ELUM Software Package
User Documentation

Version 1.3
February 2015

Contents

1. Description

The ELUM software package allows users to obtain estimates of soil greenhouse gas (GHG) fluxes caused by land-use transitions to grow bioenergy crops anywhere in the UK, up to the year 2050.

1.1 Overview

Results may be obtained for any combination of the following:

Transitions:

From:

- Arable (including all rotational crops)
- Grass (permanent)
- Forest

To:

- Wheat
- Oil Seed Rape (OSR)
- Sugar Beet
- Short Rotation Coppice (SRC) Willow
- Short Rotation Forest (SRF) Poplar

- Miscanthus

N.B. Transitions from arable to wheat, OSR and sugar beet assume no transition takes place, i.e. the initial arable use is the same as the end use. Transitions from arable to all other land uses assume that arable is wheat (see below for further description of rotational crops).

Output variables:

- CO_2 (net carbon dioxide exchange)
- CH_4 (net methane exchange)
- N_2O (net nitrous oxide exchange)
- Soil C (net change in soil organic carbon)
- GHG ($CO_2 + CH_4 + N_2O$)

Outputs are for net biome productivity (i.e. excluding harvested plant material). All definitions are positive for emissions, except for soil C which is positive for sequestration. Soil C (as carbon dioxide equivalent) is the negative of CO_2 due to the sign convention and the insignificant contribution of CH_4 to C flux from the soil (note that CH_4 only has a significant contribution to net GHG flux due to its high global warming potential). Maps of CO_2 and soil C therefore appear the same, with only the colour-bar showing any difference.

Units:

- t CO_2e /ha (cumulative net tonnes of carbon dioxide equivalent per hectare of land)
- t CO_2e /odt (cumulative net tonnes of carbon dioxide equivalent per oven-dry tonne of harvest mass; N.B wheat and OSR are not odt, and contain 14% and 9% moisture respectively)

Carbon dioxide equivalent values for each emission are calculated according to IPCC inventory 100-year global warming potentials (IPCC, 2001).

Time:

- Transitions occur in 2015
- Results are provided in 5 year increments up to a maximum end year of 2055

N.B. 2055 results are extrapolated from 2050 results, and are only included for compatibility with other projects.

Area:

- Selection by:
  - Coordinates:
    - Single point
    - Circle
    - Rectangle
  - Areas:
    - Countries
    - Regions
    - Counties
    - Districts

A 1km grid is used for all results.

N.B. Although a single grid point can be selected, confidence in results is greater over larger areas, where variability in uncontrolled factors averages out.

Climate change:

- Low
- Medium
- High

Climate projections are obtained from UKCP09 unperturbed scenarios.

Land-cover and constraints masks:

- Existing land-cover mask:
  - When applied, per-hectare outputs are rescaled according to the appropriate fractional land-cover, giving the effective per-hectare value for each grid cell.
- Constraints mask:
  - Results are excluded for inappropriate land; users can select the level of mask, but a minimum mask is imposed for all results.

Fertiliser:

- Percentage of Defra recommendation.

Yield:

- Percentage of estimates based on current technology and practice.

Further details are provided in the Outputs, Model and Data sections.

1.2 Result types

Description of results:

- Results are for the difference between the transition and no transition, and therefore show directly the effect of the transition itself.
- Results account for changes in vegetation and land management associated with the transition.
- Results are cumulative up to each time point.
- Users are responsible for correctly interpreting results. Please see the sections on model outputs and the model itself for further information.

The following are not considered:

- Irrigation of crops.
- Autotrophic respiration (respiration from the crop and its roots; this is excluded as it has no long term effect on net GHG).
- Land-use reversion (transitioning to another land-use after growing bioenergy crops).
- Associated emissions (emissions of farming processes, manufacturing, transportation and power generation from the biomass feedstock).
- Mitigation of emissions (the effects of using bioenergy in place of other energy sources).
- Indirect land-use change (changes in the use of other land caused by transitions to grow bioenergy crops).

Results are presented as:

- Spatial maps, from red (worse) to yellow (better).
- Time-series graphs.
- Frequency distribution histograms.
- Files which can be opened as a spreadsheet or in a GIS.

Further to obtaining results for different land-use transitions, options also exist to compare the effects of transitions. For each variable, the following can be obtained spatially and temporally:

Analysis:
- Minimum
- Maximum
- Mean
- Range (maximum-minimum)
- Ratio (maximum/minimum)
- Standard deviation
- Index of minimum (i.e. which transition gives the minimum value)
- Index of maximum

1.3 Requirements

The ELUM software package is supplied as a stand-alone folder which does not require installation; the folder can be stored anywhere on the computer and administration privileges are not required.

In order to use the ELUM software package, the following requirements apply:

Computing requirements:
- Microsoft Windows, 32-bit or higher.
- Java installed (www.java.com); Java may need updating if it is already installed.
- 5GB free data storage space to store the software package.
- Over 5GB further free storage space for results, depending on the number and spatial extent (see Outputs for further information).
- Approximately 1GB of RAM or higher.

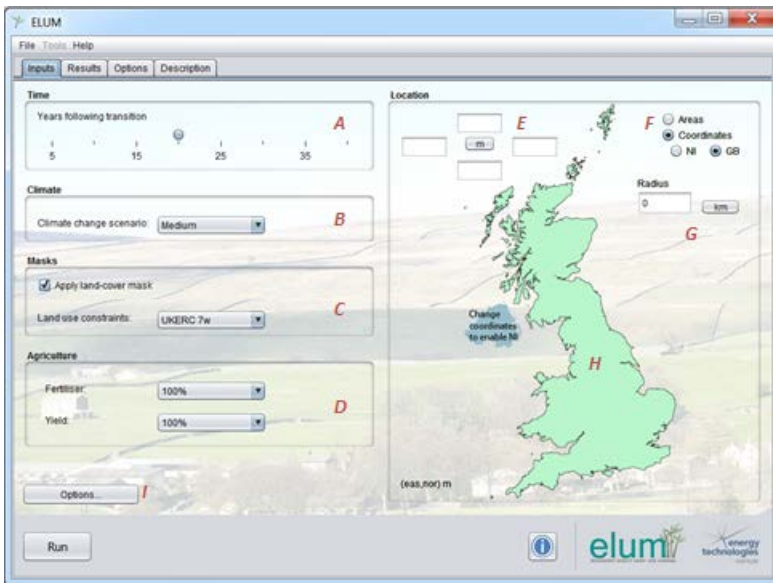
2. Operation

2.1 User selections

The graphical user interface (GUI) is divided into 4 tabs, from which all options can be accessed.

2.1.1 Inputs tab

Users are able to select from a range of options to obtain results according to their interests:

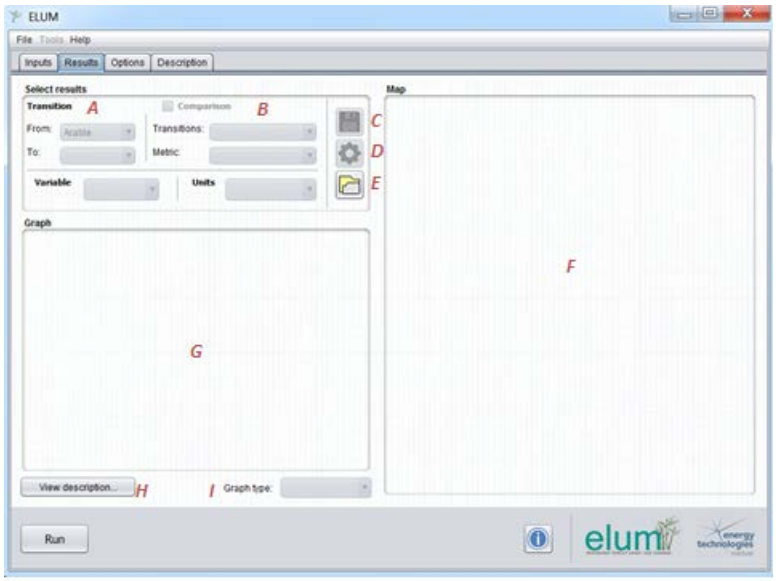


- Time (*A*):
  - Slide to select time period for results.
- Climate (*B*):
  - Select climate change scenario from drop-down list.
- Masks (*C*):
  - Select existing land-cover mask on or off.
  - Select level of constraints mask from drop-down list.
- Agriculture (*D*):
  - Select fertiliser options from drop-down list (as a percentage of Defra recommendations (Defra, 2010)).
  - Select yield options from drop-down list (as a percentage of estimates based on current technology and methodology).
- Location:
  - Coordinates (GB or NI, using British or Irish National Grid respectively) (*F*):
    - For a single grid cell, click a single point (*H*); the coordinates of the current cursor location are shown at the lower left-hand corner of the map. The selected coordinates are shown in the coordinates text boxes *(E)*, and the nearest grid cell will be identified in the meta-model.
    - Click and drag rectangle (*H*).
    - Enter coordinates (in m) in text boxes (*E*) for either a single point (i.e. minimum and maximum values are equal) or a rectangle; click button in centre of text boxes to update map. Coordinates are for the south-west corner of each grid cell.
    - For a circle, select a single point and enter the radius (in km) in text box (*G*); click adjacent button to update map.
  - Areas (*F*); n.b. map view will be replaced by a text list:
    - Select level of region from radio buttons.
    - Click on region(s) in list:
      - For multiple selections, hold Shift or Ctrl while clicking (for continuous or discontinuous selections respectively).
      - Enter initial letter to skip to place name.

- Options button (*I*):
    - Click to go to the Options tab; this allows users to pre-select what results to obtain as well as plotting and file options.

2.1.2 Results tab

Users are able to load, view, save and process results:

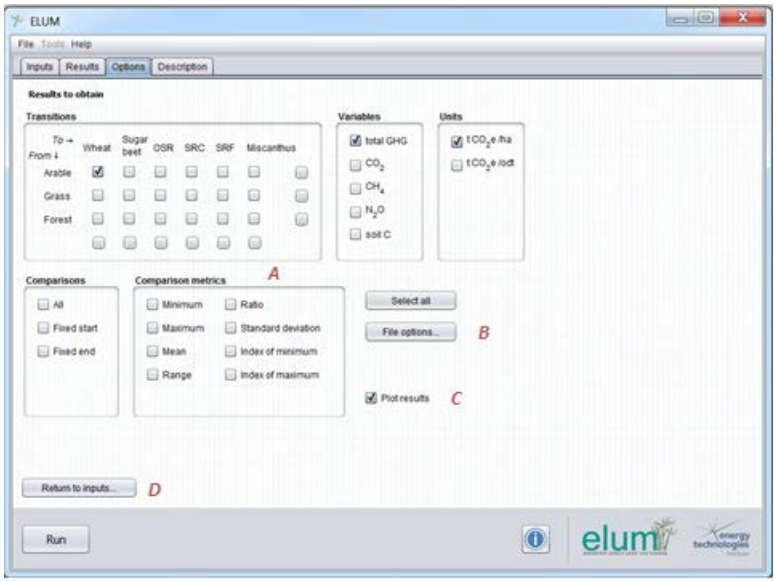


- Loading results (*E*):
    - Saved results can be loaded by clicking the Load Results button, or by selecting Load Results from the File menu, or clicking Ctrl+O:
        - This will open a file chooser window, from which users can select any folder which contains results from the ELUM software package.
        - The user inputs and options which correspond to the results will also be loaded in the Inputs tab and Options tab respectively, along with a description in the Description tab.
        - Following simulation, no action is required to load results as this is done automatically.
- Viewing results:
    - Users can select what results to view from the drop-down lists (*A*).
    - Availability of results is dependent on selections made in the Options tab prior to running the program:
        - Selections are shown in grey if unavailable.
        - Permitted selections in each drop-down list are updated according to other current selections. Depending on what results are available, users may sometimes need to select a greyed-out option in one drop-down list in order to obtain a particular selection in another drop-down list.
    - If results have not already been plotted (because 'Plot results' in the Options tab was not selected and the result has not already been selected), results will be plotted upon selection. If the selected results are not displayed, then:
        - Check results for selected the option exist (see above).

        - If results exist, re-select any of the drop-down lists to prompt plotting again.
    - Comparisons can be viewed by clicking the Comparison check box, if these have been enabled by users (*B*):
        - For comparisons with a fixed start or end land-use, these can be selected from the respective drop-down Transitions lists on the left.
    - Maps (*F*):
        - Maps show the spatial results at the end of the selected time period.
        - Users can adjust the map display:
            - Zoom in and out by using the mouse scroll wheel or by using the zoom buttons and slider at the lower right-hand corner of the map panel.
            - If zoomed in, the map can be scrolled by dragging the image.
            - For convenience, the current zoom and scroll is automatically applied when selecting different results.
    - Graphs (*G*):
        - Users can select (*I*) from two types of graph showing summation results:
            - Time series:
                - Shows the summed or averaged emissions for the selected area at each time point in the selected time period.
            - Histogram:
                - Shows the frequency distribution of emissions at the end of the selected time period, i.e. the number of grid cells which contain emissions within specified value ranges.
- Tools (*D*)
    - Users can convert loaded results to different formats by clicking the Tools button, or by selecting Tools from the menu bar.
    - If users do not wish to convert all loaded results, the Options tab can be used to restrict which results are converted, using the same check boxes as for choosing which results to obtain. Selections will be ignored for any results which do not already exist.
    - Results can be converted to (see Format conversion for details):
        - Ascii Grid files.
        - Keyhole Markup Language (kml) files.
        - BVCM format.
- Saving results (*C*):
    - Loaded results (including all model outputs, plots and converted files, as well as the corresponding user inputs) can be saved to any location by clicking the save button; users can alternatively select Save Results from the File menu, or click Ctrl+S.
    - Using the file chooser, users must create a new folder to save the results to, or choose an existing ELUM results folder to overwrite.
    - For large folders, this process may take some time, as it involves copying all files and subfolders. In order to remove the need to perform the save process, users may pre-select a folder to save results to before running the program (see 'Set output folder', under 'File options' in the Options tab).
- Description button (*H*):
    - Click to go to the Description tab; this allows users to view a description of the loaded results.

2.1.3 Options tab

Users can pre-select results of interest, as well as selecting plotting and file options:



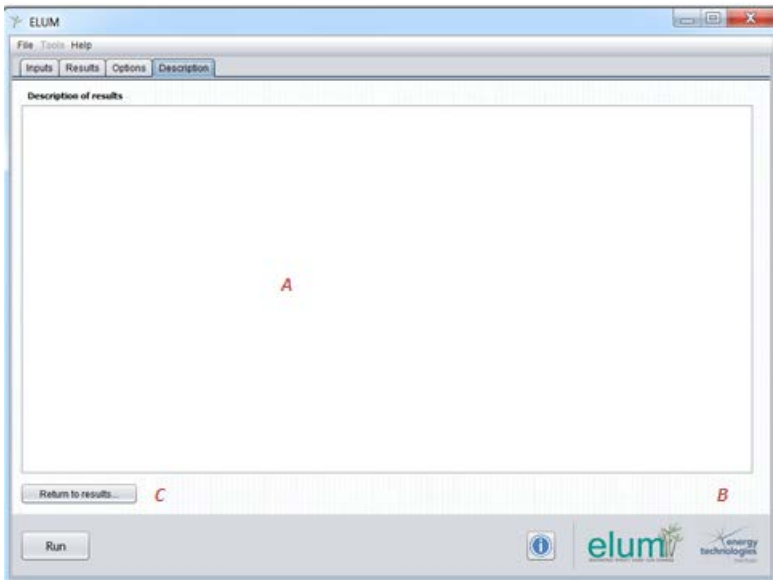
N.B. Obtaining and plotting results can take a long time to complete, depending on the selected area and number of different results. The duration will depend on the computer being used, but can range from a few seconds to a few hours, hence pre-selection is advised to obtain only results of interest.

- Results check boxes (*A*):
  - Results for only one transition, variable and units are obtained by default.
  - Users can choose to obtain results for all transitions, variables and units they are interested in by using the check boxes prior to running.
- Plot results check box (*C*):
  - Users may select whether to plot automatically all results, in order to make viewing quicker.
  - If not selected, results will be plotted when they are selected in the Results tab; in this case, the initial run time will be shorter, but the time taken to view each result for the first time will be longer.
- File options (*B*); these can also be accessed from the File menu, or by the shortcuts noted for each:
  - Set output folder (Ctrl+F):
    - To avoid using the default temporary results folder, users may pre-select an output folder for results before running the program.
    - Results will be saved to the specified location, which removes the need to perform the potentially slow task of saving results later.
  - Set data source folder (Ctrl+D):
    - If users wish to store the source data in a location other than the default directory, or wish to use alternative source data (see Data description), the data source folder can be specified.

        - If the source data folder does not exist in the default location, then users will be prompted to specify its location before obtaining results.
    - Save inputs (Ctrl+I):
        - User inputs can be saved without obtaining results.
    - Load inputs (Ctrl+P):
        - Saved user inputs can be loaded into the Inputs tab.
- Inputs button (*D*):
    - Click to go to the Inputs tab.

2.1.4 Description tab

Users are able to view a description of the loaded results:



This tab contains a description of what user options were selected for the displayed results, as well as details of results files (*A*).

For new results (rather than saved results which have been loaded), the time taken to obtain the results is shown at the lower right-hand corner of the tab (*B*). While the meta-model is running, the elapsed time is shown here.

Click the Results button (*C*) to go to the Results tab.

2.2 Run

In order to obtain results, users can simply click the Run button at the lower-left hand corner of the program window. A progress bar will be displayed while results are obtained, during which time the operation may be cancelled by clicking the Cancel button (which replaces the Run button while running). Results may also be obtained by selecting Run from the File menu, or by clicking Ctrl+R. While the programming is running, the elapsed time is shown at the lower right-hand corner of the Description tab.

3. Outputs

3.1 Description of results

3.1.1 Spatial results

- Results are provided for each grid cell in the selected area, at each time point in the selected time period; further details of how the results are obtained are provided in the model description.
- Results for the final time point are used to plot the corresponding map.
- Results are cumulative net values.
- Results for t CO_2e /odt assume a hypothetical harvest yield up to that time point (e.g. for SRF, the crop is only harvested every 20 years, but results assume an annual harvest equal to the annual dry matter yield).
- The result for each grid cell is an average of the result for each of the soil types present (up to a maximum of 5) within the cell, weighted according to the fractional coverage of each soil type; this is performed since there is no way of knowing which soil types are under what land-uses in each cell.
- Land-cover mask effects (see Masks for further details):
    - Existing land-cover:
        - If the existing land-cover mask is applied, t CO_2e /ha results are adjusted by the fractional land-cover for the initial land-use for each grid cell, hence results show the effective result for the whole grid cell, rather than the result for the land that is used (i.e. the results represent a combination of the emissions and the available land).
        - If the existing land-cover mask is not applied, the t CO_2e /ha results show emissions from the land that is used, but no information is provided on how much land, if any, is available for the initial land-use in each grid cell.
        - Results for per-odt values are not affected by the mask, except for excluding results from grid cells where the mask shows there is no land available.
    - Constraints:
        - Results are excluded from inappropriate grid cells (due to environmental constraints); if the grid cell is permitted then results are not affected.

3.1.2 Summation of spatial results

- Time series:
    - Results are summed at each time point for the selected area:
        - If the existing land-cover mask is applied, the effective t CO_2e /ha result for each grid cell is multiplied by the size of the grid cell and added together to give a total t CO_2e value, which represents the expected total value for the selected area if all available land (according to the land-cover map) were used.
        - If the existing land-cover mask is not applied, and for all t CO_2e /odt results, the mean rather than total is plotted, which is the mean of emissions on productive land.

    - Summation files also contain other results, as described in the Result file format section.
- Frequency distribution:
    - Results are summed at the end of the selected time period in order to obtain the frequency distribution of results.
    - Only grid cells which contain results are included (i.e. null values are excluded from the frequency distribution).
    - Results are grouped into discrete intervals (or 'bins'); the number of bins is equal to the square root of the number of grid cells present which contain results (rounded down to the nearest integer), as is common for frequency distributions.
    - A separate file is created, as described in the Result file format section.

3.1.3 Comparison results

- Spatial results are compared between different transitions according to a range of analysis metrics.
- These spatial comparisons are also summed, similarly to summation of spatial results.
- The summation of some comparison metrics differs from other results due to the nature of the metric, as described in the Result file format section.

3.1.4 Yields

For simplicity, yields are not directly reported in the package, but yield data files may be accessed from the look-up table, and maps of mean yields are shown in the description of the yield models. Alternatively, the odt/ha yield can be inferred by dividing the t CO_2e /ha result by the t CO_2e /odt result (n.b. if the land-cover mask has been applied to results, then this will give the effective yield per hectare of each grid cell; remove the land-cover mask to obtain the yield per hectare of productive land, which is the more commonly required value). Either of these options could be performed in a spreadsheet application (such as Microsoft Excel) or a GIS.

Yields are stored in the look-up table as cumulative values for oven-dry harvest mass. The values reflect total mass up to each time point. Mean annual yields within a specified time range can be obtained by subtracting the first yield value from the last, and dividing by the number of years between the two values. Further details and maps of yields are provided in the description of the yield models.

Recorded yields measure the following quantities:

Crop	**Yield measurement**
Wheat	Combined grain and baleable straw mass*
Sugar beet	Root mass
OSR	Seed mass
SRC	Above ground harvest mass
SRF	Above ground harvest mass
Miscanthus	Above ground harvest mass

*For wheat, baleable straw is assumed to be harvested with the grain. The following values can be

used to disaggregate the grain and baleable straw fractions (Stoddart and Watts, 2012):

- Fraction of above ground biomass at harvest which is grain ('harvest index'): 0.51
- Fraction of above ground biomass at harvest which is baleable straw: 0.258

N.B. wheat and OSR are not odt, and contain 14% and 9% moisture respectively. The yields are not used directly in the model but are used to calculate plant inputs of C to the soil. The use of non-odt values will not qualitatively affect results, because both of these 1st generation crops perform very poorly on a GWP basis, even with the slightly elevated yields (and corresponding plant inputs to the soil). If the wheat/OSR yields were correctly converted to dry weight, the plant inputs to the soil from these crops would be proportionately lower (14% and 9% respectively), resulting in a higher net GWP following conversion of grass/forest to these two crops (conversion from arable is treated as a null transition for 1st generation crops). In terms of the individual crop impacts on soil this error is noticaeble, but it is within the year-to year variation in crop yield. The error will be magnified when considering t CO2e/ odt, but will still qualitatively hold. More importantly, the net GWP following conversion from grass and forest to 1st generation bioenergy crops is dominated by soil C released as a result of soil disturbance during crop establishment. A 14% and 9 % variation in crop yield will have very little impact on the overall net GWP within the 35 year simulation period, particularly as these crops have low C inputs to the soil; the issue is therefore minor.

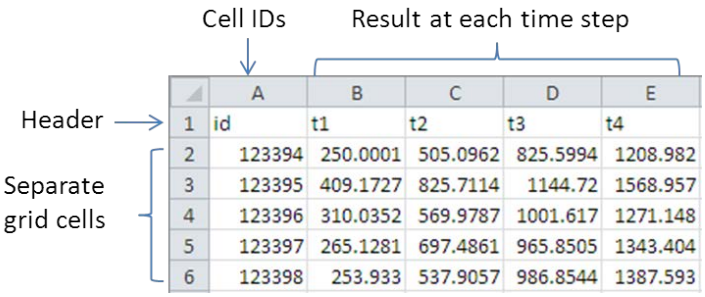
3.2 File format

Users may be interested in the format of outputs in order to process them externally to the ELUM software package.

3.2.1 Result files

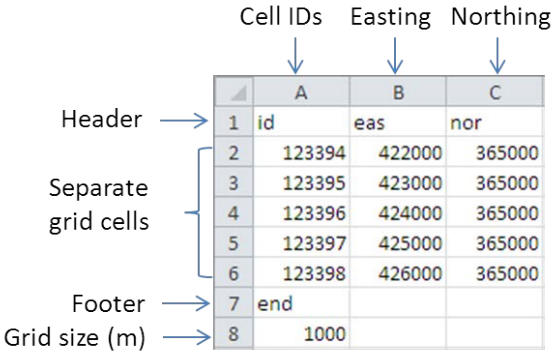
- Results from a model run are collected in a single folder (as described below).
- A separate file is created for each output variable and transition (e.g. LUs1\LUe1\var1.csv is the result for variable 1 (as defined in the description file) for the land-use transition from LUs1 to LUe1).
- A single grid file is created which gives the coordinates of each grid cell (called grid.csv); the cell id (and row) of each point in the grid file corresponds to those in each result file. Coordinates are for the south-west corner of each grid cell, following convention for the National Grid.
- Files are output in a comma separated value (csv) format, which can be opened in a spreadsheet application (such as Microsoft Excel) or in a text editor; the column delimiter is a single comma.
- Null value is -999.0 (indicating no result).
- Results in the final column are used to plot the map displayed in the GUI (these are the cumulative results for the final time point).

Result file example:



	A	B	C	D	E
1	id	t1	t2	t3	t4
2	123394	250.0001	505.0962	825.5994	1208.982
3	123395	409.1727	825.7114	1144.72	1568.957
4	123396	310.0352	569.9787	1001.617	1271.148
5	123397	265.1281	697.4861	965.8505	1343.404
6	123398	253.933	537.9057	986.8544	1387.593

Grid file example:



	A	B	C
1	id	eas	nor
2	123394	422000	365000
3	123395	423000	365000
4	123396	424000	365000
5	123397	425000	365000
6	123398	426000	365000
7	end		
8	1000		

3.2.2 Summation files

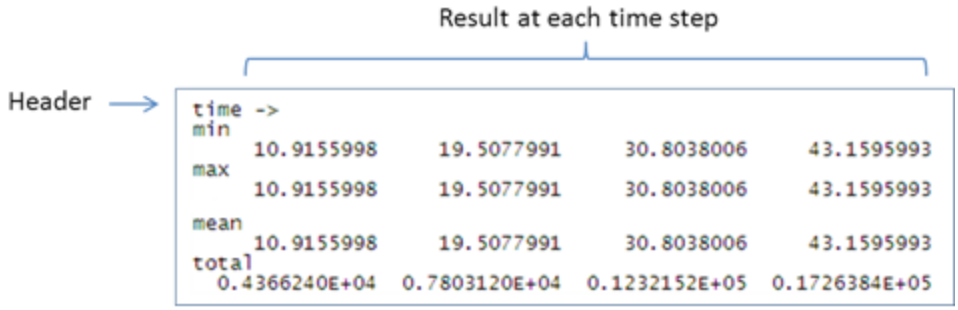
For each result file, a corresponding summation file is also created:

- Summation files contain information for the entire area covered in the corresponding result file.
- Summation results are obtained for each time step.
- Types of result in the summation files depend on the corresponding result file:
    - All summation files (except index of minimum/maximum comparisons) contain, in order:
        - Minimum value
        - Maximum value
        - Mean of values
    - Summation files for per-hectare outputs with the land-cover mask applied also contain:
        - Summed total accounting for land area
    - Summation files for comparison results have the following changes:
        - For the ratio metric of per-hectare values, no total is calculated.
        - For the standard deviation metric of per-hectare values, the total is obtained as a Pythagorean sum (due to the nature of combining standard deviations) instead of an area-adjusted sum.
        - For index of minimum/maximum comparisons, the mode is calculated in place of any other summation result.
- Results in the final row of summation files are used to plot the time-series graph displayed in the Results tab (for per-hectare units with the land-cover mask, this is the total value over the whole area; for per-odt units or unmasked results, this is the mean value; for index of minimum/maximum comparisons, this is the mode).
- Summation files have a .dat file extension to distinguish them from other files, but can be

opened in a text editor.

- Each summation file corresponds to a single result file (e.g. var1Sum.dat corresponds to var1.csv).
- Columns are a fixed width and padded with spaces.

Summation file example:

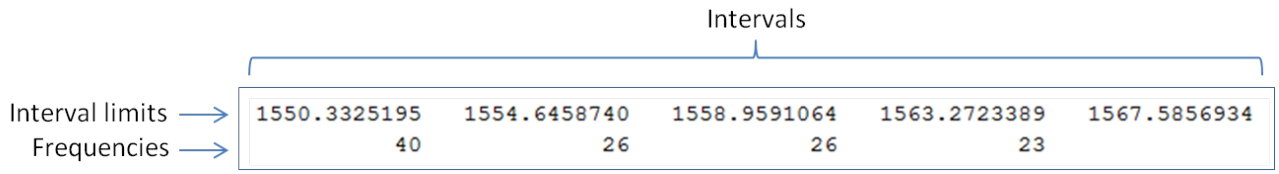


3.2.3 Frequency distribution files

For each result file, a corresponding frequency distribution file is also created:

- Frequency distribution files contain information for the entire area covered in the corresponding result file.
- Frequency distribution results are obtained for the end of the selected time period.
- Each frequency distribution file corresponds to a single result file (e.g. var1Fd.dat corresponds to var1.csv).
- Columns are a fixed width, padded with spaces.
- The number of intervals (or 'bins') equals the square root of the number of data points (rounded down to the nearest integer).
- Each interval is inclusive of the lower limit and exclusive of the upper limit, except the final interval which is inclusive of both limits
- Intervals are of equal length.
- Frequency distribution files are not obtained for comparison metrics for the indices of minimum or maximum values.

Frequency distribution file example:



3.3 Format conversion

Users can convert the format of result files from the Results tab in the GUI. For kml and Ascii Grid format, only the final column of each result file (i.e. results for the end of the selected time period) is converted.

- Converted files are saved to the same directory as the original files.
- Converted files are identified by a different file extension, and do not replace the original

files.

- Keyhole Markup Language:
    - Files have a .kml file extension.
    - Files can be viewed in applications such as Google Earth or Marble, or applications based on WorldWind (users are responsible for using 3rd party software, including observance of any licence restrictions).
    - Files can also be viewed online or embedded in webpages.
    - Coordinates are projected from the British/Irish National Grid to longitude-latitude by methods described by Ordnance Survey.
    - **Please note**: for large geographical areas, conversion to kml format may take a long time to perform, and when the converted files are opened in viewing programs they may be unresponsive.
- Ascii Grid:
    - Files have a .txt file extension.
    - Files can be directly opened in Geographical Information System (GIS) packages; this method is convenient for individual files.
    - For loading multiple files, or analysis of time-series results, users should see the method for opening standard outputs in GIS.
- BVCM format: please see BVCM section for further details.

3.4 Opening in GIS

3.4.1 Ascii grid

Results which have been converted to ascii grid format can be directly opened in Geographical Information System (GIS) packages. This is the most straightforward option for opening single files in order to observe spatial results at the end of the selected time period; to open multiple files or to observe time-series results, users should refer to opening standard outputs in GIS.

Instructions are given for ArcMap:

Using *Conversion Tools->To Raster->ASCII to Raster*, select as the *Input ASCII Raster File* the ascii grid file of interest. Users should set the data type as FLOAT, and can optionally choose the name of the output raster. This operation should also load the raster into the workspace; if not, the user should add the converted raster data to the workspace by using the *Add Data* button.

3.4.2 Standard outputs

Result or look-up table files can be opened in GIS packages by linking a grid of cell ID values (id.txt) with individual result files. Instructions are given for ArcMap, but equivalent methods exist in other GIS packages, and the procedure can be programmed within the GIS to make repeated operations straightforward. GIS packages allow users to manipulate data in a number of ways, including aggregation of cells to larger grid sizes.

1. Using *Conversion Tools->To Raster->ASCII to Raster*, select as the *Input ASCII Raster File* the id.txt file from the look-up table or ELUM results folder of interest (similarly to the method described above for Ascii grid files). Users should set the data type as INTEGER, and can optionally choose the name of the output raster. This operation should also load the raster into the workspace; if not, the user should add the converted raster data to the workspace by using the *Add Data* button.
2. Using *Conversion Tools->To dBASE->Table to dBASE*, select as the *Input Table* any csv result file in the ELUM results folder (or the look-up table) of interest. Multiple files can be chosen at once; users can also select the folder where the new dbf files will be saved.
3. Using *Join Data*, select VALUE as the field of the ID raster to join, the dbf file of interest as the table to join, and id as the field in the table on which to base the join.
4. Using *Symbology*, select the value field of interest (e.g. t1 for results for the first time step).

3.5 Results directory structure

Results from a simulation are saved in a single ELUM results folder, either in a default location or in a directory specified by the user. Files are organised into different subfolders, although the presence of different files and subfolders is dependent on user selections made in the Options tab; the presence of these is listed in a description file, which is displayed in the Description tab when results are loaded.

The directory structure within an ELUM results folder is:

- grid.csv (list of cell IDs which are present, and corresponding coordinates)
- id.txt (Ascii grid format of grid.csv)
- outputDescription.txt (text file describing results)
- modelInputs.elu (file containing user inputs)

🗀 selection (folder containing files which indicate user selections)

🗀 LUsX (folder for start land-use X)

- 🗀 LUeY (folder for end land-use Y)
  - varZ.csv (result file for per-hectare values of variable Z)
  - varZ_odt.csv (result file for per-oven dry tonne values of variable Z)
  - varZ.png (map of varZ)
  - varZCB.png (colour bar for map of varZ)
  - varZSum.dat (summation file for varZ)

🗀 comparison (folder for comparison of results)

- comparisonDescription.txt (description of comparison files)
- 🗀 varZ (comparisons for variable Z)
  - 🗀 all (comparisons for all transitions)
    - metric.csv (results for a particular metric)
  - 🗀 fixedStart (comparisons with fixed start land-use)
    - 🗀 LUsX (comparison of transitions from land-use X)
      - metric.csv
  - 🗀 fixedEnd (comparisons with fixed end land-use)

🗀 LUeY (comparison of transitions to land-use Y)
- metric.csv

4. Model

4.1 Model descriptions

4.1.1 Underlying model

Results are based on the ECOSSE model (Smith et al., 2010). ECOSSE is a development of the models ROTHC (Coleman and Jenkinson, 1996) and SUNDIAL (Bradbury et al., 1993). It uses a pool-type approach to represent inert organic matter, humus, biomass, resistant plant material and decomposable plant material. ECOSSE has been extensively validated, including against field measurements across the UK for biomass crops (Dondini et al., 2014).

ECOSSE uses soil data inputs for:

- Soil texture
- Soil C
- Bulk density
- pH

and monthly and long-term average meteorological data inputs for:

- Temperature
- Precipitation

The model is initialised to equilibrium conditions at year zero, when the land use transition then occurs.

Transitions (see also Grass and rotational crops initial land use, below):

- Arable to wheat, sugar beet and OSR assume no transition (that is, the arable crop prior to transition is assumed to be the same as following the transition).
- Arable to other crops assumes the arable is wheat.
- Wheat is winter wheat.
- Miscanthus is *Miscanthus* × *giganteus*.
- SRC is Willow due to its more widespread use as SRC than Poplar, and thinner stems making it more suited to regular harvesting.
- SRF is Poplar.
- Grass is permanent; rotational grass is represented by arable.

Management assumptions:

- Fertiliser is applied according to Defra guidelines for each crop (Defra, 2010), assuming SNS index 3, medium soil.

Grass and rotational crops initial land use:
The 'grass' initial land-use type represents permanent grassland. While the term grassland may also be applied to grass in rotation with arable crops, in these circumstances it can be regarded as

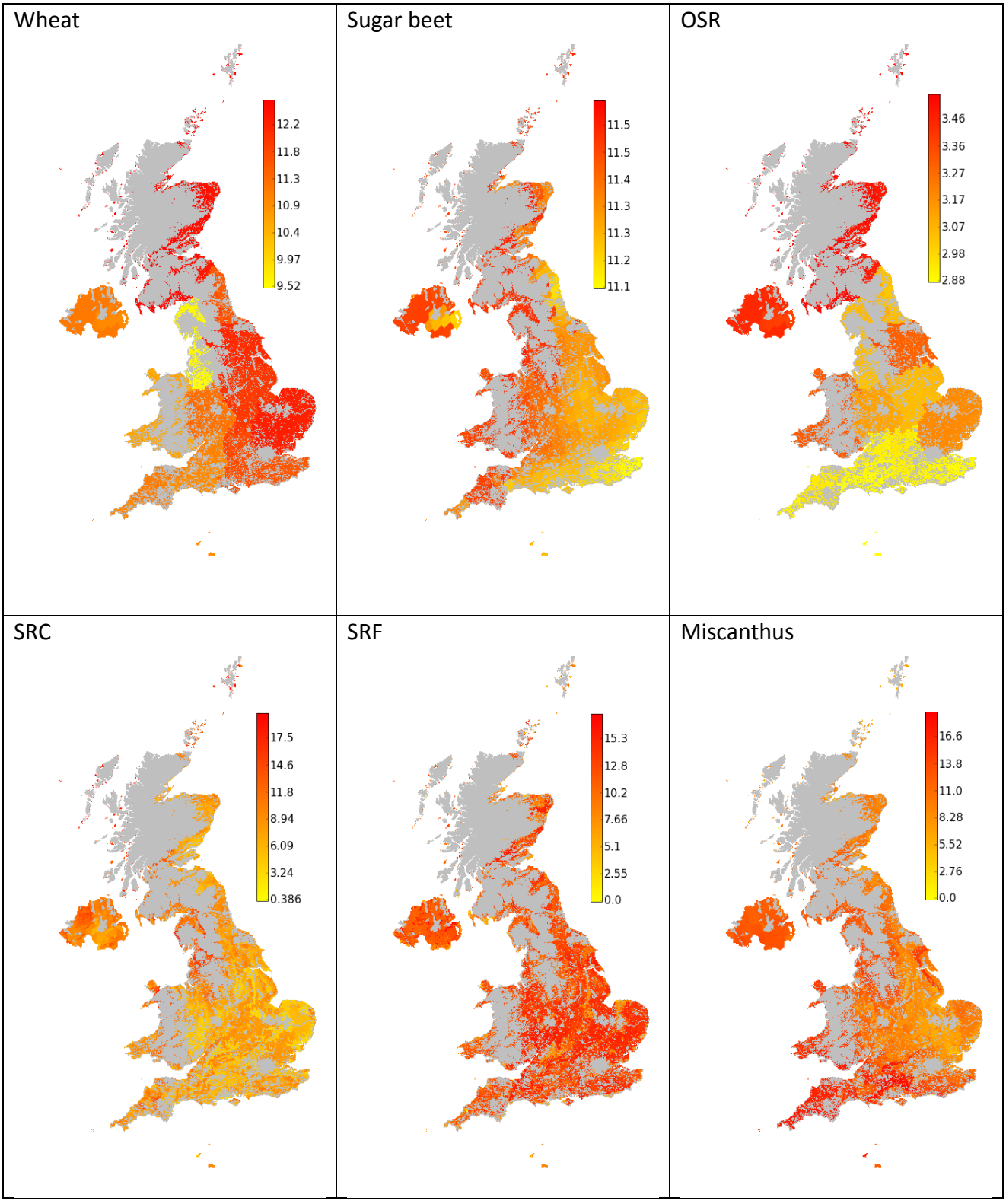
a crop within an arable rotation, and so is considered as 'arable' in ELUM. Permanent grassland is the most abundant type of grassland in the UK, covering 5.3 million ha in 2010, compared to 1.1 million ha of temporary (mostly rotational) grassland at any one time (Khan et al., 2011). Rotational grassland in any given year would be categorised as an arable crop in different years, so the 1.1 million ha in any year represents a snapshot of the area of rotational grass. As such, rotational grass is not a land-use, it is simply one component of rotational farming, which includes all-arable rotations as well as grass-arable rotations. Rotational grassland is usually represented as a crop within a rotation in most existing SOM models, and in ECOSSE is assumed to be a subset of arable rotational land. Permanent grassland represents a separate land-use as this land is only used for grass/livestock production. Rotational grass (by definition) occurs on the same land as is used for growing arable crops, so bioenergy conversion on rotational grass is equivalent to removal of land used for arable production.

Rotational grassland can therefore be simulated in ECOSSE in the same way as arable-only rotations. Although there may in reality be a slightly higher initial soil carbon content with rotational grassland, this is likely to be small. It is expected that rotational grassland would behave in a similar way to arable land in terms of GWP response to LUC to bioenergy crops because: a) it undergoes frequent cultivation and b) it typically receives more fertiliser than permanent grassland. This expectation is supported by empirical evidence. Long-term experiments at the Woburn Research Station (run by Rothamsted Research) in the UK found that conversion of continuous arable to rotational grassland (in this case either a 3-year grass or grass-clover ley followed by two arable crops in a 5-year cycle), resulted in only a 10-15% increase in SOC after 60 years (Johnston et al., 2009). In contrast, the conversion of arable land to permanent grassland at the Rothamsted Research Station resulted in a doubling of organic matter (indicated by total nitrogen), in 50 years (Johnston et al., 2009). The small observed increase in SOC under rotational grassland suggests that the response of rotational grassland to LUC would fall between that of arable and permanent grass, but will be close to the all-arable rotations represented by the 'arable' rotational crops category.

4.1.2 Yield models

Baseline yields for 1st-generation crops are obtained from EUROSTAT, which provides mean wheat and OSR yields across 12 regions in the UK, and a single mean national yield for sugar beet, based on Defra farm surveys; percentage shifts from the baseline yields under a changing climate are estimated from the Miami model (Lieth, 1975). Yields for SRF, SRC and Miscanthus are input to ECOSSE using simulated yields obtained by the models ESC-CARBINE (Pyatt et al., 2001; Thompson and Matthews, 1989), ForestGrowth-SRC (Tallis et al., 2013) and MiscanFor (Hastings et al., 2009) respectively; these yields are all obtained using the same soil and climate data as ECOSSE. The results from these yield models are also present in the look-up table.

Mean 2015-2050 yields under medium climate change are shown below in terms of odt/ha/y (except wheat and OSR which are t/ha/y, containing 14% and 9% moisture respectively); users can obtain all other yield values from the look-up table.



4.1.3 Meta-model

Results from ECOSSE are stored in a look-up table within the ELUM software package, which are processed according to user inputs; this combination of look-up table and processing is referred to as the 'meta-model', and ECOSSE is referred to as the 'underlying model'. The meta-model is used

instead of the ECOSSE model in order to simplify operation and to decrease computing time significantly.

The majority of results from the meta-model are directly obtained from the ECOSSE model look-up table, subject to processing to convert units and apply masks. However, results for non-default fertiliser and yield options are adjusted by equations obtained by statistical regression of ECOSSE results; this is necessary because the look-up table would be too large if all ECOSSE results were stored for all the possible options.

Benefits of the look-up table approach for the meta-model:

- Results are as reliable as possible, since results from the underlying model are directly reported (except for non-default fertiliser and yield).
- Comparatively fast to use.
- Future modifications are relatively straightforward, since results for different transitions, climates and regions, for example, can be obtained from the underlying model and used to create a new look-up table, without further modelling work to approximate the results of the underlying model.

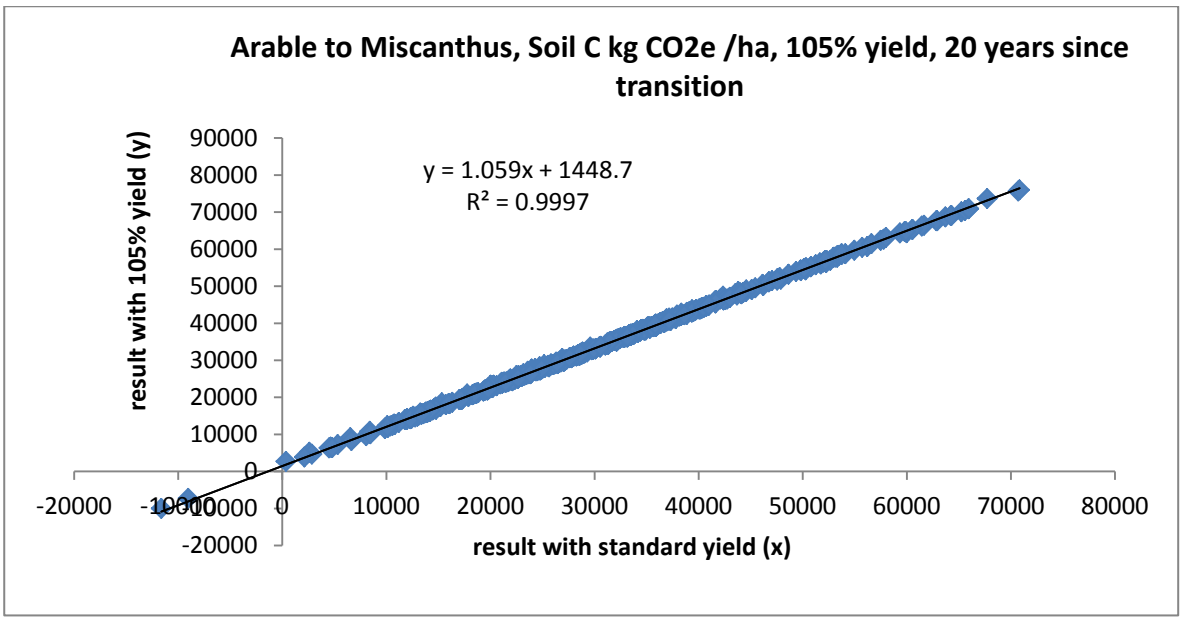
Limitations of the meta-model:

- The data storage space for the meta-model is comparatively large.
- Results are restricted to those considered by the underlying model (although use of regression equations for non-default options works around this).

4.1.4 Regression equations

Results for non-default fertiliser and yield options are not stored in the look-up table for reasons of storage space. In order to obtain results for different fertiliser and yield options, results in the look-up table are adjusted by equations obtained by statistical regression of ECOSSE results for different fertiliser and yield values.

A statistical analysis of a random spatial sample of ECOSSE results in the UK was obtained for a range of fertiliser and yield changes, for each transition, emission and climate. These were used to obtain linear relationships between the 'standard' results and the 'altered' ones, and hence provide a method to adjust the look-up table results according to user interests. This method provides a separate relationship for each transition, emission and climate, which are stored in a separate look-up table. The R^2 correlation coefficient was typically over 0.9 for each. An example is shown below.



For regression of fertiliser levels, the yield is held constant; i.e. the effect of fertiliser on yield is not considered.

For regression of yield, the fertiliser application is adjusted accordingly for wheat, sugar beet and OSR, due to their established fertiliser requirements. For SRC, SRF and Miscanthus, the fertiliser application is unchanged due to lack of data.

4.2 Look-up table

4.2.1 Description

Results from ECOSSE are stored in the look-up table for each:

- Grid cell
- Time step
- Climate projection
- Output variable (e.g. soil C)

Results are stored as t CO_2e /ha values; in order to calculate t CO_2e /odt values, the oven dry yields for each crop are also stored in the look up table, for each:

- Grid cell
- Time step
- Climate projection

Yields are stored as odt/ha values; hence emission values in the look-up table are divided by yield values in the look-up table to obtain t CO_2e /odt values.

Data in the look-up table can easily be opened in a GIS. Results are cumulative up to each time point; to obtain average values for any time period, simply subtract the value at the start of the

time period from the value at the end of the time period, and divide by the length of the time period.

4.2.2 Directory structure

The look-up table is divided into several files and subfolders for convenience. The structure is similar to the ELUM results folder layout, including the use of a single grid file and separate files for each variable. Differences include the presence of separate folders for different climate projections, as well as separate yield folders.

The directory structure of the look-up table is:

- Grid (grid.csv)
- Land-cover (lcm.csv)
- Constraints mask (cons.csv)
- Regions map (reg.csv)
- ID raster (id.txt)

🗀 Low climate change (low)
- 🗀 Yields (yield)
  - Wheat (LUe1.csv)
  - Sugar beet (LUe2.csv)
  - OSR (LUe3.csv)
  - SRC (LUe4.csv)
  - SRF (LUe5.csv)
  - Miscanthus (LUe6.csv)
- 🗀 From arable (LUs1)
  - 🗀 To wheat (LUe1)
    - GHG (var1.csv)
    - CO_2 (var2.csv)
    - CH_4 (var3.csv)
    - N_2O (var4.csv)
    - Soil C (var5.csv)
  - 🗀 To sugar beet (LUe2)
    - …
  - 🗀 …
- 🗀 From grass (LUs2)
  - 🗀 …
- 🗀 …

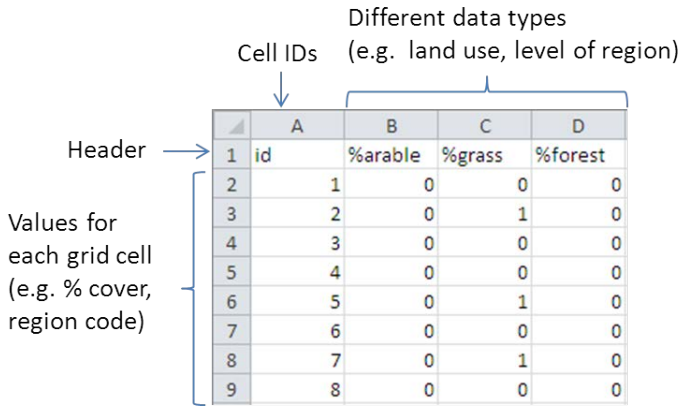
🗀 Medium climate change (med)
- 🗀 …

🗀 …

4.2.3 File formats

The format of the grid file and result file for each variable (or yield) is the same as for ELUM results. Masks for land-cover, constraints and boundaries all follow a similar layout.

Mask file example:



	A	B	C	D
1	id	%arable	%grass	%forest
2	1	0	0	0
3	2	0	1	0
4	3	0	0	0
5	4	0	0	0
6	5	0	1	0
7	6	0	0	0
8	7	0	1	0
9	8	0	0	0

4.3 Masks

4.3.1 Existing land-cover

If the existing land-cover mask is applied, then per-hectare results in each grid cell are rescaled according to the fractional area of each existing land-cover. For example, for transitions from grass, results are adjusted for each grid cell to reflect the amount of grass land available. This gives the effective emissions per unit area for the whole grid cell. Total values in the time series results therefore represent expected values if all available land of any given type were converted.

If users remove the land-cover mask, t CO_2e /ha values apply only to land which is converted (so values are unaffected by the available land area).

Users can apply their own land-cover masks by post-processing outputs in a GIS. Any land-cover mask can be applied, but users are responsible for applying appropriate masks (i.e. applying masks which represent the initial land-uses assumed in the results).

4.3.2 Constraints

Results are excluded for grid cells which contain inappropriate land for growing bioenergy crops, based on data from UKERC.

For Great Britain (GB), the constraints are:

Exclusions	**UKERC 7w**	**UKERC 7**	**UKERC 9w**	**UKERC 9**
Slope ≥ 15%	•	•	•	•
Peat (soil C ≥ 30%)	•	•	•	•
Designated areas	•	•	•	•
Urban areas, roads, rivers	•	•	•	•
Parks	•	•	•	•
Scheduled Monuments/World Heritage Sites	•	•	•	•
Woodland (except transitions to SRF)	•	•	•	•
Woodland (all transitions)		•		•

Naturalness score ≥ 75%			•	•
Naturalness score ≥ 65% inside national parks/areas of outstanding natural beauty			•	•

For Northern Ireland (NI), only grid cells which contain peat are excluded due to lack of data coverage for further constraints. Peat is defined for NI as grid cells with a dominant soil which contains at least 30% soil C in the top 30cm layer.

The constraints do not guarantee the suitability of land, but are a reasonable guide. The following important points should be noted:

- The constraints masks use a 1km grid, based on data from UKERC which use a 100m grid. Binary values (i.e. 'suitable' or 'unsuitable') in the 1km grid are obtained from the mode of binary values in the corresponding 100m grid cells. Grid cells which are excluded from ELUM results might therefore contain some suitable land, and **grid cells which contain results might include some unsuitable land**.
- The woodland category, which is permitted for SRF in the 7w and 9w masks, includes all types of woodland; users should therefore be aware that **some of the woodland category is inappropriate to use**.
- Due to the lack of data, **constraints for NI are insufficient**.

The UKERC 7w constraints are the lowest level of mask permitted; this mask is implicit to results in the look-up table and cannot be removed. This prevents results being obtained for land conversion which is not only inappropriate but also not sufficiently studied to be properly modelled. For all crops other than SRF, use of UKERC 7w and UKERC 9w exclusion masks is automatically changed to 7 and 9 respectively.

4.4 Uncertainty

Comparison of model results against field measurements provides the following uncertainties, as a 95% confidence interval:

Wheat, sugar beet, OSR:

Output	**Uncertainty, t CO_2e /ha/y**
CO_2	0.5
CH_4	0.5
N_2O	0.3
Soil C	0.5
Net GHG	0.9

SRC

Output	**Uncertainty, t CO_2e /ha/y**
CO_2	0.8
CH_4	0.3
N_2O	0.3
Soil C	0.8
Net GHG	1.2

SRF

Output	Uncertainty, t CO_2e /ha/y
CO_2	0.5
CH_4	0.2
N_2O	0.3
Soil C	0.5
Net GHG	0.8

Miscanthus

Output	Uncertainty, t CO_2e /ha/y
CO_2	0.8
CH_4	0.3
N_2O	1.5
Soil C	0.8
Net GHG	1.7

The following should be noted:

- Uncertainties in the summation of results are plotted as error bars in the time series graphs, accounting for the number of cells present and time point.
- Uncertainties in per-odt results are estimated from the above per-hectare uncertainties by using averages of emissions and yields, and an assumed 10% uncertainty in yields.
- Insufficient data exist to estimate spatial variation of uncertainty, so for simplicity uncertainties are not plotted on maps.
- Uncertainties in climate projections are beyond the scope of this project and are not accounted for, but it is noteworthy that results show little sensitivity to different climate projections.

5. Data

5.1 Global Warming Potentials

Values from IPCC inventory 100-year global warming potentials (IPCC, 2001).

ELUM emission	ECOSSE output	Molecular to atomic mass ratio	IPCC GWP Factor to obtain CO_2 equivalent
CO_2	C	11/3	1
CH_4	C	4/3	23
N_20	N	11/7	296
Soil C	C	11/3	1

For ELUM results, ECOSSE outputs are multiplied by the molecular to atomic mass ratio and IPCC factor to obtain the global warming potential CO_2e.

Although the 2001 GWP factors have since been revised (in 2007 and 2013), the 2001 definitions are used in the IPCC National GHG Inventories (IPCC, 2014), and it is therefore convention to use these values.

5.2 Soil data

Soil data from the Harmonized World Soil Database (HWSD) version 1.2 (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012) were used as inputs to the ECOSSE model to obtain the results in the look-up table.

Separate data for the top- and sub-soil (0-30cm and 30-100cm respectively) were used for:

- Soil C
- Sand, silt and clay percentages
- Bulk density
- pH

HWSD data are on a 30 arc-second grid. Data for the UK were extracted using ArcMap and exported as Ascii grid files. These were aligned to a 1km grid, with coordinates projected from longitude-latitude to the British/Irish National Grid by methods described by Ordnance Survey.

5.3 Meteorological data

Meteorological data were obtained from UKCP09 spatially coherent projections and used as inputs to the ECOSSE model to obtain the results in the look-up table. The 25km rotated pole grid (based on longitude-latitude) was aligned to the same 1km grid as the soil data, with coordinates projected to the British/Irish National Grid by methods described by Ordnance Survey. Results for unperturbed scenarios were used (scenario 1 of the HADCM3 model).

UKCP09 data are provided for the central decade of a moving 30 year average (e.g. 2040s data represent the mean predicted climate for 2030-2050). Data are provided from the 2020s (i.e. no data for the 2010s decade are given). In order to obtain results from 2015, the 2020s data were used in the model for 2015-2030; for each subsequent decade, the model used the corresponding data for the decade. This method was used instead of obtaining alternative climate data for the 2010s in order to avoid any artificial sudden change in climate at 2020. For similar reasons, climate data for the 2020s was also used to spin-up the ECOSSE model to equilibrium prior to the land-use transition.

5.4 Land-cover data

Land-cover categories were taken from CEH LCM2007 on a 1km grid.

ELUM category	**Corresponding CEH categories**
Arable	Arable and Horticulture
Grass	Improved Grassland
Forest	Forest

5.5 Boundary data

Shapefiles were obtained from OS OpenData Boundary-Line GB. These shapefiles were processed in ArcMap to provide a 1km raster for each level of region.

ELUM category	Corresponding OS Boundary-Line shapefile layer
Countries	Inferred from European Region layer
Regions	European Region layer
Counties	Obtained from data within District Borough Unitary Region layer
Districts	District Borough Unitary Region layer

5.6 Constraints data

Data were obtained from UKERC for GB (Lovett et al., 2014). Data were converted from a 100m grid to a 1km grid using ArcGIS; the binary value of each 1km cell was determined according to the mode of the binary 100m grid cells it contained. The woodland category was separated from the rest of the constraints in order to permit simulation of conversion of woodland to SRF. Due to lack of data coverage for NI, constraints were based on soil C using HWSD soil data.

ELUM category	Corresponding UKERC category
UKERC 7w	Constraints 7b, but with woodland permitted for SRF
UKERC 7	Constraints 7b
UKERC 9w	Constraints 9b, but with woodland permitted for SRF
UKERC 9	Constraints 9b

5.7 Yield data

Baseline yield data for 1st generation crops were obtained from EUROSTAT, based on Defra farm surveys.

6. Notes for BVCM

Due to the anticipated use of ELUM results in the ETI Biomass System Value Chain Modelling (BVCM) project, special provision has been made to supply results which are in a convenient format.

6.1 Operation

- Users who wish to obtain results for use in BVCM should first obtain result as normal, including selection of the time period, climate scenario and transitions to consider.
- Once results have been obtained, users can convert the format of results for use in BVCM

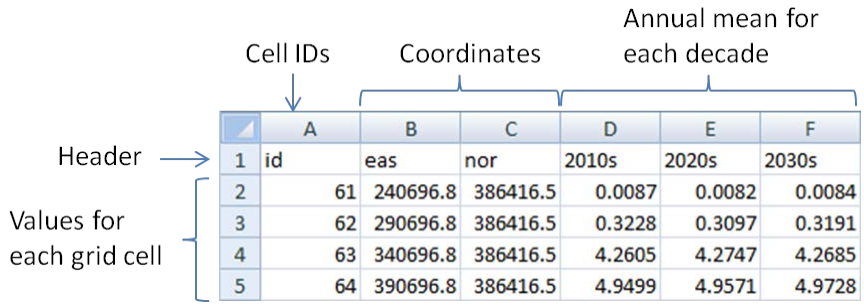
by using the Tools button in the Results tab, and selecting 'convert to BVCM format…'. This converts results to annual mean values for each decade, on a 50km grid. The procedure is similar to other format conversions.

- Converted files are located in the same folder as the original results files, and are distinguished by the suffix '_BVCM.csv'. These files can be used as inputs to BVCM as required.

6.2 File format

- Converted files are saved in tab-delimited csv format.
- Results are aligned to the BVCM-defined 50km grid.
- Per-hectare results are given as mean t CO_2e /ha/y for each decade.
- Per-odt results are given as mean t CO_2e /odt for each decade.
- The ID (as defined by BVCM) and coordinates of each cell are also listed with the results.

BVCM file format example:



	A	B	C	D	E	F
1	id	eas	nor	2010s	2020s	2030s
2	61	240696.8	386416.5	0.0087	0.0082	0.0084
3	62	290696.8	386416.5	0.3228	0.3097	0.3191
4	63	340696.8	386416.5	4.2605	4.2747	4.2685
5	64	390696.8	386416.5	4.9499	4.9571	4.9728

6.3 Calculations

Area:

- Each 1km grid cell in the original ELUM results is allocated to the corresponding grid cell on the 50km BVCM grid, and results for all the 1km cells within each 50km cell are averaged.
- Effects of the land-cover mask on per-hectare results:
  - If the land-cover mask was applied to results, then the effective value for each cell is obtained (i.e. per hectare of the whole 50km grid cell).
  - If the land-cover mask was not applied, then results are given per hectare of productive land.

Time:

- Cumulative per-hectare values in the original ELUM results are averaged to give annual results for each decade. Annual per-hectare averages are obtained from the difference between the start and end cumulative values for each decade, divided by the number of years; this applies also for 'incomplete' decades (e.g. results for 2015-2020 are used for the 2010s decade).
- Cumulative t CO_2e /odt values in the original ELUM results are averaged for each decade by calculating the arithmetic mean of values in each decade.

6.4 Interpreting results

- ELUM provides results for transitions occurring in 2015, but due to the uncertainty in predicted climate data (which are decadal averages from the central decade of a moving 30 year average) the transition year may reasonably be assumed to be ±10 years.
- Equilibrium is assumed prior to transition.
- It is important to remember that results are dependent on the time since transition:
    - Results always assume a 2015 transition.
    - There is likely to be a trend of emissions within each decade; this may not be clear when using mean annual values.
- Land-cover and constraints masks:
    - Land-cover masks rescale results according to available land for the initial land-use.
    - Constraints masks exclude results from inappropriate areas, and there is a minimal level of constraints masks which cannot be removed.
    - If users wish to apply different masks to results within a GIS:
        - It is important remember to remove the land-cover mask before obtaining results.
        - Users are responsible for applying appropriate masks (i.e. masks which correspond to the initial land-uses).
- It is the responsibility of users if they use results to represent transitions which are not explicitly considered by ELUM.
- Due to the coarse resolution of the 50km grid, the potential range of results within each grid cell is large. Particular attention should be given to results obtained without the land-cover mask, as in this case only productive 1km cells are aggregated to the 50km grid (which might represent only a small fraction of the whole 50km grid cell).

7. FAQ

7.1 About the ELUM software package

- **What is the purpose of the ELUM software package?**
    - The ELUM software package allows users to obtain estimates of greenhouse gas (GHG) emissions or reductions caused by land-use transitions to grow bioenergy crops anywhere in the UK.
    - The ELUM software package also performs analysis of results and comparisons of the effects of different transitions.
    - Result files from the software package are in a clearly documented format; this allows users to process results according to their interests, or use results as inputs to other models.
    - The Package is intended to be accessible to all users interested in the effects of converting land to grow bioenergy crops in the UK. Likely users include:
        - Energy, environmental and agricultural policy makers.
        - Soil and climate scientists.
        - Energy producers and suppliers.
        - Investors and traders in energy or carbon credits.

        - Land owners and managers.
    - See also: Description.
- **What is the ELUM software package based on?**
    - The ELUM software package forms part of the ELUM project, which combines field studies with computational modelling in order to map the UK bioenergy GHG balance from soil respiration up to 2050.
    - Results in the software package are based on the soil organic matter model ECOSSE.
    - See also: Model, About.
- **What do the results show?**
    - Results show the level of GHG emissions or reductions caused by different land-use transitions, in terms of soil respiration in the top 1m of soil.
    - Results are for the difference between GHG fluxes following transition and the fluxes if no transition took place, and therefore show directly the effects of the transition.
    - Results can be obtained with a choice of climate projections, time periods and fertiliser options, with optional land-cover and constraints masks applied.
    - See also: Description, Operation, Outputs.
- **How can I use the results?**
    - Within the ELUM user interface, results can be used in a number of ways, including:
        - View how emissions vary spatially.
        - Compare emissions between different transitions.
        - View how emissions for any selected area change over time.
        - Find which transitions give the lowest emissions in different locations.
        - Obtain emissions per unit area or per unit of biomass yield.
        - View the frequency distribution of emissions for any selected area.
    - Outside the user interface, such as within a GIS or spreadsheet application, results can be processed for a range of purposes, including:
        - Apply any shapefile or mask to results.
        - Perform calculations based on results.
        - Aggregate results to different grid sizes.
        - Use results as inputs to other models.
        - View yield predictions for different crop types.
    - See also: Description, Operation, Outputs.
- **What is the coordinate system used?**
    - Different coordinate types are used for GB and NI:

Area	Projection name	Ellipsoid	Datum
GB	British National Grid	Airy 1830	OSGB36
NI	Irish National Grid	Airy 1830 modified	Ireland 65

    - The coordinate systems are the same as those used in Ordnance Survey maps.
    - Coordinates give the south-west corner of each grid cell.
    - Coordinates of each corner of grid cells are converted to longitude-latitude (WGS84) when results are converted to kml format.
    - See also: Operation, Outputs.
- **What is the grid size?**
    - 1km

- **What colour map is used?**
    - The ‘autumn’ colour map is used, ranging from red to yellow. It is reversed for soil C results so that red corresponds to environmentally worse results and yellow is environmentally better. It is chosen due to its perceptual ordering (i.e. it uses a predictable sequence of colours) and its use of colour to avoid contrast effects (i.e. judgement of results is less affected by neighbouring values than a grey scale) (Borland and Taylor, 2007).
    - A rainbow, or ‘jet’, scale is used for the comparison indices as this helps to distinguish non-continuous values.
    - Grey is used to show places where there is no result due to masking or zero crop yield.
    - White is used to show the sea, other areas of water, or areas beyond the selected area
- **What is the large diagonal grid which is visible in some results?**
    - Although the grid size is 1km, the input climate data uses a 25km grid with a diagonal pattern, which is evident in some results.

7.2 Using the ELUM software package / Troubleshooting

- **How do I install the software package?**
    - The package is supplied as a stand-alone folder which does not require installation; the folder can be stored anywhere on the computer and administration privileges are not required.
    - The package contains executable files (i.e. computer programs rather than documents) which might be mistaken by some antivirus software as a potential threat when the package is first placed onto the computer; please contact us if you think you may be experiencing problems with this.
- **How do I select the whole UK?**
    - Use Areas (rather than Coordinates) in the Location section of the Inputs tab, and using the Countries option, select the whole list (Ctrl+A).
    - The Coordinates method cannot be used to selected GB and NI together because they use separate coordinate systems.
    - See also: Operation.
- **Can I obtain results for transitions in different years?**
    - Results are given for transitions occurring in 2015; this is fixed in the look-up table.
    - The only reason that results would be different for other transition years is because of the effects of a changing climate.
    - Due to the uncertainty in predicted climate data (which are decadal averages from the central decade of a moving 30 year average), the transition year may reasonably be assumed to be ±10 years.
    - Please contact us if you would be interested in using an updated look-up table to reflect a different transition year.
    - See also: Model.
- **What do the masks do to results?**
    - There are two different types of mask.
    - The ‘existing land-cover’ mask rescales results according to the availability of land.
    - The ‘constraints’ masks exclude results from inappropriate areas.

    - See also: Model, Data.
- **Should I use the 'existing land-cover' mask?**
    - Yes, if:
        - Users want summed time-series results to reflect the total available land.
        - Users want spatial per-hectare results to show the combination of emissions and available land (i.e. the effective per-hectare emissions from each grid cell).
    - No, if:
        - Users want to apply their own land-cover mask in a GIS after simulation.
        - Users want time-series results to show the mean of emissions per hectare of productive land.
- **What should I do if I get an error message about being unable to remove existing results, or the program stops working?**
    - Users should first close the application and reopen, which may resolve the issue.
    - If the user has chosen to overwrite results, then the ELUM program will automatically delete the existing directory before obtaining new results. Occasionally the directory cannot be deleted for reasons relating to the operating system.
    - If the automatic deletion is unsuccessful, users should make sure they do not have the results folder open in the Windows file manager, or any of the output files open in any other application.
    - If this does not resolve the problem, users should use the Windows file manager to delete the directory. The default ELUM output folder, where results are saved if no output folder is chosen, is located in the 'programs' folder of the directory where ELUM is stored (e.g. C:\My Documents\ELUM), and is called 'results'. Users must be careful not to inadvertently delete anything else in the ELUM folder.
    - In order to avoid this problem, it is always a good idea to create a new output folder (Ctrl+F) before running the meta-model, so that existing results do not need to be overwritten.
    - See also: Operation.
- **Why are results given in 5-year intervals?**
    - The software package uses a look-up table for results. Although results in the look-up table were generated using a monthly time interval, a 5-year time interval is used for the reason of storage space.
    - See also: Outputs, Model.
- **Can I apply my own mask to results, change the grid size, obtain per-annum values, or process results in other ways?**
    - Yes, users can open results in a GIS or spreadsheet application to do any processing they choose.
    - A special conversion tool is included for BVCM users to convert results to annual averages for each decade on a 50km grid.
    - See also: Outputs, Notes for BVCM.

8. Glossary

Term	Description

Ascii grid	ASCII raster GIS format (also known as Esri Grid ASCII format)
BVCM	Biomass System Value Chain Modelling
CEH	Centre for Ecology and Hydrology
CO_2e	Carbon dioxide equivalent
Constraints mask	Spatial mask used to prohibit results in inappropriate grid cells
csv	Comma separated value file format
ECOSSE	Estimating carbon in organic soils – sequestration and emissions
ELUM	Ecosystem Land-use Modelling & Greenhouse Gas Flux Trial
ETI	Energy Technologies Institute
FAQ	Frequently asked questions
GB	Great Britain
GHG	Greenhouse gas
GIS	Geographical information system
Grid cell	Spatial unit of results
GUI	Graphical user interface
ha	Hectare
HWSD	Harmonized World Soil Database
kml	Keyhole Markup Language
Land-cover mask	Spatial mask used to rescale results according to existing land-cover
Look-up table	Store of data from the underlying model which is used in the meta-model
LUC	Land-use change
Meta-model	Combination of look-up table and processing used to generate results in ELUM software package
NI	Northern Ireland
odt	Oven-dry tonne
OS	Ordnance Survey
OSR	Oil seed rape
Software package	Combination of program files and data used to obtain and present ELUM results
Soil C	Soil carbon
SOM	Soil organic matter
SRC	Short rotation coppice
SRF	Short rotation forest
UK	United Kingdom
UKCP09	UK Climate Projections 2009
UKERC	UK Energy Research Centre
Underlying model	SOM model (ECOSSE) used to create meta-model

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10. About

The Ecosystem Land-use Modelling & Soil Carbon GHG Flux Trial (ELUM) project was commissioned and funded by the Energy Technologies Institute (ETI) to produce a framework for predicting the sustainability of bioenergy deployment across the UK. The ELUM project closely combines field studies with computational modelling in order to map the UK bioenergy GHG balance from soil respiration up to 2050.

Participating organisations:

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10.1 Authorship

Software package programmed by Mark Pogson
Look-up table data generated from ECOSSE simulations by Mark Richards

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10.2 Version history

Version 1.3
February 2015

- Updated look-up table results to account for outlying cells due to poor data coverage.
- Corrected wheat yields in look-up table to include baleable straw.
- Updated help file to correct wheat yield map and description.
- Updated help file to clarify that wheat and OSR are not odt yields.
- Updated help file to clarify increased uncertainty in results over small areas.
- Updated help file to provide new URL for EUROSTAT website.
- Updated help file to improve description of deleting results in the FAQ section.
- Updated help file to correct hyperlink for FAQ section.

Version 1.2
November 2014

- Corrected error in meta-model when applying regression equations.
- Corrected BVCM conversion method to obtain annual mean values.
- Corrected y-axis unit label in time-series graphs without land-cover mask applied.

- Removed standard deviation from summation files due to lack of clarity over method.
- Updated help file to reflect removal of standard deviation from summation files.
- Updated help file FAQ to improve explanation of troubleshooting.
- Updated help file to clarify the effect of the land-cover mask when inferring yields by dividing per-hectare results by per-odt results.
- Updated help file to clarify descriptions of output variables.
- Updated help file to correct output directory diagram labels for OSR and sugar beet.
- Updated help file to clarify what the yield values measure.
- Updated help file to insert missing hyperlink for Data section.

Version 1.1
July 2014

- Updated 1st generation crop yields in look-up table to reflect Defra survey data.
- Corrected ordering of yield files in look-up table.
- Added to look-up table a small area of previously missing results in north Wales.
- Updated help file to reflect updated 1st generation yields.
- Updated help file and GUI to improve description of arable and grass initial land uses.

Version 1.0
May 2014

- Software package allows users to obtain estimates of soil greenhouse gas (GHG) fluxes caused by land-use transitions to grow bioenergy crops anywhere in the UK.