Cost and potential of carbon abatement from the UK perennial energy crop market

Peter Alexander[1,2], Dominic Moran[1], Mark Rounsevell[2], Jonathan Hillier[3] and Pete Smith[3]

[1] Land Economy and Environment Research Group, SRUC, West Mains Road, Edinburgh, EH9 3JG, UK.

[2] School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, UK.

[3] School of Biological Sciences, University of Aberdeen, 23 St Machar Drive, Aberdeen, AB24 3UU, UK

Leading the way in Agriculture and Rural Research, Education and Consulting

What are perennial energy crops?

- Source of biomass
  - Renewable energy (electricity, heat or both)
  - Potential to produce biofuels
- Compared to annual energy crops less inputs and emissions[1]
- Short rotation coppice (SRC)
  - Typically willow or poplar
  - Harvested every 3-4 years
  - 20-30 year productive life
- Miscanthus
  - 3.5m high grass
  - Harvested annually
  - 16+ year productive life

[1] St. Clair, S., Hillier, J. & Smith, P. 2008 Estimating the pre-harvest greenhouse gas costs of energy crop production. *Biomass and Bioenergy* **32**, 442–452.

UK policy environment

- 8-11% of primary energy from biomass by 2020[2]
- Greatest growth in UK supplied biomass from agricultural residues and energy crops[2]
- Energy industry subsidies
  - Electricity generation: Renewable Obligation Certificates
  - Changes proposed under Electricity Market Reform
  - Heat used: Renewable Heat Incentive
- Farm subsidies
  - Grants of 50% establishment costs
  - Scheme closed for new applications in August 2013

[2] DfT, DECC, DEFRA (2012) *UK Bioenergy Strategy*. Department of Energy & Climate Change, London, UK.

Areas established to date

- Uptake lower than anticipated
- Planting areas in England under energy crop schemes
  - 8,200 ha from 2000-06[3]
  - 1,300 ha from 2007-11[4]

2011

10,800 ha[5]

2020

350,000 ha,
equivalent to 6.5 % of UK arable land
producing 18 TWh year^{-1} primary energy[6]

[3] Natural England (2006) *Summary of area planted and establishment grant payments made for the duration of the Energy Crops Scheme (ECS 1).*
[4] Natural England (2011) Summary of area under agreement and establishment grant payments made for the Energy Crops Scheme (ECS 2).
[4] DEFRA, 2013.Area of Crops Grown For Bioenergy in England and the UK : 2008-2011. *Department for Environment Food and Rural Affairs.*
[5] DEFRA, 2007. Biomass Strategy. *Department for Environment Food and Rural Affairs*.

Research background

- Existing research conducted on:
  - Biophysical behaviour
  - Environmental impact
  - Land use constraints
  - Modelling of supply with exogenous demand (or demand given supply)
- Work required to include:
  - Contingent interaction of supply and demand
  - Economic case for all market participants
  - Endogenous market price movements
  - Behavioural aspects of farmer adoption

Research Aims

- To investigate:
  - Reasons for the low levels of uptake to-date
  - Potential UK perennial energy crops supply
  - Factors affecting the path, rate and level of market development
  - Costs and potential of greenhouse gas emissions abatement from the market
  - Cost-effectiveness of alternative policy measures.

Modelling requirements

SRUC

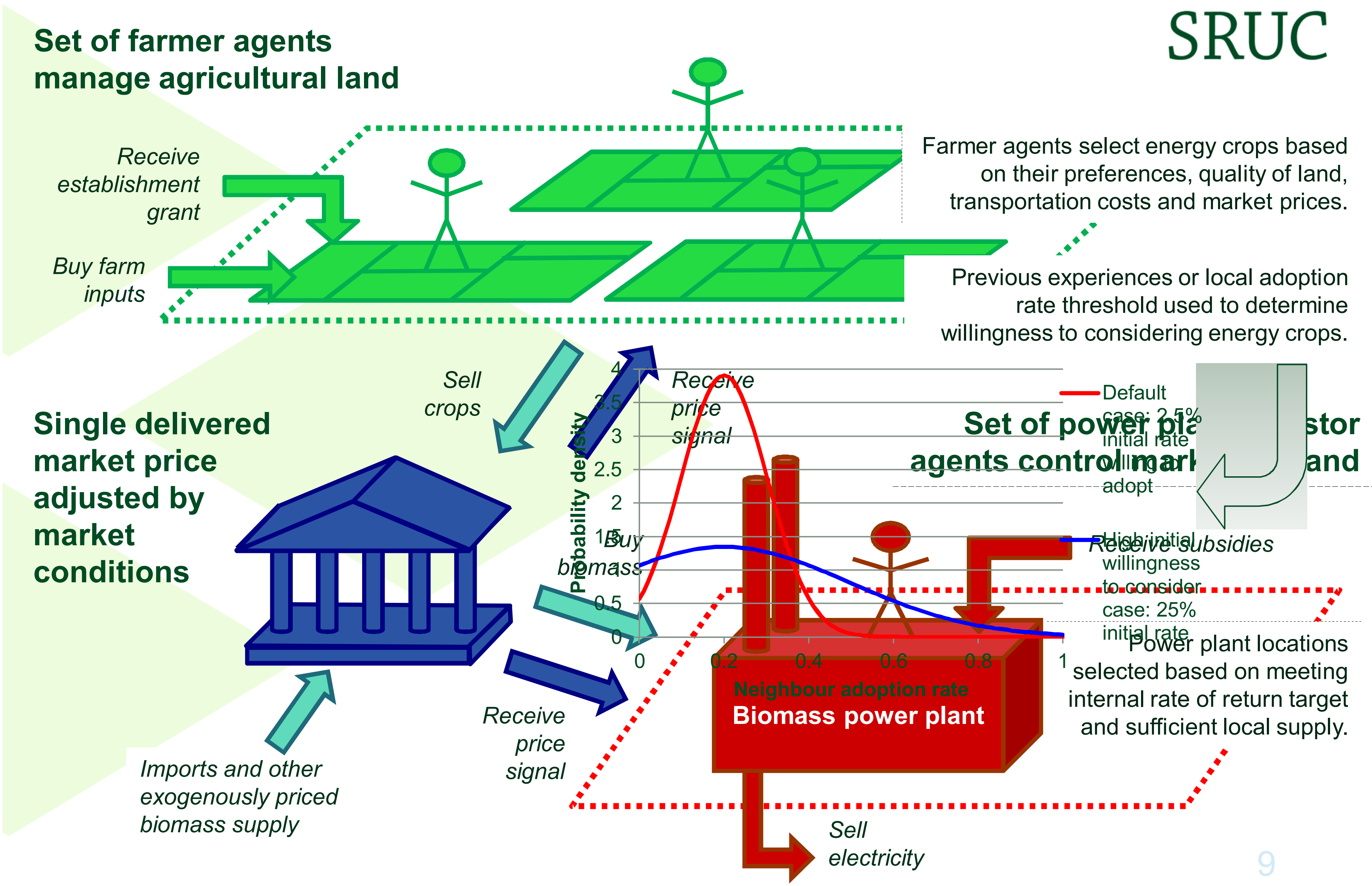
- Spatially explicit crop yields, 1km^2 grid
- Heterogeneous preferences
  - Farmer risk aversion, resistance to adoption.
  - Investor required rate of return
- Range of power plant technologies and sizes
- Contingent behaviour
- Disequilibrium market
- Diffusion of innovation
- Learning

Agent-based modelling approach selected

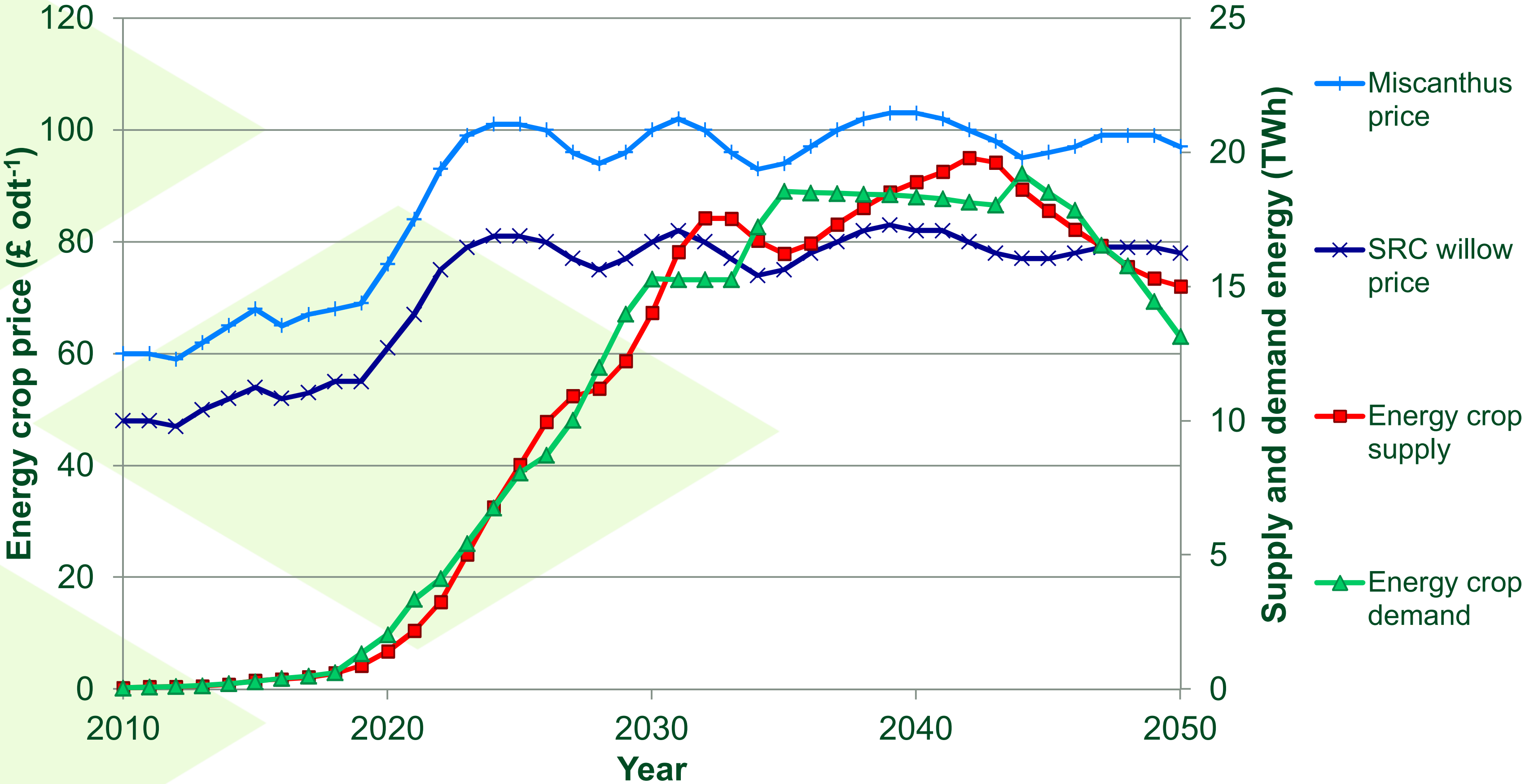
What are agent-based models?

- Dynamic representation of decision makers (the agents) and their interactions, often within a spatial framework
- System behaviour emerges, based on the decisions of the agents and their interactions with their environment and one another
- Supports the two-way interaction of behaviour between micro and macro scales

Agent-based model construction

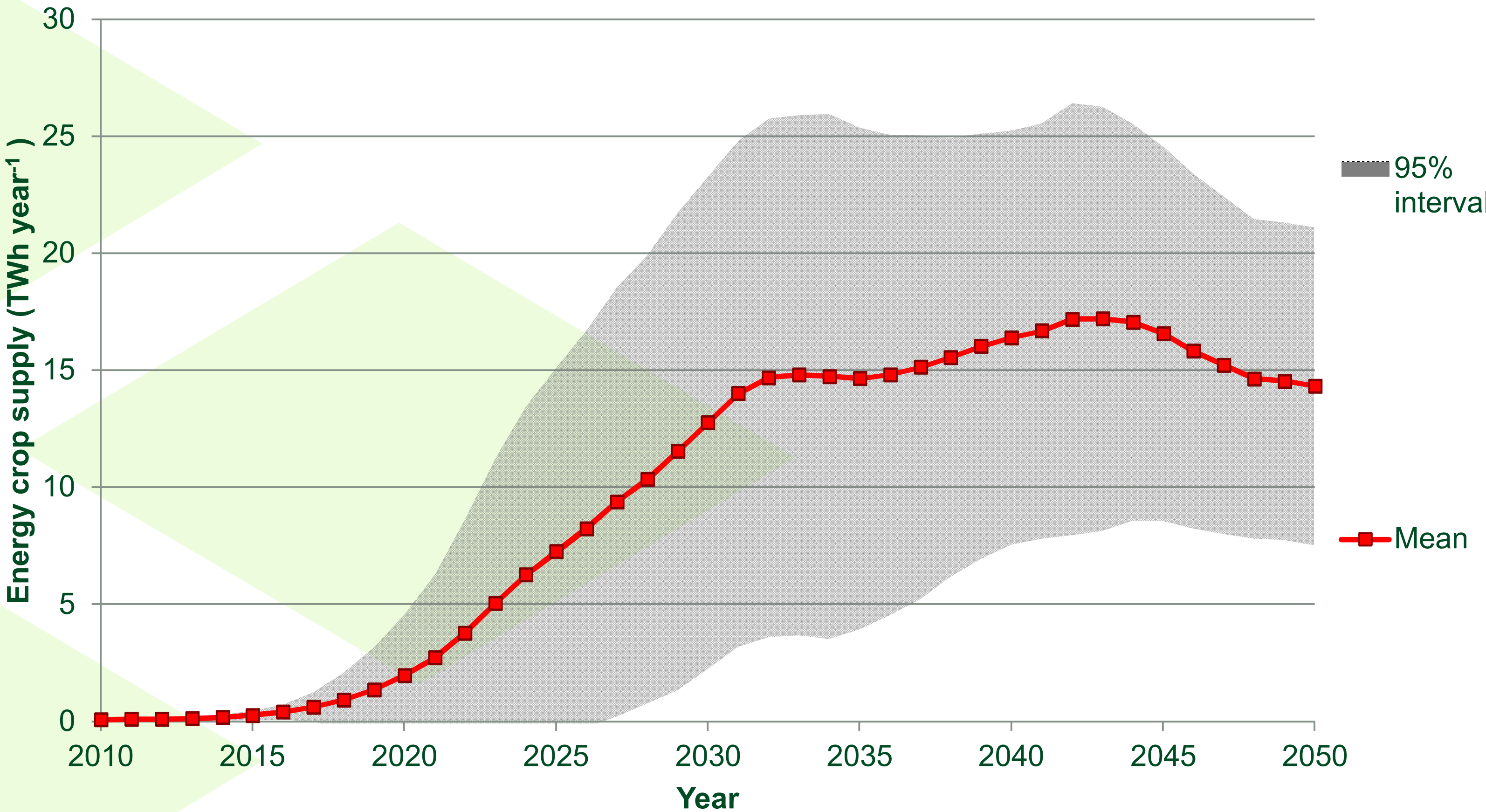


Results: Supply/demand and prices



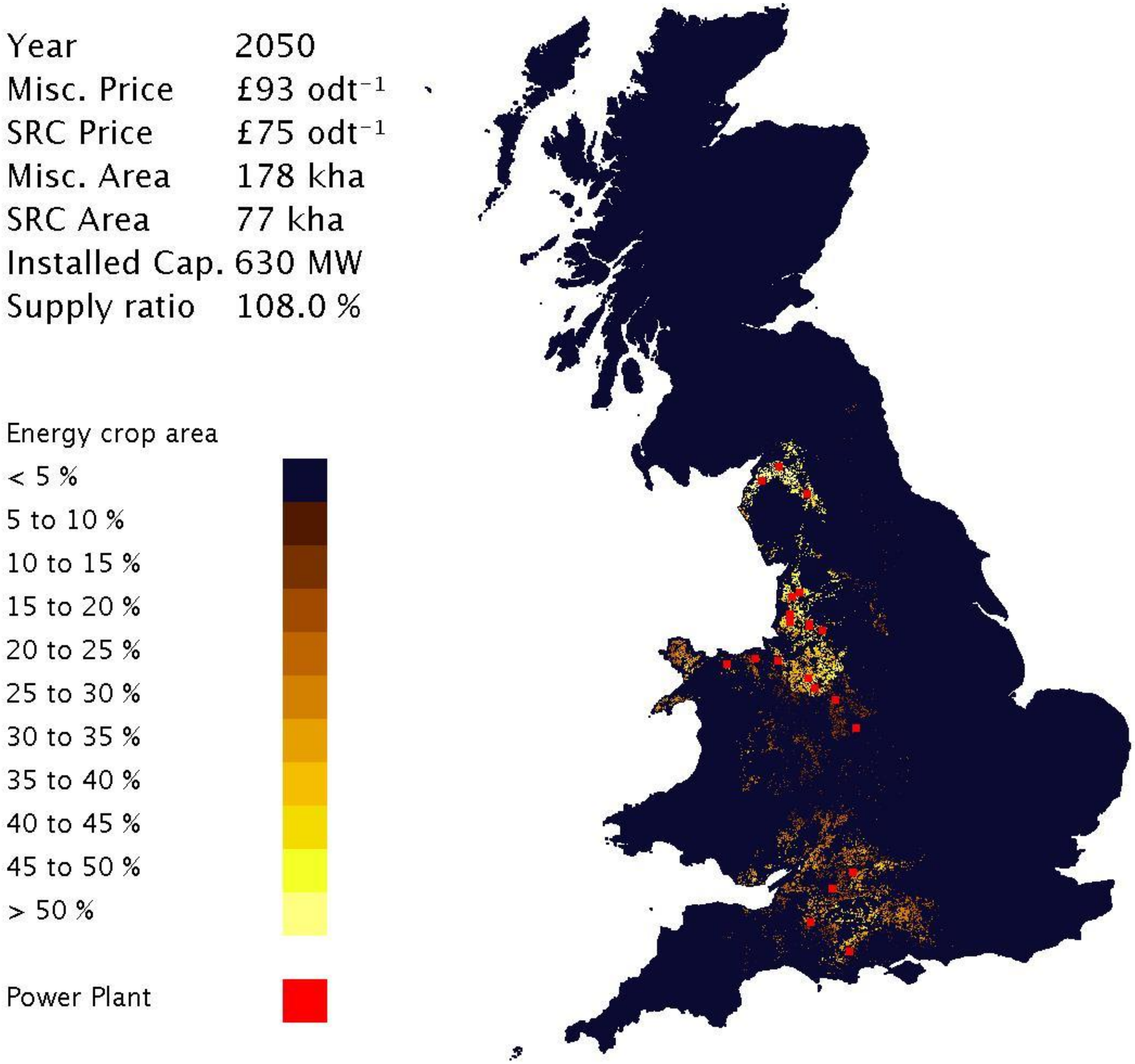
Energy crop prices and biomass supply and demand over time from one model run.

Energy crop supply result distribution



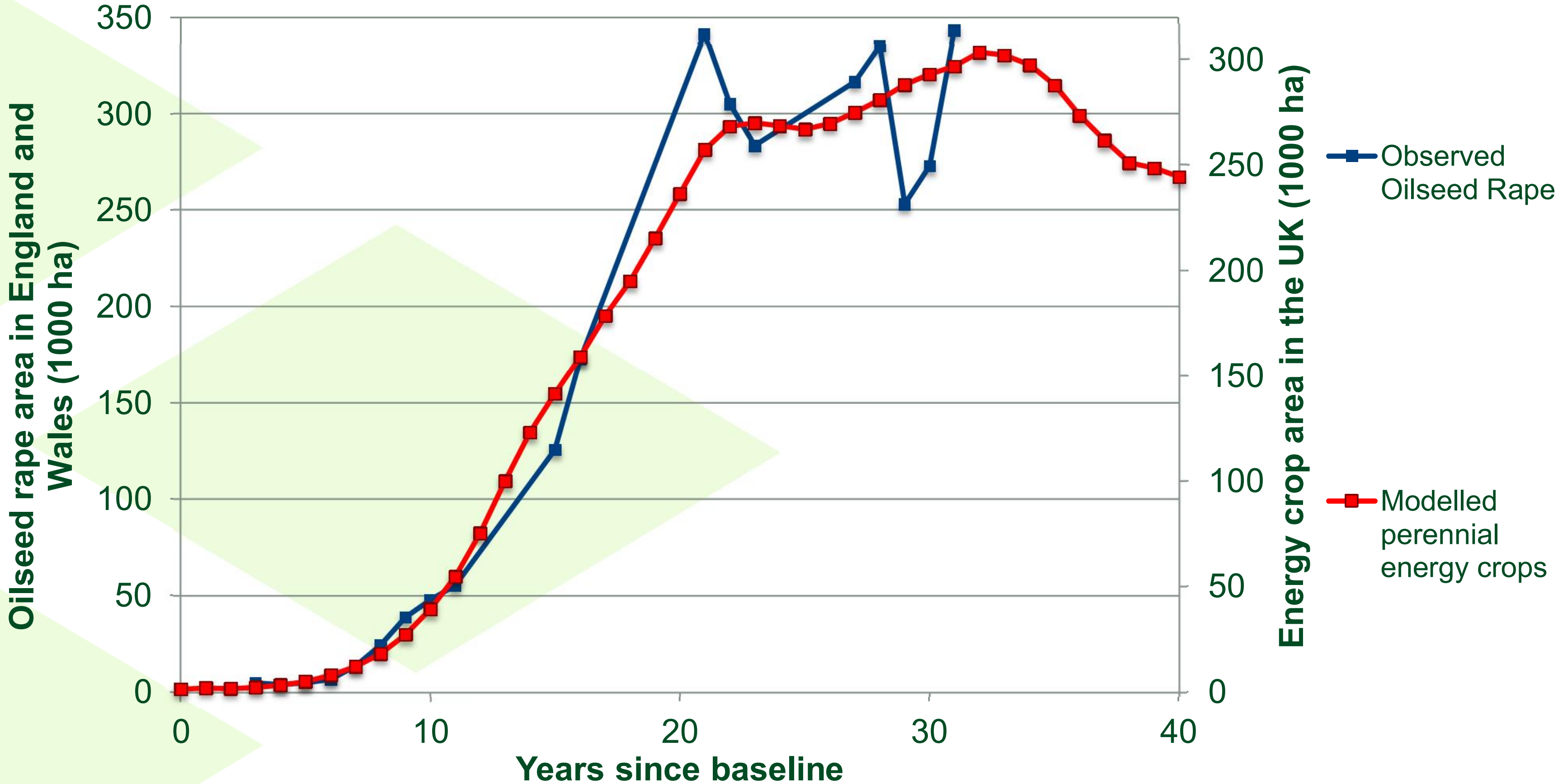
Energy crop supply in biomass energy terms over time for 12 model runs

Spatial diffusion pattern



Sample output maps of energy crop selection and power plant locations between 2010 and 2050.

Comparison with oilseed rape adoption



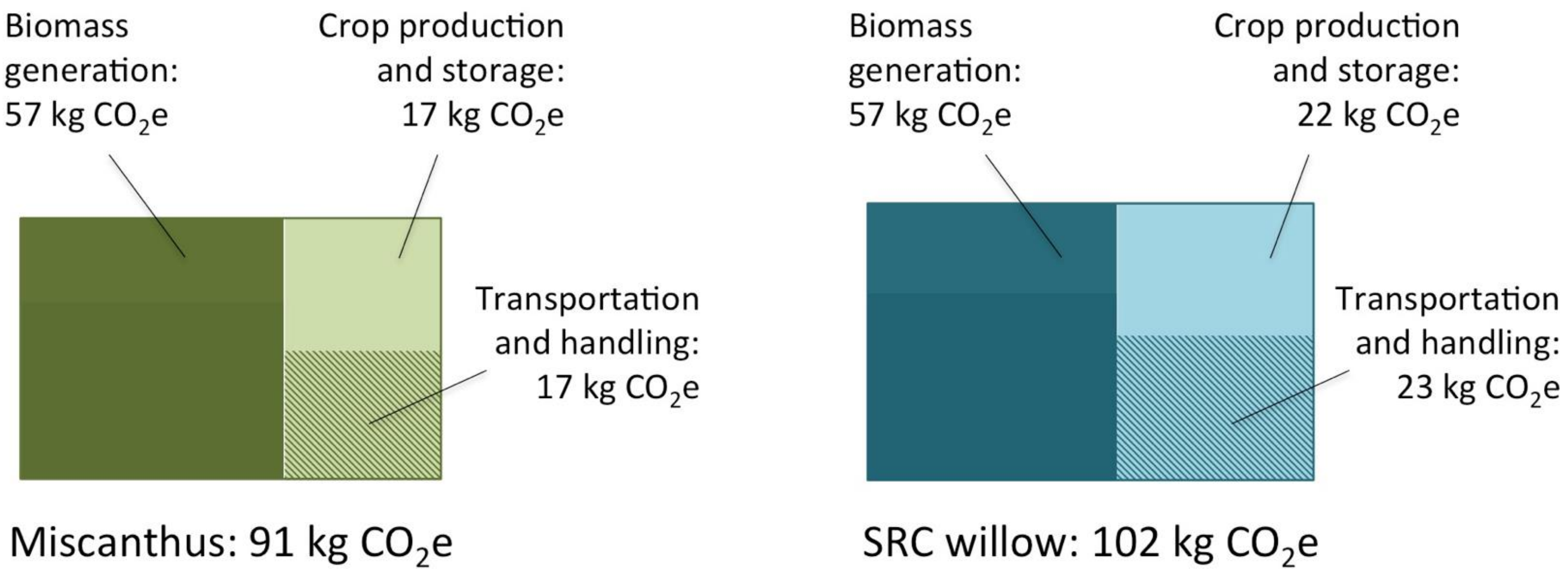
Historic oilseed rape data for England and Wales, against a baseline year of 1966, and mean modelled perennial energy crop areas, using a baseline year of 2010.

Comparison to previous studies

- Adoption lower and slower than previous studies
  - 39,000 ha in 2020
    - Between 9 and 25 times lower than previous figures[5, 6]
  - 236,000 ha in 2030
    - Between 6 and 9 times lower than previous figures[7,8]
- Evidence behaviour arises from spatial diffusion
  - High initial farmer adoption rate bring results broadly into line with these previous results.

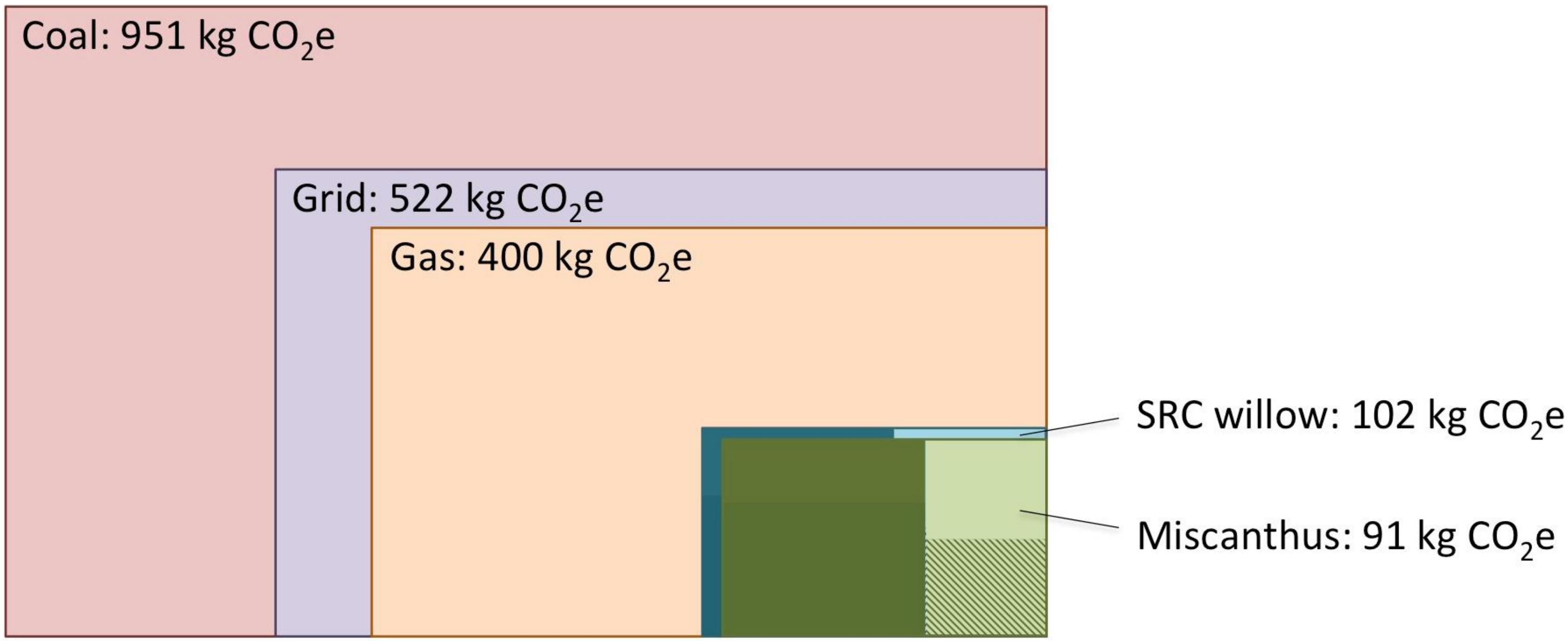
[5] DEFRA (2007) Biomass Strategy. *Department for Environment Food and Rural Affairs*.
[6] Gill B, MacLeod N, Clayton D, Cowburn R, Roberts J, Hartley N (2005) Biomass Task Force. *Report to government. London, UK*.
[7] Bauen AW, Dunnett AJ, Richter GM, Dailey AG, Aylott MJ, Casella E, Taylor G (2010) Modelling supply and demand of bioenergy from short rotation coppice and Miscanthus in the UK. *Bioresource Technology*, **101**, 8132–43.
[8] E4tech (2009) Biomass supply curves for the UK.

Energy crop electricity emissions



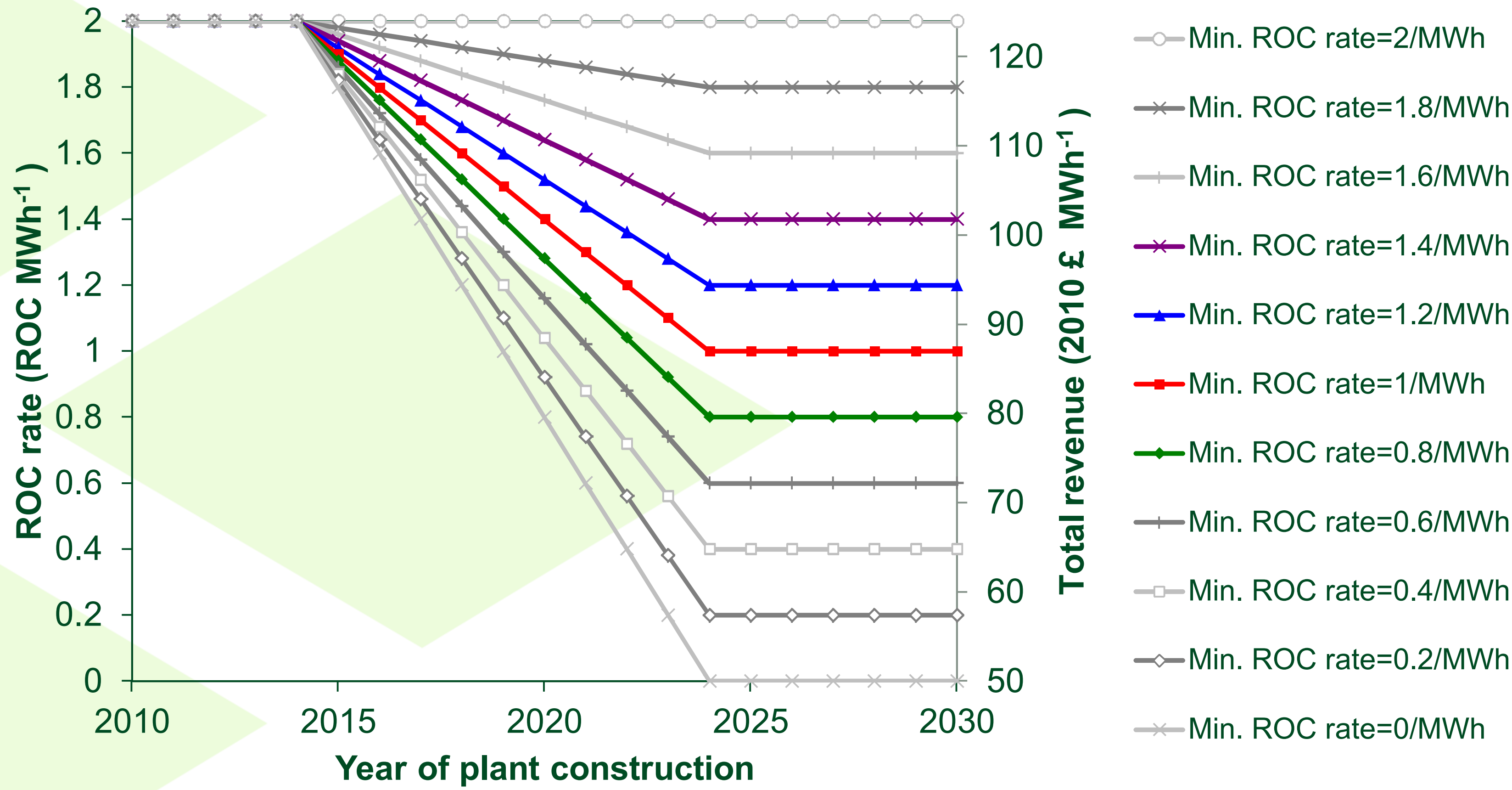
CO_2 equivalent emissions for 1MWh of electricity generated from Miscanthus and SRC willow, assuming a yield of 12 odt ha^{-1} and a 50 km transportation distance, area proportional to emissions.

Comparative electricity emissions



Total (direct and indirect) emissions, as CO_2 equivalent, to generate 1MWh of electricity in the UK.

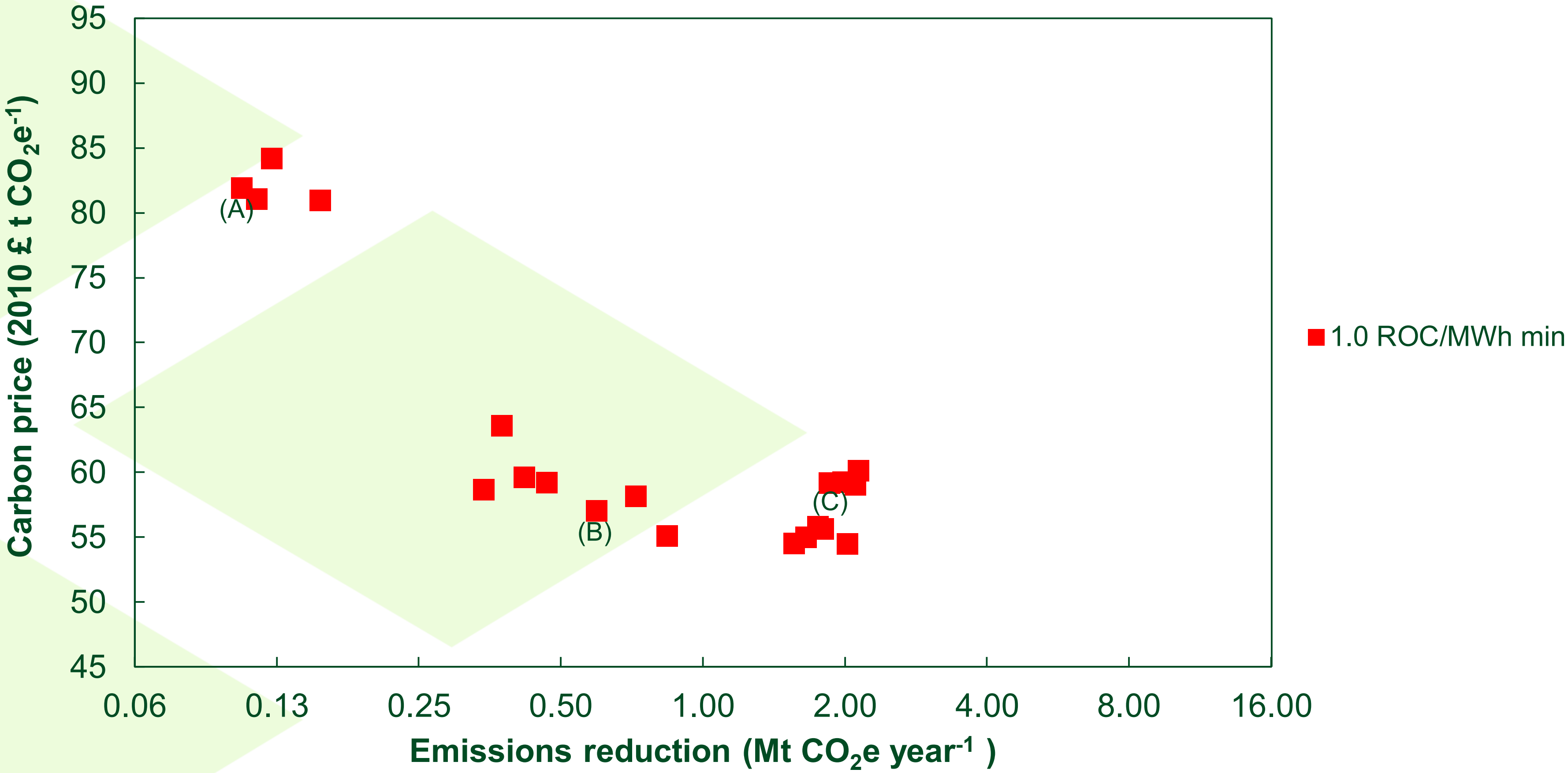
Electricity generation policy scenarios



Renewable Obligation Certificate (ROC) rates scenarios by year of plant construction

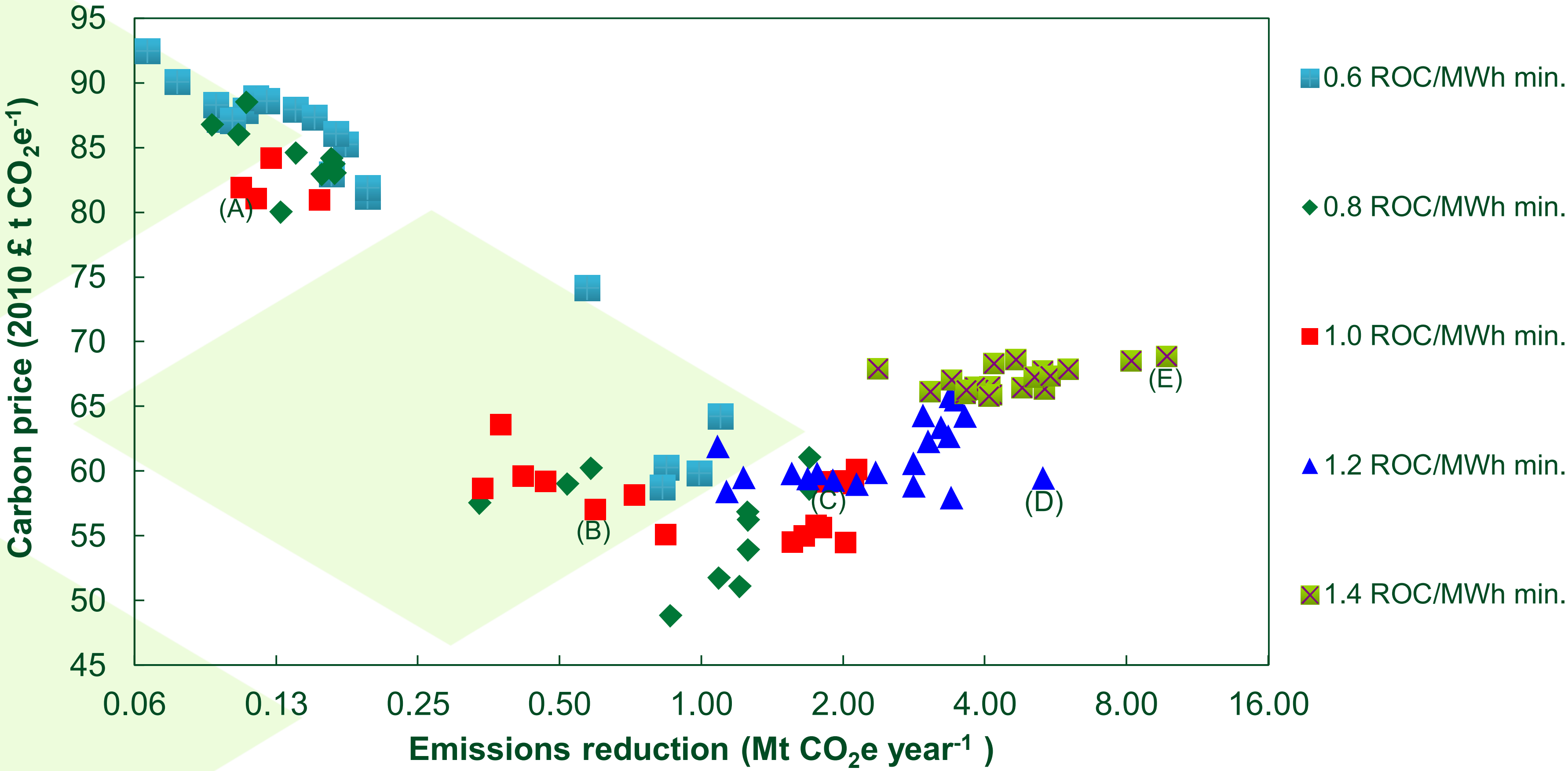
Carbon price and abatement for runs

SRUC



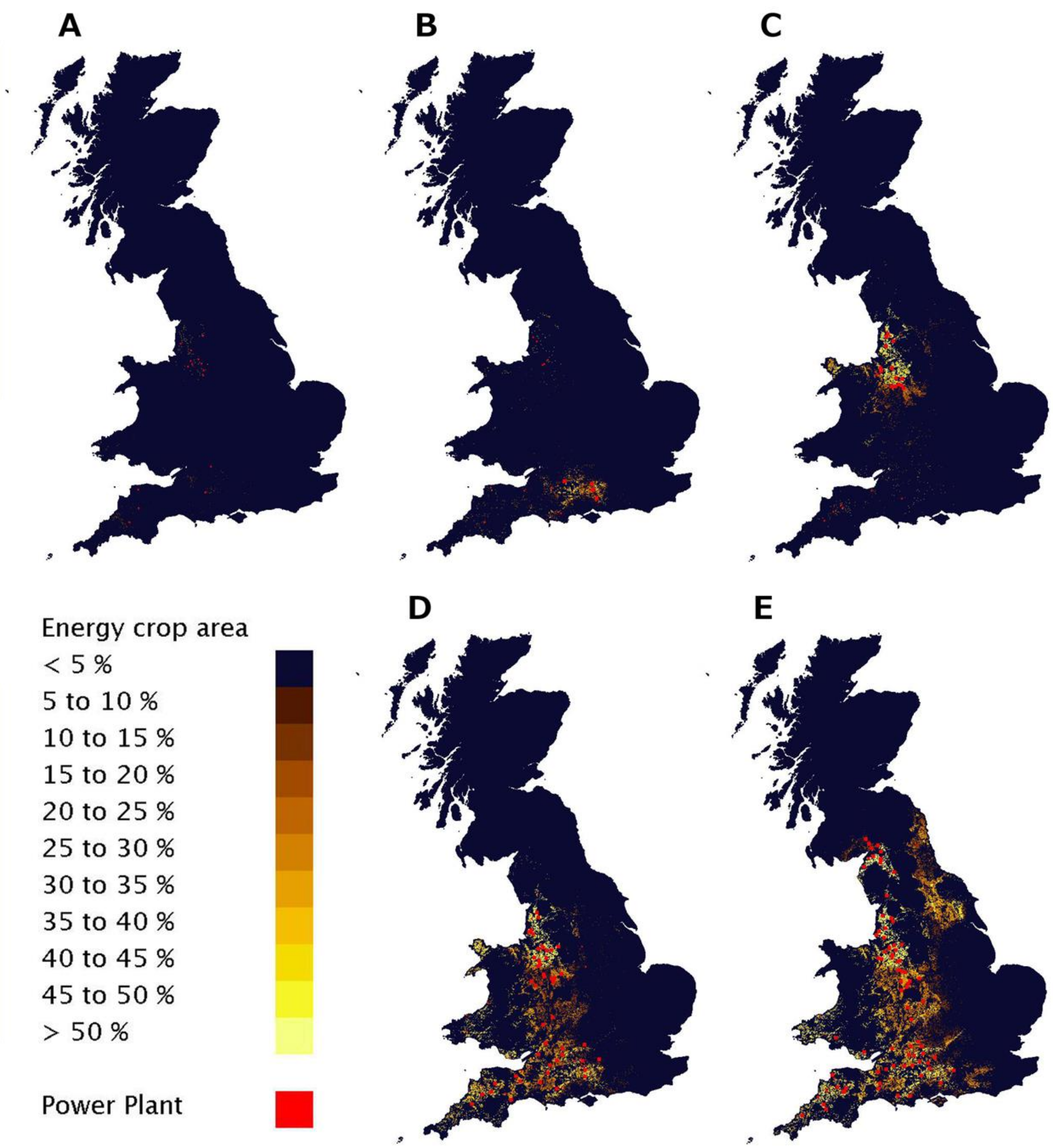
Scatter plot of individual runs with various ROC rates and 50% establishment grant showing cost of carbon abatement against emission reduction, with coal generation displaced

Carbon price and abatement for runs



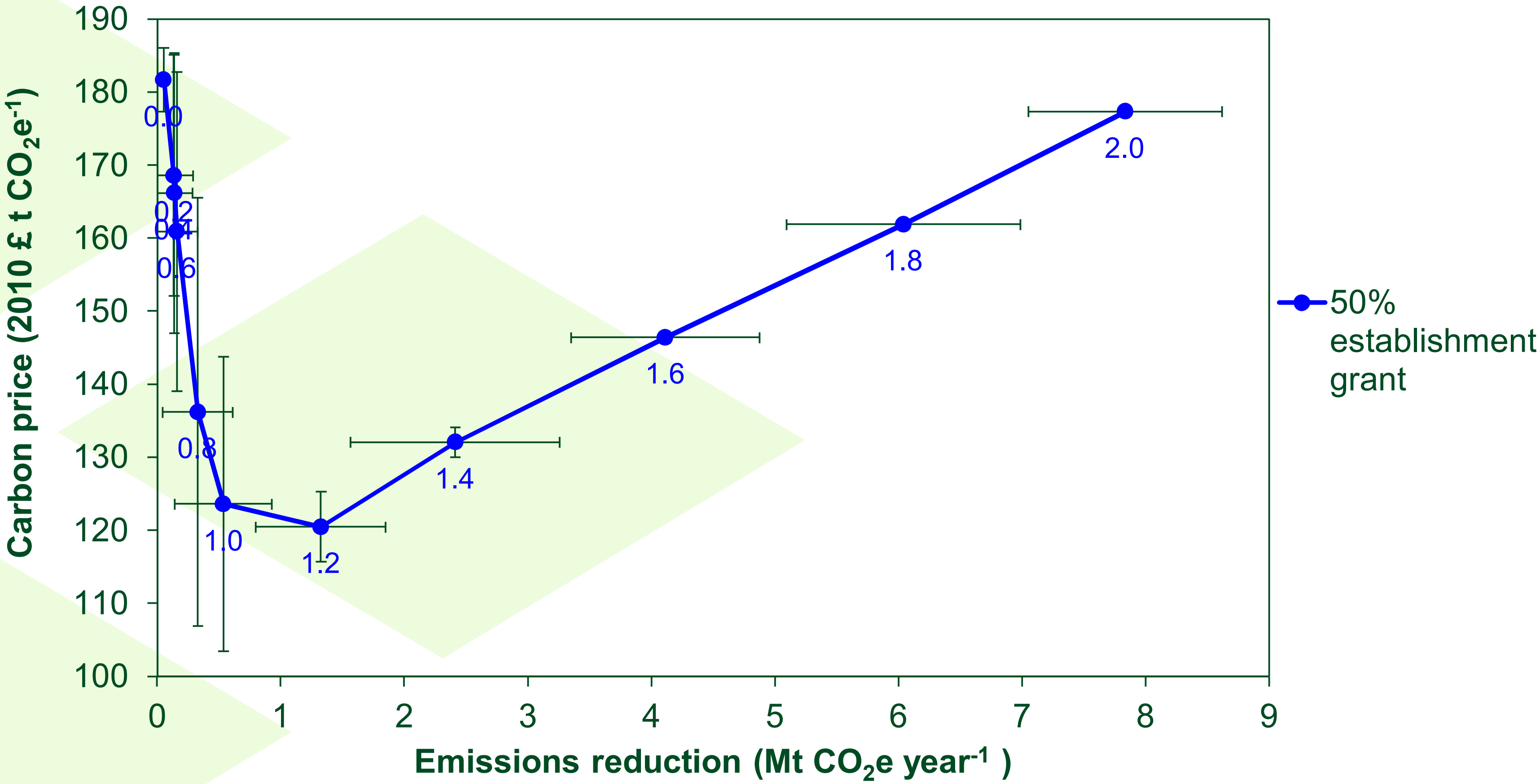
Scatter plot of individual runs with various ROC rates and 50% establishment grant showing cost of carbon abatement against emission reduction, with **coal generation displaced**

Example spatial distributions



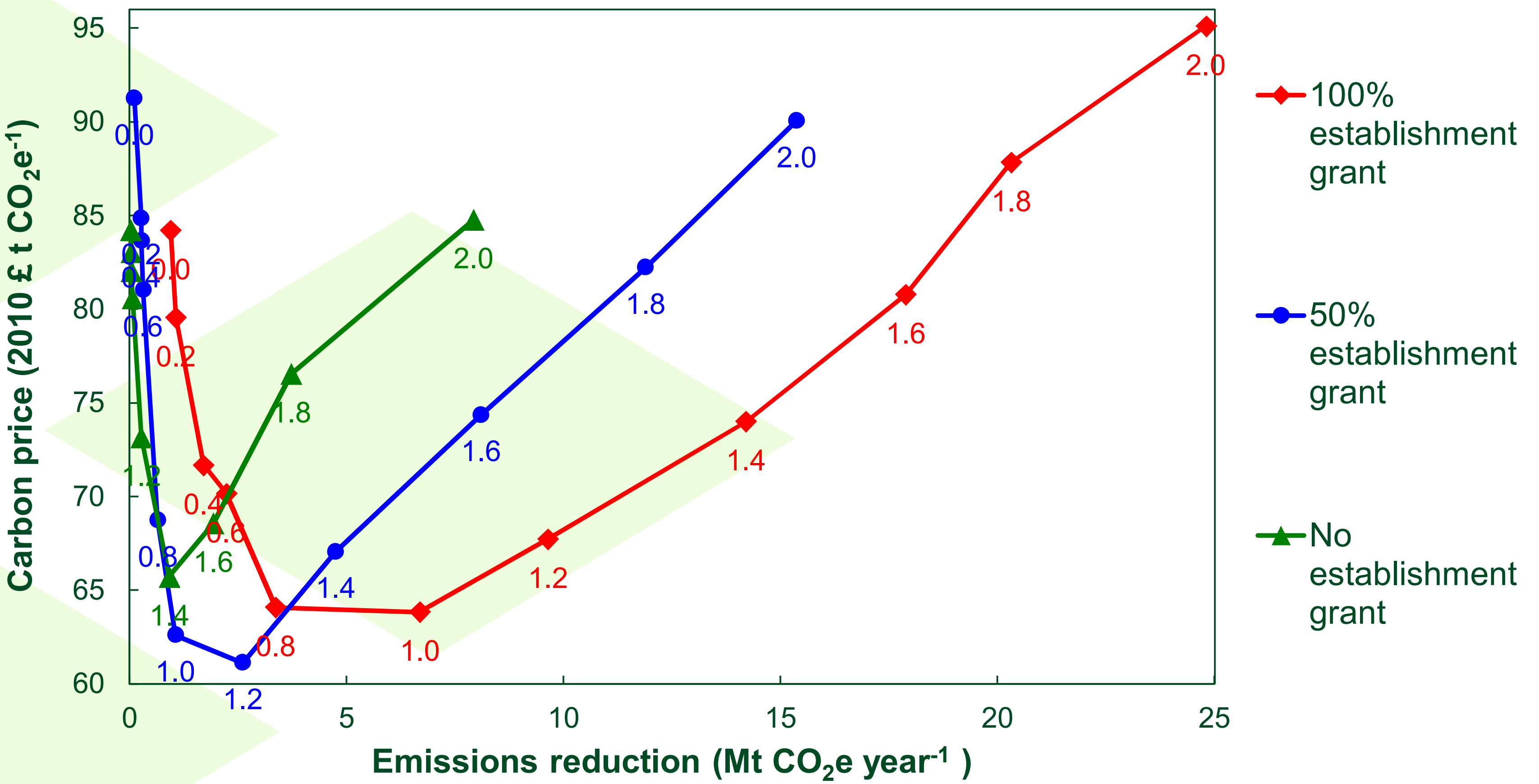
Example distributions of energy crop selection and power plant locations at 2040, A,B & C from examples 1.0 ROC MWh^{-1} minimum ROC rate scenario, D & E showing highest CO_2 equivalent abatement from 1.2 & 1.4 ROC MWh^{-1} minimum ROC rates runs runs

Carbon abatement (grid average)



Carbon price against emission reduction, using gird average generation displacement, as minimum ROC rate is varied with 50% establishment grant, error bars showing standard deviations from a set of 20 runs

Carbon abatement (coal)



Cost of carbon abatement against annual emission reduction for various subsidy policies, assuming displacement of coal generation. Values below points show the minimum ROC rates (ROC MWh^{-1}) used in that scenario

Conclusions

- Area of UK perennial energy crops may be less than previously published due to time lags in farmer adoption
  - Implications for land use change or adoption of other novel crops or technologies.
- Farm support may lower overall costs and increase abatement
- Minimum abatement cost at intermediate energy generation subsidy level

Potential further work

- New policy mechanisms
- Other biomass facilities
  - CHP, co-firing, bio-refineries
- Other sources of biomass
  - Short-rotation forestry, agricultural and forestry residues
- Increased geographic area
- Imports
  - Exogenously specified supply
  - International trade model
- Imperfect market competition

Questions

Thank you…