A Stochastic LCA Framework for Embodied Greenhouse Gas Analysis

Dr David Shipworth
School of Construction Management and Engineering
University of Reading - UK

Objectives

- Model effect of policies encouraging low carbon technologies (e.g. Carbon taxes & Emission Trading)
- Avoid misrepresentation of single ‘average’ CO_{2eq} figures for materials
- To capture lost information (variance, skewness, etc)
- Model the ‘carbon diversity’ of materials

Requirements of model

- **Stochastic:**
  - Require probability distributions 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 National Environmental Accounts (UKNEA)
  - 91 sector IO accounts
  - Aggregated for environmental homogeneity
- UK National Atmospheric Emissions Inventory (NAEI)
  - ~4400 emissions estimates by economic sector, source and fuel (thousand tonnes) for C, CH_4 & N_2O
  - Includes non-fuel emission sources
- UK Annual Business Inquiry (ABI)
  - Total purchases data for 3-digit sub-sectors at basic prices
- Existing process analysis data
  - Anonymous, process level data by UKNEA sector

Components of model: Expanded UKNEA

- UKNEA is 91x91 Environmental I-O matrix
- Transaction between sectors is in £M
- Annual emissions vectors allow conversion to emissions flows ($T.CO_{2eq}$) or intensities ($T.CO_{2eq}$/£M)
- Each sector contains between 0 and 9 SIC 3-digit sub-sectors
- Expanding to sub-sectors creates 91 by 161 (2-digit by 3-digit) matrix

Components of model: Expanded UKNEA

- New column totals available from ABI
- New 3-digit sub-sector row transaction totals are existing 2-digit transaction values
- 2-digit sales to 3-digit sub-sectors reconstructed using GME method
- Product can be viewed either as:
  - a 91 by 161environmental IO table; or
  - a 91x91 IO table with cells containing multi-state data

Components of model: Emissions Intensities

- Use ~4400 NAEI data for C, CH_4 & N_2O
- Allocate to SIC 3-digit (161) sub-sectors based on primary sector definitions
- Gives total emissions from 3-digit sub-sector
- Use ABI data to convert to emissions intensities (T/£M) at the 3-digit level

Components of model: Bayesian Prior

- Apply 3-digit sub-sector emissions intensities to reconstructed transaction values between 2-digit sectors and 3-digit sectors
- This gives Dirichlet emissions intensity distribution within each 2-digit sector
- The number of states of the Dirichlet distribution equals number of 3-digit sub-sectors

Components of model: Process Analysis Data

- Use anonymous process level data
- Data collected by UK ETS sector level entrants
- System boundary is UKNEA sector definition
- Data expressed as $T.CO_{2eq}$/£M
- Represent data as multinomial distribution

Components of model: Bayesian integration

- Integrate prior I-O distribution (Dirichlet), with process data process distribution (Multinomial)
- Done using Markov Chain Monte Carlo package (WinBUGS)
- Resulting ‘Posterior’ distribution is most heavily influenced by the stronger data set
- New data can continually be integrated

The UKNEA in graph theory terms

- The UKNEA is a 91 sector (node) deterministic graph
- Connected sectors are linked by a single pathway (edge)
- The I-O matrix is the ‘adjacency’ matrix of this graph – a value in a cell indicates a pathway between sectors
- Each pathway has an emissions intensity
- Total emissions into a sector are found by tracing back along the carbon pathways
- The pathways create a carbon ‘tree’ for that sector

The Model in graph theory terms

- The Model is a 91 sector *stochastic* graph
- Connected sectors are linked by *one or more* pathways
- The expanded I-O matrix is the ‘adjacency’ matrix of this graph – a distribution in a cell indicates multiple pathways between sectors
- The distributions combine prior I-0 data integrated with process analysis data on an ongoing basis

The Model in graph theory terms

- Each of the pathways has a different emissions intensity
- Total emissions into a sector are found by tracing back along the carbon pathways – where there are multiple pathways one is chosen at random
- The set of all possible pathways creates a carbon ‘forest’ for that sector
- The carbon diversity of the forest is the carbon diversity of the sector