the CGE model, sectoral productivity differences together with difference in tradability of goods imply that the purchasing power parity exchange rate is endogenously adjusting in response to structural changes. Thus, in a model with sector productivity growth there is less need for mechanisms to enforce empirically desirable properties on the growth process than in the macro-economic model.[3]

[2] GDP measured in PPP and volume (constant prices and exchange rates) share the same growth rate, but the relative weight of sectors differs.

[3] This statement is valid when physical quantities, such as greenhouse gas emissions coefficients, do not depend on the initial level of sector output. Otherwise, particular attention has to be devoted to the consistency between the growth rate of physical quantities and sector output.

3.2.3 Comparison of GDP projections in the medium run

Table 2 summarizes different "business-as-usual" projections found in the literature. Overall, these projections take place at the individual country level, covering a significant part of world GDP (from 132 to 230 countries), with yearly frequency. The time coverage is however very heterogeneous, ranging from short-term forecasts to 2020-2023 to medium--run horizons (2040, 2050).

Table 4. Summary of medium-term GDP projections

Source	Last year available	Regional coverage	Frequency	Unit
EconMap (CEPII)	2050	167 individual countries	1 year	Volume and PPP
Env-Growth (OECD)	2060	230 individual countries	1 year	PPP
ERS (USDA)	2030	182 individual countries	1 year	Volume
Global Economic Prospects (WB)	2020	132 individual countries	1 year	Volume
World Economic Outlook (IMF)	2023	194 individual countries	1 year	Volume
World Energy Outlook (IEA)	2040	8 individual countries, 8 regions	15 years	PPP

Source: Author construction`s.

As shown in Figure 3, these projections are generally consistent across sources. This means that the variations they introduce around the initial neoclassical paradigm they all share do not lead to large divergences, without being able to settle if another paradigm would have led to significant differences. Nevertheless, two groups can be distinguished: ERS, Env-Growth and EconMap are slightly lower than other sources.

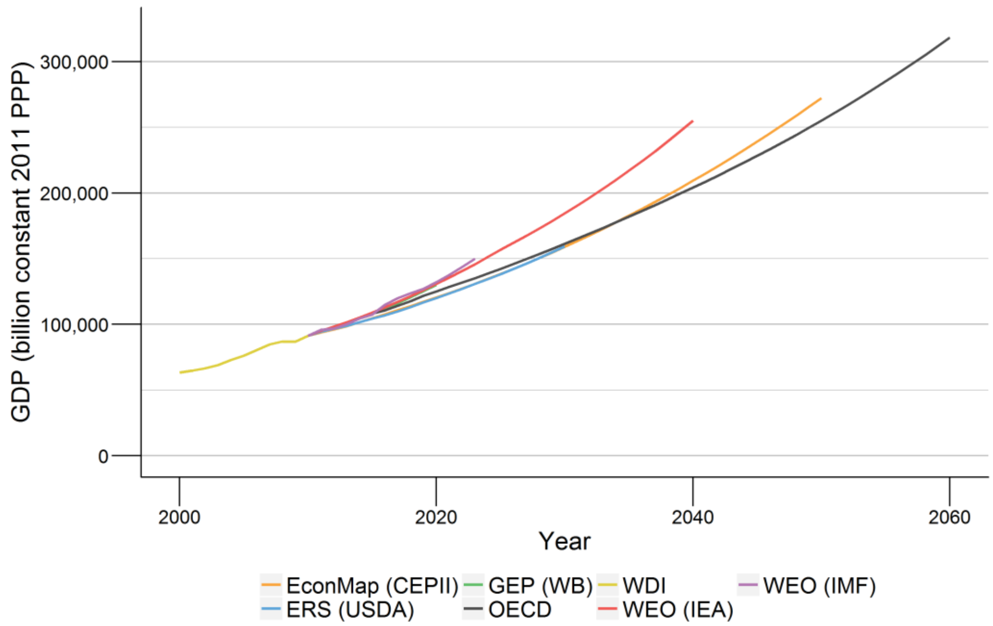

Figure 3. Comparison of medium-term projection sources

Notes: We applied the growth rates (in volume/PPP) from the different sources to historical data from World Development Indicators (2000-2010). Abbreviations used in this figure are explained in Table 2.

Source: Author calculations

3.2.3 Comparison of projection sources in the long-run: the SSP scenarios

Building on an initiative by the Integrated Assessment Modeling Consortium (IAMC), between 2011 and 2017, researchers in the climate change field have been conducting an interdisciplinary exercise in order to identify the key elements that will affect the potential magnitude and cost of climate change mitigation during the 21st century. The outcome of these working groups has been the elaboration of five illustrative scenarios – the SSPs – meant to be a common basis for climate change impacts and mitigation and adaptation policy analyses, but also highly relevant for any prospective economic scenario analysis. The narratives can be found in O'Neill et al. (2017). A schematic representation of these scenarios is reproduced in Figure 2. The narratives cover a broad range of potential economic situations, obviously including population and GDP growth, but also for instance income convergence, urbanization, trade openness or technological transfers. Riahi et al. (2017) summarizes the quantification process on selected variables (population, GDP, urbanization, energy, land-use, and greenhouse gas and air pollution emissions) and results.

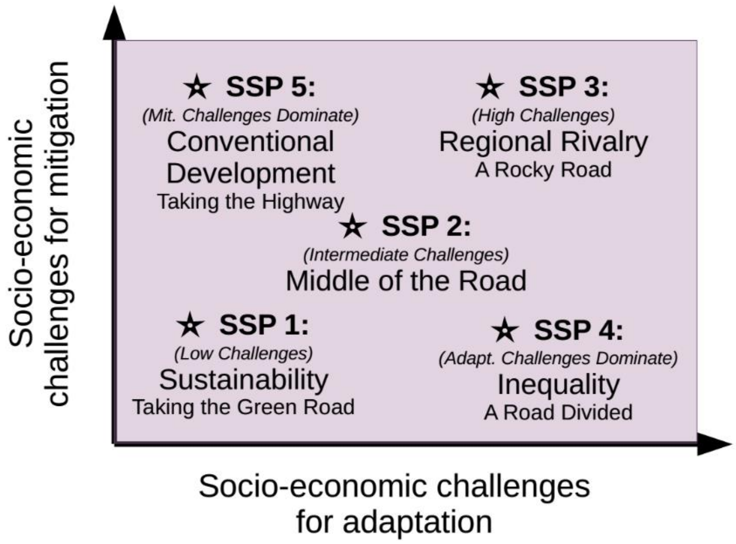

Figure 4. Schematic representation of the SSP scenarios

Source: O'Neill et al. (2017).

Regarding GDP projections, different teams have contributed by producing model-based quantitative evaluations. IIASA (Crespo Cuaresma, 2017), the OECD (Dellink et al., 2017), PIK (Leimbach et al., 2017) – the three of them being available in the official SSP database – and CEPII (Fouré and Fontagné, 2016). All implementations rely on the same narratives, take the same population projections from IIASA, and make assumptions on education and TFP growth rates. In addition, Dellink et al. (2017), or ENV-Growth, also add assumptions on natural resource, while Fontagné and Fouré (2016), or EconMap, also quantifies institutional convergence and fossil energy prices. Finally, the GDP projections by Dellink et al. (2017) were selected as representative for the specific SSP scenarios and formed the basis of the baseline and climate change mitigation scenarios developed by the IAM community (Riahi et al, 2017). These different SSP implementations are detailed in Table 5.

Table 5. Summary of SSP GDP projection sources

Source	Last year	Regional coverage publicly available	Frequency publicly available
EconMap (CEPII)	2100	167 individual countries	1 year
Env-Growth (OECD)	2100	176 individual countries	1 year
IIASA	2100	32 regions	5 years[a]
PIK	2100	32 regions	5 years

Notes: [a] Higher frequency available upon request from the corresponding authors.
Source: Author construction.

All 4 implementations share a time horizon to 2100 and a nearly global coverage, with all but one of the projections being country-based. The only difference resides in the time frequency, which is 5 years or 1 year. This difference is however minor, because at that horizon, uncertainty is so large that yearly fluctuations may not significantly impact the results.

3.3.4 Central scenario: the SSP2

Among the five SSP storylines, the SSP2 is the central scenario ("Middle of the Road") and the most commonly used reference scenario, although neither probability nor likelihood are attached to any of the five SSPs. We therefore start by comparing the different implementations of SSP2. The comparison of growth at a global level has already been covered in the literature, and we confirm that all the different sources, although with different models and assumptions, are well aligned up to 2075, while afterwards IIASA projections seem on the lower side. More interesting for our topic is the allocation between regions and countries, which may imply significantly different patterns in the long run. Figure 5 presents the average annual GDP growth rates by geographical area (nomenclature from the SSP database) for the period 2010-2100.

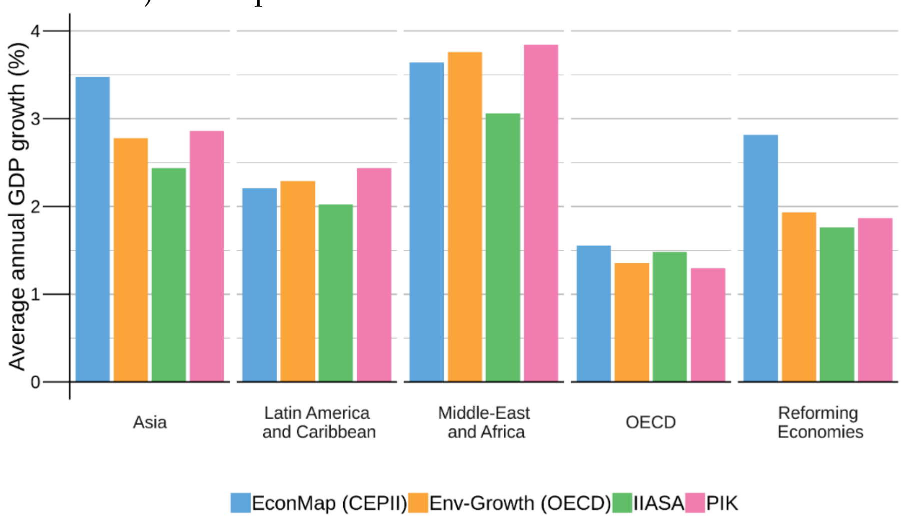

Figure 5 – Average annual GDP growth by region in SSP2 scenario, 2010-2100

Source: Author calculations.

For OECD countries and countries from Latin America and the Caribbean, all the different sources are closely aligned, but it should be noted that EconMap projections are higher than others for reforming economies and Asia to a lesser extent, while IIASA projections are lower for Middle-East and Africa (for 2010-

2050, EconMap is even lower). In our opinion, there is no projection that should be prioritized over another. While all of them are based on rigorous estimations and models, they pursue different objectives (for instance, provide projections for a specific model, or on the contrary provide generic projections to be used with models of different kinds). In addition, these differences represent the uncertainty inherent to projection exercises. It is however important to note that the relative economic power of regions in the world might differ significantly from one study to the other. For instance, a 1% average annual growth difference leads in 90 years to a 145% difference in volume.

3.3.5 Other SSPs

In order to encompass a wider range of potential long-term trends, the 4 other SSP scenarios are also available from the same sources, as depicted in Figure 6. Once again, the four projection sources are rather consistent, both in terms of ranking between the different SSPs and in terms of order of magnitude. At the end of the period however, it seems that for SSP1, 4 and 5, the EconMap projections represent an upper bound, while IIASA projections represent the lower bound.

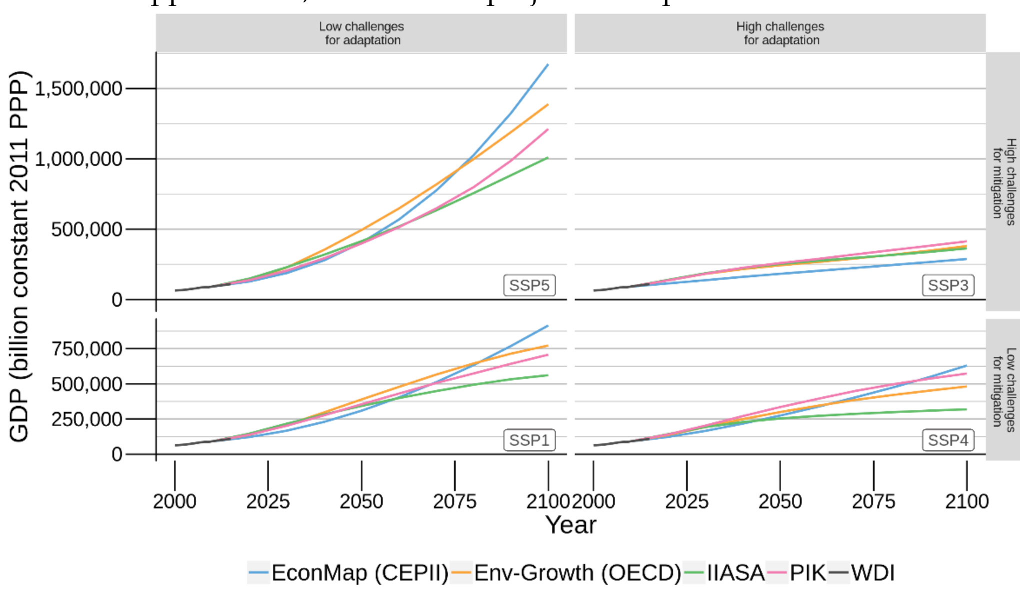

Figure 5. Comparison of projection sources for SSP1, SSP3, SSP4 and SSP5

Notes: We applied the growth rates from the different sources to historical data from World Development Indicators (2000-2010).

Source: Author calculations.

4. Best-practices, recommendations and proposal for future research

4.1 Best practices

Given the relative homogeneity of the different models in terms of population and GDP projections, the use of exogenous trajectories for population and GDP has not really been challenged and could not strictly qualify for a best practice. Nevertheless, using external projections for population and GDP, that are documented and publicly available, and achieving these trajectories in the baseline exercise by endogenous productivity parameters, which is the most common case in the reviewed models, is the most reasonable alternative, all the more when projections are based on sound macroeconomic literature. It is in addition very easy to implement, as external sources for projections are available.

Converting population projections into labor force is trickier: the growth in labor force can differ significantly from the working-age population, especially for younger age groups with longer time spent on education or when taking into account rising labor participation rates for women. Although corresponding projections are less standardized, we recommend to adhere as much as possible to the concept of labor force rather than working-age population, and if labor force projections are not available (typically beyond 2030, where ILO projections are missing) to try to adjust for the difference. The second issue with labor force is the skill allocation. Because of the mismatch of concepts (projections available are education-oriented while CGE models use occupation-oriented information to measure skills), both approaches (using a common or differentiated growth rate between skill levels) are not satisfactory. In the short term, there is no out-of-the-box solution, but this strongly suggest the need for further research.

Capital formation is another topic where there is no consensus. Regarding savings, the clear best-practice is to rely on a theoretically-founded framework, whether this framework is embedded in the CGE model or come from an external source. It is furthermore clear that considering a constant savings rate is not supported by any evidence and should be avoided whenever possible. The same conclusion also holds for current account trajectories (and equivalently investment rates): there is no evidence of a constant S-I balance, nor evidence for a convergence to zero. These assumptions should therefore be avoided whenever it is possible, and replaced with a more reasonable trajectory, among those discussed extensively in Bekkers et al. (2020).

Regarding land and natural resources, common practices in CGE models can be easily implemented even when agriculture or energy-related issues are not the core of the model's focus. This is true for land availability and land use changes (using CET structure and simple supply curves), but also for fossil resources availability (calibration by targeting energy prices or energy consumption).

4.2 Recommendations

4.2.1 Rely on theoretically-sound assumptions

Among the reviewed models, the most reliable criterion we found was to rely on sound assumptions taken from existing literature, mostly out of the CGE field. The long-term growth literature is the main source of knowledge for modelers and should be referred to when designing baselines. Some key issues have been sorted out in this field, such as the fact to rely on PPP volumes when considering convergence across countries (and not volumes in base-year prices), or the absence of convergence between savings and investment at the country-level. There is still debate in this field, for instance regarding the relevance of considering steady-states, versus estimating dynamic relationships. When such debate exists, the only recommendation we have is to clearly state the assumptions retained and refer to the corresponding debate in the literature.

4.2.2 Consistency

In several models, demographic data and other information such as GDP, saving rates, energy consumption and land use are obtained from external sources. In some cases, data comes from a single source. For instance, the SSP database may be used to calibrate labor force, education and GDP that are consistent with IIASA population projections, while EconMap proposes projections of GDP, population, education, savings and investment and capital stocks consistent with both IIASA and UN population projections depending on the scenario. However, this is not standard practice. We have identified that long-term baselines are generally built based on different external data sources or are linked to partial equilibrium models (see Delzeit et al., 2020), which are based on their own assumptions. A good practice requires the consistency between variables. Otherwise, the gap between the inconsistent projections and the consistent one will pass through the endogenous productivity without properly shaping sector endowments (for instance on skill level, or availability of natural resources). Therefore, when building a baseline, it should be made sure that projection data is consistent with other key variables, especially regarding factors that are also among the main determinants of macroeconomic growth such as demographics. Ideally, both projections should be taken from the same original source. This can be achieved using socio-macroeconomic projections from an external growth model as in ENV-Linkage or MIRAGE-e models. When such an alternative is not possible, a particular attention has to be paid to the consistency between sources by providing evidence that the difference does not matter much or that the alternative source used is necessary. For instance, this could be the case with a comparison between GDP projections underlying energy prices and the actual GDP trajectory used in the model.

4.2.3 Suggestions for future research

Our paper also identified gray areas where future research could help improve the way macroeconomic baselines are designed. Two topics are in our opinion of greater importance and require a joint effort by the modelling community: the evaluation of the implications of baseline assumptions on model simulation results, and the treatment of labor issues in projections and modelling.

First and maybe more importantly, we have not yet found a comprehensive and systematical investigation on the relative importance of baseline assumptions on model results. This special issue proposes some insights on the impact of energy prices on trade (Bekkers et al., 2020). From the perspective of the present study it is of likewise importance to quantify the impact of current-account baseline assumptions on results from trade policy shocks. This is not yet settled with our models. Apart from such specific challenges, however, we think a more thorough investigation is required. This applies to both GDP trajectories and factor accumulation.

Corresponding analyses could take the form of a model comparison where each model compares the implications of different baseline assumptions on a single policy scenario. Model comparison exercises could also help the community find out if sector-specific aspects such as land availability and use changes, fossil and non-fossil natural resources, need to be tackled in every model or only for studies focusing on the corresponding topics. In particular, we noted that almost nothing is done on the availability of natural resources in forestry, fishing and non-fossil extraction sectors. We have to join Chateau et al. (2020) in the same special issue to suggest further research on this subject to know whether these issues are of importance or not.

We also suggest to put in place an important and coordinated research effort on labor issues, which have been broadly neglected so far. First, the availability and standardization of projections of economically active population (instead of working-age population) should be increased, and could in our opinion be achieved in the short term. Second, we also pointed out the absence of a satisfactory treatment on labor by skill, and the gap between existing projections measured in education levels and the representation of labor skills in CGE models which uses occupation standards must be bridged, along with the development of more comprehensive data on sectoral differences in skill-intensity, such that this data can be ported to the GTAP Data Base. Finally, we cannot but deplore the lack of interest for evidence-based modelling of unemployment issues in our community, and we hope that the proposed agenda on better data and better projections could help in this direction, though this topic goes beyond projection exercises and is a modelling issue *per se*.

References

Aguiar, A. H. 2009. "An Analysis of U.S. Immigration and Policy Reforms." Ph.D. Dissertation, Purdue University, West Lafayette, U.S.A.

Aguiar, A., Chepeliev, M., Corong, E. L., McDougall, R. and D. van der Mensbrugghe. 2019. "The GTAP Data Base: Version 10." Journal of Global Economic Analysis 4(1):1-27. http://dx.doi.org/10.21642/JGEA.040101AF.

Aizenman, J. and Y. Sun. 2010. "Globalization and the sustainability of large current account imbalances: Size matters." *Journal of Macroeconomics* 32, 35-44. https://doi.org/10.1016/j.jmacro.2009.11.001

Alfaro L., Kalemli-Ozcan S and V. Volosovych. 2008. "Why doesn't Capital Flow from Rich to Poor Countries? An Empirical Investigation." *The Review of Economics and Statistics* 90(2):347-68. https://doi.org/10.1162/rest.90.2.347

Bekkers, E., Antimiani, A., Carrico, C., Flaig, D., Fontagné, L., Fouré, J., Francois, J., Itakura, K., Kutlina-Dimitrova, Z., Power, W., Saveyn, B., Teh, R., van Tongeren, F. and M. Tsigas. 2020. "Modelling trade and other economic interactions between countries in baseline projections." *Journal of Global Economic Analysis* 5(1): 273-345.

Benjamin, N. 1994. "Investments, Expectations, and Dutch Disease: A Comparative Study (Bolivia, Cameroon, Indonesia)", in Mercenier, J., and T.N. Srinivasan, ed., *Applied General Equilibrium and Economic Development*. The University of Michigan Press.

Böhringer, C., Löschel, A., and A. Rohde. 2002. "PACE-Policy analysis based on computable equilibrium." In *Forum für Energiemodelle und Energiewirtschaftliche Systemanalysen in Deutschland, Energiemodelle zum Kernenergieausstieg in Deutschland, Effekte und Wirkungen eines Verzichts auf Strom aus Kernkraftwerken*, Umwelt und Ökonomie Bd (Vol. 34, pp. 436-450).

Bulavskaya, T., Hu, J., Moghayer, S. and F. Reynes. 2016. "EXIOMOD 2.0: EXtended Input-Output MODel. A full description and applications." https://doi.org/10.13140/RG.2.2.16186.80321.

Burneaux, J., Nicoletti, G. and J. Olivera-Marins, 1992. "GREEN: A Global Model for Quantifying the Costs of Policies to Curb CO2 Emissions," *OECD Economic Studies* 19, OECD.

Capros, P., Van Regemorter, D., Paroussos, L. and P. Karkatsoulis. 2013. "GEM-E3 model documentation." *JRC Scientific and Policy Reports*, 26034.

Chateau, J., Corong, E., Lanzi, E., Carrico, C., Fouré, J. and D. Laborde. 2020. "Characterizing supply-side drivers of structural change in the construction of economic baseline projections." *Journal of Global Economic Analysis* 5(1):109-191.

Chateau, J., R. Dellink and E. Lanzi. 2014. "An Overview of the OECD ENV-Linkages Model: Version 3." *OECD Environment Working Papers*, n° 65, Éditions OCDE, Paris, https://doi.org/10.1787/5jz2qck2b2vd-en.

Chen, Y.-H.H., S. Paltsev, Reilly, J., Morris, J., Karplus, V., Gurgel, A., Winchester, N., Kishimoto, P., Blanc, E. and M. Babiker. 2017. "The MIT Economic Projection and Policy Analysis (EPPA) Model: Version 5." http://globalchange.mit.edu/publication/16620.

Chen, S. 2011. "Current account deficits and sustainability: Evidence from OECD countries." *Economic Modelling* 28, 1455-1464. https://doi.org/10.1016/j.econmod.2011.01.011

Chinn M.D. and E.S. Pasad. 2003. "Medium-term determinants of current accounts in industrial and developing countries: an empirical exploration." *Journal of International Economics* 59:47-76. https://doi.org/10.1016/S0022-1996(02)00089-2

Cunha, B. S. L., Garaffa, R. and A. C. Gurgel. 2020. "TEA Model documentation", *FGV EESP – FGVAGRO n.001. Working Paper Series* 520. São Paulo, Brazil. https://hdl.handle.net/10438/28756

Dellink, R., Chateau, J., Lanzi, E., and B. Magné. 2017. "Long-term economic growth projections in the shared socioeconomic pathways." *Global Environmental Change*, 42:200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

Dellink, R., van der Mensbrugghe, D. and B. Saveyn. 2020. "Shaping baseline scenarios of economic activity with CGE models: introduction to the special issue". *Journal of Global Economic Analysis* 5(1):1-27.

Delzeit, R., Beach, R., Bibas, R., Britz, W., Chateau, J., Freund, F., Lefevre, J., Schuenemann, F., Sulser, F., Valin, H., van Ruijven, B., Waitzel, M., Willenbockel, D. and K. Wojtowicz. 2020. "Linking global CGE models with sectoral models to generate baseline scenarios: Approaches, challenges, and opportunities." *Journal of Global Economic Analysis* 5(1):162-195.

Dixon, P. B. and M.T. Rimmer. 1998. "Forecasting and Policy Analysis with a Dynamic CGE Model of Australia." *Centre of Policy Studies/IMPACT Centre Working Papers* op-90, Victoria University, Centre of Policy Studies/IMPACT Centre.

Dixon, P. and M. Rimmer. 2002. "Dynamic General Equilibrium Modelling for Forecasting and Policy: A practical Guide and documentation of MONASH." Emerald Group Publishing Limited.

Duval, R. and C. de la Maisonneuve. 2010. "Long-run growth scenarios for the world economy." *Journal of Policy Modeling*, 32(1):64–80. https://doi.org/10.1016/j.jpolmod.2009.10.001

Faehn, T., Bachner, G., Beach, R., Chateau, J., Fujimori, S., Ghosh, M., Hamdi-Cherif, M., Lanzi, E., Paltsev, S., Vandyck, T., Cunha, B., Garaffa R. and K. Steininger. 2020. "Capturing key energy and emission trends in CGE models – assessment of status and remaining challenges." *Journal of Global Economic Analysis* 5(1):196-272.

Feenstra, R. 2016. "Penn World Table 9.0." Groningen Growth and Development Centre.

Feldstein, M., and C. Horioka. 1980. "Domestic Savings and International Capital Flows." *Economic Journal*, 90 (June), 314-329. https://doi.org/10.1016/0014-2921(93)90130-3

Fontagné, L., Fouré, J. and M.P. Ramos. 2013. "MIRAGE-e: A General Equilibrium Long-term Path of the World Economy." *CEPII Working Paper* N°2013-39, December. http://www.cepii.fr/CEPII/en/publications/wp/abstract.asp?NoDoc=6266

Fontagné, L., Fouré, J. and A. Keck. 2017. "Simulating World Trade in the Decades Ahead: Driving Forces and Policy Implications." *World Economy*, 40: 36-55. https://doi.org/10.1111/twec.12479

Fouré, J., Bénassy-Quéré, A. and L. Fontagné. 2013. "Modelling the world economy at the 2050 horizon." *Economics of Transition*, 21(4), 617-654. http://doi.org/10.1111/ecot.12023.

Fouré, J. and L. Fontagné. 2016. "Long term socio-economic scenarios for Representative Concentration Pathways defining alternative CO2 emission trajectories." *CEPII Research Report* n°2016-01. http://www.cepii.fr/CEPII/en/publications/reports/abstract.asp?NoDoc=8565

Fricko, O., Havlik, P., Rogelj, J., Klimont, Z., Gusti, M., Johnson, N., Kolp, P., Strubegger, M., Valin, H., Amann, M., Ermolieva, T., Forsell, N., Herrero, M., Heyes, C., Kindermann, G., Krey, V., McCollum, D.L., Obersteiner, M., Pachauri, S., Rao, S., Schmid, E., Schoepp, W. and K. Riahi. 2017. "The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century." *Global Environmental Change*, Volume 42, Pages 251-26. https://doi.org/10.1016/j.gloenvcha.2016.06.004.

Fujimori, S., Hasegawa, T., Masui, T. and K. Takahashi. 2014. "Land use representation in a global CGE model for long-term simulation: CET vs. logit functions." *Food Security* 6(5):685-699. https://doi.org/10.1007/s12571-014-0375-z

Fujimori, S., Masui, T. and Y. Matsuoka. 2012. "AIM/CGE [basic] manual" *Center for Social and Environmental Systems Research NIES Discussion Paper* No. 2012-01. https://doi.org/10.13140/RG.2.1.4932.9523.

Goettle, R. J., Ho, M. S., Jorgenson, D. W., Slesnick, D. T., Wilcoxen, P. J., and C. E. Branch. 2009. "Analyzing Environmental Policies with IGEM, an Intertemporal General Equilibrium Model of US Growth and the Environment Part." Dale Jorgenson Associates.

Golub, A., and R. McDougall. 2012. "Household Saving Behavior in the Dynamic GTAP model" In. *Dynamic Modeling and Applications in Global Economic Analysis*, edited by E. Ianchovichina and T. Walmsley. Cambridge University Press

Gurgel, A. 2012. "Modelo de equilíbrio geral. Economia de Baixo Carbono: Avaliação de Impactos de Restrições e Perspectivas Tecnológicas." Núcleo de Estudos em Economia de Baixo Carbono. Ribeirão Preto, SP, 2012.

Gurgel, A., Reilly, J. M. and S. Paltsev. 2007. "Potential Land Use Implications of a Global Biofuels Industry." *Journal of Agricultural & Food Industrial Organization* 5(2). https://doi.org/10.2202/1542-0485.1202

Haqiqi, H., Taheripour, F., Liu, J. and D. van der Mensbrugghe. 2016. "Introduction Irrigation Water into GTAP Data Base Version 9" *Journal of Global Economic Analysis* 1(2), 116-155. http://dx.doi.org/10.21642/JGEA.010203AF.

Hertel, T. W. 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge University Press.

Ho, Mun, W. Britz, R. Delzeit, F. Leblanc, R. Roson, F. Schuenemann and M. Weitzel. "Modelling consumption and constructing long-term baselines in final demand." *Journal of Global Economic Analysis* 5(1):63-108.

Howe, H. 1975. "Development of the Extended Linear Expenditure System from Simple Saving Assumptions." *European Economic Review* 6: 305-310. https://doi.org/10.1016/0014-2921(75)90014-8

Ianchovichina, E. and R. McDougall. 2012. "Theoretical Structure of Dynamic GTAP" In *Dynamic Modeling and Applications in Global Economic Analysis*, edited by E. Ianchovichina and T. Walmsley. Cambridge University Press

Ianchovichina E. and T. Walmsley 2012. *Dynamic Modeling and Applications in Global Economic Analysis.* Cambridge University Press

International Labour Office (2017). ILO Labour force estimates and projections: 1990-2030. November 2017.

KC, S. and W. Lutz. 2017. "The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100." *Global Environmental Change*, Volume 42, Pages 181-192, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2014.06.004.

Klepper, G., Peterson, S., and K. Springer. 2003. "DART97: A description of the multi-regional, multi-sectoral trade model for the analysis of climate policies" *Kiel Working Paper* No. 1149. http://hdl.handle.net/10419/2953.

Laborde, D. and H. Valin. 2012. "Modeling land-use changes in a global CGE: Assessing the EU biofuel mandates with the Mirage-BioF model." *Climate Change Economics* **03**(03), 1250017. https://doi.org/10.1142/S2010007812500170

Lee, H. L., Hertel, T. W., Rose, S. K., and M. Avetisyan. 2009. "An integrated global land use data base for CGE analysis of climate policy options". In *Economic Analysis of Land Use in Global Climate Change Policy*, edited by Hertel, T. W., Rose, S. K., and Tol, R. S. J. Taylor & Francis.

Leimbach, M., Kriegler, E., Roming, N., and J. Schwanitz. 2017. "Future growth patterns of world regions – a GDP scenario approach." *Global Environmental Change*, 42:215–225. https://doi.org/10.1016/j.gloenvcha.2015.02.005

Luderer, G., M. Leimbach, N. Bauer, E. Kriegler, L. Baumstark, C. Bertram, A. Giannousakis, et al. (2015). "Description of the REMIND Model (Version 1.6)." SSRN Scholarly Paper. Rochester, NY: Social Science Research Network, November 30, 2015. https://papers.ssrn.com/abstract=2697070.

Mayer, J., Bachner, G. and K.W. Steininger. 2017. "Macro-economic implications of switching to process-emission-free iron and steel production in Europe." *Journal of Cleaner Production*, 210, 1517-1533. https://doi.org/10.1016/j.jclepro.2018.11.118

McKibbin, W.J. and P.J. Wilcoxen. 1999. "The Theoretical and Empirical Structure of G-Cubed model." *Economic Modelling*, 16 (1): 123-148. https://doi.org/10.1016/S0264-9993(98)00035-2

McDougall, R. 2002. "A New Regional Household Demand System for GTAP" GTAP Technical Paper No. 20. Purdue University, West Lafayette. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=942

OECD. 2019. *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*. OECD Publishing, Paris, https://doi.org/10.1787/9789264307452-en.

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., and W. Solecki. 2017. "The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century." *Global Environmental Change*, 42:169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Riahi, K., van Vuuren, D.P., Krieger, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cruespo Cuaresma, J., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Aleluia Da Silva, L., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A. and M. Tavoni. 2017. "The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview", *Global Environmental Change* 42:153-168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.

Rogner, H. 1997. "An assessment of world hydrocarbon resources", *Annual Review of Energy and the Environment*, 22, 217-262. https://doi.org/10.1146/annurev.energy.22.1.217

Sands, R. D., Scott M., Shellye A. Suttles, and E. Marshall. 2017. "Dedicated Energy Crops and Competition for Agriculture Land." ERR-223, U.S. Department of Agriculture, Economic Research Service, January 2017. https://www.ers.usda.gov/publications/pub-details/?pubid=81902

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G. C., Fujimori, S., Gurgel, A., Havlík, P., Heyhoe, E., D'Croz, D. M., Popp, A., Sands, R. D., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A. and H. Valin. 2014. "Land-use change trajectories up to 2050: Insights from a global agro-economic model comparison." *Agricultural Economics* **45**(1), 69-84. https://doi.org/10.1111/agec.12090.

Solow, R. M. 1957. "Technical change and the aggregate production function." *The Review of Economics and Statistics*, 39(3):312. https://doi.org/10.2307/1926047.

Speller W., Thwaites G. and M. Wright. 2011. "The future of international capital flows." *London: Bank of England, Financial Stability Paper*, No. 12. https://dx.doi.org/10.2139/ssrn.1979424

Taheripour, F., Hertel, T.W., Tyner, W.E., Beckman, J.F. and D. K. Birur. 2010. "Biofuels and their by-products: Global economic and environmental implications." *Biomass and Bioenergy*, 34(3), p. 278-289, https://doi.org/10.1016/j.biombioe.2009.10.017.

Tyers, R., Shi, Q. and M. Chan. 2005. "Global Demographic Change and Economic Performance: Implications for the food Sector." Report to the Rural Industries Research and Development Corporation. Canberra: RIRDC.

Tyers, R., and Q. Shi. 2007. "Demographic change and policy responses: Implications for the global economy." *World Economy*, 30(4), 537-566. https://doi.org/10.1111/j.1467-9701.2007.01004.x

United Nations, Department of Economic and Social Affairs, Population Division (2017). "World Population Prospects: The 2017 Revision, Methodology of the United Nations Population Estimates and Projections." Working Paper No. ESA/P/WP.250. New York: United Nations.

Unites Nations, Department of Economic and Social Affairs, Population Division (2019). "World Population Prospects : The 2019 Revision, Methodology of the United Nations Population Estimates and Projections." Working Paper No. ST/ESA/SER.A/425. New York : Unites Nations.

van der Mensbrugghe, D. (2010). "The environmental impact and sustainability applied general equilibrium (ENVISAGE) model. Version 7.1." The World Bank.

Walmsley, T., Aguiar, A. and S.A. Ahmed. 2017. "Labour Migration and Economic Growth in East and South-East Asia." *World Economy*, 40(1), 116-139. https://doi.org/10.1111/twec.12334.

Waisman, H., Rozenberg, J., Sassi, O., and J.C. Hourcade. 2012. "Peak oil profiles through the lens of a general equilibrium assessment." *Energy Policy*, 48, 744-753. https://doi.org/10.1016/j.enpol.2012.06.005.

Wang, Y. and Y. Yao. 2003. "Sources of china's economic growth 1952–1999: incorporating human capital accumulation." *China Economic Review*, 14(1):32–52. https://doi.org/10.1016/S1043-951X(02)00084-6

Wilson, D. and R. Purushothaman. 2006. "Dreaming with brics: The path to 2050." In *Emerging Economies and the Transformation of International Business*, chapter 1. Edward Elgar Publishing.

Winning, M., A. Calzadilla, R. Bleischwitz and V. Nechifor 2017. "Towards a circular economy: insights based on the development of the global ENGAGE-materials model and evidence for the iron and steel industry." *International Economics and Economic Policy*, 14 (3): 383-407. https://doi.org/10.1007/s10368-017-0385-3

Woltjer, G., Kuiper, M., Kavallari, A., van Meijl, H., Powell, J., Rutten, M., Shutes, L. and A. Tabeau. 2014. "MAGNET Model, Module description." The Hague: LEI Wageningen UR (Manual / LEI 14-57). http://edepot.wur.nl/310764

World Energy Resources, 2013. Survey of Energy Resources

Zhao, X., van der Mensbrugghe, D. and W. Tyner. 2017. "Modeling land physically in CGE models: new insights on intensive and extensive margins." Presented at 20th Annual Conference on Global Economic Analysis, West Lafayette, IN, USA. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5291.

Appendix A

Table A1. Key macroeconomic data source of reviewed models

Model name	**GDP**	**Population**
AIM/CGE	SSP Database	UNPD / IIASA
DART	OECD Env Outlook 2012	PHOENIX model
EC-MSMR	E3MC	E3MC
ENGAGE	SSP Database	IIASA
ENVISAGE	SSP Database	IIASA
ENV-Linkages	ENV-Growth (SSP) / OECD ECO/LTB [MIX]	IIASA/UNPD
EPPA	IMF/WM/UN/own [MIX]	?
EU-EMS	?	?
EXIOMOD	CEPII or EU or SSP Database	UNPD
FARM	SSP Database	IIASA
GDyn	Endog. or exo	UNPD, or other
GEM-E3	OECD/IMF/EU [MIX]	UNPD
ICES	SSP Database	IIASA/UNPD
IGEM	Endog. or own path	US Census
Imaclim-R		UNPD
MAGNET-TI	USDA/ERS	USDA/ERS
MAGNET-Wageningen	SSP Database, USDA, OECD, DG AGRI	IIASA
MESSAGE (IIASA)	MACRO link	IIASA SSP
MIRAGE-e	CEPII SSP	UNPD/IIASA
PACE	IEA	UNPD
REMIND	SSP Database	IIASA
TEA	SSP Database	IIASA
Weg_Center	SSP Database	IIASA

Source: Author construction.

Table A2. Key factor assumptions of reviewed models

Model name	Land supply	Savings	Investment	Depreciation	Labor	NatRes (Fossil)	NatRes (Other)	Current Account
AIM/CGE	Endog. (coupled with AIM/PLUM)	Endog.	'=S	Constant (5 %)	Exo. (working age pop, growth)	Calib.	Fixed	Fixed (0)
DART	Fixed	Fixed	'=S	5-7%	Exo.	?	NO	Endog.
EC-MSMR	?	?	Endog.	Calib. or constant (7 %)	?	Calib.	Endog.	Fixed
ENGAGE	Endog.	Exo.	Endog.	4 to 6%	Exo. (working age pop, growth)	Calib.	Fixed	Exo.
ENVISAGE	Endog.	Fixed	'=S	?	Exo. (working age pop, growth)	Endog.	Endog.	Endo.
ENV-Linkages	Exo. (IMPACT/ IMAGE/ MAGNET)	Endog.	Exo. (ENV-Growth)	Exo.	Exo. (educ., growth)	Calib.	Endog.	Exo. (ENV-Growth)
EPPA	?	Fixed	Fixed	?	?	Endog.	?	Fixed
EU-EMS	?	?	Endog.	?	?	?	?	?
EXIOMOD	?	?	Exo.	NO (K exo)	?	?	?	?
FARM	?	Fixed	'=S	?	?	?	?	Exo. (Fixed or CV 0)
GDyn	Endog.	Endog.	Endog.	4 %	Exo. (educ, growth)	Fixed	Fixed	Endog.
GEM-E3	NO	NO	Endog.	?	Exo. (ILO)	?	?	Fixed or endog.
ICES	Fixed	Endog.	'=S	?	Exo. (educ, growth)	Calib.	Fixed	Fixed (0)
IGEM	NO	Endog.	Endog.	?	Endog. (leisure)	NO	NO	Exo. (CV vers 0)
Imaclim-R	NO	Endog.	Endog.	Constant (sector), endog. Vintages for energy	Exo (working age pop)	Endog.	?	Exo (Fixed of CV 0).
MAGNET-TI	Exo. (IMAGE model)	Fixed	Endog.	?	Exo. (pop)	Calib.	Calib.	Endog.
MAGNET-Wageningen	Endog.	Fixed	Fixed	?	Exo. (pop)	Calib.	Calib.	Endog. or Fixed
MESSAGE (IIASA)	Calib. (GLOBIOM)	?	?	?	?	Calib.	?	?
MIRAGE-e	Endog.	Exo. (EconMap)	Exo. (EconMap)	Constant (6 %)	Exo. (educ., growth)	Calib.	Fixed	Exo. (EconMap)
PACE	?	?	?	?	Fixed	?	?	Fixed (0)
REMIND	Exo. (MagPIE)	Endog.	Endog.	?	Exo. (working age pop, growth)	Endog.	Endog.	Endog.
TEA	Endog.	Fixed	'=S	Constant (5%)	Exo. (working age pop, growth)	Exo. (COFFEE)	Endog.	Exo. (CV vers 0)
Weg_Center	Exo.	Fixed	Fixed	Constant (PWT)	Exo. (working age pop, growth)	Calib.	?	Fixed

Notes: "Fixed" means the variable is maintained at its initial value. "Exo." means the variable is taken from an exogenous source (mentioned when available between parenthesis). "Calib" means the variable is calibrated to match the trajectory of another variable. "Endog." Means the model endogenously determines the variable. "NO" means the variable is absent of the model. "?" means the team did not explicitly answer the question in their contributed template. For investment, "=S" means investment are equal to savings.

Source: Author construction.

Table A3. GDP projections download links

Name	Institution	Ref.	SSPs	Hyperlink
EconMap	CEPII	X	X	http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=11
ERS	USDA	X		https://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx
ENV-Growth	OECD	X		
ENV-Growth (SSP)	OECD		X	https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about
GDP	IIASA		X	https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about
GDP-32	PIK		X	https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about
Global Economic Prospects	World bank	X		http://www.worldbank.org/en/publication/global-economic-prospects
World Economic Outlook	IMF	X		https://www.imf.org/en/Publications/SPROLLS/world-economic-outlook-databases
World Energy Outlook	IEA	X		https://www.iea.org/weo2017/

Source: Author construction.