Electronic Supplementary Material (ESI) for Energy and Environmental Science


# Estimating bio-energy resource potentials to 2050: Lessons from the UK experience – Electronic Supplementary Information

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## Research Protocol

The research presented in this article was undertaken using a systematic review methodology pioneered by the Technology and Policy Assessment (TPA) function of the UK Energy Research Centre, led by Imperial College. The TPA function aspires to raise the standard of evidence available to policymakers and practitioners in the energy field. Systematic review is an *evidence based* approach that is common in areas such as education, criminal justice and healthcare. The goal is to achieve high standards of rigour and transparency, however, it is important to recognise that energy policy gives rise to a number of difficulties for prospective systematic review practitioners (discussed in detail by Sorrell [1]). We have therefore set up a process that is inspired by the evidence based approach, but that is not bound to an overly prescriptive method or technique.

The assessment followed a generalised approach developed for all TPA work, outlined in Figure 1 below. The search terms and databases examined are listed in Tables ESI.1 and ESI.2

An overview of the studies reviewed in the main report is provided in Table ESI.3. A summary of the estimates contained in each study is shown in Table ESI.4

***Figure ESI. 1 – process for TPA studies***

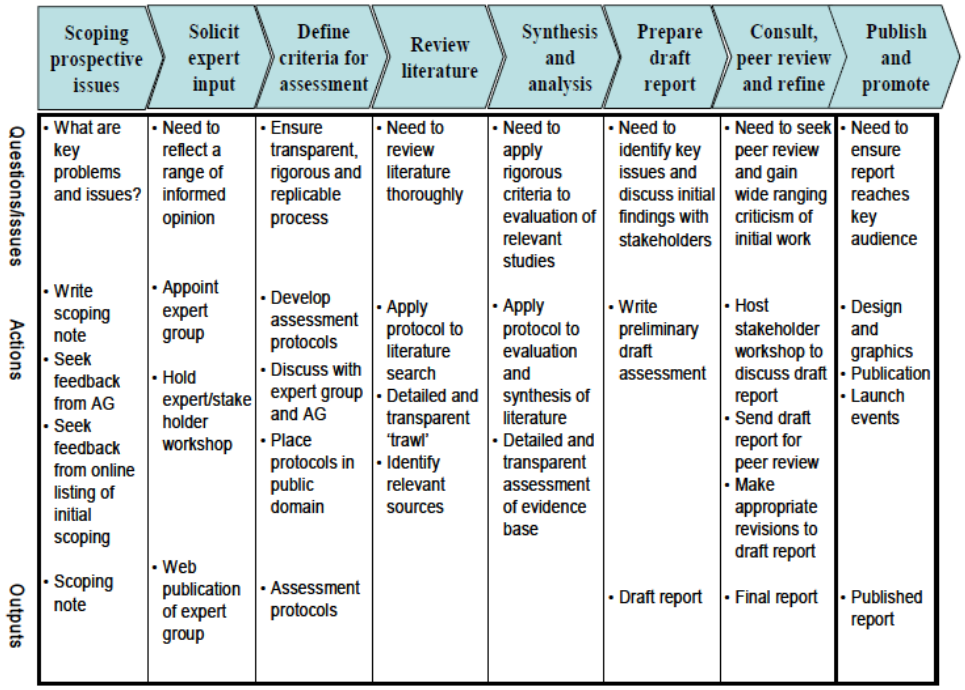


***Table ESI.1: Search terms included in the systematic review***

| | | | |
|---|---|---|---|
| • Bioenergy | • Resource assessment | • Methods | • UK |
| • Biomass | • Potential | • Yield | • World |
| • Short rotation coppice | • Resource potential | • Constraints | • Europe |
| • Energy crops | • How much | • Estimates | |
| • Miscanthus | • Land availability | | |
| • Energy from waste | • Supply | | |
| | • Production | | |

*Table ESI.2: Databases and other information sources included in the search*

| |
|---|
| **Databases / search engines** |
| Elsevier 'Science Direct' |
| Google Scholar |
| **Ongoing research projects** |
| TSEC Biosys |
| Supergen Bioenergy |
| RELU |
| Foresight Land Use Futures |
| Foresight Global Food and Farming Futures |
| Biomass Bioenergy Europe |
| Biomass futures |
| **UK Governmental and related organisations** |
| DECC |
| BERR |
| DEFRA |
| DTI archive |
| Carbon Trust |
| WRAP |
| EEA |
| NNFCC |
| Biomass Energy Centre |
| Forestry commission |

***Table ESI.3: Approach, timeframe and definition of potential used in the reviewed studies***

| Study Label | Definition of potential | Focus and approach | Time-frame |
|---|---|---|---|
| Oxera02 | Constrained technical potential | UK electricity only - a summary of regional assessments. Biomass figures estimated using a bottom up resource inventory informed by GIS mapping | 2010 |
| E4 Tech03[a] | Technical potential (constrained / unconstrained) | UK electricity only - bioenergy fuel chain analysis. Report develops fuel chains populated with literature data, these are used to estimate the % contribution to UK electricity | 2020 |
| RCEP04 | Theoretical potential based on land use scenarios | UK electricity and heat. Resource inventory combined with a top down estimate of land requirement for energy crops to meet a 16GW by 2050 target. | 2005 and 2050 |
| CT05 | Existing potential plus estimate of land availability | Inventory of all major UK biomass sources excluding MSW. Resource inventory from literature sources. Top down estimates for each resource type moderated by expert judgement | 2005 and "future" |
| Taskforce05 | Existing potential | UK biomass for energy (excl. biofuels). Resource inventory with simple availability assumptions, includes MSW | 2005 |
| AEA05 | Technical potential | UK biomass for heat. Resource inventory based on previous literature, includes MSW | 2020 |
| UKBioStrat07 | Technical potential | UK Biomass. Resource inventory estimate assuming no impact on existing markets. Based on same dataset as Taskforce05, MSW included but not explicit. | 2010 and “future” |
| E&Y07 | Technical and market potential | Renewables for heat, including UK biomass. Biomass figures are derivative of AEA05 and CT05. I.e. a resource inventory based on previous literature. Inventory includes MSW. | 2020 |
| EEA07 | Potential not leading to environmental harm | EU Focus, UK is included as one datapoint. Resource focussed assessment predicated on modelled land availability and top-down estimates of residue availability overlaid with sustainability criteria | 2010, 2020, 2030 |
| Fischer07 [b] | Technical potential based on land use scenarios | EU Focus, report estimates bio-mass for biofuels potential. Resource focussed assessment, land availability and productivity estimated using GIS databases. Self sufficiency ratios used to subtract land required for food and fodder crops. Inventory includes woody crops and residues. | 2000, 2030 |
| Kilpatrick08[c] | Existing potential plus future land use scenarios | UK Biomass for energy. Detailed UK resource inventory. Estimates of Land availability and the potential availability of materials from existing sectors based on expert judgement | 2010, 2030 |

| Study Label | Definition of potential | Focus and approach | Time-frame |
|---|---|---|---|
| E4tech09 | Market potential and technical potential | UK biomass supply curves. Supply curves estimated using existing resource inventory literature and scenarios. Notable inputs include EEA07, Kilpatrick08. | 2010, 2020, 2030 |
| Thornley09 | Sustainable potential | Sustainable UK bio-energy resource potential. Literature based resource inventory overlaid with sustainability criteria and constraints. Includes MSW | No date |
| deWit09 | Technical potential based on land availability scenarios | EU cost and supply potential, UK included as a single data point. Bottom up cost and resource assessment from detailed spatial yield modelling driven by top-down estimations of land availability assuming productivity gains and a "food first" paradigm. | 2030 |

[a] To derive a figure for total UK biomass potential it was assumed that that total UK electricity use was 234 TWh.yr-1 The conversion efficiency to electricity given in the report was 40%.
[b] 2030 figure is a rough estimate for the UK based on Fischer's land suitability distribution, suggested average yield for biofuel crops and assumed planted area of 1.1Mha
[c] Results converted from oven dry tonnes to PJ using a conversion factor of $17GJ.odt^{-1}$.

***Table ESI.4: Summary of estimates of potential included in the reviewed studies.*** *Estimates are grouped into five categories: agricultural residues, forestry and forest residues, perennial energy crops, conventional energy crops and wastes.*

| Report | Year of estimate | Agricultural residues PJ.yr$^{-1}$ | Forestry and forestry residues PJ.yr$^{-1}$ | Perennial energy crops PJ.yr$^{-1}$ | Conventional energy crops (grain/oil seed) PJ.yr$^{-1}$ | Wastes PJ.yr$^{-1}$ | Total - Primary energy PJ.yr$^{-1}$ | Notes |
|---|---|---|---|---|---|---|---|---|
| Oxera02 | 2010 | | 42.0 | | | 64.8 | 106.8 | 2010 low - electricity only - Agricultural residues and forestry not differentiated |
| Oxera02 | 2010 | | 42.0 | 36.0 | | 93.6 | 171.6 | 2010 high - electricity only - Agricultural residues and forestry not differentiated |
| E4Tech03[a] | 2020 | 52.7 | 0.0 | 126.4 | 0.0 | 92.7 | 271.7 | Constrained potential - figure shown here is derived from % contribution of biomass to UK electricity supply presented in original report |
| E4Tech03[a] | 2020 | 61.1 | 0.0 | 252.7 | 0.0 | 139.0 | 452.8 | Future unconstrained tech potential |
| RCEP04 | 2005 | 75.0 | 13.0 | 0.2 | | | 88.2 | |
| RCEP04 | 2050 | 75.0 | 25.0 | 550.0 | | | 650.0 | |
| CT05 | 2005 | 46.8 | 21.6 | 0.7 | | 79.2 | 266.4 | 2005 |
| CT05 | 2020 | 46.8 | 21.6 | 118.8 | | 79.2 | 299.8 | Future Low (no date - assumed 2020) |
| CT05 | 2020 | 46.8 | 21.6 | 151.2 | | 80.2 | 191.3 | Future High (no date - assumed 2020) |
| Taskforce05 | 2005 | 40.5 | 21.9 | 3.9 | 0.0 | 135.5 | 201.8 | |
| Taskforce05 | 2005 | 49.5 | 26.0 | 6.7 | 0.0 | 156.5 | 238.7 | |
| AEA05 | 2020 | 60.5 | 22.2 | 69.4 | | 625.0 | 777.0 | Technical potential - assumes Calorific value of AD gas is primary energy |
| UKBioStrat07 | 2010 | 40.5 | 23.6 | 2.8 | | 166.8 | 233.7 | 2010 low |
| UKBioStrat07 | 2010 | 49.5 | 27.6 | 4.0 | | 201.0 | 282.0 | 2010 high |
| UKBioStrat07 | 2020 | 128.7 | 70.4 | 64.7 | 0.0 | 316.2 | 580.0 | Future Low (no date - assumed 2020) |

| Report | Year of estimate | Agricultural residues PJ.yr$^{-1}$ | Forestry and forestry residues PJ.yr$^{-1}$ | Perennial energy crops PJ.yr$^{-1}$ | Conventional energy crops (grain/oil seed) PJ.yr$^{-1}$ | Wastes PJ.yr$^{-1}$ | Total - Primary energy PJ.yr$^{-1}$ | Notes |
|---|---|---|---|---|---|---|---|---|
| UKBioStrat07 | 2030 | 137.7 | 74.4 | 65.9 | 50.0 | 350.4 | 678.3 | Future High (no date - assumed 2030) |
| E&Y07 | 2020 | | | | | | 225.0 | Technical potential - low |
| E&Y07 | 2020 | | | | | | 1073.0 | Technical potential - high |
| E&Y07 | 2020 | | | | | | 96.0 | Market potential - low |
| E&Y07 | 2020 | | | | | | 180.0 | Market potential - High |
| EEA07 | 2010 | | 62.8 | 142.4 | | 360.1 | 565.2 | Wastes includes agricultural residues |
| EEA07 | 2020 | | 62.8 | 368.5 | | 364.3 | 795.5 | Wastes includes agricultural residues |
| EEA07 | 2030 | | 46.1 | 615.5 | | 360.1 | 1021.6 | Wastes includes agricultural residues |
| Fischer07 | 2000 | 194.0 | | | | | 194.0 | |
| Fischer07[b] | 2030 | 174.0 | | 235.0 | | | 409.0 | |
| Kilpatrick08[c] | 2010 | 137.9 | 71.5 | 1.5 | | 39.0 | 250.0 | |
| Kilpatrick08[c] | 2030 | 158.4 | 71.5 | 248.0 | | 39.0 | 516.9 | |
| E4Tech09 | 2010 | 13.8 | 6.4 | 0.0 | | 145.3 | 165.5 | Constrained |
| E4Tech09 | 2020 | 69.0 | 36.8 | 134.0 | | 343.2 | 583.0 | |
| E4Tech09 | 2030 | 69.0 | 36.8 | 538.0 | | 440.2 | 1084.0 | Unconstrained - effectively the same as the technical potential |
| Thornley 2009 | 2020 | 18.0 | 12.8 | 44.0 | 43.3 | 95.1 | 213.2 | Sustainable potential (not date - assumed 2020) |
| de Wit09 | 2030 | 200.0 | 25.0 | 225.0 | | | 450.0 | |

[a] To derive a figure for total UK biomass potential it was assumed that that total UK electricity use was 234 TWh.yr-1 The conversion efficiency to electricity given in the report was 40%.
[b] 2030 figure is a rough estimate for the UK based on Fischer's land suitability distribution, suggested average yield for biofuel crops and assumed planted area of 1.1Mha
[c] Results converted from oven dry tonnes to PJ using a conversion factor of 17GJ.odt$^{-1}$.

1. S. Sorrell, *Energy Policy*, 2007, **35**, 1858-1871.