Modelling to generate alternatives: A technique to explore uncertainty in IAMS

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ADVANCE

Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies

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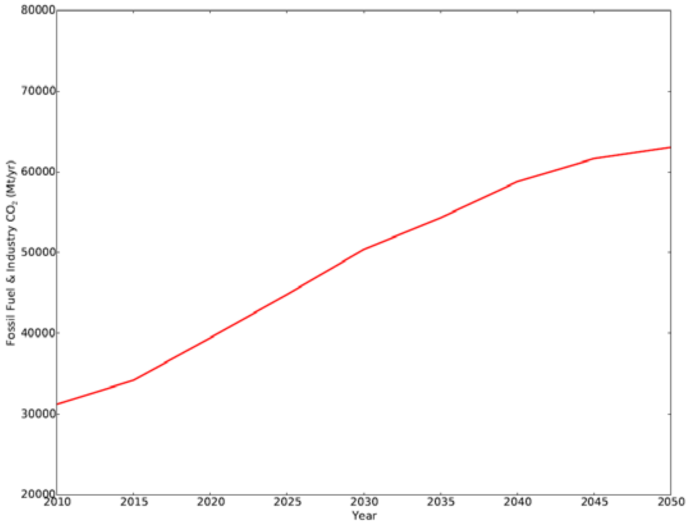
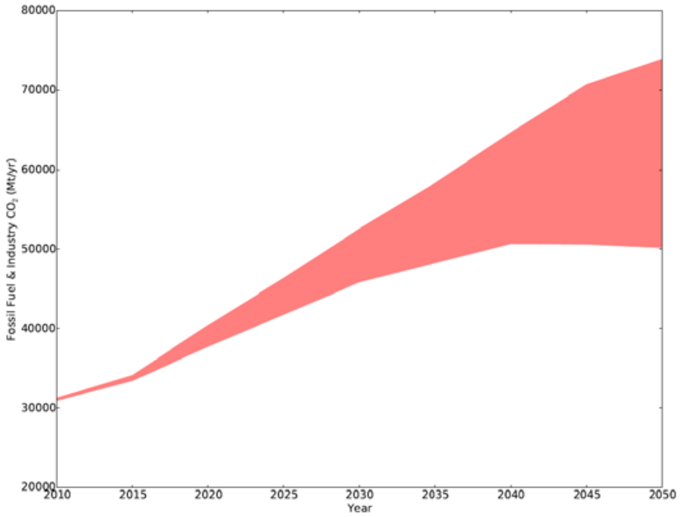
Motivation

- Typically, energy-environment-economy (E3) models function in a deterministic way → output is a single transition pathway.
- Such precise output masks inherent uncertainties and can mislead analysts and policy makers alike.





- Need to assess and communicate how uncertainty impacts our results.

Uncertainty

- Input parameter uncertainty → e.g. how does the capital cost of solar PV change over the models time horizon.
  - Impact usually mapped using some form of sampling/Monte-Carlo method (which may include more targeted scenario type analysis).

- Structural uncertainty (**the focus here**) → e.g. decision maker(s) don't function in a purely cost optimising fashion.
  - Explored here using the method of modelling to generate alternatives (MGA) to (slightly) relax the cost optimality assumption and assess solution stability.

- Disclaimer: **This work focuses on a cost optimising model** but concept of altering structural assumptions and exploring resultant uncertainty could be applied to other frameworks.

Modelling to generate alternatives

- MGA is a catchall term for any method that seeks to sample the near optimal solution space of a model:

  1. Solve the model in standard formulation → obtain cost optimal pathway.
  2. Optimal total system cost, increased by some slack (~1+%), is entered as a new constraint.
  3. Formulate a new objective function that aims to explore the subset of energy systems in the solution space defined by the cost constraint.

- Here use an objective function that generates pathways which are maximally different from all previously generated pathways in terms of the fuel mix of their primary energy consumption.

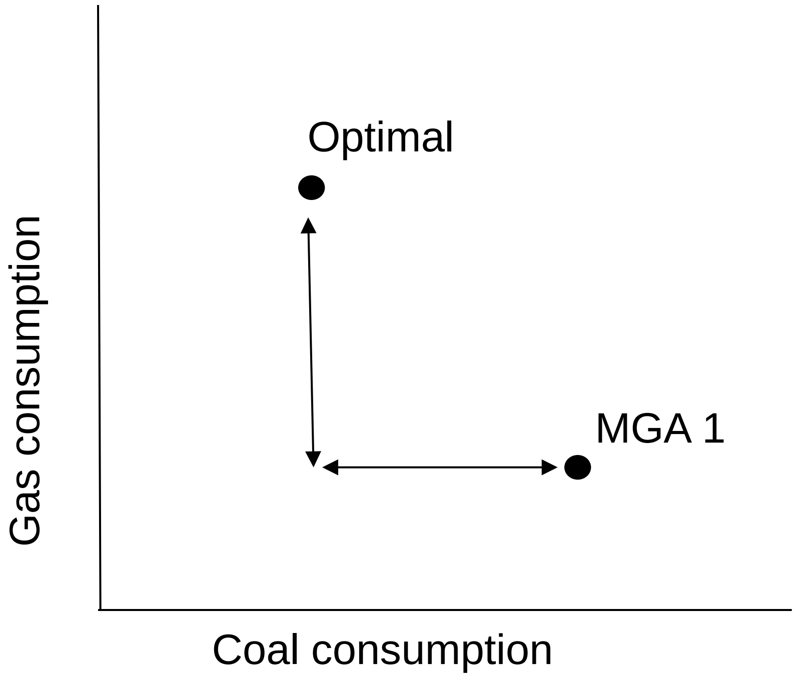
MGA

$$\text{maximise } D^{jk}_{min}$$

$$D^{jk} = \sum_{i} |PE^{j}_{i} - PE^{k}_{i}|$$

- PE is the cumulative (summed globally and temporally) consumption of primary energy carrier i (coal, gas, oil, nuclear, biomass and renewables).
- j is the current MGA iteration and k is the set of all previous runs.
- D^{jk} is the set of absolute (Manhattan) distances between j and all k.
- Objective is to maximise the minimum distance in D^{jk} and as such create a new pathway maximally different from all previous.

Example



- Example of first MGA iteration.
- Only two primary energy carriers.
- Code tries to maximise D while remaining within the cost slack.

$$D = |PE^{1}_{coal} - PE^{optimal}_{coal}| + |PE^{1}_{gas} - PE^{optimal}_{gas}|$$

MGA applied to TIAM-UCL

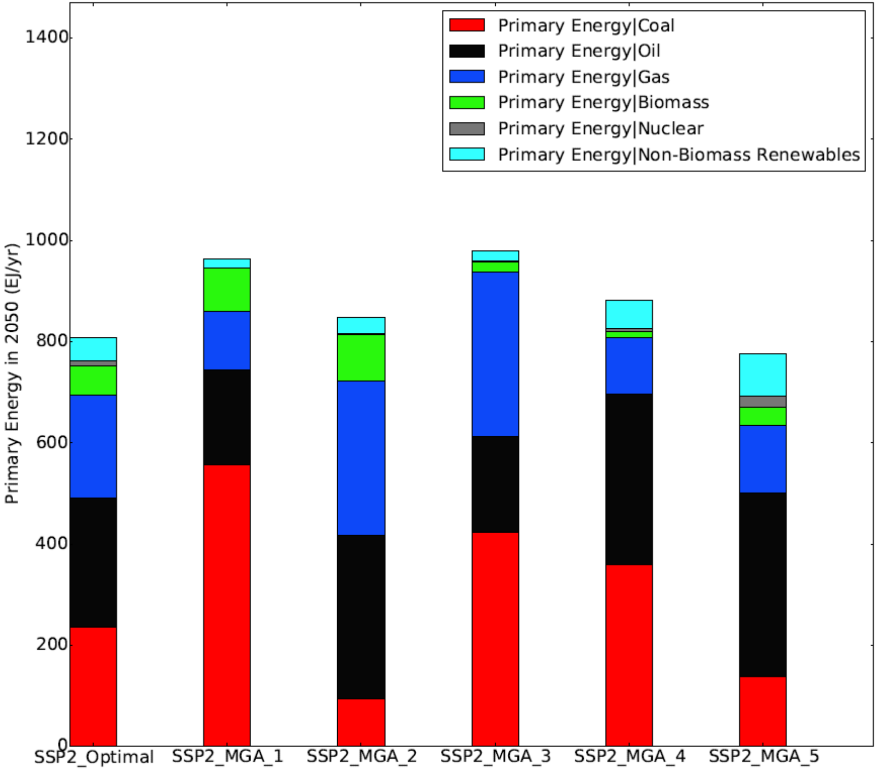
- TIAM-UCL is a technology rich, bottom-up, cost optimising whole energy system model with its own coupled climate module.

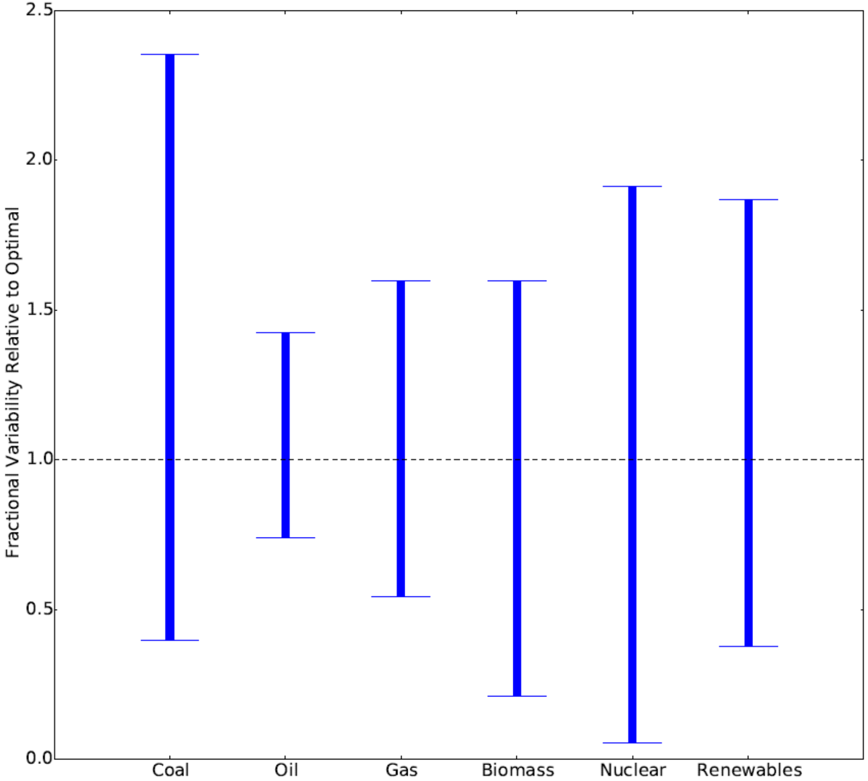
- Tested this formulation of MGA with:
  - TIAM-UCL's implementation SSP2, both BAU and a 50% (relative to 2005) global CO_2 cut by 2050 (linear decline from 2015).
  - Slack of 1% (i.e. cost constraint has a ceiling of 1.01*total optimal system cost).

- Technique is computationally expensive → runs performed to 2050.

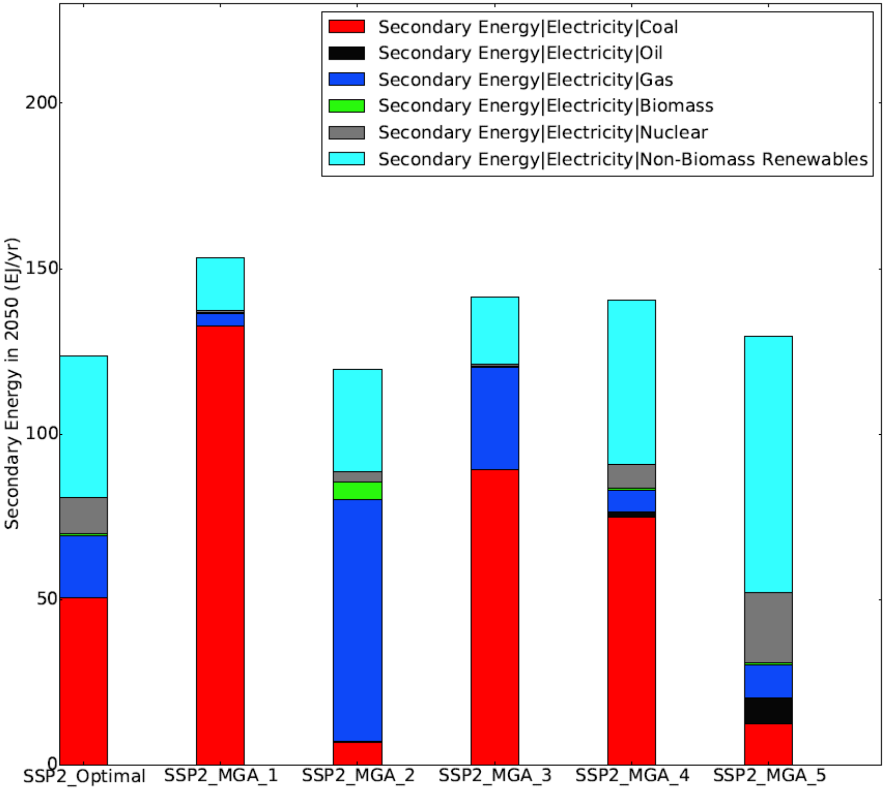
- In economic terms, MGA does not detail the specifics how a given PE fuel mix is achieved, e.g. perhaps a quantitative regulatory target was set for that mix, but the **total system cost constraint must be respected.**

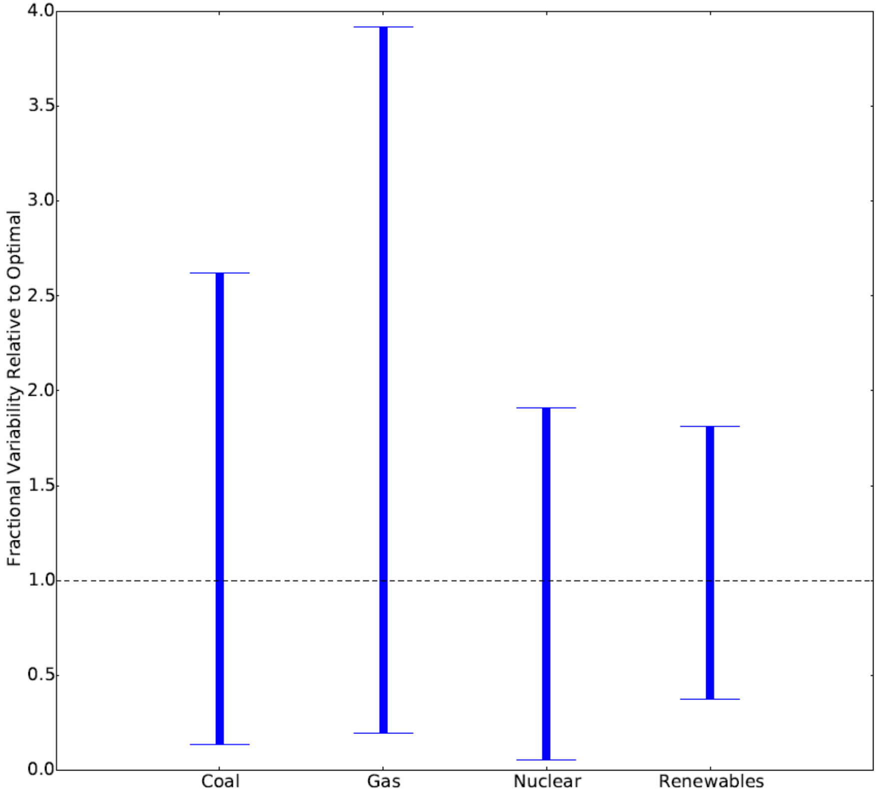
Results – BAU – PE consumption in 2050



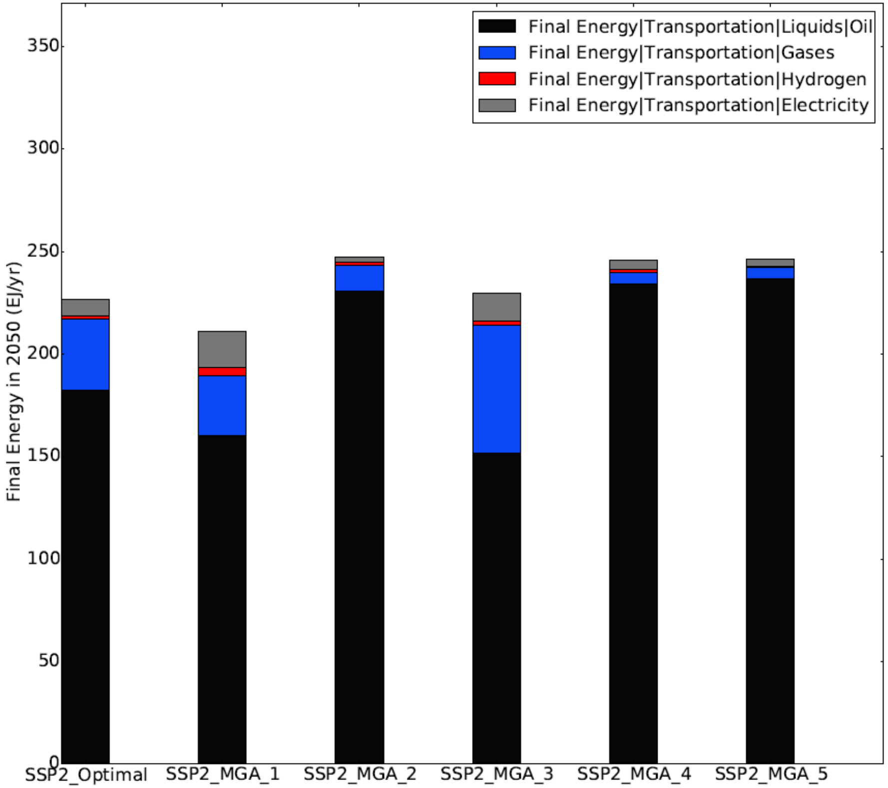


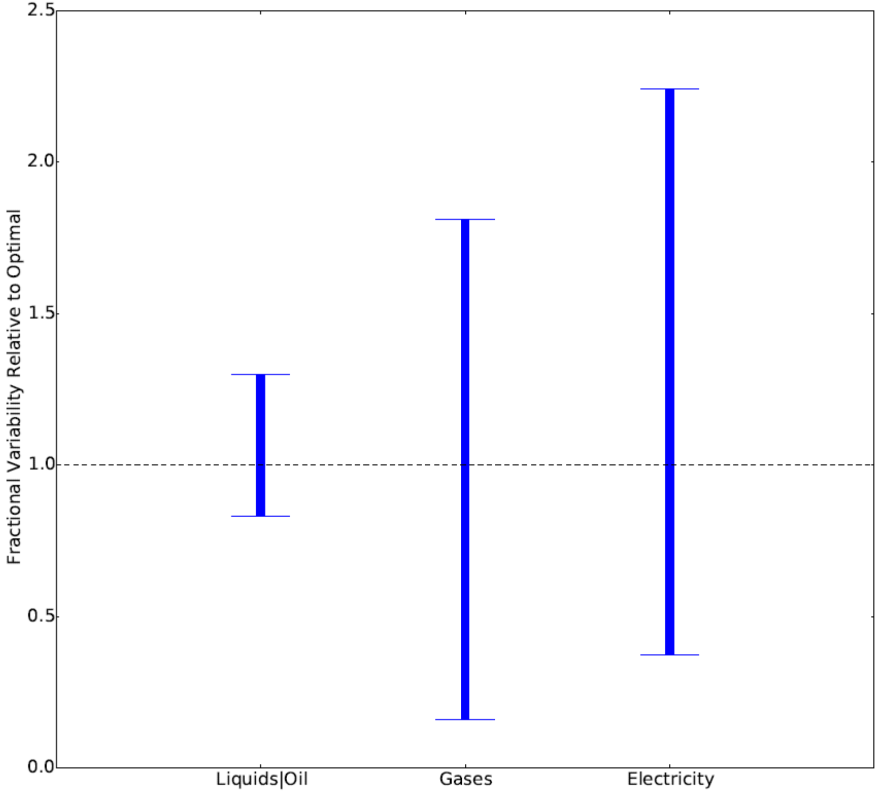
Results – BAU – Electricity production in 2050



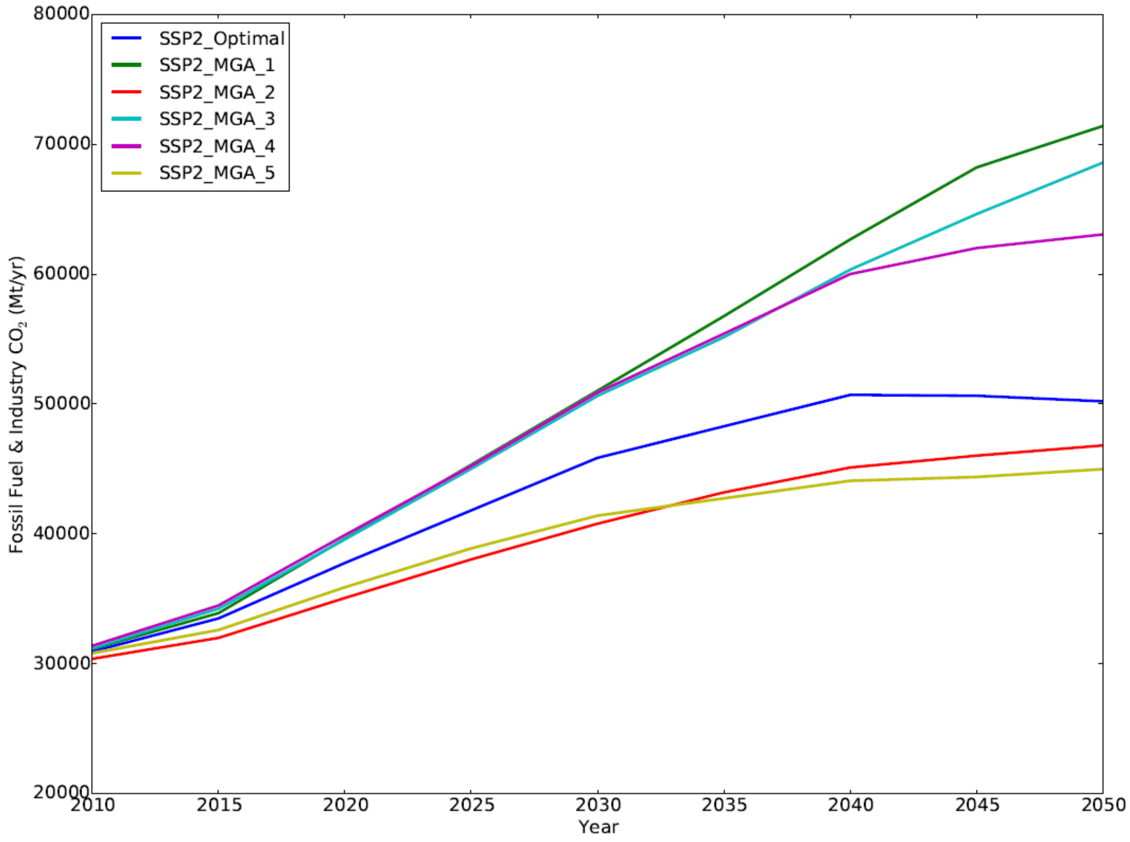


Results – BAU – Transport FE in 2050

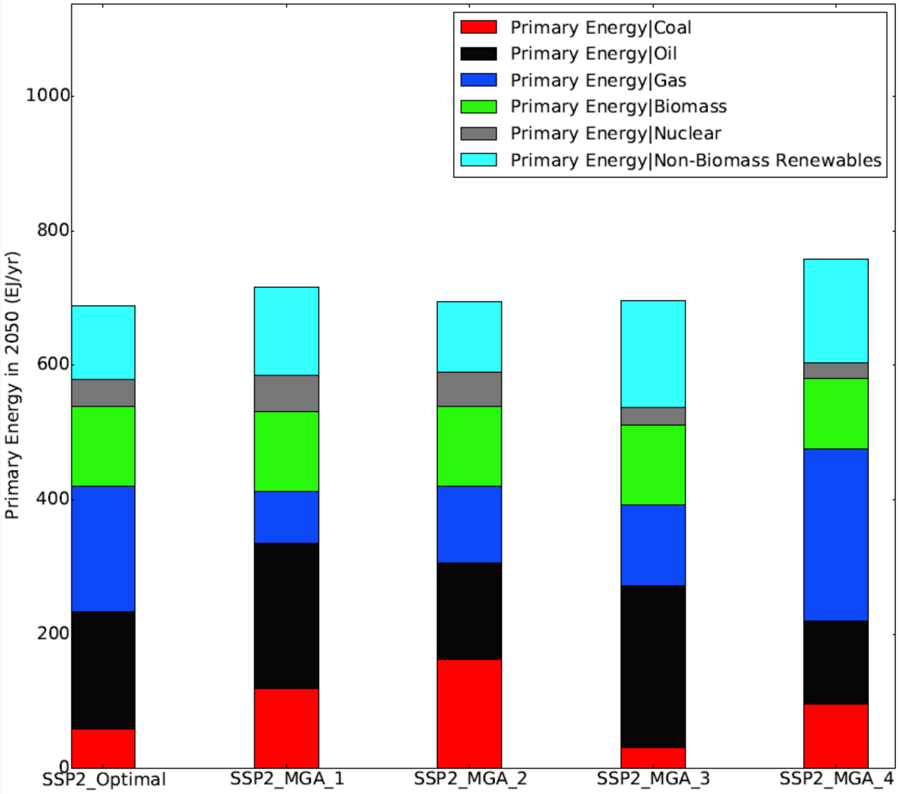


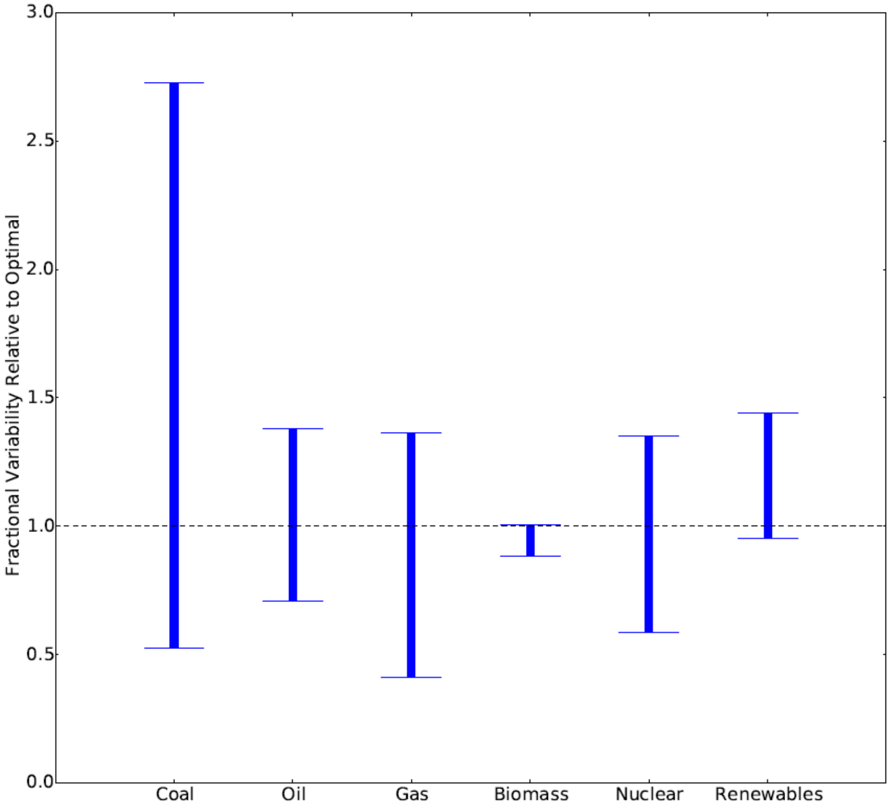


Results – BAU – Fossil Fuel & Industry CO2

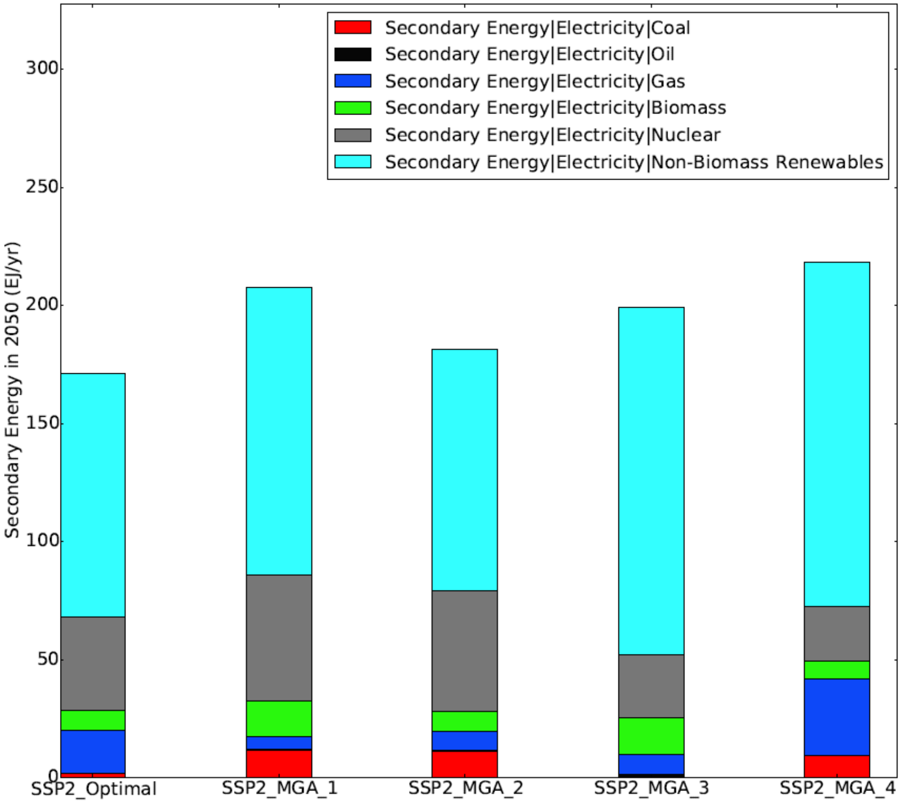


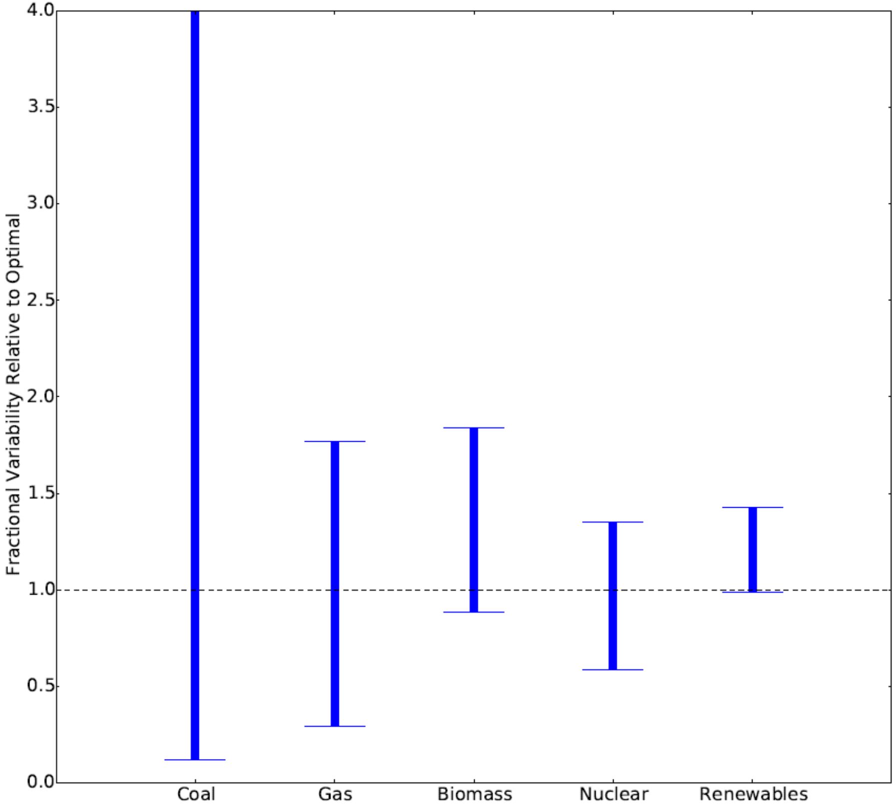
Results – Mitigation – PE consumption in 2050



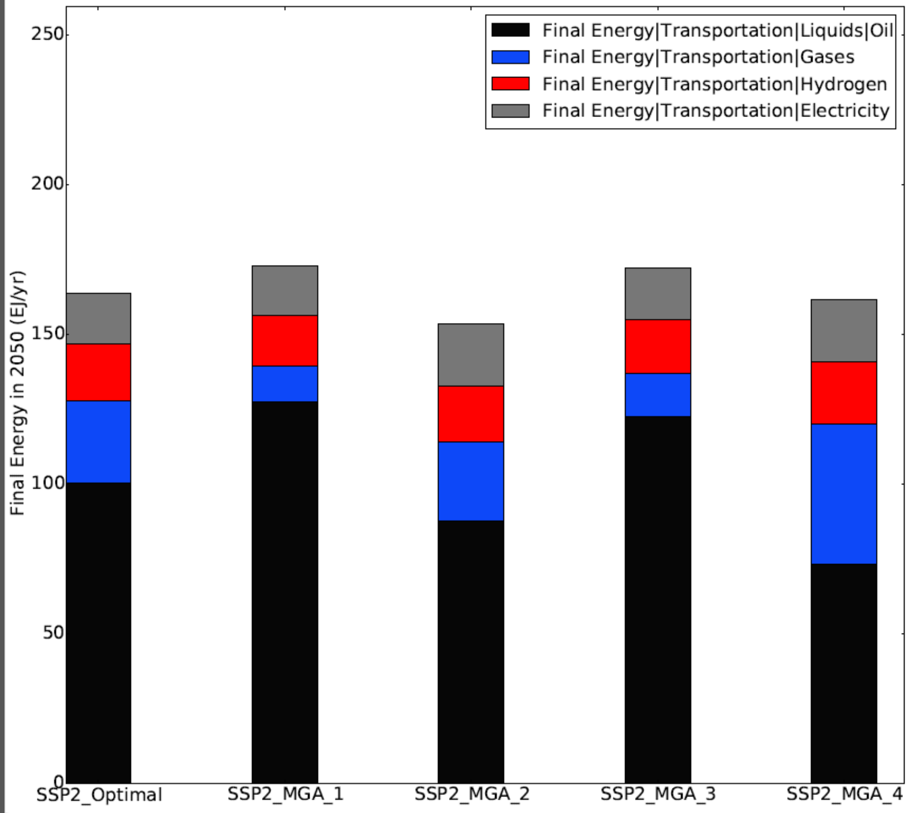


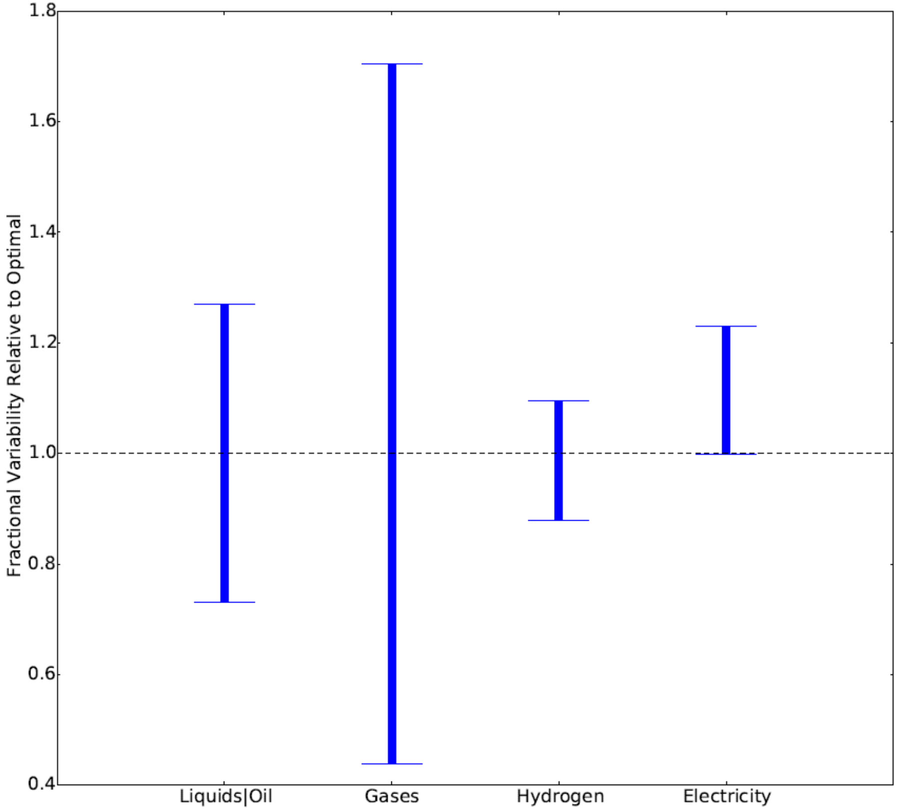
Results – Mitigation – Elec production in 2050





Results – Mitigation – Transport FE in 2050





Results – Summary 1

- BAU runs:
  - Within the small cost slack we see significant variability in some types of primary energy carrier consumption (e.g. coal) but less variability in others (e.g. oil).
  - This maps through to sectoral fuel use variability, e.g. electricity (coal and gas) vs transport (oil).
  - As a result total CO_2 emissions are also subject to significant variability:
    - ~+45% in MGA_1 relative to optimal in 2050, power sector emissions alone almost triple.
    - ~-10% in MGA_5 relative to optimal in 2050, power sector emissions down by 60%.

Results – Summary 2

- Mitigation runs:
    - PE consumption of coal and to a lesser extent gas again variable but consistent insights emerge (e.g. renewables and biomass).
    - Renewable consistency follows through into the power sector, nuclear is also a consistent feature here. Gas is again variable in the transport sector.
- Final thoughts:
    - Technique demonstrates the, at times, sizable impact of one aspect of structural uncertainty.
    - Allows analyst to look for consistent insights throughout the energy system between cost minimisation and some decision maker deviation (here 1%) from that assumption.

Thanks!

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Marginal costs in MGA

- Technique does not assess how the marginal required for a specific quantity of a PE fuel might be obtained (e.g. regulatory instrument) but its **impact on total system cost is constrained**: