




# 1 rfasst: An R tool to estimate air pollution impacts on 2 health and agriculture

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## Software

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## 7 Summary

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

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

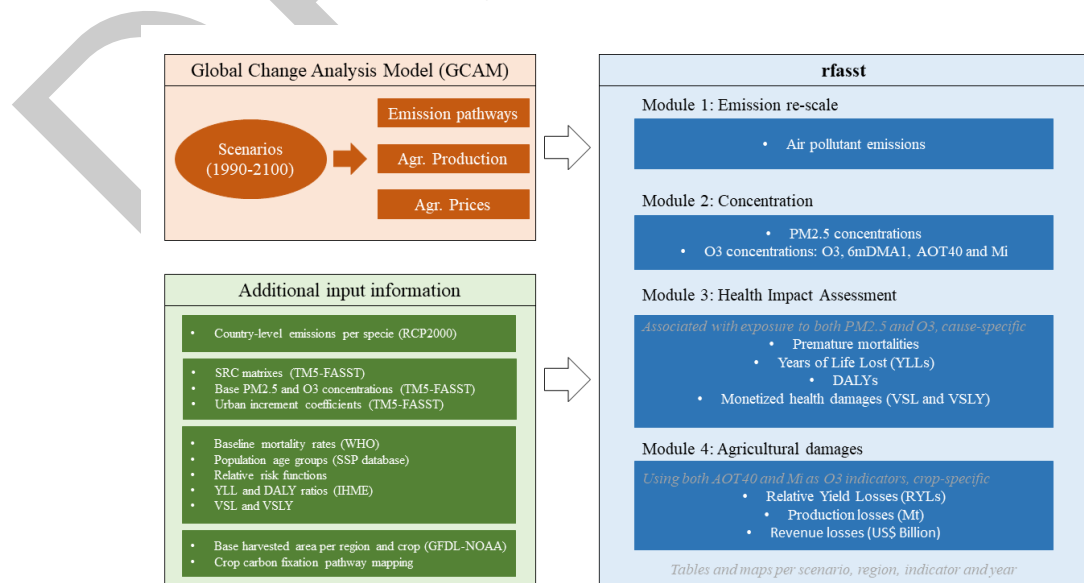


Figure 1: Structure of the rfasst package

22 rfasst can be accessed via the web at the public domain <https://github.com/JGCRI/rfasst>.  
23 We provide an R vignette step-by-step tutorial for users to get started with rfasst which is  
24 accessible here: [Tutorial](#).

## 25 Statement of need

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

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

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

## 66 Functionality

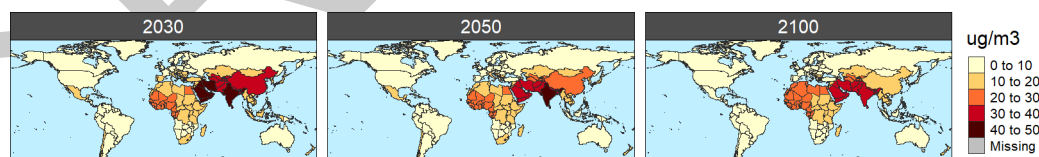
67 The package includes several functions that have been classified in four different modules.  
68 Note that all the functions are listed in the [Tutorial](#), which includes individual documentation

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/m<sup>3</sup>)

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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## References

- Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C. A., Apte, J. S., Brauer, M., Cohen, A., Weichenthal, S., & others. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proceedings of the National Academy of Sciences*, 115(38), 9592–9597.
- Calvin, K., Patel, P., Clarke, L., Asrar, G., Bond-Lamberty, B., Cui, R. Y., Di Vittorio, A., Dorheim, K., Edmonds, J., Hartin, C., & others. (2019). GCAM v5. 1: Representing the linkages between energy, water, land, climate, and economic systems. *Geoscientific Model Development (Online)*, 12(PNNL-SA-137098). <https://doi.org/10.5194/gmd-12-677-2019>
- Emberson, L. D., Pleijel, H., Ainsworth, E. A., Van den Berg, M., Ren, W., Osborne, S., Mills, G., Pandey, D., Dentener, F., Büker, P., & others. (2018). Ozone effects on crops and consideration in crop models. *European Journal of Agronomy*, 100, 19–34.
- Gidden, M. J., Riahi, K., Smith, S. J., Fujimori, S., Luderer, G., Kriegler, E., Vuuren, D. P. van, Berg, M. van den, Feng, L., Klein, D., & others. (2019). Global emissions pathways under different socioeconomic scenarios for use in CMIP6: A dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development*, 12(4), 1443–1475.
- Kyle, G. P., Luckow, P., Calvin, K. V., Emanuel, W. R., Nathan, M., & Zhou, Y. (2011). *GCAM 3.0 agriculture and land use: Data sources and methods*.
- Markandya, A., Sampedro, J., Smith, S. J., Van Dingenen, R., Pizarro-Irizar, C., Arto, I., & González-Eguino, M. (2018). Health co-benefits from air pollution and mitigation costs of the paris agreement: A modelling study. *The Lancet Planetary Health*, 2(3), e126–e133.
- Sampedro, J., Smith, S. J., Arto, I., Gonzalez-Eguino, M., Markandya, A., Mulvaney, K. M., Pizarro-Irizar, C., & Van Dingenen, R. (2020). Health co-benefits and mitigation costs as per the paris agreement under different technological pathways for energy supply. *Environment International*, 136, 105513.
- Sampedro, J., Waldhoff, S. T., Van de Ven, D.-J., Pardo, G., Van Dingenen, R., Arto, I., Del Prado, A., & Sanz, M. J. (2020). Future impacts of ozone driven damages on agricultural systems. *Atmospheric Environment*, 231, 117538.
- Van Dingenen, R., Dentener, F., Crippa, M., Leitao, J., Marmer, E., Rao, S., Solazzo, E., & Valentini, L. (2018). TM5-FASST: A global atmospheric source–receptor model for rapid impact analysis of emission changes on air quality and short-lived climate pollutants. *Atmospheric Chemistry and Physics*, 18(21), 16173–16211.
- Van Dingenen, R., Dentener, F. J., Raes, F., Krol, M. C., Emberson, L., & Cofala, J. (2009). The global impact of ozone on agricultural crop yields under current and future air quality legislation. *Atmospheric Environment*, 43(3), 604–618.