A stochastic, hybrid, LCA model of embodied CO_{2eq} in materials

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Policy Objectives

- To be able to model the likely effect of policies aimed at encouraging preferential selection of low embodied CO_{2eq} suppliers within supply trees
  - Carbon taxes
    - E.g. UK Climate Change levy
  - Kyoto Protocol Flexibility Mechanisms
    - CDM; JI; Domestic Carbon Offset projects

Academic objectives

- To avoid the misrepresentation of embodied CO_{2eq} inherent in single 'average' figures for materials
- To capture the information lost (standard deviation, variance, skewness, etc) in deriving single 'average' figures
- To better understand the embodied CO_{2eq} heterogeneity inherent within material's supply trees

Requirements of model

- **Stochastic:**
  - Require probability density functions (PDFs) of embodied CO_{2eq} in materials
- **Complete:**
  - Incorporate the system boundary completeness of Input-Output (IO) with the product specificity of Process Analysis (PA) (a 'hybrid' model)
- **Evolutionary:**
  - Model to support progressive integration PA data as and when it becomes available

Data Sources

- UK Environmental Accounts (UKENA)
  - 93 sector IO accounts aggregated for environmental homogeneity
- UK National Atmospheric Emissions Inventory (NAEI)
  - ~4400 atmospheric emissions estimates by economic sector, source and fuel (in thousand tonnes) for C, CH_4 & N_2O
- UK Annual Business Inquiry (ABI)
  - Provides data at the Standard Industrial Classification 3 digit level
- Meta-analysis of published process analysis embodied energy/CO_{2eq} data

Components of model 1: Input-Output

- UKENA expanded to the Standard Industrial Classification (SIC) 3 digit level (220 sectors)
- Row and Column totals for SIC 3 digit subsectorial transaction matrices estimated from ABI data
- Inter-subsectorial transaction data at the SIC 3 digit level reconstructed using the Maximum Entropy method
- Product is a hypothesized reconstruction of a 220 square environmental IO table

Components of model 2: Emissions Vector

- Use ~4400 NAEI atmospheric emissions estimates by for C, CH_4 & N_2O
- Allocate to SIC 3 digit (220) sectors based on primary sector definitions
- Use ABI data to convert to T/£M
- Post-multiply reconstructed SIC 3 digit IO by emissions vector to get SIC 3 digit disaggregated transaction matrix in $T.CO_{2eq}$

Components of model 3: Bayesian Prior

- Use variation of spanning tree backtracking algorithm from graph theory (following Treloar)
- Algorithm stochastically constructs a *sample set* of possible supply trees at the SIC 3 digit level from within the *single supply tree* at the UKENA 93 sector level from the Euler series approximation to the Total Requirements matrix
- System boundary of simulated supply trees to match that of PA data collected in the meta-analysis
- The set of values from the supply trees forms the Bayesian Prior(s) of embodied CO_{2eq} for the products of a given UKENA sector

Components of model 4: Conditioning Data

- Meta-analysis of published process analysis embodied energy/CO_{2eq} data
  - Data evaluated for:
    - System boundary definition
    - Allocation method
    - Recycling assumptions
    - Energy to CO_{2eq} conversion coefficients, etc
- Other datasets to also be investigated
  - Suggestions very welcome!
  - Datasets need to be transparent

Components of model 5: Bayesian integration

- Use WinBUGS (Bayesian inference Using Gibbs Sampling) Markov Chain Monte Carlo (MCMC) package
- Use Metropolis Hastings algorithm to numerically integrate the conditioning data (from PA) into the Prior distribution(s) (from IO)
- If there are multiple posterior distributions then calculate final joint distribution
- Final joint distribution incorporates system boundary completeness of IO with product specificity of PA

Limitations

- Model is still under development
- ‘Reasonableness’ of prior distributions yet to be established
- Rigorous statistical error analysis difficult due to:
  - lack of error propagation models for IO
  - Lack of transparency of most Process Analysis data
  - Lack of transparency of NAEI data

Conclusions: The model is...

- Primarily of interest to analysts & policy makers looking to test effects mitigation strategies
- Secondarily of interest to material manufacturers and product designers
- Applicable to all sectors (not just construction materials)
- Evolutionary (in allowing progressive integration of new process analysis data)
- In principle extensible to Europe due to concordance of:
  - national emissions inventories under the Kyoto Protocol
  - standard industrial classifications under NACE rev.1