Incorporating impacts on water and land use in an energy systems analysis – a case study for the UK

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34\textsuperscript{th} International Energy Workshop
Abu Dhabi, 3\textsuperscript{rd} – 5\textsuperscript{th} June 2015
Motivation

- Strong interdependencies between the most important resource systems, esp. energy, water and land use
- Growing research focus on the resource nexus
- Quantitative systems approach needed to analyse the impacts of low-carbon energy transitions on other resource systems

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Energy / water / food security
Equitable & sustainable development
Resilient eco-systems
The resource nexus in energy modelling

Overview on existing approaches

- **Integrated Assessment Models (IAMs)** that analyse the interactions between human activities and physical earth systems on an aggregate scale
- First studies on the economic implications of the resource nexus with macroeconomic models
- Growing number of **technology-focused, bottom-up nexus frameworks**: CLEWS, the WEF Nexus tool, PRIMA

Importance of the regional perspective for integrated nexus analyses

Hibbard and Janetos (2013) highlight the necessity of “an integrated regional modelling approach that accounts for the dynamic interactions among physical, ecological, biogeochemical, and human processes and provides relevant information to regional decision makers and stakeholders”

This analysis

**Objective**: analyse the implications of potential low-carbon energy transitions in the UK on the wider resource use (water and land use)

**Methodology**: Soft-linking the optimizing energy system model UKTM with the resource nexus accounting tool Foreseer UK
UKTM – The UK TIMES Model

• **Overview**
  Integrated energy systems model - Least cost optimization - Partial equilibrium - Technology rich - sensitivity and uncertainty analysis

**Successor of UK MARKAL**

• **New functionality of UKTM**
  - Higher temporal flexibility; storage
  - All GHG emissions & non-energy mitigation options;
  - Industrial & residential sector disaggregation;

• **Open source modelling**
  - Transparency at the forefront of development
  - Full open source release in summer 2015
  - Strong policy engagement

• **Ongoing research development**
  - Behaviour & fuel poverty
  - Land-Energy-Water nexus
  - Macro-economic impacts;
  - Spatial & temporal detail
  - Technology learning
The resource nexus model Foreseeer UK

**ENERGY-WATER-LAND CONNECTIONS**

- **Energy**
  - Mechanised farming
  - Bioenergy feedstock
  - Extraction, refining, transformation

- **Land**
  - Irrigation
  - Water quality

- **Water**
  - Irrigation

**DEMAND DRIVERS**

- Increased demand for:
  - Food
  - Water
  - Housing
  - Energy

**POPULATION GROWTH**

- Increased demand for:
  - Food
  - Water
  - Housing
  - Energy

**CLIMATE CHANGE**

- Increased:
  - Irrigation
  - Drought
  - Floods
  - Cooling and heating

**GHG REDUCTION**

- Demand for Low-carbon energy:
  - CCS
  - Bioenergy
UK Energy System 2010 – main connections to Land & Water
Methodology for soft-linking

The analysis is triggered by UKTM → One-directional link of UKTM energy system results to Foresee UK

**Whole energy system model**

UKTM

**Energy system results:**
- Technology deployment (supply & demand)
- **Fuel use** (domestic extraction & imports)

**Least-cost pathways for the UK energy system**

**Resource nexus tool**

Foresee UK

**Accounting of land and water use for the energy system**
# Energy scenarios for UKTM

Two low-carbon scenarios (-80% GHG reduction until 2050)
- alternative energy futures for the UK
- with different availability of technologies and resources that are particularly sensible for water and land use

### Optimistic

<table>
<thead>
<tr>
<th>High availability of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: &gt; 1900 PJ in 2050</td>
</tr>
<tr>
<td>Nuclear: up to 79 GW in 2050</td>
</tr>
<tr>
<td>CCS: up to 50 GW in 2050</td>
</tr>
</tbody>
</table>

### Pessimistic

<table>
<thead>
<tr>
<th>Low availability of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: &lt; 400 PJ in 2050</td>
</tr>
<tr>
<td>Nuclear: up to 10 GW in 2050</td>
</tr>
<tr>
<td>CCS: not available</td>
</tr>
</tbody>
</table>
Land use scenarios for Foreseer UK

Three land scenarios (based on change of energy crop yields to 2050)

→ **LBAU** - Business-as-usual no change in yield relative to 2010

→ **YIELD10** - 10% improvement in bioenergy crop yield to 2050

→ **YIELD30** - 30% improvement in bioenergy crop yield to 2050

Two assessments were carried out:

A. Comparison with 900kha of "sustainable" land use change - according to the Bioenergy Review (DECC, 2012) - **physical feasibility**

B. Comparison with area of UK unused arable land – **availability of land**
Water scenarios for Foreseer UK

Two water scenarios (based on cooling technology and future location of power plants):

→ **WBAU** Business-as-usual - same cooling technology mix and distribution of sites power stations as current.

→ **CNUC** – Constrained Nuclear – total nuclear capacity on the coast limited to the currently licensed 16GWe to 2030.

Assessment:

Comparison of water abstraction under each water scenario with current limits to total abstraction on a national basis – assessment of potential conflicts between energy and water management policies in UK.
UKTM results (1)

Primary energy consumption

GHG emission reduction in 2050 (compared to 2010)

Modelling the resource nexus
Birgit Fais
UKTM results (2)

Electricity capacity in 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fossil fuels</th>
<th>Nuclear</th>
<th>Biomass</th>
<th>Biomass CCS</th>
<th>Wind</th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTIMISTIC</td>
<td>62%</td>
<td>6%</td>
<td>7%</td>
<td>6%</td>
<td>18%</td>
<td>6%</td>
</tr>
<tr>
<td>PESSIMISTIC</td>
<td>30%</td>
<td>32%</td>
<td>6%</td>
<td>6%</td>
<td>28%</td>
<td>6%</td>
</tr>
</tbody>
</table>

* Total installed capacity in 2050

Bioenergy use in 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electricity generation</th>
<th>Hydrogen generation</th>
<th>Industry</th>
<th>Residential</th>
<th>Services &amp; Agriculture</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTIMISTIC</td>
<td>1914 PJ</td>
<td>14%</td>
<td>65%</td>
<td>91%</td>
<td>21%</td>
<td>375 PJ</td>
</tr>
<tr>
<td>PESSIMISTIC</td>
<td>21%</td>
<td>91%</td>
<td>65%</td>
<td>14%</td>
<td>375 PJ</td>
<td>1914 PJ</td>
</tr>
</tbody>
</table>

* Total installed capacity in 2050
UKTM results (3): Cost indicators

Carbon price

Difference in annual undiscounted welfare cost

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>PESSIMISTIC</td>
<td>0%</td>
<td>5%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>vs. OPTIMISTIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulated 2010 - 2050</td>
<td>6% (£1080 Bn)</td>
<td></td>
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</tbody>
</table>
Land Area for **UK bioenergy feedstock production** - projections to 2050 for the UKTM Optimistic and Pessimistic energy scenarios

- OPT - LBAU
- OPT - Y10
- OPT - Y30
- PESS - LBAU
- PESS - Y10
- PESS - Y30
- Sust. Limit
  - UKBS2012
  - Unused Arable land

**Area of Land/kha**

**Years:**
- 2010
- 2015
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
Foreseer Land Impact Assessment (2) – Solar PV

Land Area for **ground mounted PV** - projections to 2050 for the UKTM Optimistic and Pessimistic energy scenarios

- Low grade land UK (grade 4 & 5)
- PV - PESS
- PV - OPT
Total water abstraction for UK energy system - projections to 2050 for the UKTM Optimistic and Pessimistic energy scenarios

- OPT - WBAU
- OPT - CNUC
- PESS - WBAU
- PESS - CNUC
- Abstraction Limit

Modelling the resource nexus
Birgit Fais
Summary of Foreseer analysis

→ **Optimistic energy scenario** has higher land and water impacts across most land and water scenarios

→ **Optimistic energy scenario** with potential conflicts with water and land use management policies

**OPTIMISTIC**

**Impact on land** – does not meet sustainability criteria (900kha for bioenergy), availability of land borderline in 2050

**Impact on water** – constrained nuclear significant impact on water resources – above 2010 water abstraction levels

**PESSIMISTIC**

**Impact on land** – meets sustainability and availability criteria

**Impact on water** – below 2010 abstraction levels for both water scenarios
Conclusions

- Integrated nexus analyses highlighting the interactions between long-term decarbonisation strategies and the wider resource use will play an essential part in designing consistent and holistic environmental policy instruments.

- Soft-linking an optimizing energy system model and a resource nexus model can help to highlight the trade-offs between least-cost decarbonisation pathways for the energy system and wider environmental impacts.

- Not all decarbonisation strategies are automatically “no-regret” options for the environmental system!

- **Future work:**
  - Increase spatial disaggregation
  - Feedback link from Foreseer to UKTM to present environmental limits directly in the energy system analysis.
Thank you for your attention!

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This research was supported under the Whole Systems Energy Modelling Consortium (WholeSEM) – Ref: EP/K039326/1
www.wholesem.ac.uk/
Conclusions from Foreseer analysis - Land

→ Pessimistic energy scenario has lower land use impact across all land scenarios.

→ Optimistic energy scenario - land area requirements above land use sustainability criterion for all land yield improvement scenarios and could require more than available unused arable land in 2050

→ Pessimistic energy scenario – meets both sustainability criterion and availability of land in 2050

→ Optimistic energy scenario could face significant deployment issues, as rate of production after 2040 ramps up significantly – could be an issue for perennial crops.

→ No substantial land availability issues for ground mounted PV – max. of 16% of low quality land for PV in 2050 for Pessimistic energy scenario.
Conclusions from Foreseer analysis - Water

→ Generally both energy scenarios could have **impact on fresh and tidal water** resources **similar to current system** (actual 2010).

→ **Impact on coast could be significant for the Optimistic energy scenario** – as this requires more than 40GWe of nuclear generation on the coast – higher than the 16GWe currently licensed.

→ If new nuclear coastal sites limited to 16 GWe (**Constrained Nuclear scenario**) – fresh and tidal water abstractions substantially higher than 2010 levels – **Optimistic energy scenario** could have **significant water impacts and potential conflicts with water management policies**.