Downscaling 2024 SSP scenario's to NUTS2 regions of Europe using global SCGE model EU-EMS

European policy makers are increasingly interested in higher spatial representations of future long-term scenarios that are relevant for both climate mitigation and climate adaptation. The most important global long-term scenarios are the five SSP scenarios of IPCC that come with the new update in 2024. At the present moment however, EU-wide quantitative sub-national level SSP scenarios are missing in the literature. In this paper, we make use of the global Spatial Computable General Equilibrium model EU-EMS that includes explicit representation of all 242 NUTS2 regions of Europe in order to regionalize the new SSP scenarios. We start from the quantitative macro-level data (population and GDP developments) and storylines of the five SSP scenario's and translate them to regional quantitative data as well as sectoral story lines. The later helps us to implement specific changes in sectoral productivity developments, governmental consumption and household preferences that fits the global story lines of the SSP scenarios.

The SSPs are a set of alternative global development scenarios, characterized by distinct narratives and quantified by various socioeconomic and environmental indicators. The new SSPs offer five pathways that the world could take. Compared to previous scenarios, these offer a broader view of a "business as usual" world without future climate policy, with global warming in 2100 ranging from a low of 3.1C to a high of 5.1C above pre-industrial levels. The SSPs are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures.

They include: a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5).

The European Economic Modelling System (EU-EMS) is a spatial computable general equilibrium (SCGE) modelling system developed by PBL Netherlands Environmental Assessment Agency (web.jrc.ec.europa.eu/modinv/discovery/midas/explore/models/model-eu-ems/).

It relies on the notion of the representative agent, representing the typical (average) behaviour of households or firms in a region/sector. By assumption, the behaviour of each firm (household) is driven by profit (utility) maximisation or, which numerically is the same, by cost minimisation. Firms produce goods and services which are consumed by households, governments and other firms and traded in the (perfectly or imperfectly competitive) markets. The model represents a real economy, thus market clearing is ensured by relative prices. Starting from this core, the EU-EMS has a flexible modular structure which can be adapted to specific policy and research questions.

The model covers 62 countries specifically and one rest of the world region representing countries not explicitly included in the model. The model further disaggregates between 242 NUTS 2 regions selected from the 28 EU countries using a database for 2019. All the regions in the EU-28 are linked with each other and with the largest non-EU countries and with the rest of the world by trade of goods and services (subject to trade and transport costs), knowledge spillovers, capital (investment) and labour movement (migration) flows.

Combining qualitative storylines with a CGE (Computable General Equilibrium) model is a useful and widely used approach to generate different scenarios for the future. This approach is used by the European Commission and various international organizations such the OECD, FAO and ILO for their scenario studies .

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By combining qualitative storylines of the SSP scenarios with the use of EU-EMS, we are able to generate a range of future scenarios that capture both narrative descriptions and quantitative economic outcomes in a consistent manner. The use of a CGE model for the analysis ensures that the main economic balances and restrictions are in place while taking into account various trade-offs. This means that EU-EMS is able to take into account the developments in the rest of the world (other European and non-European countries) that influence the economic developments in the European regions.

In Computable General Equilibrium (CGE) models such as EU-EMS several factors can drive structural change and future regional and sectoral development. Here are some of the main drivers of structural change in CGE models:

- Technological Progress: Changes in technology play a crucial role in driving structural change. Technological advancements can lead to the development of new industries, changes in production processes, and improvements in productivity. These changes can result in shifts in the relative importance of different sectors in the economy.
- Changes in consumption patterns: Shifts in consumption patterns can drive structural change by influencing the demand for different goods and services. As income increases, consumers can spend their income on different consumption goods, which can lead to the growth or decline of specific sectors, affecting the overall structure of the economy.
- Trade Liberalization: Opening up to international trade and reducing trade barriers can have significant effects on the structure of an economy. Trade liberalization allows countries to specialize in industries where they have a comparative advantage, leading to changes in the allocation of resources and the relative importance of sectors.
- Demographic Changes: Changes in population dynamics, such as population growth, aging populations, or shifts in the composition of the workforce, can drive structural change. These changes can affect labor supply, consumption patterns, and the demand for different types of goods and services.

It's important to note that these drivers of structural change are often interrelated and can reinforce or counteract each other. CGE models aim to capture these complex interactions and provide insights into how different factors shape the structure and dynamics of an economy.

In order to improve the quality of our quantitative scenario results we validate the outcomes of scenarios generated by EU-EMS model by comparing them with historical time-series data for a number of EU countries. This helps us to assess the model's accuracy and reliability. We use historical data and in particular annual growth rates of different economic variables as a benchmark to evaluate how whether the outcomes of the model are realistic.

Calibrating CGE models on the external macro-economic growth path is crucial for accurately representing future economic scenarios. In order to capture the differences in the five SSP scenarios, we use the outcomes of CEPII MaGE 3.1 model as our main macro-economic input for different EU and non-EU countries. The calibration process involves targeting GDP and macro-productivity changes provided externally by adjusting the efficiency of labor and total factor productivity (TFP). In our model, productivity growth is allocated to sectors and regions on the basis of our own sector and country specific analysis based on the EU-KLEMS database (see separate note on TFP). As such, the

EU-EMS model incorporates sectoral and regional differences in productivity that are required to provide projections of changes in sectoral economic structure.

In order to create regional NUTS2 level population scenario's that are consistent with 2024 SSP update we combine SSP demographic scenarios for EU countries with the regional demographic trends from Eurostat. This allows us to regionalize the country-level demographic projections of SSP scenarios. Regional population scenario's at NUTS2 level are used as one of the main inputs in EU-EMS model and capture the development of labour force in each SSP scenario. We continue by combining macro-economic productivity developments from SSP scenarios with econometric analysis using latest EU-KLEMS data in order to be able to project the developments of sector-specific productivity in different SSP scenarios. Finally we combine demography, productivity and assumptions about future developments of globalization and trade under the structure of EU-EMS model. We further analyze the impacts of different SSP scenarios on regional economic growth and disparities in Europe on the basis of maps as well as using the calculated Theil index.