Dependence of Direct Carbon Intensities on Input Coefficients in the Uncertainty Quantification of Carbon Footprints

Topic: Input-Output Theory and Methodology (7)
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Environmentally extended inputâ€“output (EEIO) models have been widely used to quantify carbon footprints, and the associated uncertainty needs to be quantified and reported alongside the footprint. Direct carbon emission intensities depend on the input coefficients that reflect sectoral fossil fuel consumption. However, this dependence has rarely been incorporated into the quantification of uncertainty. This study proposes a methodology for incorporating this dependence. For the first time, we investigated how disregarding this dependence distorts the uncertainty quantification results.

We used Monte Carlo simulations in which the elements of an IO table were assumed to independently follow lognormal distributions, as proposed by Lenzen et al. (2010, Econ. Syst. Res.). We compared the Monte Carlo simulation results with and without the dependence. We incorporate the dependence by representing the direct carbon intensity vector as a function of the input coefficient matrix, which mimics steps to construct the satellite accounts of an EEIO table. In contrast, for the independent case, the direct carbon intensities and the input coefficient matrix individually follow the same distributions as those for the dependent case, whereas the direct carbon intensities are independent of the input coefficients and are mutually independent. We used the 2015 Japan National IO Table and 3EID (Embodied Energy and Emission Intensity Data for Japan Using Inputâ€“Output Tables), in which the number of sectors in the IO table and 3EID was extended to 509 using data released by the Japanese Ministry of Internal Affairs and Communications.

For example, the carbon footprint of household consumption expenditure in a region can be expressed as a non-negative linear combination of sectoral embodied intensities, where the non-negative weights represent the consumption expenditure on goods and services produced by different sectors. The relative standard deviation (RSD), defined as the ratio of standard deviation to mean, was used as the uncertainty indicator. The change in the RSD of a carbon footprint is affected by changes in the means, RSDs, and correlations between the sectoral embodied intensities that comprise it. We found that by considering the dependence, (1) the changes in the means were negligible, ranging from âˆ’0.1% to 0.2%; and (2) the RSDs of sectoral embodied intensities increased overall, remaining almost the same (between âˆ’5% and 5%) for 297 sectors, moderately increasing (from 5% to 20%) for 187 sectors, and substantially increasing (20% or more) for 24 sectors. For sectors with large shares of direct emissions in total embodied emissions, the RSDs of the embodied intensities were more likely to increase. (3) The correlation between sectoral embodied intensities was positive for 99.64% (126,800) pairs of embodied intensities in the independent case, and this proportion increased only slightly to 99.67% (126,834) in the dependent case. The positive correlation between sectoral embodied intensities was strengthened for sectors with large fossil fuel consumption when the dependence was accounted for, whereas for other sectors, the correlation remained unchanged.

The above findings suggest that incorporating the dependence of direct carbon intensities on input coefficients increases the uncertainty result of carbon footprints. In other words, if this dependence is disregarded, the uncertainty in the carbon footprint will be underestimated, especially when it is related to sectors with large shares of direct emissions in total embodied emissions or sectors with large fossil fuel consumption. We thus conclude that the dependence of direct carbon intensities on input coefficients should be considered in the uncertainty quantification of carbon footprints to avoid systematic underestimation of uncertainty and propose the above-summarized methodology for researchers interested in quantifying the uncertainty of carbon footprints in EEIO

models.