A Stochastic LCA framework for embodied greenhouse gas analysis: integrating process and I-O data within a Bayesian graphical model

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A stochastic, hybrid, CO_{2eq} LCA model is presented. Current hybrid I-O models present single figure mean values for embodied CO_{2eq} emissions for the analysed materials. Such mean values fail to convey any information regarding the form of the distribution of individual values around that mean. Understanding the variability of embodied CO_{2eq} in materials is important for assessing the extent to which emissions reductions can be achieved through economic mechanisms which drive preferential selection of low embodied CO_{2eq} materials through the supply chain – such as carbon taxes and emissions trading.

The model is developed using Bayesian methods. Construction of Bayesian statistical models requires integrating prior information with new data to form posterior probability distributions. In this context, prior distributions are generated from the stochastic I-O model and, after integration of process analysis data, a posterior distribution is generated. The form of the posterior distribution is determined through the process of Bayesian integration, with the posterior distribution deriving its primary form from the prior distribution, or the available data, according to their relative strengths. The rationale for employing the Bayesian approach in this context is to permit the integration of the more product-specific process analysis embodied CO_{2eq} data, into the more system boundary complete stochastic I-O model. Bayesian methods also support the progressive integration of new data into the model. This allows the model to 'learn' and for uncertainties to be reduced over time.

Constructing the Stochastic I-O model: The stochastic I-O LCA model is created from a disaggregated expansion of the UK National Environmental Accounts (UKNEA), data from the National Atmospheric Emissions Inventory (NAEI) and data from the Annual Business Inquiry (ABI). The stochastic input-output model is effectively a stochastic map of CO_{2eq} flows between sectors of the economy broken down to the Standard Industrial Classification (SIC) 3-digit level. The National Environmental Accounts differ from National Economic Accounts (standard I-O tables) in that sectors are defined by environmental similarity rather than economic similarity. This gives stricter adherence to input-output homogeneity assumption than is possible using the traditional economic sector based input-output tables. Disaggregation is done using Generalized Maximum Entropy (GME) reconstructions of transaction values between SIC 3-digit level sectors. This is performed using a beta release of the SAS 9.0 programming environment and follows Golan, A.; Judge, G.; et al. (1996). Within each of the 91 sectors of the UKNEA defined at the SIC 2-digit level there are some number of SIC 3-digit sub-sectors. The reconstructed transaction values at the 3-digit level then form a Dirichlet prior distribution for that 2-digit sector.

Stochastic process analysis data: Available process analysis data is then aggregated at the 2-digit level and multinomially distributed. This is then integrated with the Dirichlet prior using Bayesian methods implemented in the WinBUGS software.

The final model: The final model then takes the form of a stochastic graph (here 'graph' is used in the mathematical sense). This graph contains 91 nodes corresponding to the 91 SIC-2 digit sectors of the UKNEA. These nodes are linked by directed edges showing the flow between sectors. Within each node there is a posterior distribution generated by integrating the prior I-O distribution with available process analysis data. A data set of sampled values from each of these 91 posterior distributions is then exported from WinBUBS into the SAS Interactive Matrix Language (IML). In a Monte Carlo process, a single value is then drawn from each of these 91 data sets and the Leontif inverse of the stochastic I-O matrix is approximated using the Euler series method. This is repeated until the histogram of the final embodied CO_{2eq} distribution for the selected material is sufficiently dense.