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

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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

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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

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]

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

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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

• Spatially explicit crop yields, 1km² 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

Set of farmer agents manage agricultural land
- Receive establishment grant
- Buy farm inputs
- Sell crops
- Imports and other exogenously priced biomass supply
- Farmer agents select energy crops based on their preferences, quality of land, transportation costs and market prices.
- Previous experiences or local adoption rate threshold used to determine willingness to considering energy crops.

Single delivered market price adjusted by market conditions
- Sell crops
- Receive price signal
- Buy biomass
- Imports and other exogenously priced biomass supply
- Neighbour adoption rate
- Default case: 2.5% initial rate
- High initial willingness to consider case: 25% initial rate

Set of power plant investor agents control market demand
- Buy biomass
- Sell electricity
- Receive subsidies
- Power plant locations selected based on meeting internal rate of return target and sufficient local supply.
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

Year: 2050
Misc. Price: £93 od t\(^{-1}\)
SRC Price: £75 od t\(^{-1}\)
Misc. Area: 178 kha
SRC Area: 77 kha
Installed Cap: 630 MW
Supply ratio: 108.0 %

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.

[^8]: E4tech (2009) Biomass supply curves for the UK.
Energy crop electricity emissions

CO₂ 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\textsubscript{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
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 price against emission reduction, using grid 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\textsuperscript{-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...