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rfasst: An R tool to estimate air pollution impacts on health and agriculture

Jon Sampedro[1], **Zarrar Khan**[1], **Chris R. Vernon**[1], **Steven J. Smith**[1], **Stephanie Waldhoff**[1], **and Rita Van Dingenen**[2]

1 Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD, USA **2** European Commission, Joint Research Centre (JRC), Ispra, Italy

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Summary

Existing scientific literature shows that health and agricultural impacts attributable to air pollution are significant and should be considered in the integrated analysis of human and Earth-system interactions. The implementation of policies that affect the power sector, the composition of the vehicle fleet or the investments and deployment of different energy sources will in turn result in different levels of air pollution. Even though the various methodologies for estimating the impacts of air pollution, such as exposure-response functions, are extensively applied by the scientific community, they are normally not included in integrated assessment modeling outputs.

`rfasst` is an R package designed to estimate future human-health and agricultural damages attributable to air pollution using scenario outputs from the Global Change Analysis Model (GCAM), namely emission pathways and agricultural production and prices. The package combines these with the calculations from the TM5-FASST air quality model to estimate the associated adverse health and agricultural impacts. The structure of the `rfasst` package is summarized in Figure 1.

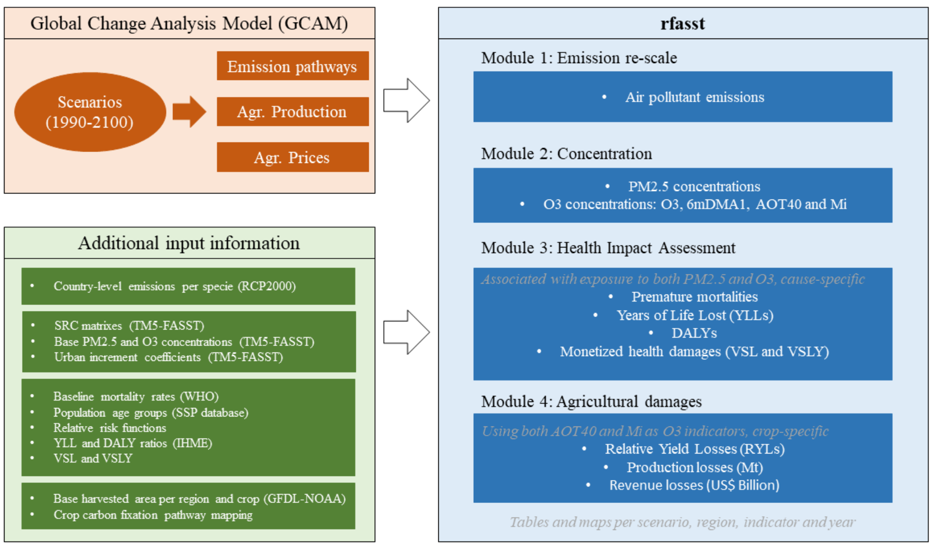

Figure 1: Structure of the `rfasst` package

`rfasst` can be accessed via the web at the public domain https://github.com/JGCRI/rfasst. We provide an R vignette step-by-step tutorial for users to get started with `rfasst` which is accessible here: Tutorial.

Statement of need

According to the World Health Organization's (WHO) Ambient air quality database, more than 90% of people breathe unhealthy air at a global level. Therefore, premature mortality associated with air pollution is one of the biggest threats for human health, accounting for more than 8 million deaths globally per year (Burnett et al., 2018), but heavily concentrated in developing Asia. Likewise, air pollution leads to a significant decrease of crop yields. Ozone, which is formed by the reaction of air pollutants with solar radiation, is considered the most hazardous pollutant for crop yields (Emberson et al., 2018). Current high ozone concentration levels entail substantial economic damages and would increase pressures on several measures associated with food security (Van Dingenen et al., 2009). The integration of these effects into integrated assessment models, such as GCAM, can provide valuable insights for scenario analysis.

The GCAM model (Calvin et al., 2019), developed at the Joint Global Change Research Institute (JGCRI), is an integrated assessment multi-sector model designed to explore human and Earth-system dynamics. For each scenario representing an alternate future, GCAM reports a full suite of emissions of greenhouse gases and air pollutants, by region and time period through 2100. GCAM outputs also include regional agricultural production projections for a range of crops, detailed in online documentation. However, GCAM does not include the atmospheric and meteorological information required to translate the greenhouse gas and air pollutant emissions into particulate matter ($PM_{2.5}$) and ozone (O_3) concentration levels. This transformation from emissions to concentration is addressed by full chemistry models or by simplified air quality emulators, such as TM5-FASST (Van Dingenen et al., 2018). These concentration levels are the inputs for the exposure-response functions that are normally used to calculate adverse human-health and agricultural effects associated with exposure to $PM_{2.5}$ and O_3.

Therefore, the combined use of these models, which is the essence of `rfasst`, is a powerful methodology to estimate a consistent range of health and agricultural damages and the co-benefits associated with different strategies or climate policies. Prior to the development of this package, we have used GCAM and TM5-FASST to analyze these co-benefits in different studies. We showed that health co-benefits attributable to air pollution are larger than mitigation costs for different technological scenarios consistent with the 2°C target of the Paris Agreement (Sampedro, Smith, et al., 2020). Previously, we demonstrated that these health co-benefits outweigh mitigation costs in multiple decarbonization scenarios based on different emissions abatement efforts across regions (Markandya et al., 2018). In addition, we have applied this methodology to show how high O_3 levels generate substantial crop losses and, subsequently, negative economic impacts in the agricultural sector (Sampedro, Waldhoff, et al., 2020). Taking all these results into consideration, we understand that a tool that systematically addresses air pollution driven human-health and agricultural damages within an integrated assessment modeling framework, is a significant contribution to this community, and of interest for a range of stakeholders, particularly for the designers of alternative transition strategies.

Functionality

The package includes several functions that have been classified in four different modules. Note that all the functions are listed in the Tutorial, which includes individual documentation pages for each of these modules.

- Module 1: Static downscaling of GCAM emissions to country-level and re-aggregation into a new regional distribution (consistent with TM5-FASST), and some additional pollutant-related adjustments (e.g., organic carbon to organic matter).
- Module 2: Calculation of regional fine particulate matter ($PM_{2.5}$) and ozone (O_3) concentration levels using different indicators.
- Module 3: Estimation of health impacts attributable to $PM_{2.5}$ and O_3 exposure. The package reports both physical damages, such as premature mortality, years of life lost (YLLs), and disability adjusted life years (DALYs), and the associated monetized damages based on the Value of Statistical Life (VSL).
- Module 4: Estimation of agricultural damages attributable to O_3 exposure, including relative yield losses (RYLs) and losses in agricultural production and revenue ($Revenue = Prod \cdot Price$).

The package also includes additional input information, namely constant values and mapping files, that need to be read in for running the different functions and can be modifiable by the user. The Tutorial explains which values can be changed within each module. These include the time horizon (from 2010 to 2100 in 10-year periods, +2005), the crop categories to be included in the analysis (see Kyle et al. (2011) for a detailed mapping of GCAM crop categories), the coefficients or counterfactual values for the exposure-response functions (both for health and agricultural damages), the base Value of Statistical Life (VSL) or Value of Statistical Life Year (VSLY), and additional ancillary information.

The outputs generated by the package consist of both comma-separated values (CSV) files and maps (as Portable Network Graphic files) that can be controlled by the user. If the parameter `saveOutput` is set to `TRUE`, the function writes a CSV file with the selected outcome in the corresponding sub-directory. In addition, if `map` is set to `TRUE`, the function generates a suite of maps and animations for the corresponding output. We note that these maps are generated using the rmap package, documented in the following website. As an example, the following Figure 2 shows the average $PM_{2.5}$ concentration levels per region, for a GCAM-v5.3 reference scenario.

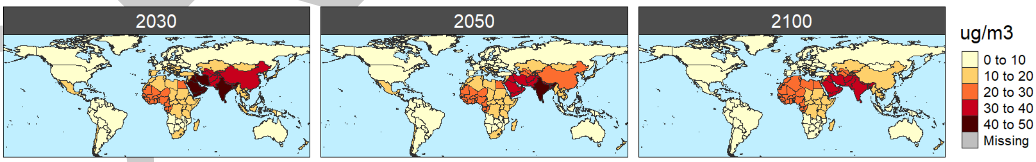

Figure 2: $PM_{2.5}$ concentration per country and period in a reference scenario (ug/m3)

Finally, the package is continually being developed to address science objectives and some additional features are scheduled for future releases. For example, an alternative dynamic GDP-based downscaling technique for re-scaling GCAM emissions in Module 1 (as developed in Gidden et al. (2019)), additional age-specific functions for the health impact assessment, as well as a more flexible structure, to allow users to be able to read in emission pathways from different models.

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