A unified modelling framework for projecting sectoral GHG emissions

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I. Introduction

Effectively tackling climate change requires sound knowledge about greenhouse gas (GHG) emissions and their sources. Currently however, there is a lack of comprehensive, sectorally disaggregated projections for GHG emissions. Recent contributions [1, 2] provide projections for carbon emissions but ignore sector specificities.

We propose a novel modelling framework for projecting sectoral GHG emissions in a unified manner. It projects emission intensities on the sector level assuming no abrupt shifts in technological advancement and policy-making in the future, resulting into "*business-as-usual*" projections. The use of a flexible hierarchical Bayesian prior setup further allows for straightforward uncertainty quantification surrounding these projections.

II. Methods

Conceptually, we characterise sectoral GHG as product of their main drivers using a simple, sector-specific Kaya identity:

$$E_s = \frac{E_s}{G} \times \frac{G}{L} \times L,$$

where E_s denotes emissions in sector s, G/L denotes output (GDP) per person, E_s/G being the corresponding emission intensity, and L total population.

Augmenting this specification with information on human capital, age structure and urbanization, we assume these quantities (collected in vector $\boldsymbol{y}_{i,s,t}$) to follow a vector autoregressive (VAR) process of order p:

$$\boldsymbol{y}_{i,s,t} = \sum_{j=1}^{p} \boldsymbol{A}_{i,s,j} \boldsymbol{y}_{i,s,t-j} + \boldsymbol{B}_{i,s} \boldsymbol{w}_{i,s,t} + \boldsymbol{\varepsilon}_{i,s,t}.$$

The autoregressive coefficients collected in matrices $\boldsymbol{A}_{i,s,j}$ are assumed to arise from a common global distribution:

$$\boldsymbol{\alpha}_{i,s} | \bar{\alpha}_s, \boldsymbol{\Omega}_{\alpha_{i,s}} \sim \mathcal{N}(\bar{\alpha}_s, \boldsymbol{\Omega}_{\alpha_{i,s}}),$$

with $\bar{\alpha}_s$ denoting the global common mean and $\boldsymbol{\Omega}_{\alpha_{i,s}}$ effectively controlling country-specific deviations from it.

Conditioning on established trajectories of the other variables given by the Shared Socioeconomic Pathways (SSPs) [3, 4], we obtain projections for sectoral emission intensities and resulting emissions on a sector level. Incorporation about short-term forecasts for economic output and population additionally allows us gauging the effect of specific events such as COVID-19 or the Russian war in Ukraine on GHG emissions.

III. Data & Coverage

We utilize a novel synthetic dataset on sectoral GHG emission [5] as well as obtaining historical data and SSP-consistent projections for GDP [6], population and demographics [7], and urbanization [8]. The historical observation period is from 1980 to 2018; projections from 2019 to 2050.

The resulting projections cover a global sample of 173 countries and five main sectors (energy systems, industry, transportation, agriculture, buildings) up to the year 2050. In 2018, 99% of global emissions of relevant Kyoto GHGs are included.

IV. Sectoral GHG emissions

The multiplicity of results lends itself for detailed analyses of country-sector combinations (see figure below). While in most cases sectoral emission intensities are continuing a downward path, this does not necessarily translate into falling sectoral emissions. Rather modest sectoral technological advancements are outweighed by strong output and population growth in many emerging markets, though at least some (e.g. Chinese energy-related emissions) are projected to peak also under business-as-usual. Advanced economies are expected to reduce GHG emissions over the coming decades in the majority of sectors; transport emissions, however, are often still increasing or reducing only very slowly.

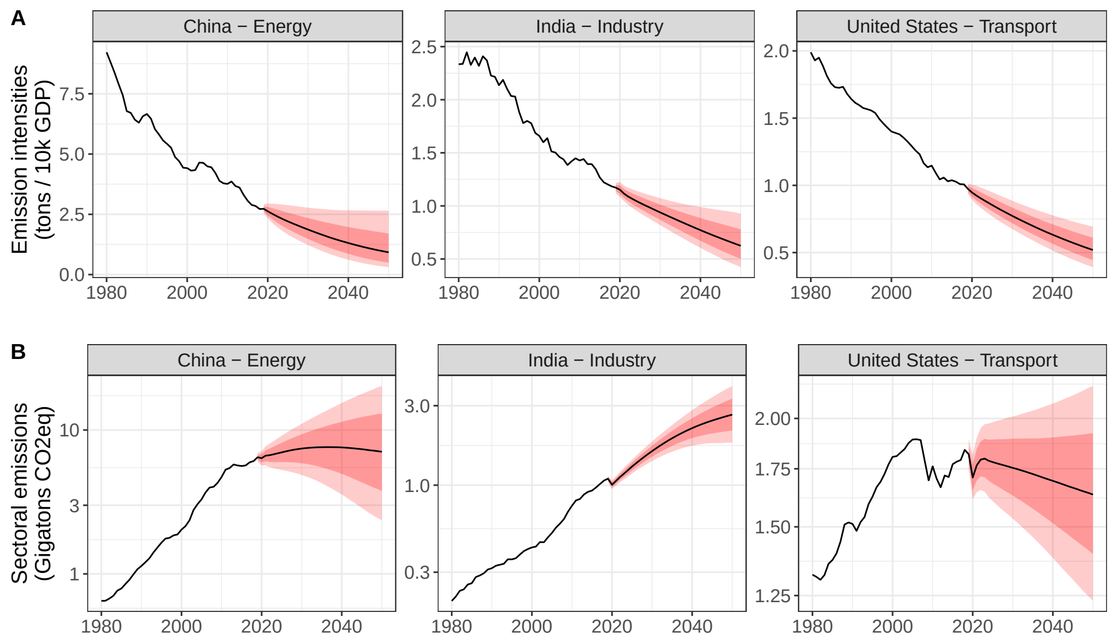

Figure: (A) Emission intensities and (B) GHG emissions (log scale) resolved by sector for selected countries.

V. Assessing IAMs

The probabilistic nature of our model setup naturally accounts for parameter uncertainty, an important aspect often neglected in Integrated Assessment Models (IAMs). Thus, our projections can be used as a reference for IAM results with similar underlying narratives. For a baseline scenario, our forecasts align with projections from Integrated Assessment Models on a global level, but show some deviations on the regional level (see figure below). Future work could use different SSP narratives into account to validate and inform IAM runs.

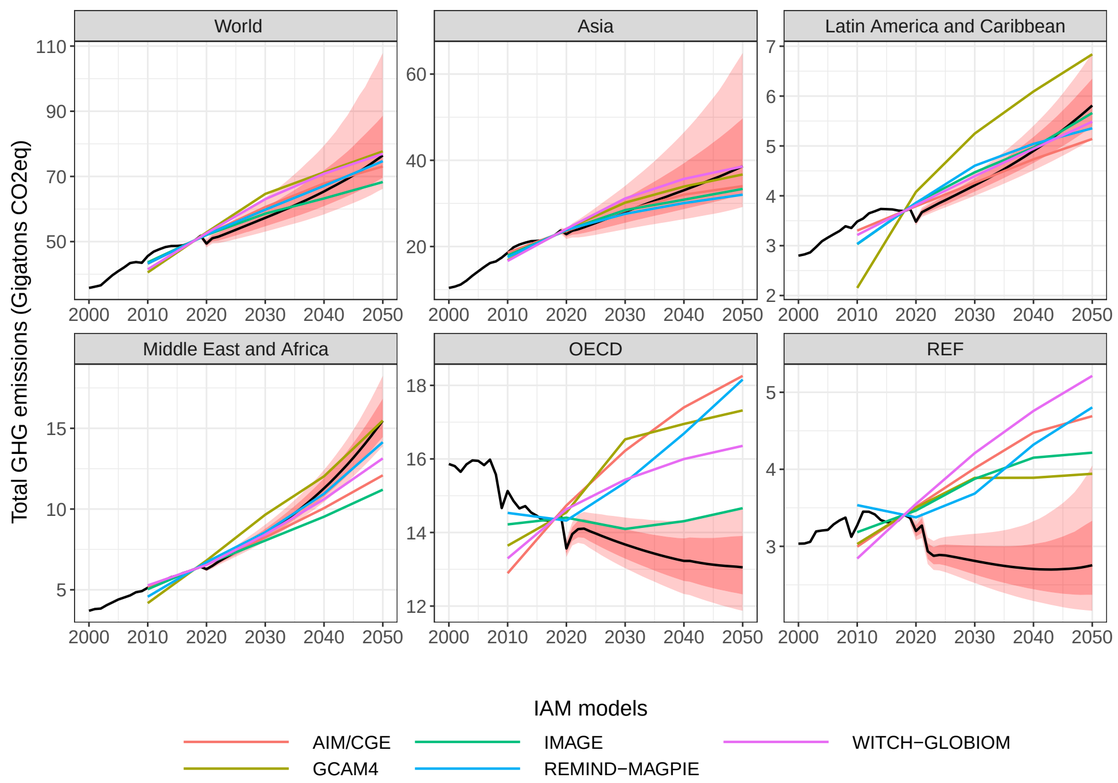

Figure: Comparison of forecasts with projections of different Integrated Assessment Models.

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