EUCALC

Explore sustainable European futures

Formulation of baseline projections and documentation on modeling approach review

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Short Description

This deliverable documents the development of the baseline projection to 2050 for use in the modelling work contained in WP7. The main purpose of the baseline construction is to establish a likely business-as-usual scenario towards 2050, against which the transboundary effects of alternative EU de-carbonization pathways can be estimated. The main components of the baseline are annual GDP projections and the associated main drivers such as population, labor force, capital stock, and total factor productivities for individual countries including all EU member states. The main sources of these data are recent model based projections, particularly the EU-Reference scenarios 2016 and various other projections related to the SSP2 scenarios. This deliverable also contains a review of the existing modelling approach towards baseline constructions and a discussion on how the baseline can be replicated/calibrated in the subsequent modelling work in WP7. A brief review on the model choice and on how to represent the alternative EU de-carbonization pathways relative to the baseline in the chosen model is also offered.

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This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

List of Tables

List of Figures

List of abbreviations

BAU	Business As Usual
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
EM-Ref	Reference projections in EconMap 2.4
EM-SSP2	Projections for SSP2 in EconMap 2.4
EU AR2015	EU Ageing Report 2015
EU-Ref	EU Reference Scenario 2016
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
IAM	Integrated Assessment Model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IIASA-SSP2	Projections for SSP2 by the IIASA modelling team
IMF	International Monetary Fund
ILO	International Labor Organization
MER	Market Exchange Rate
OECD	Organization for Economic Co-operation and Development
OECD-SSP2	Projections for SSP2 by the OECD modelling team
PPP	Purchase Power Parity
ROW	Rest Of the World
SSP	Shared Socioeconomic Pathway
TFP	Total Factor Productivity

1 Executive Summary

Evaluations of climate policy require the establishment of future baseline scenarios against which alternative de-carbonization pathways can be compared. In the case of WP7 of the EUcalc project, the transboundary effects of EU de-carbonization pathways can be estimated against such a baseline in a trade-focused global Computable General Equilibrium (CGE) modeling framework. This deliverable documents the efforts for constructing such a baseline. The baseline itself is included as the data appendix to this document.

The starting point of constructing such a baseline is to define the likely business-as-usual scenario. Through a review of the existing baseline construction exercises including the underlying modeling approaches, the EU-Reference Scenario 2016, used as the de facto "official" EU reference scenario in many modeling exercises in the climate and energy policy analysis and modeling exercises, is adopted as the business-as-usual scenario of the EU. For the rest of the world, several alternative global projection databases are considered, including the Econ-Map reference and SSP2 scenarios, the IIASA-SSP2 scenario, and the OECD-SSP2 scenario. Through an extensive review, mainly regarding their consistencies with the EU-Reference scenario, their resemblances to the situation of today, as well as the modeling approaches applied, the OECD-SSP2 projection is considered to be the most suitable data source for the rest of the world. Therefore, the GDP baseline is mainly a combined data set covering the projections from the EU-Reference Scenario 2016 and the OECD-SSP2 scenario.

All the projection exercises reviewed in this deliverable are built on structural or reduced-form economic models, which specify projected GDPs as outcomes of a series of fundamental economic determinants. These are considered the "drivers" of the GDP projections. To replicate the projected GDP, it is necessary to also include these drivers into the baseline data set, including projected population, labor forces, capital stocks, and total factor productivities. These data are also sourced from the projection exercises reviewed in the deliverable.

The end product of the work underlying this deliverable therefore contains two components: projected annual GDP for individual countries during the 2010-2050 period, and also on a yearly basis the projected GDP determinants for individual countries during the same period.

The last part of the deliverable discusses the plan for implementing/replicating the baseline in the trade-focused CGE modeling framework. Towards this end, a conceptual modeling approach is sketched.

2 Introduction

The economic baseline construction for EUCalc requires designing a future baseline towards the year 2050 that represents likely global macroeconomic situation, economic structure, and inter-country trade linkages (and implied energy demand and supply, as well as greenhouse gases emissions). This baseline will form the foundation for the modeling and simulation work as described in WP7 to project and compare how different combinations of "lever" settings at the sectoral levels would lead to different trans-boundary effects within EU Member States and between the EU and the rest of the world.

By assumption, such a baseline should resemble a trajectory of social-economic development that is mostly likely to occur, given current and historical trends regarding the fundamental determinants of aggregated economic activities across countries. These aggregates are population and demographical changes, education and skill levels of the labor force, technological progresses, investment and capital accumulations, and anticipated changes in economic policy and institutions.

Facing the challenges of climate changes and rising temperature, the key uncertainties in projecting the future are:

- How historical and current GHG emissions would influence the outcomes of current and future economic activities;
- How mitigation and adaptation efforts would alter the trajectories of future economic development.

Such considerations make the construction of a "likely" baseline to be a particularly difficult task, as climate considerations may imply long-term structural changes in the economic systems at national and global levels. To abstract from such complications, we interpret the "most likely prospect of the world economy to 2050", as mandated by the EUCALC project, as a "business as usual (BAU)" scenario. In the recent literature, a number of "reference projections" for GDP, population, labor force, capital stocks and total factor productivity have been built for similar and related purposes. In addition, the recent efforts of conceptualizing and substantiating the so-called "Shared Socio-economic Pathways" (SSPs) (O'Neill et al., 2014) provide further insights and templates towards building such a baseline.

The SSPs describe alternative trends in the evolution of society and ecosystems from 2005 to 2100 at the world and regional levels. Each of these SSPs consists of a narrative and a set of quantified indicators of development. The SSPs can be considered as "reference" pathways since they do not impose any climate change impacts on socioeconomic development, and contain no assumptions on new climate policies (Kriegler et al., 2014). The SSPs are part of a framework that the climate change research community has adopted to facilitate the analysis of future climate impacts, vulnerabilities, adaptation, and mitigation through integrated assessment models (IAMs) (Riahi et al., 2017). The narratives serve as the starting point for the identification of internally consistent assumptions for the quantification of SSP elements, and are defined to describe four combinations of high/low challenges to adaptation and mitigation. A fifth narrative (SSP2) can be considered the middle-of-the-road narrative, a central pathway. The five narratives are shown in figure 1.

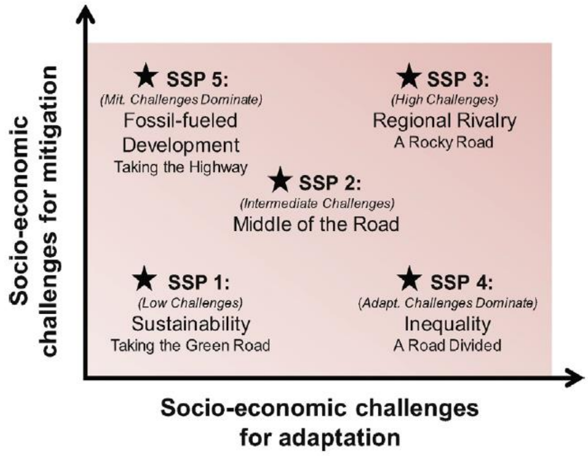

Figure 1 – Five SSPs representing different combinations of challenges to mitigation and adaptation

Source: O'Neill et al. (2017)

In SSP2, the world would undergo a transformation in which social, technological and economic trends do not deviate much from historical patterns observed over the past century (Fricko et al., 2017). In terms of its relationship with the sectoral "lever settings" to be defined in other WPs of EUCalc, it seems that the SSP2 would generally represent "neutral" settings regarding energy demands, fossil energy supply, energy conversion technologies, as well as land use (see appendix A), resembling a BAU scenario. Furthermore, such a representation of the future would allow for deviations from these "medium" settings to model a large set of alternative scenarios. Therefore, the baseline projections around the SSP2 seem to be a sensible choice for the purposes of EUCalc. It should be noted, however, that this central case is not "more likely" than any of the other storylines (O'Neill, 2016).

In this report, we mainly present our efforts in collecting and processing data to construct the economic baseline for WP7 of the EUCalc project, with the focus on the BAU "reference scenarios" and those explicitly built around the SSP2 storylines. Since the analysis of transboundary flows, production and carbon leakages will be carried out using the GTAP (Hertel et al., 1997) and GTAP-E (Burniaux and Truong, 2002, McDougall and Golub, 2009) models, the baseline assembled from these existing baseline exercises will have to be re-produced in the GTAP modeling framework. Therefore, a discussion on the model implementation of the baseline is part of this report, with reference to the currently available GTAP version 9 database (Aguiar et al., 2016), which provides a full characterization of the world economy in the year 2011. Therefore, the relevant projection will be for the period of 2011-2050.

The rest of the report is organized as follows. Section 2 presents an overview of the data sources that we have surveyed and discusses the selection of the GDP projection data and the complementary data on the GDP drivers. More detailed discussions on the data sources and a review of the underlying modeling approaches are available in the Appendices. Section 3 offers a description of the baseline data set. In Section 4, a discussion on how this baseline projection data set can be implemented and used in the modeling work in WP7 is offered.

3 Data

3.1 Data sources and data availabilities

The most important element of an "economic baseline" is the projected aggregated economic activities at country level, as measured by Gross Domestic Products (GDP) for individual countries and for the world as a whole. In the context of the EUCalc project, the GDP measure is also regarded as one of the most important economic aggregates, as the growth of a country's GDP generally reflects energy demand and supply of that country at aggregated level. Short-term projections on GDP may be conducted by simple extrapolations of current macroeconomic aggregates. Longer-term GDP projections, on the other hand, typically rely on projected economic "drivers" such as population, total labor force, skilled/unskilled labor force, capital stocks, and total factor productivities. For the purposes of constructing a baseline towards 2050, we opt to survey existing long term projection exercises based on structural economic approaches, including projection conducted by researchers from OECD (OECD-SSP2), IIASA (IIASA-SSP2), CEPII (EconMap), as well as those adopted in official EU publications (EU Reference Scenarios 2016 and EU Ageing Report 2015) and EUROSTAT. Table 1 provides a summary on the country coverage, time horizons and data frequencies, and key variables contained in each of these projections.

Table 1 – Data sources: existing baseline projections.

Data sources	No. of countries/regions	Time horizon	Frequencies	Variables included (V indicates data available)					
				GDP	Population	Labor Force	Education	Capital Stock	TFP
OECD-SSP2	184+ ROW	2005-2100	1-year	V					
IIASA-SSP2 GDP	172	2005-2100	5-year	V					
EconMap 2.4	167	1980-2100	1-year	V	V	V	V	V	V
EU AR2015	EU28+ Norway	2013-2060	5-year	V	V	V			V[1]
EU-Ref	EU28	2000-2050	5-year	V	V				
IIASA-SSP2 POP	193	2005-2100	5 year		V		V		
EUROSTAT	EU28+ 21[2]	2010-2017	1-year		V				
EUROSTAT	EU28+ Switzerland	2010-2016	1-year			V			

Source: authors' compilation; detailed sources of each projection can be found in Appendix C. Note: ROW refers to an aggregated rest of world region; EU28 refers to individual member states of the European Union. Eurostat is listed twice as data sources due to the fact that it contains population data for EU28 and 21 other countries and labor force data for only the EU28 and Switzerland.

[1] The EU AR2015 data show the growth rate of TFP, but not the absolute TFP value for each country. Therefore, no comparisons across countries are possible.
[2] The 21 countries other than EU28 are the following: Iceland, Liechtenstein, Norway, Switzerland, Montenegro, Former Yugoslav Republic of Macedonia, Albania, Serbia, Turkey, Andorra, Belarus, Bosnia and Herzegovina, Kosovo (under United Nations Security Council Resolution 1244/99), Moldova, Monaco, Russia, San Marino, Ukraine, Armenia, Azerbaijan, Georgia.

As can be observable in Table 1, these projections differ from their respective country coverages, time horizons and frequencies. The five projections containing GDP predictions are listed in in the first five rows in Table 1 and it can be seen that all five project GDP at least to 2050, thereby making them candidate sources for constructing the WP7 baseline. However, not all the five projections provide the same country/region coverage. The first three projections (OECD-SSP2, IIASA-SSP2 and EconMap 2.4) essentially cover the whole world, whereas the last two (EU Reference 2016 and EU Ageing Report 2015) focuses only on the EU28 (and Norway in the case of EU Ageing Report 2015).

Regarding the essential GDP drivers, only the EconMap data set contains all five drivers to complement the GDP projections. OECD-SSP2 and IIASA-SSP2 only include GDP projections but not any of the drivers (however, another IIASA data set contains population and education). This is also the case for the EU Reference 2016 (EU-Ref) projection. The EU Ageing Report 2015 (EU AR2015) does have some GDP drivers such as population, labor force and TFP. Finally, the EUROSTAT dataset provides some coverage on population and labor force for the 2010-2016/7 period on an annual basis for the EU28 and selective other countries.

It is apparent that the public available data sets surveyed above provide limited options on using the same sourcing data on GDP as well as the key GDP drivers to construct the WP7 baseline. In fact, this would effectively imply the use of only one data source, namely, the EconMap dataset. However, during the consultation stage within the EUCalc project, a position was taken to use the "official" projections for the EU Member States, for the purposes of maintaining consistency with sister EU projects and to align our baseline with the official EU projection concerning the EU member states. This therefore rules out the use of the entire EconMap dataset. Following this position, for GDP projections, we decided to use the EU-Ref dataset and the related EU AR2015 for the EU28 and Norway. For the rest of the world, we chose to use data from other projections that are most similar to the "official" EU projections. After obtaining GDP projections, it is then necessary to source data to plot the trajectories for the individual GDP drivers. The selection of GDP drivers, once again, is based on their consistency with the GDP projections, and on availability of these data. These choices are discussed in details in the next section.

3.2 GDP data selection

3.2.1 GDP data sources

Taken together, the five data sources we have gathered provide GDP projections for up to 184 countries – including all the world's major economies – and an aggregated "rest of the world" region. However, as these different GDP projections have different base-years, and since some of them are expressed in "international dollars" computed on the basis of purchase power parities (PPP) while others are expressed in US dollars measured in market exchange rates (MER), it is necessary to convert all these projections into the same currency concept before any comparisons and potential mergers of data can be made. To ensure comparability across data sources, GDP data from all five data sources are converted into 2005 USD MER, as discussed below.

OECD-SSP2. The OECD working group for the SSP database (Dellink et al., 2017) contains GDP projections purported for the SSP2 for 184 countries (plus a ROW region), based on the OECD Env-growth model, a macroeconomic growth model based on a conditional convergence framework (Chateau and Dellink, 2012). In the OECD-SSP2 projection, GDP values are expressed in both 2005 USD PPP (covering 184 countries/regions and a ROW region) and in 2005 USD MER (covering 178 of the 184 countries/regions, excluding Aruba, New Caledonia, Ecuador, French Polynesia, Somalia, Taiwan, and the ROW). As the conversion rate between the PPP and MER values is fixed for each country, the GDP growth rates for each individual country remains the same in the projections based on PPP and MER values.

IIASA-SSP2. The IIASA working group for the SSP database (Crespo Cuaresma, 2017) projects GDP for 172 countries in 2005 USD PPP. These data are converted into MER values by using conversion rates from the Penn World Table 7.0 (Heston et al., 2011). For additional information regarding the conversion of the unit of measurement, please refer to Appendix B.

EconMap. Fouré and Fontagné (2016) and Fontagné and Fouré (2017) for EconMap 2.4 SSP2 (EM-SSP2), and (Fouré et al., 2012, Fouré et al., 2013) for EconMap2.4 Reference Scenario (EM-Ref) contain projections on GDP (expressed in 2005 USD MER), population, labor force, educational attainment, capital stocks (expressed in 2005 USD MER) and total factor productivity for 167 countries. These GDP projections are carried out by using MaGE, a macroeconometric model based on a three-factor production function of labor, capital and energy, and two forms of technological change. Population is respectively gathered from Kc and Lutz (2017) and from United Nations (2017).

EU-Ref. The EU Reference Scenario 2016 (European Commission et al., 2016) gathers projected GDP growth rates for the EU member states from the EU Ageing Report 2015 (European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2014, European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2015). To project GDP for the 28 EU countries over the long-term, a two-factor (labor, capital) production function framework is used in this modeling exercise. Values of projected GDP in this data source are expressed in 2013 EUR MER. To make the data from this source consistent with other sources, we convert these data (expressed in 2013 EUR MER) into 2005 USD PPP and also into 2005 USD MER values. To do so, we first move from the base year 2013 to 2005 by using the actual real GDP data from Eurostat[3] for each of the EU28 countries. Then, we convert GDP values in EUR in 2005 into 2005 USD by using the average exchange rate in 2005, as provided by Eurostat[4]. These procedures give us GDP in 2005 USD MER for all 28 EU member states. Finally, to obtain GDP in 2005 USD PPP, we can convert MER data into PPP data by using applicable PPP/MER conversion ratios.

[3] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=namq_10_gdp&lang=en
[4] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en

3.2.2 Selection of GDP data sources for EUCALC WP7

After comparing the different data sources (as documented in Appendix D) and taking into consideration of the positioning of the EUCalc project in related EU projects, we have chosen to use projections from EU-Ref for the EU Member States, and projections from OECD-SSP2 for the rest of the world. The first choice regarding GDP projections for the EU Member States is to maintain consistencies with other EU modeling efforts and the EU policy making process, as the EU-Ref projections are considered "official" projections. However, as the publically available EU-Ref projections only offer GDP trajectories for the EU28, it is necessary to combine the GDP projections from EU-Ref with other data sources that extend coverage to other parts of the world. Towards this end, we have chosen the OECD-SSP2 to cover the rest of the world. As detailed in Appendix D, the OECD-SSP2 projections are preferred to other ones as they are the most consistent to the EU-Ref projections for the EU Member States. In addition, OECD-SSP2 also provides data coverage for the widest range of non-EU countries, thereby allowing for more flexibilities to aggregate the rest of the world for the subsequent modeling work in WP7.

3.3 GDP determinants

As detailed in Appendix C, GDP projections in all the data sources as presented in section 3.2 are mostly driven by a combination of increases in primary inputs such as labor and capital, labor-augmenting (human capital) efficiency improvements, and progresses in total factor productivity (TFP). Differences in the GDP projections are due to the growth of these drivers, the weights these drivers have in the calculation, and the convergence assumptions. A more specific presentation of the models used to project GDP in the future can be found in Appendix C.

In order to represent the GDP projections for individual EU Member States and the rest of the world in the modeling work in WP7, it is necessary to build an accompanying data set covering these determinants. This section is therefore devoted to the description of these supplementary data to be included in the baseline dataset.

3.3.1 Population

Population is a fundamental determinant of future economic conditions. The data sources gathered provide population projections for 194 countries including all the EU Member States. These sources are: EUROSTAT, EU AR2015, IIASA-SSP2 population, and OECD-SSP2 assumptions on population. To maintain as much consistency as the EU-Ref GDP projections, population data from EUROSTAT and EU AR2015 are used for the EU Member States. This is supplemented by population projections from the other sources to develop a complete population projection for the entire world.

For individual members of the EU28 and Norway, we gathered data from:

- for the period 2010-2015: annual data from EUROSTAT
- for the period 2020-2050: projections at 5-year intervals from the EU AR2015(which are also used in EU-Ref)

Based on the above data, annualized population data during the 2010-2050 can be obtained for the 28 EU Member States and Norway, with the 2010-2015 actual data being sourced from EUROSTAT, and the 2020-2050 data being interpolated from the 5-years intervals data from EU AR2015 (assuming a constant growth rate within each 5-years interval).

For Albania, Armenia, Azerbaijan, Belarus, Switzerland, Georgia, Russia, Turkey and Ukraine, we have gathered data from EUROSTAT and IIASA WIC POP projections for SSP2. The annual data from EUROSTAT during 2010-2015 are directly applied, with missing values being filled in by assuming constant growth rates between available years. For the future period 2020-2050, the IIASA-SSP2 population projections, which are also used by OECD-SSP2, are selected. As the IIASA population projections are at 5-year intervals, annual data are obtained through interpolations, assuming constant annual growth rates during each 5-year intervals.

For the remaining 155 countries/regions except Taiwan, population projections are solely sourced from IIASA-SSP2 population projections. As previously mentioned, IIASA database has 5-years intervals data and the same interpolation method is applied to generate the annual data. For Taiwan which is not included in the IIASA-SSP2 population projection data file, we have gathered data from the population assumptions applied for OECD-SSP2 projections, and follow the same interpolation procedure to annualize the 5-year interval data.

3.3.2 Labor force

Projected labor force is one of the main drivers of the GDP projections. Our database includes data from EUROSTAT, EU AR2015 and EM-SSP2. In total, there are 167 distinct countries/regions represented in these data sources. The definition of labor force we adopt is the ILO description[5], which defines labor force as population of the 15-64 age-group (with 15 being used as a proxy for "minimum working age").

For EU28 Member States and Norway, we have gathered data from:

- for 2010-2016: annual data from EUROSTAT
- for 2020-2050: projections at 5-year intervals from the EU AR2015

Based on the above data, annualized labor force data during the 2010-2050 period can be obtained for the 28 EU Member States and Norway, with the 2010-2015 actual data being sourced from EUROSTAT, and the 2020-2050 data being interpolated from the 5-years intervals data from EU AR2015 (assuming a constant growth rate within each 5-years interval).

For Switzerland and Turkey, we gather and combine data from these sources:

- 2010-2016: annual data from EUROSTAT
- 2017-2020: annual data from EM-SSP2

For the remaining 136 countries, annual data from EM-SSP2 are directly used.

5 "The labor force (economically active population) is the sum of the number of persons employed and the number of unemployed. The working-age population is the population above the legal working age – often aged 15 and older, but with variation from country to country based on national laws and practices." Available at: http://www.ilo.org/wcmsp5/groups/public/---dgreports/---stat/documents/publication/wcms_422090.pdf

3.3.3 Skilled/unskilled labor force

In addition to the aggregated labor force and population projections, EM-SSP2 further includes detailed population projections, divided by sex, age and educational attainment, from the SSP database[6]. This provides the possibility to obtain projected skilled and unskilled labor forces.

Following Chappuis and Walmsley (2011), we assume that skilled labor force will grow at the same rate as the tertiary educated population. Unskilled labor, consequently, is calculated as a residual. Since EM-SSP2 has data on the percentage of working-age population with tertiary education, we multiply these shares with our labor force data. Then, we calculate unskilled labor as the difference between the total labor force and the skilled labor force. This procedure results in the split of total labor force projections into skilled and unskilled labor forces for each country where labor force projection is available.

3.3.4 Capital Stock

The only projection consistent with the adopted SSP2 (out of the five data sources; see Table 1) with capital stock trajectories is EM-SSP2, which provides projected capital stock for 167 countries[7]. These data are therefore directly included in our baseline database.

3.3.5 Total factor productivity

The EU AR2015 and EM-SSP2 provide total factor productivity projections for a total of 167 countries. We again follow the approach to use the EU AR2015 projections for the EU Member States (and Norway) and the EM-SSP2 projections for the rest of the world.

For EU28 and Norway, data are gathered from the EU AR2015. However, AR15 shows average growth rates within the interval 2013-2020 with 2013 as the base year, and then provides data at 5-year intervals until 2050. To obtain annualized TFP growth rates during 2010-2050, we first extrapolate the data during 2013-2020 to the period of 2010-2012 and then interpolate the 5-year interval data during 2021-2050, assuming constant growth rates during each of the 5-year intervals.

For the rest of the world, we simply apply the TFP projections by EM-SSP2, as there are no alternative sources covering SSP2.

6 Available at: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about

7 The EM-Ref projection also contains projections of capital stock; however, as the EM-Ref projection is not consistent with the SSP2 assumptions, we opt to not adopt the EM-ref capital stock projections.

4 The Baseline Dataset for WP7

The baseline dataset is stored in an MS Excel file that contains individual worksheets storing annual projections of GDP and the associated main drivers (as discussed in section 3) at country level, from 2010 to 2050. This dataset and its metadata can be accessed by following this link: https://cloud.pik-potsdam.de/index.php/s/e3gYMKycXTY6nzD with the password: tbd_euc_02.

GDP projections are gathered from EU-Ref (European Commission et al., 2016) and from OECD-SSP2, as developed in Dellink et al. (2017). A total of 184 countries, plus a ROW region, are covered. There are three data sheets on projected GDPs. The first data sheet contains 2013 EUR MER data for EU28 and 2005 USD PPP data for the rest of the world. In the second, we have 2005 USD PPP data for a total of 184 countries, plus a ROW region. In the third, we have 2005 USD MER data for 178 countries (as MER data are not available for Aruba, New Caledonia, Ecuador, French Polynesia, Rest of the world, Somalia and Taiwan). As previously mentioned, in the projection exercises that we have surveyed, the conversion rates between PPP and MER are fixed over time, implying that the growth rate for each country is the same regardless whether GDP is expressed in MER or PPP. For this reason, in order to have a wider coverage for individual countries and since we are more interested in the growth rates than absolute values, we have decided to present three different data sheets for GDP. In addition, we also supply a separated data sheet on both the cumulative GDP growth rates and annualized GDP growth rates for each country during the projected period. Similarly, the cumulative and annualized growth rates for population, labor force, capital stock and TFP are also provided.

Population (in the "POP" worksheet) projections are collected from European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2015), from EUROSTAT and from Kc and Lutz (2017). A total of 194 countries/regions are covered.

Labor force (in the "LF" worksheet) projections are assembled from Fouré and Fontagné (2016), EUROSTAT and European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2015). There are 167 countries covered. Total labor force is divided into skilled and unskilled (in the "Skilled LF" and "Unskilled LF" worksheets, respectively), drawing from education projections obtained from Fouré and Fontagné (2016), which in turn are gathered from Kc and Lutz (2017).

Capital stock projections (in the "Capital Stock" worksheet) are gathered from Fouré and Fontagné (2016). They are expressed in billion constant 2005 USD, and cover 167 countries.

TFP projections (in the "TFP" worksheet) are collected from Fouré and Fontagné (2016) and from European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2015). There are 167 countries covered. Note that the values of TFP in the starting year (i.e. 2010) differ across countries but this does not prevent us from calculating the TFP growth rates across the projection period by country.

Finally, a "mapping" worksheet is included in our dataset to show the correspondences between the sets of countries used in the different parts of the baseline data set. This serves two purposes. First, it offers an overview of the country coverage of the various components contained in the baseline data set. Second, it provides a correspondence between countries covered in the baseline data set and countries/regions covered in the GTAP database. The GTAP database is composed of 140 individual countries or aggregated regions, corresponding to 235 different countries and territories. Such a correspondence will be needed when the baseline data set is deployed into the modeling development of WP7, which is to be based on the GTAP database.

5 Modeling considerations in replicating the baseline and building alternative scenarios in WP7

5.1 Energy and environment focused CGE model for simulating transboundary effects in WP7

The main purpose of constructing the economic baseline in WP7 is to provide a BAU scenario against which counter-factual simulations of alternative EU de-carbonization pathways can be conducted for obtaining the trans-boundary effects of such alternatives. Trans-boundary flows refer to the trade of goods and services amongst the EU member states, as well as between the EU and the ROW. As the envisioned de-carbonization pathways impose changes in both energy demand and supply, levels and structures of production and consumptions at sectoral and country levels would also be altered, resulting in deviations from the projected baseline in 2050. This in turn would change the internal and external economic dependences concerning the EU Member States at sectoral levels and lead to changed trade patterns. Furthermore, as transboundary flows of goods and services also embody energy consumption and GHG emissions, projecting transboundary flows is therefore also an important consideration in evaluating the options and tradeoffs of EU de-carbonization pathways.

Modeling the transboundary effects therefore mandates the use of an economic modeling system that takes into considerations of not only inter-sectoral linkages such as the input-output linkages connecting raw materials and fossil fuels to final outputs but also linkages through the competition/allocation of available economic resource such as labor and capital. Further, EU member states and the rest of the world must also be connected in the model such that imbalances between demand and supply at sectoral levels for each country can be accounted for via transboundary trade flows. Essentially, this requires the use of a global CGE model focused on trade linkages. The GTAP model, initially developed for addressing the need to evaluating the consequences of international trade agreements and trade liberalizations in general on domestic production, consumption and international trade amongst countries/regions in the world, is widely considered the standard tool for analyzing transboundary effects. Given the energy and emission focus of the EUCalc project, sufficient details on energy and GHG emissions should also be presented in the model. Therefore, the energy and environment focused variant of the GTAP modeling framework named GTAP-E and the accompanying datasets will be used as the starting point for the further modeling development work specified in the Description of Work for WP7. For details of the GTAP and GTAP-E modeling framework, please see Hertel et al. (1997), Nijkamp et al. (2005), and McDougall and Golub (2009). Below we include a short description of the GTAP-E model and a brief survey on how this model and its various extensions have been used in the climate change literature.

5.2 The GTAP-E model and its application in climate policy analysis

Aiming at providing a model to explore the energy-economy-environment-trade linkages, the GTAP-E model extends the standard GTAP model (Hertel et al., 1997) by introducing an energy production system that features substitutions among different energy sources and between energy and other inputs such as capital. This modeling framework is supported by the addition of a satellite data base on CO2 emissions arising from combustions of fossil fuels to the core GTAP database. The key of this extension is to link the emission quantity data sourced from the International Energy Agency measured in physical units to economic activities related to fuel uses measured in monetary terms. To facilitate the evaluation of climate policy, the GTAP-E model further incorporates policy instruments such as carbon tax and allows for emission trading across countries and within groups of countries. The initial version of the GTAP-E model was developed by Burniaux and Truong (2002) and an updated version was due to McDougall and Golub (2009).

The GTAP-E model has since been used extensively in the evaluation of energy, environment and climate studies. Earlier applications of the GTAP-E model have mainly on the evaluations of international climate change policies (e.g. Nijkamp et al. (2005), Dagoumas et al. (2006)). More recently, the GTAP-E modeling framework has been adopted for the analysis of renewable energies such as biofuels (e.g. Banse et al. (2008)). The evaluation of biofuel policies have also led to further extensions of the GTAP-E model on characterizing the substitutability of biofuels and petroleum products (see Birur et al. (2008), and Taheripour et al. (2010)). In relation to the need to model biofuel development and the associated land use effects, another extension based on the GTAP-E has been developed by Hertel et al. (2008) to include a land use module based on the agricultural-ecological zones, which results in the creation of a further extended model named GTAP-AEZ. On the linkages of trade and environment, the issues of embodied emission in trade flows and carbon leakages have also been investigated with the GTAP-E model and its extensions (see e.g. studies included in the survey by Wiedmann et al. (2007)). Further development to disaggregate the electricity sectors have also led to the creation of the GTAP-Power database and the accompanying variant of the GTAP-E model. In summary, as pointed out by Wei et al. (2015), CGE models such as the GTAP-E have become one of the most prominent models used in climate policy analysis, a conclusion that is further echoed in a more focused survey by van Tongeren et al. (2017) on the contributions of the GTAP modeling framework to global economic issues including quantitative environmental assessment.

It should be noted that while the standard GTAP-E model is publicly available, its various extensions are not. Therefore, the GTAP-E model is chosen as the base model for our further model development to suit the modeling needs in WP7. In subsections 5.3 and 5.4, we lay out a few model considerations to be implemented in Tasks 7.2 and 7.4 in WP7.

5.3 Modeling considerations on replicating the baseline

In relation to the baseline data set developed for the current deliverable (i.e. D7.1), the main modeling work in WP7 is the "implementation" of the 2050 baseline in the GTAP/GTAP-E modeling. In essence, this means that the model itself should be able to reproduce the essential elements of the baseline for each country/region towards 2050. In a comparative static framework such as the GTAP-E model, it requires model simulations from its current base year to 2050. The current base year of the GTAP model is 2011, represented by the GTAP version 9 database (Aguiar et al., 2016). The GTAP version 9 database contains about 140 countries or aggregated regions including all of the EU Member States as individual members and 57 sectors.

Similar to the models used for generating the GDP projections in the various data sources reviewed in this deliverable, aggregated economic activities as manifested by national GDPs for individual countries are also driven by the fundamental drivers such as population/labor forces, capital stock, land used for mainly agricultural and livestock production, and natural resources upon which minerals and fossil fuels are produced. In the medium and longer run, technological progresses are also permitted in the GTAP framework to allow for higher productivities from the use of a given set of inputs and other economic resources. Therefore, the baseline data set constructed here can be used as the building blocks to update the 2011 GTAP database to the 2050 baseline. The usual set-up of such an exercise is to declare a set of model variables to be exogenous and to have them updated to the desirable levels according to information outside of the model – in this case to the levels contained in the baseline data set, while allowing other model variables to adjust endogenously. The realization of the "update" is obtained by numerically solving the CGE model (i.e. the GTAP model) with the exogenous inputs from the baseline data set. For instance, population (representing the demand side forces in the model) and labor forces (representing one of the key production factors for all sectors in the model) are typical exogenous variables in the model. The differences between the levels of such variables shown in the 2011 GTAP database and those in the 2050 baseline can then be used as the exogenous shocks in the model simulation.

However, several complications render the implementation/replication of the 2050 baseline in the GTAP modeling framework a non-trivial task:

- First, the data in the 2050 baseline are sourced from outside of the GTAP modeling framework and database; so they are not necessarily completely consistent with the GTAP framework. In fact, as the individual pieces of the baseline are procured from different sources, internal consistencies may not be fully satisfied.
- Second, the 2050 baseline as reflected in the baseline data set contains both GDP projections and the underlying GDP drivers – in economic terms, the GDP can be considered as endogenous outcomes whereas the drivers may be considered exogenous instruments. Therefore, they cannot be both exogenously determined in the GTAP model.

- A third complication relates to the accounting of GHG emissions generated by production and consumption. In the GTAP-E model, it is assumed that emission intensities, defined as the ratio between economic indicators (GDP, production, and consumption) and emissions related to those indicators, are fixed. Such a postulation does not allow for changes in 'carbon efficiency' between 2011 and 2050 unless specific assumptions regarding technologies in the energy system are taken.
- Lastly, in relation to the energy production system and the emission levels embodied in the projected baseline, it is also necessary to target certain broadly defined emission targets, whether to reflect the current climate policy at the global/country level or to track some broad targets in relation to future temperature. Such knowledge is not currently available in the baseline data set and will have to be gathered in the implementation stage of the baseline.

To address the first two concerns, it is necessary to take a position regarding which part of the baseline data set is to be targeted exogenously (i.e. allow the model to exactly reproduce these data) and which part of the baseline data set has to be suppressed and instead be determined by the model simulations as outcomes. This partition of exogenous and endogenous modeling variables is the design of the model "closure" rule and care has to be taken to ensure that the general equilibrium economic mechanisms to be respected and the model can be solved. Owing to the importance of the GDP, projected GDPs in 2050 for individual countries will be imposed directly. GDP drivers such as population and labor forces will also be exogenously determined according to the baseline data set. On the other hand, capital stocks and sectoral level productivity progresses, as well as the availability of fossil fuels, will likely be determined endogenously or decided through other model instruments. Detailed modeling design for developing the model closure rule and the implementation of the baseline will be developed and conducted as part of the efforts contained in Task 7.4.

To account for the third and fourth concerns listed above, further information on climate policy or emission targets will likely be calibrated into the baseline as well and further assumptions about technologies/productivities in the energy system and future energy prices will have to be considered, too. It is expected that further interactions with other WPs in the project would provide insights and information on these considerations, particularly when conducting research Task 7.2 on building the interface between WP7 and other sectoral WPs.

5.4 Modeling plan on representing alternative EU de-carbonization pathways

The third and fourth modeling concerns listed in the previous section demonstrate the need to align further model development in WP7 with other sectoral WPs. However, this need is not confined to the modeling effort of replicating the baseline, as it also concerns the formulation of the alternative scenarios corresponding to the EU de-carbonization pathways. In this regard, the key modeling tasks to be conducted in Task 7.2 and Task 7.4 of WP7 are:

- to develop a correspondence between the key variables in the various sectoral WPs (e.g. lifestyle choices, transportation, buildings, etc.) and the variables in the CGE model;

- and to interpret and quantify the individual "lever settings" as contained in WP1-6 as numerical perturbations of relevant model variables in the CGE model, relative to the levels of these variables projected and implemented in the baseline scenario.

It is expected that substantial modeling work would have to be carried out to realize the above modeling tasks, as the relevant modeling variables in the GTAP model corresponding to the sectoral variables in WP1-6 are likely to a mixture of exogenous and endogenous variables. While the exogenous variables can be directly perturbed in model simulations, endogenous variables cannot be changed to predetermined levels without resorting to additional "instrument" variables and possible new modeling structure. For instance, in the lifestyle WP, several key demand-side variables are included to characterize future lifestyle choices, such as population and urbanization, transport demand, building use, food consumption and waster, etc. various lever settings will be developed in for 2050 vis-à-vis levels of these variables in the base period. Taken together, these settings imply different emission levels from lifestyle choices. While lever settings for some of these variables such as demography changes can be formulated in the alternative scenarios as direct shocks, settings for other variables such as food demand may have to be implemented indirectly, as food demand is contingent on prices and income levels in the CGE model, as well as economic policy. Further complications can also arise from the "equilibrium" requirements in the CGE model where quantities of food demand must be matched with quantities of total food supply (i.e. for each country, domestic supply and net imports must be equalized). Therefore, lever settings in food demand in the lifestyle WP must be broadly consistent with relevant lever settings in other WPs concerning land and agriculture. If not, feasible solutions from the CGE model may not be possible.

One approach to deal with these difficulties is to develop a comprehensive plan to evaluate individual variables in the sectoral WPs and develop modeling strategy for each of these variables. As the levers in the various sectoral WPs are only dependent upon each other via limited interactions, there is also a need to evaluate the mutual consistencies of lever settings of different sectoral variables, a task that is likely to be very difficult, if not impossible. Therefore, more realistically, these difficulties should be dealt with by imposing simplifying treatment in the GTAP modeling framework through directly targeting the emission outcomes of lever settings in each of the sectoral WPs, to be realized by using some "generic" model instruments such as carbon taxes and technical changes related to the various economic activities that generate carbon emissions.

These modeling choices and the implied model development will be conducted in Task 7.2 and Task 7.4. More specifically, Task 7.2 develops the interface between the sectoral WPs and the CGE modeling in WP7, whereas Task 7.4 develops the CGE model, formulates the alternative scenarios (e.g. de-carbonization pathways), and carries out the model simulations.

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7 Appendix A – Shared Socioeconomic Pathways: narratives and assumptions

The Shared Socioeconomic Pathways (SSPs) describe alternative developments in the progress of society from 2005 to 2100. A narrative underlines each of the five SSPs detailed in Riahi et al. (2017). The narratives are defined as four combinations of challenges to adaptation and mitigation (O'Neill et al., 2017). A fifth narrative is considered as the middle-of-the-road pathway, since it does not shift significantly from historical patterns. Below a summary of each SSP is provided.

SSP1: Sustainability – Taking the Green Road. In this pathway, the world shifts progressively towards a sustainable and inclusive development path. Management of the global commons slowly improves, led by the cooperation of local, national and international institutions. Investments in education and in the health system boost the demographic transition, leading to a relatively low population in 2100. There is a shift towards a broader emphasis on human welfare, reducing inequality across and within countries, even at the expense of a slower economic growth over the longer term, if compared to its full potential. Investments in environmental technologies and shifts in tax structures improve the resource efficiency and the attractiveness of renewable energies. Consumers purchase less carbon-intensive products. This framework results in relatively low challenges to mitigation and adaptation, thanks to the international cooperation and the increased systemic flexibility.

SSP2: Middle of the Road. Social, economic, and technological developments generally follow current trends. Income growth proceeds unevenly within and between countries. Political stability in most economies, imperfect markets, and technological development with no major breakthrough, corroborated by the work of national and international institutions, lead to slow progress towards sustainable human development. Environmental degradation continues, in spite of some improvements in the resource intensity of the economy. Fossil fuel dependency decreases slowly, following historical patterns. Population growth is moderate, and education investments are not enough to accelerate the demographic transition in low-income countries, not slowing down their population growth. With significant heterogeneities across countries, this scenario poses moderate challenges to mitigation and adaptation.

SSP3: Regional Rivalry – A Rocky Road. Countries increasingly focus on domestic issues, because of resurgent nationalism and conflicts, not restrained by weak international institutions. Cooperation among countries does not flourish, leading to the creation of trade barriers and to fairly uneven and slow economic growth, focused on the achievement of energy and food security goals at the regional level. Educational and technological investments decline, leading to a slow economic development, with increasing poverty. Population growth is low in high-income countries and high in low-income areas. Adaptation and mitigation are important concerns, since there is limited progress in human development and low international coordination in facing environmental issues.

SSP4: Inequality – A Road Divided. A gap grows between internationally-connected societies, well-educated and contributing to the technological and economic development, and fragmented lower-income, poorly-educated societies, based on labor-intensive economic systems. Democracies deteriorate, with vulnerable groups having little representation in both global and national organizations. Economic growth is moderate in the developed countries and stable in developing ones, while poor countries lag behind. Uncertainty in energy markets results in underinvestment in renewable energy sources in most regions, even though energy companies diversify their investments in low-carbon technologies. Environmental policies focus in tackling local issues, mostly in rich countries. Such a framework leads to relatively low challenges to mitigation, thanks to the well-integrated part of the civilization, and major challenges in adaptation, due to the societal polarization.

SSP5: Fossil-fueled Development – Taking the Highway. The world evolves rapidly, thanks to competitive markets, technological innovation, and investments in human capital. Increasing integration improves the collaboration across and within countries. However, the push for socioeconomic fast development is the result of resource- and energy-intensive lifestyles and the exploitation of fossil fuels. Local environmental issues are addressed successfully by new technological solutions; nevertheless, no important steps towards global environmental challenges are taken. Fertility in developing and developed economies starts converging, led by education investments on the one hand and optimistic economic forecasts. Income disparities decrease as labor markets are opened up progressively. This pathway poses low adaptation challenges, thanks to its highly engineered infrastructure, and high mitigation challenges, because of its reliance on fossil fuels.

8 Appendix B – GDP conversion from PPP to MER

Projections by Crespo Cuaresma (2017) for IIASA-SSP2 express GDP in 2005 USD PPP. These PPP data are converted into MER data, as the latter are more appropriate for measuring international trade between economies. The conversion of Purchasing Power Parity (PPP) into Market Exchange Rate (MER) values relies on the suggestions contained in the supplementary note for the SSP data sets[8].

Two different methods are currently used. The first one freezes the historical PPP to MER ratio and converts PPP into MER based on it; this generates MER projections that grow at a rate identical to PPP projections. The second one prefers to use dynamic PPP to MER ratios, taking into account GDP convergence across countries in the long run.

We follow the first method, using the Penn World Table 7.0 (Heston et al., 2011) to convert PPP GDP into MER GDP. We fix the market exchange rate and the PPP 'exchange rate' at 2005 levels and use the following formula for the transformation:

$$GDP(\$, MER, 2005) = \frac{GDP(\$, PPP, 2005) * ppp\left(\frac{€}{\$}, 2005\right)}{XRAT(\frac{€}{\$}, 2005)}$$

Where

- *GDP($,MER,2005)* = GDP expressed in constant 2005 USD, MER
- *GDP($,PPP,2005)* = GDP expressed in constant 2005 USD, PPP
- *ppp(€/$,2005)* = national currency[9] units per USD in 2005. Note: Over GDP, 1 US dollar (US$) = 1 international dollar (I$).
- *XRAT(€/$,2005)* = national currency units per USD. Average market exchange rate in 2005.

[8] Available at https://tntcat.iiasa.ac.at/SspDb/static/download/ssp_suplementary%20text.pdf
[9] For simplicity, we use "€" in the formula to represent all world national currencies; this could have been DKK, SEK or whatever other national currency.

9 Appendix C – Modeling approaches behind the five GDP projections: a review

This appendix provides a review of the modelling frameworks and assumptions of the five projections.

The underlying models behind the five projections share a basic assumption that macroeconomic growth is driven by a combination of: increases in primary inputs (labor and capital, and for OECD-SSP2, EM-SSP2, and EM-Ref also natural resources/energy); labor-augmenting (human capital) efficiency improvements; and total factor productivity (TFP) improvements. The economic mechanism through which economic growth is determined by these factors differs, however, across the models. This is summarized in Table 2 and discussed in details in the following sections.

Table 2 - Drivers of macroeconomic development in models underlying the five projections

Projection	EM-SSP2, EM-REF	OECD-SSP2	IIASA-SSP2	EU-REF
Model	MaGE	OECD ENV-Growth	IIASA for SSP	EU DGFIN for EU-REF
Growth drivers	L , C , Ef , TFP , E	L , C , Ef , TFP , E, NR	L , C , Ef , TFP	L , C , Ef , TFP
TFP	Catching up to the best-performing economies			
Human capital accumulation	Demographics (educational attainment, age, sex)			
Capital accumulation	Solow model (depreciation rate: 6%)	Solow model (depreciation rate: 5%)	Solow model (depreciation rate: 6%)	Growth rate of the capital stock is set equal to the sum of growth rate of labor and labor augmenting technical progress
Energy efficiency improvements	Distance from the technological frontier in energy use and on the level of development of a country’s economy		Not applicable	

Note: L: Labor; C: capital; Ef: Efficiency improvements; TFP: Total Factor Productivity; E: Energy; NR: Natural Resource rents. Source: authors’ compilation.

9.1 EconMap 2.4: SSP2 and Reference Scenario

In the EM-Ref and EM-SSP2, GDP in 2050 is projected using a macroeconomic model named MaGE and a CGE model named MIRAGE (Fouré et al., 2012, Fouré et al., 2013, Fouré and Fontagné, 2016, Fontagné and Fouré, 2017).

As the results in the two projections are largely similar, for brevity of presentation we only review the modelling framework and the assumptions for the EM-SSP2, which are applied to EM-Ref as well. The slightly different results between two scenarios are mainly driven by different population projections: IIASA population projections are used in EM-SSP2 whereas the UN projections used for EM-Ref.

The MaGE model projects GDP using a three-factor (capital, labor, energy) and two-productivity (capital-labor, energy-specific) production function. The model is built in three steps:

- Data collection: production factor and productivity data collected for the 1980-2012 period (World Bank, United Nations, International Labor Organization data);
- Estimation: behavioral relations for factor accumulation and productivity growth are estimated;
- Projection: estimated factor accumulations and productivity growth are used to project GDP.

In the MaGE model, supply is modeled as a constant elasticity of substitution (CES) production function of energy and a Cobb-Douglas bundle of capital and labor. Energy-specific productivity is obtained from the profit-maximization program of the representative firm; TFP of the capital-labor bundle is computed as a Solow residual.[10]

For each age group, education is estimated, and then the labor force is deduced. Male labor force participation does not depend on education, following the logistic relation determined by the International Labor Organization (ILO) projections. Female participation is assumed to change with education level, which is expected to follow a catch-up process to the leaders.[11]

Investment is defined as a function of savings, which in turn are a function of economic growth and the age structure of the population. Capital accumulates according to a perpetual inventory[12] process with a constant depreciation rate. The relationship between investment and savings is estimated separately for OECD and non-OECD members. The closure rule 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 educational level. Energy efficiency catch-up depends on the distance from the technological frontier in energy use and on the level of development of a country’s economy.[13]

The conceptual implementation of the SSP narratives in the EconMap framework is illustrated in Table 3 below, as discussed in details in Fouré and Fontagné (2016).

[10] The Solow residual describes empirical productivity growth in an economy from year to year. Rising productivity is defined as rising output with constant capital and labor input. It is a "residual" because it is the part of growth that cannot be explained through capital accumulation or increased labor.

[11] The catching-up has different speeds (depending on region and age-group). 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, Russia). The best-practice targets are assumed to continue to grow at their historical pace.

[12] The Perpetual Inventory Method estimates the value of the physical capital stock of a specific sector or the whole economy. Additions to the stock, expressed in constant dollars, are calculated year by year. Assumptions are necessary about the depreciation rates, price inflation, average service lives of physical capital assets, and so on.

[13] 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.

Table 3 - 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' compilation, from Fontagné and Fouré (2017)

In Table 4, we can further observe how detailed assumptions of the SSP narratives could be quantified and included in MaGE and MIRAGE scenarios to generate the different model outcomes. It is worth noting that not all of the elements of the SSP narratives can be quantified in the EconMap modeling framework. For example, urbanization, within-country inequality, international cooperation, environmental policy, energy technology change towards renewable energy and land use are not accounted for.

Table 4 - MaGE and MIRAGE assumptions for SSPs

	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	x	x	-30% TFP	OECD: +50% TFP Non-OECD: -30%	+50% TFP Non-OECD: convergence of FE and coefficients	MaGE
TFP frontier	+50% frontier growth	x	-50% frontier growth	+50% frontier growth	+50% frontier growth	MaGE
Energy productivity	x	x	x	x	+50% energy productivity	MaGE
Fossil resource price	x	x	x	High energy price	Low energy price	MaGE MIRAGE
Agricultural productivity	x	x	x	OECD: 0,2% additional growth	0,2% additional growth	MIRAGE
Services productivity	0,45% additional growth	x	x	x	0,4% less growth	MIRAGE
Tariffs		x	Return to post-Tokyo round tariffs	x	-50% tariff	MIRAGE
Transaction costs	x	x	+20%	x	-20%	MIRAGE

Source: Fontagné and Fouré (2017)

Additionally, it can be seen from table 4 how the SSP narratives are transformed into assumptions in the two models, for purposes of generating GDP projections. In particular, the SSP2 is considered to be a middle-of-the-road scenario which is similar to the *status-quo*, whereas other SSP scenarios are built on assumptions that departs from the SSP2 scenario.

Detailed assumptions underpinning the scenarios are sourced from various sources or based on the authors' own conjectures. For example, *population and education* data are gathered from IIASA (Kc et al., 2010). Total population is converted into active population via MaGE. *Institutions* differentials across countries are estimated econometrically and scenarios of institutional convergence can be derived from these estimates. In the case of the *TFP*, the frontier is represented by the TFP levels of Ireland and Denmark and it is assumed to grow at around 1.5% annually (corresponding to the average pace during 1995-2008). Other countries converge towards this frontier conditionally on their education level. *Energy productivity* is expected to increase by 50% by 2100. Fossil constraints are materialized in the MaGE model by oil price. Its trajectory, in fact, binds the amount of energy use for a given level of energy-specific productivity. The central scenario for oil prices is taken from medium projections in the World Energy Outlook, by the International Energy Agency (IEA, 2012), as showed in figure 2.

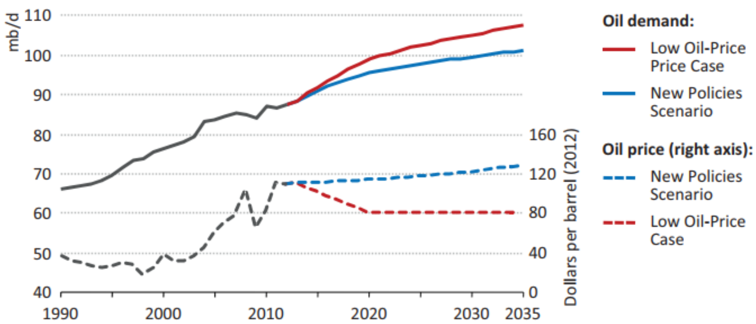

Figure 2 - Oil price and oil demand trajectories in the Low Oil-Price Case and in the New Policies Scenario (i.e. central scenario)

Source: IEA (2012)

9.2 OECD-SSP2

The OECD-SSP2 projections are obtained from the work of Dellink et al. (2017) and based on the OECD ENV-growth modeling framework proposed by Chateau and Dellink (2012). The Env-growth model is an augmented Solow growth model that includes accumulation of human capital, and includes energy as a productive input (as in MaGE) and as a generator of resource revenues for oil and gas producing countries.

The model is based on long-term projections of five key drivers of economic growth, as showed in Figure 3: employment, driven by demographic trends, labor participation rates and unemployment scenarios; human capital, as driven by education; physical capital; energy demand, driven by energy efficiency; patterns of extraction and processing of natural resources (oil and gas); and TFP as an indicator of exogenous technical progress. It assumes that each country gradually catches up to its own frontier level of per capita income, consistent with its endowments and institutions. Gradual convergence of regions towards their technology frontier is projected at a speed of 1%-5% per year, depending on the driver.

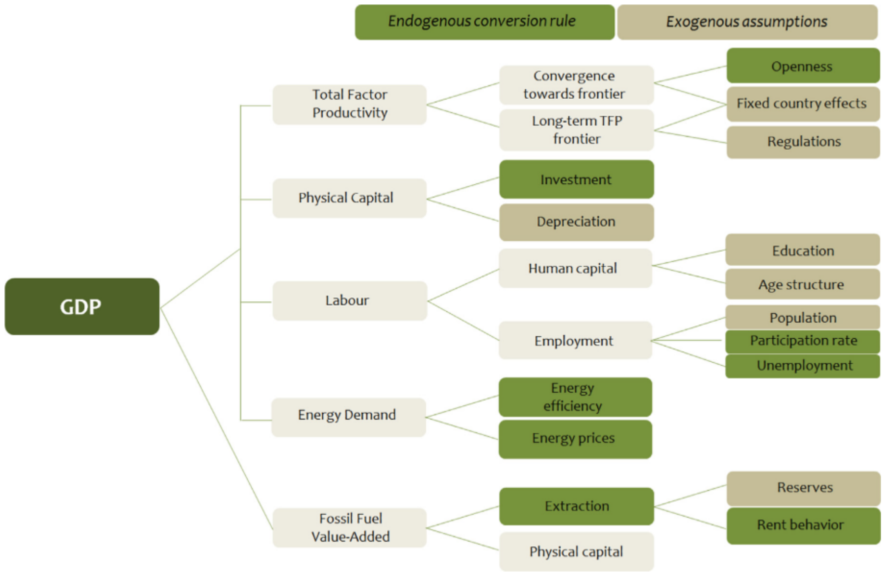

Figure 3 – Overview of the OECD ENV-growth model

Source: Chateau and Dellink (2012)

Physical capital follows the standard capital accumulation formulation in Solow, with a fixed depreciation rate. The investment rate per unit of GDP is assumed to converge towards a balanced growth path, thus depending on the structural parameters of the production function. Total employment results from the combination of trends in population and labor participation rates, specific to age group and gender. The convergence process applies to participation rates based on various relevant variables such as ratio of dependency and education levels. Unemployment rates are assumed to converge very slowly to a common structural level. Human capital improvements are linked to age- and gender-specific education levels. These are converted into a human capital index using mean years of schooling as an intermediate variable. Increases in the human capital index are reflected in the model through improvements in labor productivity. Natural resources are considered through two channels: value added created by extracting and processing natural resources[14], and natural resources used as input in production for energy consumers (gains in energy efficiency at the user side therefore act as a driver of economic growth[15]).

The ENV-growth model features input-specific factor productivity for labor and energy demand. Human capital developments through education boosts labor productivity, whereas autonomous energy efficiency improves the productivity of energy inputs. TFP growth is a combination of two factors: regions gradually grow towards their TFP frontier (driven by convergence), and the TFP frontier itself shifts over time. All countries will grow through both channels. No group of "frontier countries" achieves full convergence in the long-term. More technologically advanced countries, however, are closer to their frontier and, ceteris paribus, grow less rapidly than countries that are less technologically advanced. The country-specific long-term TFP frontier itself depends on a fixed country effect, a global

[14] Natural resources' contribution to countries' GDP is derived from region-specific resource depletion modules, focusing on oil and gas sectors in particular, inspired by fossil-fuel supply modules used by the IEA.

[15] The projection of gains in energy efficiency is based on the law of motion for autonomous energy efficiency improvements as estimated for MaGE, which describes a U-shaped relation between economic development and energy productivity.

frontier growth rate, and a country-specific product indicator that measures the extent of regulatory barriers to market access and competition (i.e. countries that have less such barriers have more incentives to innovate and can access frontier technologies more easily.

In order to carry out the projection exercise for the SSP2, an historical database was built for the period 1960-2010. The OECD Economic Outlook database (June 2012 release) is used for OECD countries, while the data for non-OECD countries draws upon the World Bank World Development Indicators database (December 2012 release). Data and historical trends are then extrapolated using short- and medium-run projections, when available, from either the OECD or the IMF. For countries covered by the OECD economic outlook database, projections to 2013 are first applied, and then extended using IMF projections to 2017. For others countries IMF projections are used for the whole 2010–2017 period. If IMF projections are not available, the long-term model is directly used. The model projections effectively start in 2018.

The labor force database (participation rates and employment rates by cohort and gender) is extracted from the International Labor Organization (2011 release) active population prospects (up to 2020) and OECD Labor Force Statistics and Projections (2011 release). The long-term structural unemployment level is assumed to be 2% for all countries. Population and education data were taken from the contribution by Kc and Lutz (2017) to the SSP framework.

Historical energy demands are extracted from IEA Extended Energy Balance (2011 release). Projections of energy efficiency improvements up to 2017 rely on IEA World Energy Outlook (IEA, 2012), and then follow a rule of convergence towards leader economies in terms of energy efficiency. Natural resource rents in the base year 2010 are calculated by comparing world prices and domestic extraction costs, using oil and gas production costs from IEA World Energy Outlook (IEA, 2012). Oil and gas reserves for 2010 are taken from BP (2011). The estimates for conventional resources are extracted from BGR (2012). Unconventional oil resources estimates (including Canada tar sands, Venezuela extra heavy oil and shale oil) are extracted from WEC (2007) while shale gas resources estimates are based on U.S. Energy Information Administration (2011). Physical capital stock was built-up from historical investment data series, assuming a 5% annual depreciation rate. TFP frontier annual growth rate is equal to 1.1%.

9.3 IIASA-SSP2

The IIASA-SSP2 projection is due to Crespo Cuaresma (2017). This projection is based on a simple aggregate production function with heterogeneous labor inputs, differentiated by educational attainment (no education, primary, secondary and tertiary) and age group (younger and older workers, cut-off age of 35 years):

$$Y_{it} = A_{it} K_{it}^{\alpha} \prod_{j=0}^{3} \prod_{k=1}^{2} L_{i,jkt}^{\beta_{jk}}$$

Where:

- the coefficients α and β can be understood as the output (GDP) elasticities of capital and labor, respectively;
- Y_{it} is total output in country *i* at time t;

- A_{it} refers to total factor productivity (TFP);
- K_{it} denotes the capital stock;
- $L_{i,jkt}$ corresponds to the labor input in age group k ($k=1,2$ denoting the younger and older age group) with educational attainment j (from $j=0$ no education to $j=3$ some tertiary education level attained).

The TFP growth rate depends on: distance to the technology frontier, with (conditional) income convergence dynamics; stock of human capital in the country (proxy for the technology innovation potential of the economy); interaction between income per capita and the ratio of population with different educational attainment levels to total population, accounting for technology adoption as a driver of income convergence.

Countries that are further away from the technological frontier profit more than proportionally from investment in human capital, since an educated labor force accelerates the process of catching up with technology advancements. Income per capita is used instead of total factor productivity to define the gap between the current technology level of an economy and that of the technology frontier[16]. For this reason, education plays the role of directly increasing labor productivity through acquired skills (since human capital is a direct input of the production function) and of enabling the creation and adoption of new technologies.

Capital stock is constructed using the perpetual inventory method making use of investment data from the Penn World Table 7.0 (Heston et al., 2011). Depreciation rate of 6% is assumed for the computation of capital stock series. Concerning physical capital accumulation, they assume that the rate of growth of the capital stock will converge across countries over the coming decades.

Projections of population by age, sex and educational attainment for the different SSPs are obtained from Kc and Lutz (2017), from the IIASA SSP database. The estimates are obtained using a panel dataset comprising information that spans the period 1970-2010 at 5-year intervals.

The specification proposed as a basis for the GDP projections contains country fixed effects, which are aimed at capturing unobserved country-specific, time-invariant characteristics of the economies modelled, as well as slow-changing institutional variables. The convergence of fixed effects (''institutional convergence'') is calibrated by defining the year at which all estimated fixed effects are assumed to converge to the value of the fixed effect estimated for the US. The growth rate of capital is assumed to converge to 4% per annum in the year 2100.

In generating the SSP2 projection, the technological frontier (not human capital driven) is expected to increase by 0.3% per year, whereas institutional convergence will be concluded in 2250.

[16] Such a choice can be justified using different arguments (Crespo Cuaresma 2017):

a. Income per capita and total factor productivity are highly (positively) correlated;
b. The inclusion of income per capita instead of total factor productivity relates the model to the large majority of empirical studies aimed at explaining income growth differences across countries, where conditional convergence is accounted for by including initial income per capita as an additional explanatory variable;
c. The qualitative implications of models including total factor productivity instead of income per capita do not differ substantially.

9.4 EU Reference Scenario 2016 (EU Ageing Report 2015)

The EU-Ref GDP projections are available only for EU Member States. Data and methods underlying the EU-Ref can be found in European Commission et al. (2016), European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2014), and in European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2015).

Similarly to the IIASA-SSP2 projection, the EU-Ref projection is based on a production function framework in the Cobb-Douglas form, as follows.

$$Y = TFP * L^{\beta} * K^{1-\beta} =$$
$$\left(TFP^{\frac{1}{\beta}} * L \right)^{\beta} * K^{1-\beta} =$$
$$(E * L)^{\beta} * K^{1-\beta}$$

Where:

- *Y* is the total output (GDP);
- *L* is the supply of labor (total hours worked);
- *K* is the stock of capital;
- *E* is the labor-augmenting technical progress (i.e. Harrod-neutral technical progress[17]).
- *E**L* is interpreted as total labor in efficiency units. TFP and the labor-augmenting technical progress are linked with a simple relationship: $TFP = (E)^{\beta}$
- β is the labor share, i.e. the share of labor costs in total value-added. It is set at 0.65[18].

In the above formulation, the projection of TFP growth and the growth in capital per hour worked, so called ‘capital deepening’, are the key drivers of projected labor productivity over the medium run.

The EU AR2015 projection follows the Solow approach: in the long run, the economy should reach a balanced growth path, where the ratio of capital stock to labor remains constant over time; in the steady state, the contribution of capital

[17] Technical progress which increases the efficiency of labor, so that the labor force in efficiency units increases faster than the number of workers available. Technical progress of this form is thus labor-saving. It is contrasted with Hicks-neutral technical progress, where the efficiency of all factors increases in the same proportion.

[18] Although there is some debate about the recent and observed decline of the labor share, most economists assume that it will remain broadly constant in a long run perspective, while allowing for a variation in the short-term. This rule is uniformly applied to all Member States in order to allow for consistent cross-country comparisons of the results. The assumption is also well-founded in economic theory. If the real wage is equal to the marginal productivity of labor, it follows that under the standard features of the production function, real wage growth is equal to labor productivity growth and real unit labor costs remain constant.

deepening to output growth is a simple function of TFP[19], which becomes the single driver of labor productivity[20].

This production function approach is applied to historical (starting in the mid-1960s) and forecast data. Data have been taken from ECFIN's AMECO databank, for the years 2014-15 the Commission Services (spring 2014) forecasts are used, and for the years 2016-23 a medium-term potential growth estimation is used.

With respect to the TFP, the approach of growth rate convergence is adopted, at the same time taking account of the catching up potential of countries with relatively low GDP per capita. The speed of convergence to the long-run TFP growth rate is determined by the relative income position in the different EU member states, with the 'followers' catching up to the 'leaders'. The lower the GDP per capita is, the higher the real catching up potential is. In the long-term, growth in labor productivity broadly coincides with TFP growth divided by the labor share (set at 0.65) in the long run, thus becoming 1.5%. The assumptions are as follows:

The 'leader' is the group of countries that have a GDP per capita above the EU-28 average. For these countries, TFP growth is assumed to converge from the estimated value in 2023 to a 1% growth rate by 2035;

The 'follower' group of countries are those with GDP per capita below the EU-28 average. For this group of countries, a differentiation is made depending on the distance to the EU-28 average, as reported in Table 5 below.

Table 5 - Assumptions on convergence & criteria for selection in 2015 Ageing Report

GDP per capita (in % of EU28)	Countries	Years (from/to)	Values	Years (from/to)	Values	Years (from/to)	Values
"Leaders" (per capita GDP higher than the EU average)							
Above 100%	LU, NL, AT, IE, SE, DE, BE, UK, DK, FI, FR	2023 (t+10) to 2035	From value in 2023 (t+10) to 1%	2036 to 2045	1%	2046 to 2060	1%
"Followers" (per capita GDP lower than the EU average)							
Below 100%	IT, ES, SI, CZ, MT, CY, SK, PT, EL, EE, LT, PL, HU, HR, LV, BG, RO	2023 (t+10) to 2035	From value in 2023 (t) to $\frac{1.5\% * \left(1 - \frac{GDP_{i,t}}{GDP_{eu,t}}\right) + 1\% * \left(\frac{GDP_{i,t}}{GDP_{eu,t}} - 0.5\right)}{0.5}$	2036 to 2045	$\frac{1.5\% * \left(1 - \frac{GDP_{i,t}}{GDP_{eu,t}}\right) + 1\% * \left(\frac{GDP_{i,t}}{GDP_{eu,t}} - 0.5\right)}{0.5}$	2046 to 2060	From $\frac{1.5\% * \left(1 - \frac{GDP_{i,t}}{GDP_{eu,t}}\right) + 1\% * \left(\frac{GDP_{i,t}}{GDP_{eu,t}} - 0.5\right)}{0.5}$ to 1%

Source: European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2014)

In the long run, the capital stocks adjust to the steady state path according to the so-called capital rule: the growth rate of capital stock is set equal to the sum of growth rate of labor and labor augmenting technical progress.

19 With the assumption of a long-run TFP growth rate equivalent to 1% per annum in the baseline scenario, this implies a long-run contribution of capital deepening to labor productivity growth equal to 0.5% and hence a labor productivity growth rate of 1.5%.
20 This in turn implies that, in the long run, the growth rate of the capital stock is set equal to the sum of the growth rate of labor and labor-augmenting technological progress, the so-called "capital rule".

10 Appendix D – Comparisons of GDP projections across data sources

To reveal the characteristics of the five GDP projections, this appendix provides a summary on the comparisons of GDP projections across the different data sources. First, projected levels and growth rates for the EU28 as a whole are compared across the five data sources. Second, projected GDP shares across major EU Member States are compared. Lastly, the projected size of the EU28 in the world economy as revealed by the EU28's GDP shares are compared across the projections.

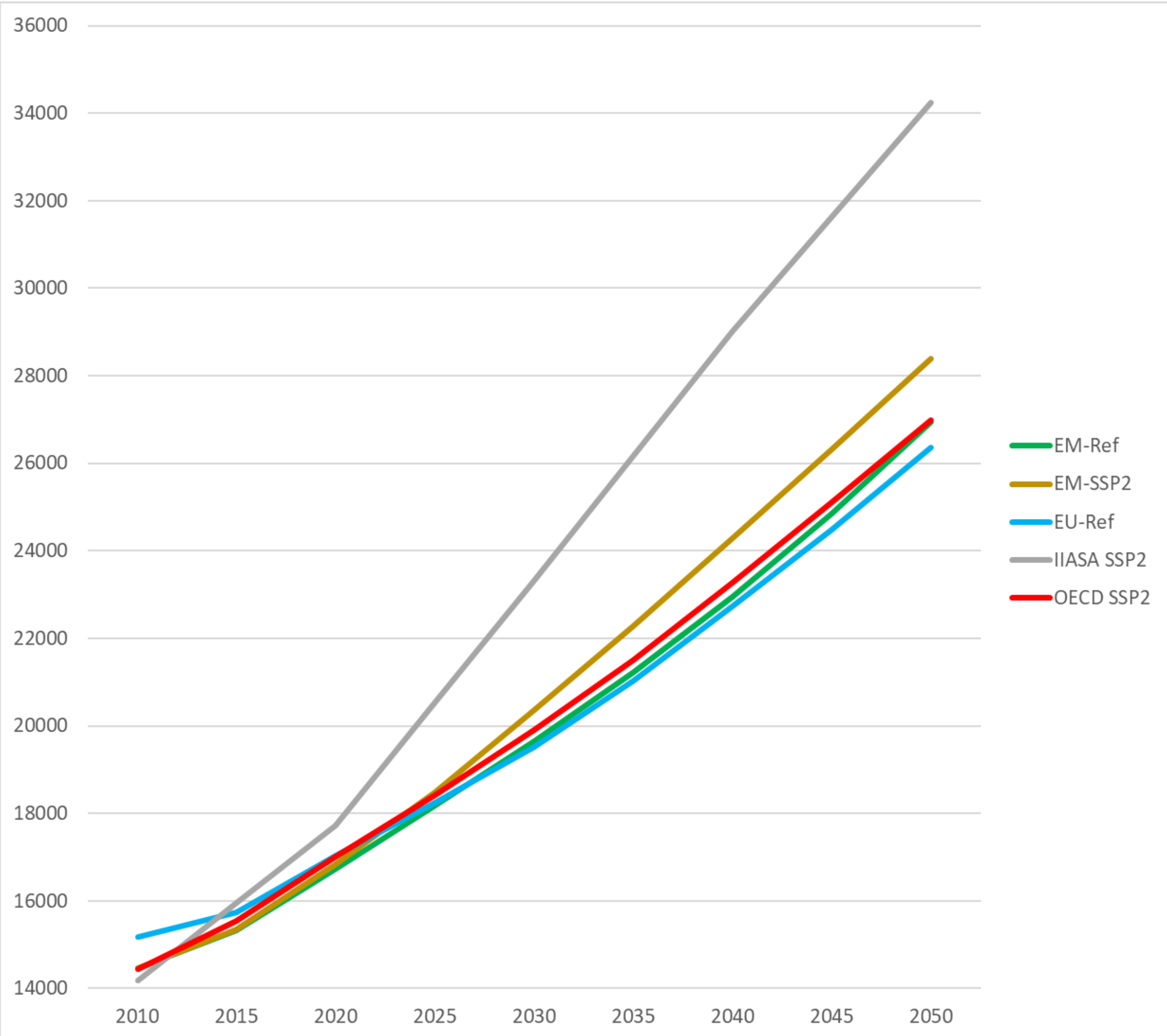

Figure 4 – GDP growth for EU28, in 2005 USD MER billions

Regarding the EU28 as a whole (i.e. the summation of its Member States; it should be noted that the projections do not have the same GDP figures in our base year of 2010, either measured in MER or in PPP), it can be seen from Figure 4 that EU-Ref has the most conservative GDP projections towards 2050 (USD 26,365 billion). However, the EU-Ref projections are closely tracked by both the OECD-SSP2 and the EM-Ref projections, in terms of GDP growth trajectories during the projection period and the projected GDP levels in 2050 (USD 26,992 billion and 26,937 billion, respectively). This gives some confidence in applying any of the three projections in EUCalc WP7. The IIASA-SSP2 projection, on the other hand, is the highest, exceeding the aforementioned projections by a wider margin by 2050, as it reaches the levels of USD 34,247 billion for EU28 in 2050. The last projection, EM-SSP2, also exceeds the first three projections by a growing margin towards 2050.

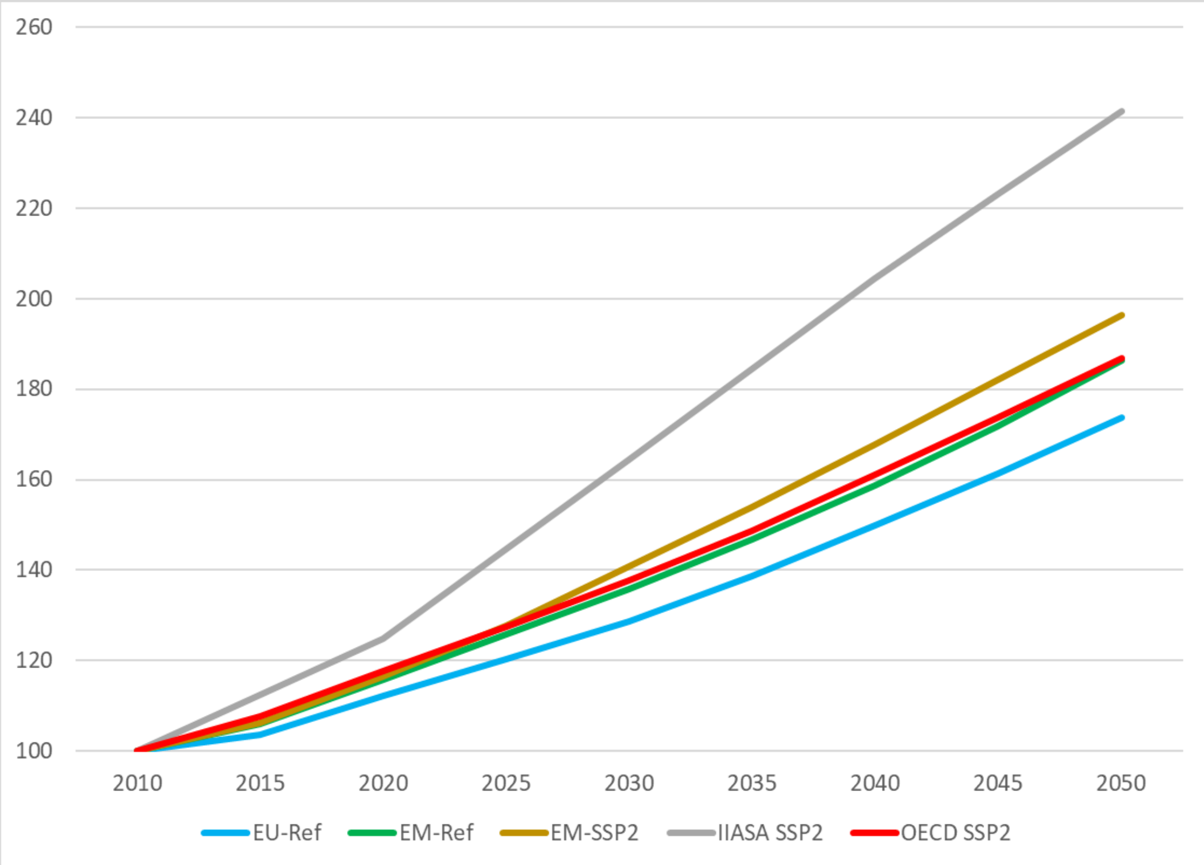

Figure 5 – GDP growth for EU28

It should be noted that GDP values in the base year differ in the five projections. Therefore, to see the differences in projected GDP growth rates, it is necessary to scale the individual projections related to their respective starting values. Figure 4 therefore presents the GDP growth rates reflected in the five projections. It can be seen that the EU-Ref projects the GDP of EU28 to grow by 74%, during the 2010-2050 period. The OECD-SSP2 and EM-Ref are closest to the EU-Ref projections, with the EU28's GDP projected to grow by 86%. While the 86% accumulated GDP growth by the latter two projections seem to be significantly larger than the EU-Ref projection, it is important to note that the differences in absolute levels of GDP in 2050 among the three projections are much smaller, due to the lower GDP values in 2010 in the OECD-SSP2 and EM-Ref. On the other hand, EM-SSP2 and IIASA-SSP2 projects EU28's GDP to grow much larger, by 96% and 141%, respectively. Again, the growth trajectories seen from these relative changes are quite similar within the EU-Ref, EM-Ref and OECD SSP2 projections, whereas the EM-SSP2 and the IIASA-SSP2 projections follow quite different patterns.

Looking at the projected GDP growth patterns at the EU Member State level, there are significant disparities in projected GDP levels. For purposes of brevity in presentation, Figure 6 lists projected GDP shares of selected EU member states including the five largest economies of today (i.e. Germany, UK, France, Italy, and Spain), an aggregated E_EST region consisting of the new member states (i.e. Bulgaria, Czech Republic, Estonia, Croatia, Hungary, Lithuania, Latvia, Poland, Slovakia, and Slovenia), and an aggregated region consisting of all other member states under the abbreviation of R_EU.

At individual member states level, **IIASA-SSP2** remains an outlier, as in 23 out of 29 cases (i.e. the 28 individual member states and the whole EU28) its projections are either the highest (EU28, Belgium, Spain, France, UK, Greece, Italy, Luxembourg, Malta, Netherlands, Portugal, Sweden) or the lowest (Austria, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Hungary, Lithuania, Latvia, Poland, Slovakia, Slovenia) among the five projections. In most of the cases (i.e. excluding Malta, Lithuania, Latvia, Poland, Slovenia and Bulgaria), the difference between IIASA-SSP2 and the other projections are quite large. According to the SSP supplementary text provided by IIASA[21], this is possibly due to the fact that "the IIASA model tends to place a larger weight on growth induced by human capital increases (in turn driven by educational improvements), which ceteris paribus implies relatively high growth rates in the coming decades and lower growth rates in the longer run." For instance, as shown in Figure 6, this projection put the GDP shares of the UK, France, Italy, and Spain in 2050 at much higher levels as compared to other projections including the EU-Ref scenario. Additionally, the relative size of the Germany economy would become significantly smaller relative to other projections.

A second notable observation is that the **EconMap 2.4 projections** for the new member states (both **EM-Ref** and **EM-SSP2**) are significantly higher than the other projections, including the EU-Ref projections. This is mainly driven by the modeling assumptions behind the EconMap projections regarding TFP growth, along with the very high education growth assumed for the new member states. The two EconMap projections are very similar to each other, with the main difference at the EU28 level in 2050 being largely due to the differences on projections on Germany (as can be seen from Figure 6).

The third key observation is that although the EU-Ref, EM-Ref and OECD-SSP2 projections generate similar projections for the EU28 as a whole (as discussed earlier) and for quite a few individual member states (particularly between EU-Ref and OECD-SSP2), some differences are still observed at member state levels. For instance, as seen from Figure 6, the EM-Ref projections on Germany are notably lower than the other two projections; the EU-Ref projection is lower for the UK but significantly higher for Italy. A closer look into the data set would further reveal that the **EU-Ref** projects the lowest GDP, compared to other models, for Finland, France, UK, Ireland, Netherlands, and Portugal; that the **OECD-SSP2** generates the lowest GDP projection for Cyprus, Spain, Croatia, and Greece, although such projections do not differ much from other 'low' projections; between **EU-Ref** and **OECD-SSP2**, differences exist regarding Bulgaria, Czech Republic, Estonia, Germany, Finland, UK, Greece, Ireland, Netherlands, Portugal and Slovenia (OECD SSP2 > EU-Ref) and Luxemburg (EU-Ref > OECD SSP2).

[21] Available at: https://tntcat.iiasa.ac.at/SspDb/static/download/ssp_suplementary%20text.pdf

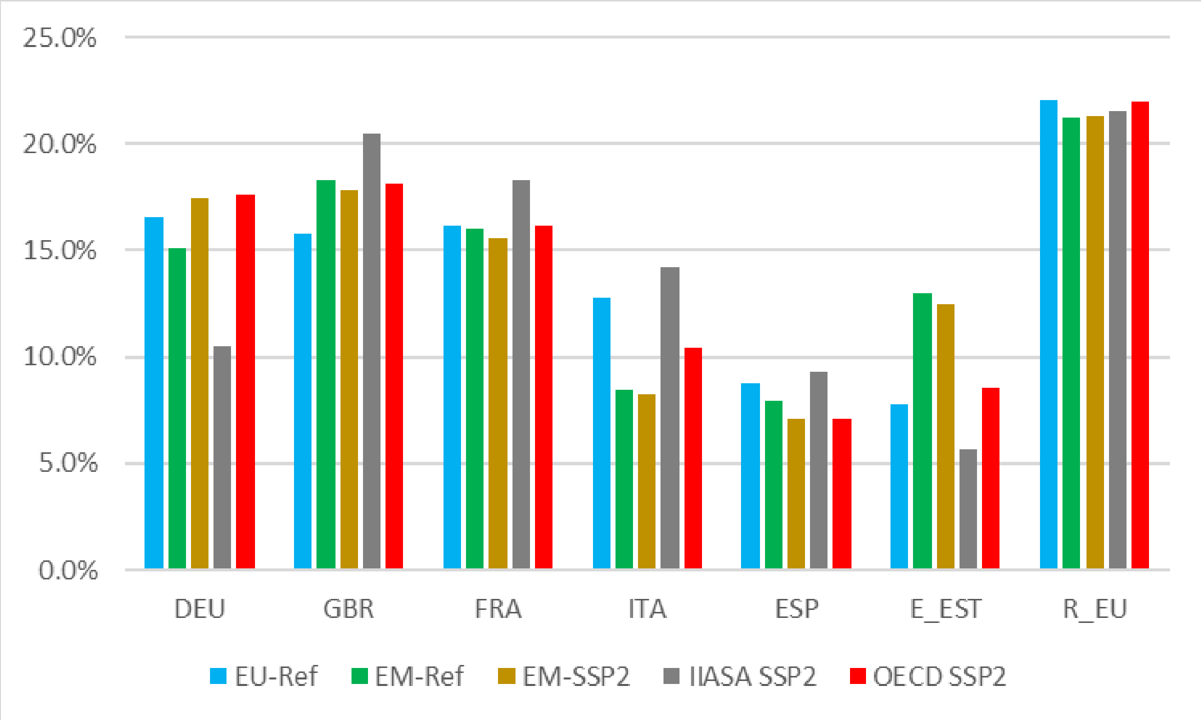

Figure 6 - GDP shares in 2050, comparison among models.

To further reveal the projected relative economic sizes of key EU member states across the five data sources, Table 6 presents the differences of GDP shares of individual Member States (or groups of member states) in the projections relative to the year 2010. It can be readily seen that the GDP share for Germany is projected to decrease by all five projections, by as much as 9.5 percentage points, although the decrease seems to be the most modest in both EU-Ref and OECD-SSP2. The UK and France are both projected to increase their GDP share in all five projections. For Italy and Spain, both increased and decreased GDP shares can be seen across the five projections. For the new member states (as in the "E_EST" group), mostly larger GDP shares are projected, except in the IIASA-SSP2 projection where a small reduction is expected. Lastly, for the rest of the EU, GDP shares are expected to remain quite stable according to all five projections.

Table 6 - Change in total EU28 GDP share between 2010 and 2050

Country	EU-Ref	EM-Ref	EM-SSP2	IIASA-SSP2	OECD-SSP2
DEU	-2.7%	-5.4%	-3.0%	-9.5%	-2.8%
GBR	1.9%	1.9%	1.5%	4.4%	1.9%
FRA	0.7%	0.8%	0.3%	2.9%	0.9%
ITA	-1.3%	-3.7%	-3.9%	2.1%	-1.8%
ESP	-0.2%	-0.2%	-1.0%	1.0%	-1.1%
E_EST	1.0%	6.0%	5.5%	-1.2%	1.7%
R_EU	0.7%	0.6%	0.6%	0.4%	1.3%

As a final summary, we present the GDP shares of the EU28 in the whole world across the different projections. For the four projections with global coverages, the actual GDP shares of the EU28 and several major economies (USA, China, India, and Japan) as well as an aggregated ROW (Rest of World) region are presented in Figure 7. As the EU-Ref projection only contains projected GDP for the EU Member States, it is therefore not possible to directly calculate the EU28's GDP shares in the global economy according to the EU-Ref projection alone. To reveal how the EU-Ref projections on the EU would fit into other projections, we choose to impose the GDP of EU28 onto the other projections and to recalculate the GDP shares of all countries/regions. These shares are presented in Figure 7 as the black dots for each country/region across the four projections. The positions of these "black dots" relative to the original shares represented by the colored bars in the figure therefore visualize how the EU-Ref projection would fit into the other global projections.

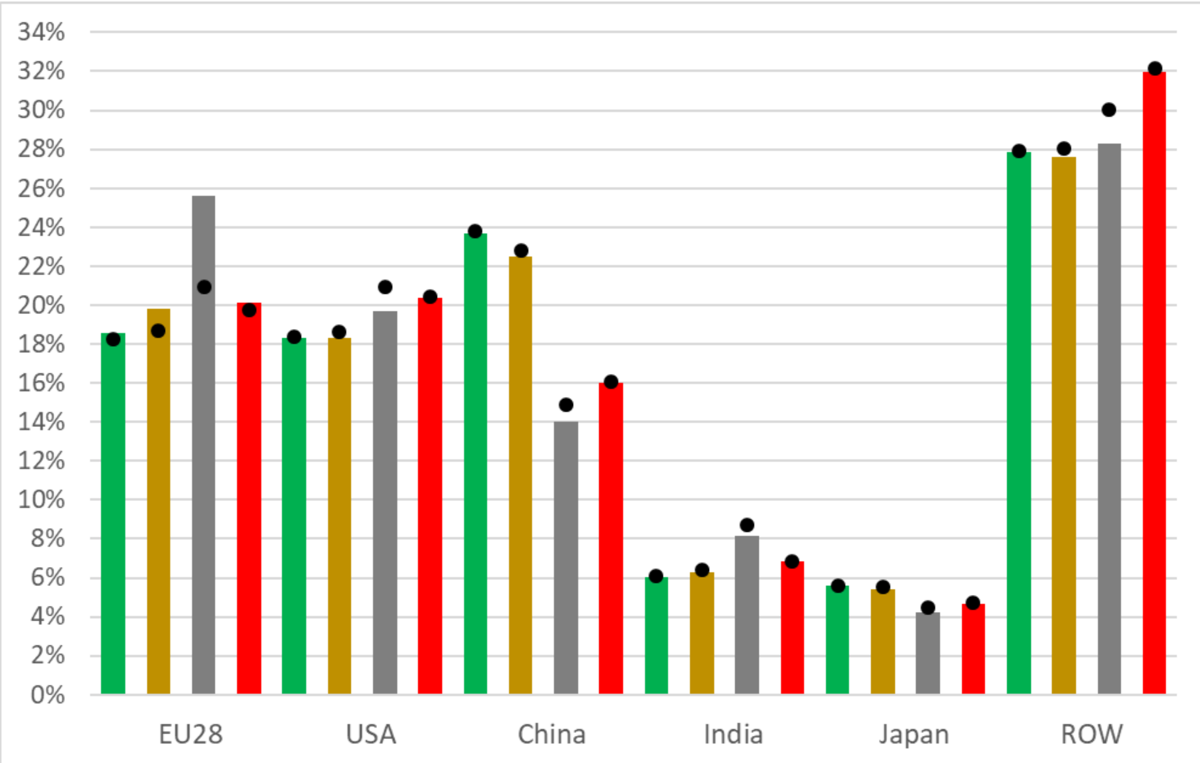

Figure 7 - Projected regional GDP shares in 2050 by data sources

Note: green: EM-Ref; brown: EM-SSP2; grey: IIASA-SSP2; red: OECD-SSP2. The black dots on top of each bar show the GDP share of each region, if EU-Ref projection for EU28 were used instead of each model's own projection

For the EU28, shares of projected GDP for the EU28 appears to be the lowest in EM-Ref (19%) and the highest in IIASA-SSP2 (26%), whereas the other two projections (EM-SSP2 and OECD-SSP2) generate similar shares at around 20%. When the total GDP for the EU28 projected by the EU-Ref is imposed on the OECD-SSP2 projections, nearly identical GDP shares for the EU28 are resulted, suggesting that the EU-Ref GDP projections for the EU28 as a whole is in fact consistent with the OECD-SSP2 projection for the whole world. This lends support to the choices of the OECD-SSP2 projections for the non-EU countries and the EU-Ref projections for the EU member states. Note that if instead the IIASA-SSP2 or the EM-SSP2 projections for the rest of the world is used in conjunctions with the EU-Ref projections, inconsistencies regarding the relative size of the EU28 GDP would arise. Therefore, it appears that the combination of EU-Ref and OECD-SSP2 turns out to be the best choices of the GDP projections for the purposes of the WP7.

For the other major economies presented in Figure 7 (USA, China, India, Japan, and the ROW), it can also be observed that the EU-Ref projections on the EU28 are consistent with the OECD-SSP2 regarding the impacts on other countries' GDP shares of imposing the former onto the latter. Again, the IIASA-SSP2 would generate the largest deviations between the GDP shares from each projection and the GDP shares implied by imposing EU-Ref projections on the EU, whereas the OECD-SSP2 projection would generate the most consistent match.