Programme Area: Bioenergy

Project: ELUM

Title: Complete Meta Analysis Database

Abstract:

This deliverable accompanies the completed Work Package 1 meta-analysis database which reviews all of the Total Soil Carbon (TSC), Greenhouse Gas (GHG) and Soil Organic Carbon (SOC) data evaluated from the selected literature sources arising in the literature review. The meta-analysis used the parameters and the methodology described in earlier deliverables - D1.3 and D1.2 respectively. The meta-analysis conducted quantifies the effects of land-use change to bioenergy but results need to be interpreted with caution, primarily due to limited primary data sources and the necessity to use modelled and boot-strapped data.

Context:

The ELUM project has studied the impact of bioenergy crop land-use changes on soil carbon stocks and greenhouse gas emissions. It developed a model to quantitatively assess changes in levels of soil carbon, combined with the greenhouse gas flux which results from the conversion of land to bioenergy in the UK. The categorisation and mapping of these data using geographical information systems allows recommendations to be made on the most sustainable land use transition from a soil carbon and GHG perspective.

Some information and/or data points will have been superseded by later peer review, please refer to updated papers published via www.elum.ac.uk

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Ecosystem Land-Use Modelling & Soil C Flux Trial (ELUM)

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Complete Meta-Analysis Database

REPORT

V2.0

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EXECUTIVE SUMMARY

This brief report accompanies the completed Work Package 1 meta-analysis database which reviews all of the Total Soil Carbon (TSC), Greenhouse Gas (GHG) and Soil Organic Carbon (SOC) data evaluated from the selected literature sources arising in the literature review. The meta-analysis used the parameters and the methodology described in earlier deliverables - D1.3 and D1.2 respectively.

This work identified published UK-relevant data for Land-Use Change (LUC) to bioenergy crops, and importantly, identified significant gaps or weaknesses in the literature.

The main finding from this analysis is that a conversion to second-generation bioenergy crops (SRC and perennial grasses) is generally beneficial in reducing GHG emissions and increasing carbon stored in the soils. Comparison of all metrics used shows that conversion to perennial grasses from arable cropping may be more beneficial than a conversion to SRC. Conversions to 1st generation cropping systems from grassland or forest has a negative impact, with increased GHG emissions and decreases in soil carbon. These findings are in agreement with those found in the extensive literature review of D1.2 and are mainly due to management practices employed during cultivation.

A limitation in this analysis was the availability of empirical data which documents the effects of land-use conversions to bioenergy crops. Field-based measurements are in short supply for soil properties and GHG emissions in these novel cropping systems. The data which were incorporated into this analysis were mainly modelled data and this highlights the need for experimental work on bioenergy crops in the UK to provide sufficiently robust real-world data that can enhance the ability to model bioenergy-related land-use transitions. These aspects are built into Work Package 2 and Work Package 3 of the ELUM project, where significant soil carbon and GHG flux data are being collected.

The meta-analysis conducted quantifies the effects of land-use change to bioenergy but results need to be interpreted with caution, primarily due to limited primary data sources and the necessity to used modelled and boot-strapped data. The deliverable confirms the essential importance of collecting empirical data on the impacts of land-use transitions on soil-based processes. This is why the research of ELUM is critical.

Although not the primary aim of the work undertaken in WP1, data from this deliverable in the form of the final database will also be fed into WP4 where any useful data can be used in the model to further improve its ability to predict land use change effects.

The deliverable and acceptance criteria for this report are as follows:

Deliverable D1.5:	Database (complete) of data for WP4
Acceptance Criteria:	This database will be in Microsoft Excel or Access, or something similar (agreed with the ETI prior to submission). All literature reviewed must be clearly listed, dated and categorised into high, medium and low in terms of 'reliability as accurate source of information'. Information will also be classified into a system which reflects 'input parameter class'. Full references / links to source must be provided, along with a short summary of information provided in the referenced papers, along with indication of whether information used in report. The database must be provided on DVD and electronically via the VPN. A clear meta-data description will be provided, which dates the database, provides key author and future contact name / details and highlights any post-processing that has occurred.

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1. AIMS

The aim of this deliverable is to assess the state of the current literature on land-use change effects to bioenergy and to quantify the scale of these effects, specifically focusing on total soil carbon, greenhouse gases and soil organic carbon. Our intention was to link the systematic review of the literature, with precisely defined search terms, to the approach of a meta-analysis, for the three metric identified here.

2. METHODS

2.1 Literature Search

The D1.2 literature search undertaken for this project was completed in a systematic manner to ensure that all relevant literature was captured without bias. The search involved a structured search string and used three search engines which would allow us to capture peer-reviewed scientific literature, government reports and other forms of grey literature. This search stage was comprised of 1024 unique searches which resulted in a total of 5786 individual references once duplicates were removed. These papers were firstly 'raw processed' by assignment of the categories 'useful' and 'not useful' based on a pre-defined selection criteria. The criteria for section were:

- the location (to be relevant to the UK context, therefore temperate and not tropical),
- the species concerned (inclusive of first and second generation bioenergy crops, but only those relevant to the temperate land-use defined above)
- the mention of the metrics which we used in the meta-analysis

After this first round of processing, the papers were more carefully inspected to extract the data in pre-defined units for the meta-analysis, performing standard unit conversions if required.

See Appendix I for full search methodology

2.2 Meta-Analytical Methods

A meta-analysis is a method used in many types of science from the biological to the social. The purpose of a meta-analysis is to review previously published data in a rigorous way to provide a quantitative result, based on a proper statistical analysis. It allows the data from many papers to be synthesised and thus enables trends and patterns to be identified, and variation between studies highlighted – this is particularly important in many areas in science due to large volumes of data that are published rapidly (Rosenthal & Dimatteo, 2001). Most notable of meta-analyses conducted in the field of plant and environmental science include that of Curtis and Wang (1998) who looked at the response of woody plants to elevated CO_2, Ainsworth *et al.* (2002) similarly looked at elevated CO_2 but in soybean and finally that of Wittig *et al.* (2009) assessing the impacts of ozone on trees of the northern hemisphere forests. Their work illustrates that the meta-analytical technique is well developed and suited to differential treatments. The main limitation of a meta-analysis in this context is the need for an 'effect size' metric which essentially is a control which all the bioenergy crop 'treatments' will be measured against to allow us to quantify their effects. If a paper has not reported means and error terms for the previous land use to bioenergy or has not quantified the result of the changes, the paper is unable to be included in the analysis as an effect size cannot be calculated. Although acceptable, this is time-consuming. A second major problem with the current meta-analysis on bioenergy crop transitions is availability of datasets from bioenergy plantations themselves. It is interesting to note that most of the ecological meta-analyses conducted to date (Medlyn *et al.,* 2001; Morgan *et al.,* 2003; Jeffery *et al.,* 2011) have been focused in areas where large amounts of funding with significant experimentation has been undertaken, globally, in many simultaneous studies over several years and decades. This has not been the case until very recently in the area of bioenergy cropping and soils, although new experimental studies, initiated from 2008 onwards are now becoming available for analysis. It was highlighted in a recent publication that the number of meta-analyses being conducted in the field of ecology has increased vastly in the past few years and in general, they are becoming an ever more powerful tool for elucidating the effects of multiple studies (Cadotte *et al.,* 2012).

In a previous deliverable (D1.2) it was stated that the statistical package to be used for the analysis was MIX however this was changed to CMA (Comprehensive Meta-Analysis), also identified as suitable in D1.2, but significantly more expensive. However following a training course by ZH in this package it was considered more suited to the project. A detailed outline of the CMA meta-analysis software and some FAQs can be found in Appendix 1 (A1.2).

Data were first sorted into spreadsheets containing the metrics of interest, total soil carbon, GHG emissions and soil organic carbon, and then each bioenergy type was given an individual workbook. Since data were limited for individual species, bioenergy types were grouped into SRC, perennial grasses, 1st generation and SRF (Table 2.2.1). Where necessary, conversions into standardised units were made to allow comparison of data across studies where they are often reported in slightly different units. Error terms were added to the data where necessary. See Appendix II for a full reference list of papers used in the analysis.

The number of papers included in the analysis is significantly less than the number of papers which were originally extracted and entered into the spreadsheets. This is because many papers which were extracted included those without a transition from an original state. These data are of value in themselves and still provide an important evidence-base for ELUM, but are difficult to apply in meta-analysis. Although one option is to use a 'standard' term for the original land use such as 'arable soil carbon', this in itself can lead to errors in interpretation. Here, a precautionary approach has been taken and only papers with a true transition have been presented in this analysis.

Table 2.2.1: Grouping of bioenergy land use types and species they could include

Bioenergy Land-Use Type	Inclusive Species
Short Rotation Coppice (SRC)	Willow Poplar
Perennial Grasses	Miscanthus Switch grass
1st Generation	Wheat Oil Seed Rape Corn Barley Triticale Sugar Beet
Short Rotation Forestry (SRF)	Eucalyptus Beech Poplar

In order to perform a meta-analysis a mean error term is required, the most basic being the standard deviation (SD) and sample size (n). In many of the papers included in the analysis error terms were not presented and in this instance authors were contacted. Of 21 authors contacted, 16 replied and most of these replies were helpful; some highlighting that data were modelled and therefore error terms often did not exist and others replied with additional data which could be added to the analysis. Where data was modelled, error terms were often not reported and upon contacting several authors it was found that these outputs do not generate error terms suitable for inclusion in the meta-analysis, since a sensitivity analysis is given in most cases which will allow the reader to gauge how effective the model has run and how accurate parameterisation has been but unfortunately does not quantify the error around the presented means. As a result, all modelled studies which do not have error terms (as well as field studies missing error terms) have been entered into the bootstrapping methodology to allow them to still be included in the analysis.

Bootstrapping works by resampling a population so many times over to generate a mean, standard error and 95% confidence limits. So data of the same transition, for example all arable to SRC means, were bootstrapped to allow their inclusion in the meta-analysis. Bootstrapping was performed using a script in R and resampling occurred with replacement at the rate of 10,000 bootstraps, exceeding the minimum recommended for data to be included in a meta-analysis (Adams *et al.*, 1997). The bootstrapped value was then included in the meta-analysis along with original research data which included error terms. Bootstrapping was only used where there were 10 or more mean values without an error term. For transitions where replication was less than this, an arithmetic mean was calculated.

A meta-analysis was run to compute an effect size of the data for one specified transition (e.g. SRC) then sub-grouped into the previous land use (e.g. from arable, etc.). A random effects model was applied to the analysis. A fixed effect model assumes that studies will share one true effect size and that studies are functionally identical (e.g. a comparison of clinical trials or highly controlled experiments) which is not the case due to the varying locations of studies and how measurements were made. Whereas the random effects model assumes that the true effect size will vary from study to study, so the calculation of the effect size will take into account the between study variance as well as the within study variance, with the fixed effect model only considering within study variance as between study variance is assumed negligible (Borenstein *et al.*, 2009).

In this report effect sizes will be reported in the format of Hedges *g*, this was chosen due to the data type being used, independent mean observations and pre-and post- study designs. Hedge's *g* is a standardized mean difference between the previous land-use group and bioenergy land-use group using the pooled standard deviation of the two groups (see equations 2.2.1 and equation 2.2.2). In the presented figures, Hedges *g* is presented as the mean effect (vertical line) with the upper and lower limits of the 25th and 95th confidence intervals shown passing through the mean (horizontal line).

(*2.2.1*)

$$g = \frac{X_{Previous\ land\ use} - X_{Bioenergy\ land\ use}}{SD_{Pooled}}$$

where

(2.2.2)

$$SD_{Pooled} = \sqrt{\frac{(n_{Prev\ land\ use} - 1)SD^2_{Prev\ land\ use} + (n_{Bionergy\ land\ use} - 1)SD^2_{Bioenergy\ land\ use}}{n_{Prev\ land\ use} + n_{Bionergy\ land\ use} - 2}}$$

Hedge's *g* is a bias-corrected standardized mean difference and is able to correct for positive bias when sample sizes are small, corresponding to an approximate 4% reduction in effect when the sample size is 20, and 2% when the sample size is 50 (Hedges and Olkin, 1985). Hedge's *g* is now the preferred means to report a standardised mean difference in meta-analyses as it provides more accurate estimates of effect size due it being based on the pooled variance rather than the variance of one study (which is the case with Cohen's *d*, the first commonly recognised effect size; see equation 2.2.3).

$$d = \frac{\bar{X}_1 - \bar{X}_2}{SD} \quad \text{vs.} \quad g = \frac{\bar{X}_1 - \bar{X}_2}{SD_{Pooled}}$$

(2.2.3)

To make the analysis more meaningful, transformation into a percentage change could be applied; however due to the nature of the available data in this case, attempting transformation will significantly lower the number of observations which can be included (if at all) producing a very weak meta-analysis.

It was originally planned to complete a comparison between field observations and modelled data however due to the limited data available it has been necessary to combine these two to allow completion of a meaningful meta-analysis.

3. RESULTS

A summary table showing the measures and transitions where there was adequate data to enter an analysis can be seen in table 3.1.

Table 3.1: Analyses that have been run for the land use transitions from arable/grass/forest to bioenergy cropping systems for the measures total soil carbon, GHGs and soil organic carbon. A tick indicates where there was sufficient data to enter into analysis, and where a cross indicates too few data points to enter analysis.

	Total soil carbon	GHG emissions								Soil Organic Carbon
		Crop Life Cycle CO_2	Crop Life Cycle N_2O	Crop Life Cycle CH_4	Crop Life Cycle All	Whole LCA CO_2	Whole LCA N_2O	Whole LCA CH_4	Whole LCA All	
Arable → SRC	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓
Grass → SRC	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗
Forest → SRC	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓
Arable→ Perennial Grasses	✓	✓	✗	✗	✓	✗	✗	✗	✓	✓
Grass → Perennial Grasses	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗
Forest → Perennial Grasses	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Grass → 1st Gen Crops	✓	✓	✓	✗	✗	✓	✗	✗	✓	✓
Forest → 1st Gen Crops	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓
Arable → SRF	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Grass → SRF	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Forest → SRF	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Results are discussed from the perspective of 'transition from' to allow a comparison of the effect to different bioenergy land-use types. In the case of transitions from arable, a transition to 1st generation bioenergy cropping systems will not be discussed as the same crops are used for 1st generation and arable farming, therefore there is no comparison. The main difference between the management of these two crops is the processing of the harvested crop which has not been found to have been discussed in any of the literature covered.

3.1. Total Soil Carbon

For all transitions covered in total soil carbon the conversion to SRC crops is by far the most extensively available and able to be analysed using meta-analytical techniques. Figure 3.1.1 shows the output from the analysis with all transitions where there was sufficient data to enter into the analysis, with effect sizes in Hedges *g*.

There were significant gaps in the data for certain transitions and they could not therefore be included in the analysis. There were no relevant data found for land-use conversions to SRF with respect to total soil carbon. Papers which were originally extracted turned out to be inappropriate for this study due to species and location, namely eucalypts in Australia. As for transitions to perennial grasses, not only was there insufficient data to cover the transitions from grassland and forest to perennial, there were no papers found which had any data extracted for these land-use conversions for the search years covered.

If we examine the individual points on the meta-analysis, as we would expect, the data with the largest error terms are those which have been bootstrapped, since these data have been amalgamated from a number of different sources and scenarios. It is also important to note that in some cases, such as arable to SRC, the bootstrapped data were consistent with the actual measured values shown in Figure 3.1.1., providing confidence in the data output and analysis.

While all summary effects can be used to show changes as a consequence of transition to bioenergy, the effect of these changes in some cases appear to be statistically significant, namely arable to perennial grasses and grass to 1st generation crops. This can be seen by looking at the p-values which are produced for these summary effect size and also if the lines representing the confidence intervals cross over the mid-line 0.00 which is the ‘null’ or no response result.

3.1.1 Transitions from Arable

It can be see that a transition from arable to SRC results in a small increase in soil carbon, which is consistent with findings from the literature in D1.2. The conversion from arable to perennial also shows an increase in the total soil carbon but this is much larger than that of SRC, and is also statistically significant. However, it must still be noted that this sample size is still very small to compute a summary effect (as shown in Figure 3.1.1). These are data from one ‘original’ study where error terms were included and the other data included in the analysis came from bootstrapping data from 25 data points from one other study.

3.1.2 Transition from Grassland

Grass to SRC shows the most profound change in soil carbon compared to the other land-use transitions, resulting in a greater decrease total soil carbon than that of a forest transition to SRC.

The only transition which was entered into the analyses for conversion to 1st generation bioenergy crops was that from grassland. However, the only data entered into the analysis is that of bootstrapped data (n=11) as there were no papers which presented error terms, since all the included papers were modelled, with no available error term. The effect of this is a statically significant moderate-to-large reduction in total soil carbon when grassland is replaced by 1st generation bioenergy crops.

3.1.3 Transition from Forest

The only forest transition to bioenergy that was covered was that to SRC which showed a small but insignificant decrease in soil carbon from forest to SRC.

Group by Transition From	Study name	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Arable to Perennial	Dondini, 2009	5.049	1.597	1.918	8.179	0.002
Arable to Perennial	Bootstrapped Arable	3.190	0.694	1.829	4.551	0.000
Arable to Perennial		3.563	0.744	2.105	5.021	0.000
Arable to SRC	Bootstrapped arable	0.184	0.321	-0.446	0.814	0.567
Arable to SRC	Grigal & Berguson, 1998	0.000	0.273	-0.535	0.535	1.000
Arable to SRC	Grigal & Berguson, 1998	-0.519	0.278	-1.064	0.025	0.062
Arable to SRC	Arevalo et al, 2009	0.244	0.225	-0.197	0.686	0.277
Arable to SRC	Arevalo et al, 2009	-0.065	0.224	-0.505	0.374	0.771
Arable to SRC	Arevalo et al, 2009	3.244	0.343	2.571	3.916	0.000
Arable to SRC	Arevalo et al, 2009	-0.436	0.227	-0.881	0.009	0.055
Arable to SRC	Arevalo et al, 2009	0.048	0.224	-0.391	0.488	0.829
Arable to SRC	Arevalo et al, 2009	-0.260	0.225	-0.701	0.182	0.249
Arable to SRC		0.249	0.295	-0.330	0.828	0.400
Forest to SRC	Arevalo et al, 2009	0.392	0.226	-0.051	0.836	0.083
Forest to SRC	Arevalo et al, 2009	0.176	0.225	-0.264	0.616	0.433
Forest to SRC	Arevalo et al, 2009	-0.975	0.237	-1.440	-0.510	0.000
Forest to SRC	Arevalo et al, 2009	-1.636	0.260	-2.145	-1.127	0.000
Forest to SRC	Arevalo et al, 2009	1.922	0.272	1.389	2.455	0.000
Forest to SRC	Arevalo et al, 2009	0.848	0.234	0.389	1.307	0.000
Forest to SRC	Bootstrapped Forest	-1.117	0.796	-2.676	0.443	0.161
Forest to SRC		-0.011	0.458	-0.908	0.887	0.981
Grass to 1st Gen	Bootstrapped grass to 1st gen	-0.966	0.490	-1.926	-0.006	0.049
Grass to 1st Gen		-0.966	0.490	-1.926	-0.006	0.049
Grass to SRC	Grigal & Berguson, 1998	0.227	0.274	-0.310	0.764	0.407
Grass to SRC	Grigal & Berguson, 1998	0.753	0.283	0.198	1.307	0.008
Grass to SRC	Grigal & Berguson, 1998	0.000	0.273	-0.535	0.535	1.000
Grass to SRC	Arevalo et al, 2009	0.178	0.225	-0.263	0.618	0.429
Grass to SRC	Arevalo et al, 2009	-0.079	0.224	-0.519	0.361	0.724
Grass to SRC	Arevalo et al, 2009	-2.707	0.312	-3.318	-2.096	0.000
Grass to SRC	Arevalo et al, 2009	-2.924	0.324	-3.559	-2.288	0.000
Grass to SRC	Arevalo et al, 2009	-0.419	0.227	-0.863	0.025	0.065
Grass to SRC	Arevalo et al, 2009	-0.488	0.228	-0.934	-0.042	0.032
Grass to SRC	Bootsrapped Grass	-1.006	0.677	-2.334	0.321	0.137
Grass to SRC		-0.625	0.351	-1.313	0.063	0.075

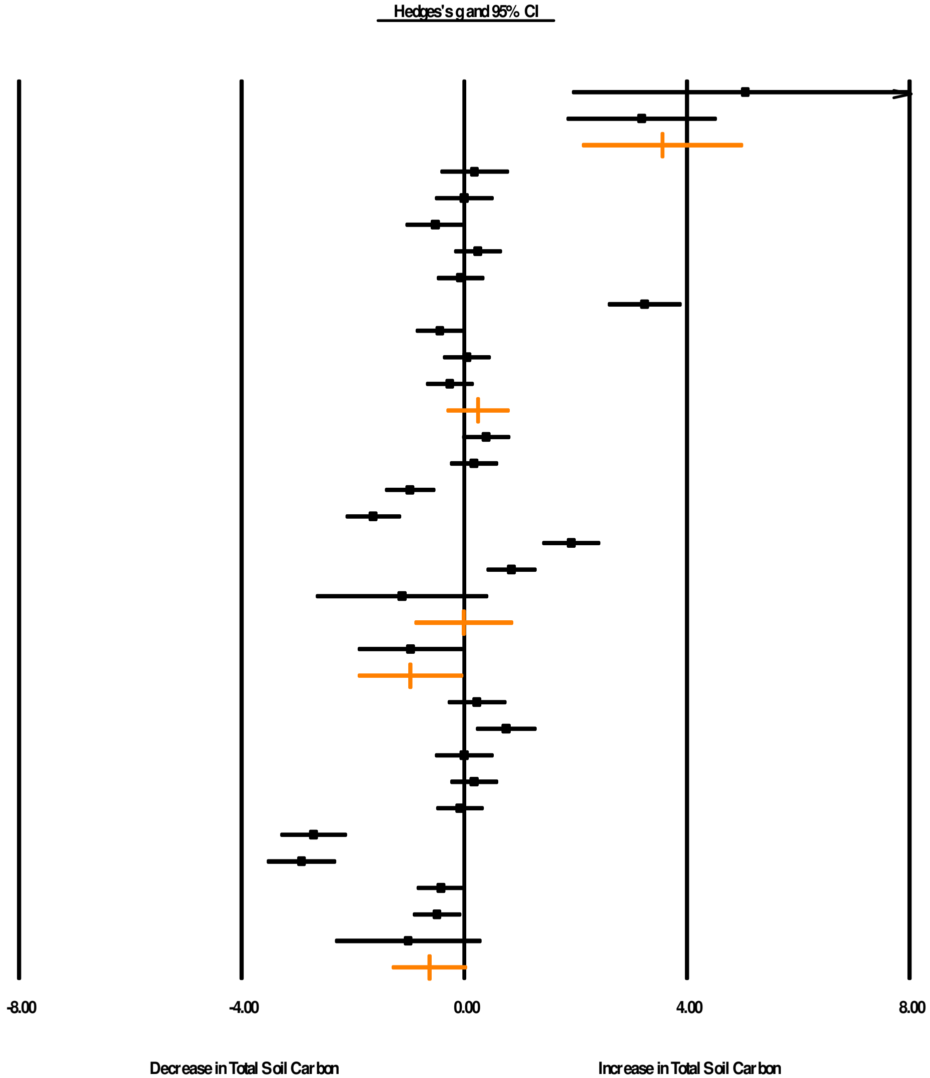

Figure 3.1.1: The effect of land-use change to bioenergy crops on total soil carbon. Bootstrapped data (where no error terms were available) and original study data are shown in black. Summary effect sizes are shown in orange with the mean and 95% confidence intervals.

3.2. Greenhouse Gas Emissions

Greenhouse gas emissions were assessed only for the crop life cycle, so through fixation by photosynthesis and respiration. Data was acquired for a 'whole LCA' approach but due to inconstancies with biomass processing methodology and conversion efficiencies these were not included in this analysis. GHGs include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and 'all', where they have been summated and reported as one value. In order to allow a more harmonious comparison, all GHG data are reported in kg CO_2-equivalents.

The error bars around the GHG data are larger when compared to those for total soil carbon data and the soil organic carbon. There could be several reasons for this: 1) the data is measured using several different techniques; 2) fluxes of some GHGs at certain sites can be very low and therefore there is inherent error in the ability of the techniques to measure such low quantities; and 3) because there are so few data.

The summary effects of the analysis (Fig 3.2.1) are grouped by the land-use transition and therefore could include individual data of the GHGs, which are shown in the figure as to which lines of data correspond to which GHG measured. Due to the limited data this is the most sensible way to try to draw some conclusions.

For all the analyses, there was insufficient data for SRF. There was one paper which presented data but because this data was modelled, it was inadequate to be included in the analyses due to lack of error terms.

3.2.1 Transitions from Arable

The transition with the most data is that of arable to SRC, the summary effect of this transition (Fig. 3.2.1) shows that there is a decrease in GHG emissions when the land is converted from arable cropping to SRC willow or poplar. This result is in agreement with findings from the literature reviewed in D1.2. Arable to perennial grasses shows a slightly larger reduction in GHG emissions compared to SRC, but this summary effect has smaller error bars which mean that the effect can be considered relatively precise, more so than arable to SRC.

3.2.2 Transition from Grassland

Grassland to SRC (Fig. 3.2.1) was the only transition which showed a decrease in the GHG emissions. This decrease is more than that when converting from arable crops as discussed above. This result is very interesting as this is one of the transitions for which less information is available and is also one of the transitions being monitored in the ELUM project. Grass to 1st generation crops shows a significant increase in greenhouse gas emissions, despite the large error bars on the summary effect, both of the lines of data entered to calculate this effect still show an increase in emissions.

3.2.3 Transition from Forest

For crop life-cycle there were no available data which could be entered into analysis to assess the effects of conversion from forest to bioenergy crops on GHG emission.

Group by Transition From	Study name	GHG Measured	Statistics for each study				
			Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Arable to Per	BS Arable to Per	All	-0.272	0.269	-0.799	0.256	0.313
Arable to Per	BS Arable to Per	CO2	-1.464	0.827	-3.086	0.158	0.077
Arable to Per			-0.611	0.538	-1.666	0.444	0.256
Arable to SRC	BS Arable to SRC	CO2	-1.712	0.998	-3.669	0.245	0.086
Arable to SRC	BS Arable to SRC	N2O	0.285	0.291	-0.285	0.855	0.328
Arable to SRC			-0.485	0.972	-2.389	1.419	0.618
Grass to 1st Gen	BS Grass to 1st Gen	CO2	6.110	2.356	1.493	10.727	0.009
Grass to 1st Gen	BS Grass to 1st Gen	N2O	0.189	0.174	-0.152	0.529	0.277
Grass to 1st Gen			2.683	2.924	-3.047	8.414	0.359
Grass to SRC	BS Grass to SRC	CO2	0.276	0.493	-0.690	1.242	0.576
Grass to SRC	BS Grass to SRC	N2O	-1.866	0.687	-3.211	-0.520	0.007
Grass to SRC			-0.742	1.069	-2.838	1.354	0.488

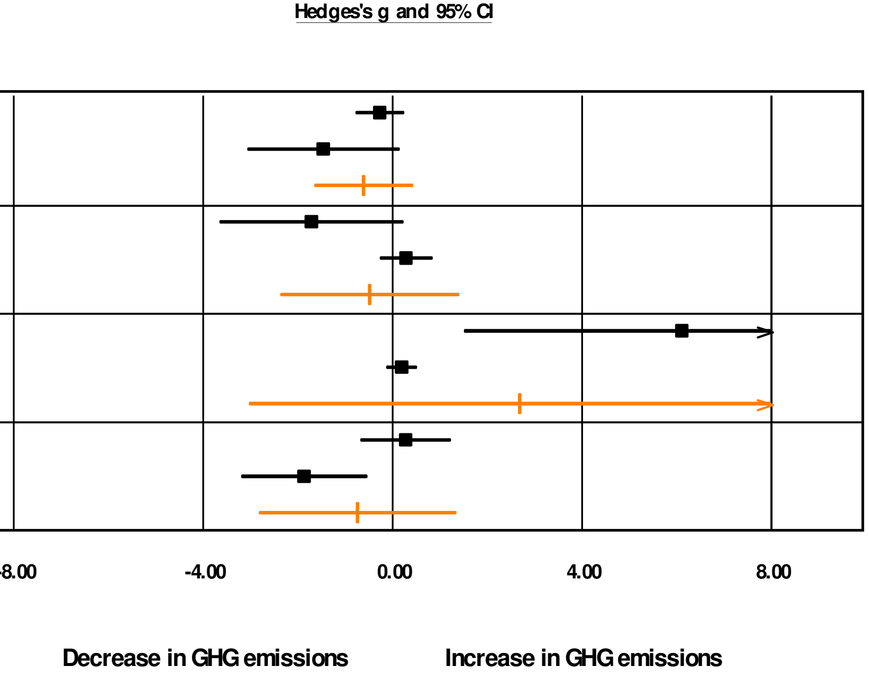

Figure 3.2.1: The effect of land-use change to bioenergy crops on GHG emissions. Transitions include arable to perennial, arable to SRC, grassland to 1st generation and grass to SRC. All data included have been bootstrapped (where no error terms were available); shown in black. Summary effect sizes are shown in orange with the mean and 95% confidence intervals.

3.3. Soil Organic Carbon

3.3.1 Transitions from Arable

The transition from arable to SRC resulted in a very slight increase in SOC, with the summary effect showing very small error bars due to the large sample size. All of the data for this transition were from field experimentation and the error terms were supplied by contacting authors and so confidence in the dataset is high. There was no opportunity to bootstrap data for this transition as there was only one study which was modelled, without error terms and was therefore excluded from the analyses.

The transition for arable to perennial grasses also showed an increase in SOC but this result must be interpreted with caution as it is only from one study, as again as with the SRC there was insufficient data to perform bootstrapping.

3.3.2 Transition from Grassland

The only transition for SOC that covers from grassland was that to 1^{st} generation bioenergy crops which shows a large decrease in SOC. This data does not include any field studies but only modelled data which have been bootstrapped.

There was insufficient data to cover the transitions to SRC and perennial grasses to assess the effects on SOC.

3.3.3. Transition from Forest

The analysis showed an increase in SOC when forest is converted to SRC. The effect is slight but is also one of the only statistically significant results seen in the analysis as it does not cross the mid-line which can be considered the null hypothesis in statistical terms. Again, caution must be exercised when interpreting these data as they were from one field study.

There is a decrease in SOC when forest is converted to 1^{st} generation bioenergy crops which is a result that is to be expected, however this is only based on modelled simulations and the data included in the meta-analysis has been bootstrapped.

Group by Transition From	Study name	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Arable to Per	Dondini, 2009	-0.559	0.673	-1.878	0.760	0.406
Arable to Per		-0.559	0.673	-1.878	0.760	0.406
Arable to SRC	Coleman, 2009	0.030	0.159	-0.282	0.343	0.850
Arable to SRC	Coleman, 2009	-0.047	0.159	-0.359	0.266	0.769
Arable to SRC	Coleman, 2009	-0.098	0.160	-0.411	0.215	0.538
Arable to SRC	Lockwell, 2011	0.879	0.414	0.068	1.690	0.034
Arable to SRC	Lockwell, 2011	5.110	0.800	3.542	6.678	0.000
Arable to SRC	Lockwell, 2011	1.273	0.432	0.426	2.120	0.003
Arable to SRC	Lockwell, 2011	-0.331	0.398	-1.112	0.450	0.406
Arable to SRC	Lockwell, 2011	0.848	0.412	0.040	1.656	0.040
Arable to SRC	Lockwell, 2011	-1.656	0.581	-2.795	-0.517	0.004
Arable to SRC	Lockwell, 2011	-2.554	0.681	-3.889	-1.220	0.000
Arable to SRC	Lockwell, 2011	-1.923	0.608	-3.115	-0.732	0.002
Arable to SRC	Lockwell, 2011	-1.380	0.438	-2.238	-0.521	0.002
Arable to SRC	Lockwell, 2011	0.408	0.387	-0.350	1.166	0.291
Arable to SRC	Lockwell, 2011	4.914	0.760	3.424	6.403	0.000
Arable to SRC	Lockwell, 2011	0.618	0.392	-0.150	1.386	0.115
Arable to SRC	Lockwell, 2011	0.374	0.386	-0.383	1.130	0.333
Arable to SRC	Lockwell, 2011	1.035	0.407	0.237	1.833	0.011
Arable to SRC	Lockwell, 2011	-1.880	0.591	-3.038	-0.722	0.001
Arable to SRC	Lockwell, 2011	-0.872	0.512	-1.875	0.132	0.089
Arable to SRC	Lockwell, 2011	-1.329	0.542	-2.390	-0.267	0.014
Arable to SRC	Lockwell, 2011	-0.638	0.392	-1.407	0.131	0.104
Arable to SRC		0.071	0.230	-0.380	0.521	0.759
Forest to 1st Gen	BS Forest to 1st gen	-0.441	0.543	-1.505	0.623	0.417
Forest to 1st Gen		-0.441	0.543	-1.505	0.623	0.417
Forest to SRC	Coleman, 2009	0.849	0.238	0.382	1.315	0.000
Forest to SRC	Coleman, 2009	0.121	0.231	-0.331	0.574	0.600
Forest to SRC	Coleman, 2009	0.525	0.234	0.067	0.983	0.025
Forest to SRC		0.495	0.210	0.083	0.908	0.019
Grass to 1st Gen	BS Grass to 1st Gen	-1.180	0.782	-2.713	0.354	0.132
Grass to 1st Gen		-1.180	0.782	-2.713	0.354	0.132

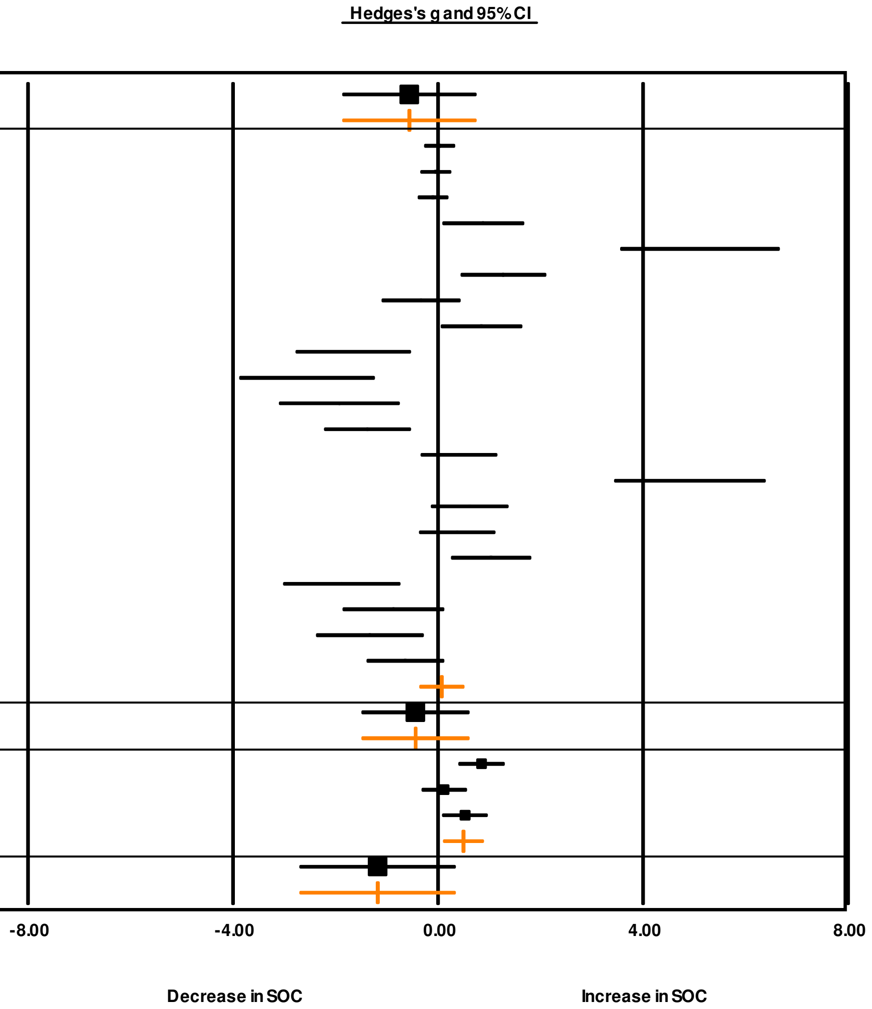

Figure 3.3.1: The effect of land-use change to bioenergy crops on soil organic carbon (SOC). Transitions include arable to perennial, arable to SRC, forest to 1st generation bioenergy crops and grassland to 1st generation. Bootstrapped data (where no error terms were available) and original study data are shown in black. Summary effect sizes are shown in orange with the mean and 95% confidence intervals.

4. CONCLUSIONS AND FUTURE WORK

We have completed a meta-analysis using available data for land-use transitions to bioenergy crops. The conclusions that can be drawn from this analysis have been summarised in Table 4.1.

Table 4.1: Summary of the effect on conversions to bioenergy cropping systems based on outputs from meta-analysis. Direction of arrow indicates increase (↑), decrease (↓) or no change (↔). Colour of arrow indicates effect with green being positive and red negative. A dash indicates where there was insufficient data.

Transition from	Transition to:	TSC	GHG	SOC
Arable	SRC	↑ (green)	↓ (green)	↔ (blue)
	Perennial grasses	↑ (green)	↓ (green)	↓ (red)
	SRF	-	-	-
Grass	SRC	↓ (red)	↓ (green)	-
	Perennial grasses	-	-	-
	1st gen	↓ (red)	↑ (red)	↓ (red)
	SRF	-	-	-
Forest	SRC	↔ (blue)	-	↑ (green)
	Perennial grasses	-	-	-
	1st gen	-	-	↓ (red)
	SRF	-	-	-

It can be seen from Table 4.1 that in general a conversion from arable to any form of bioenergy perennial cropping system, is positive, from forest is generally negative and from grass is a little less certain. This reflects the conclusions which were drawn from previous work conducted in D1.2. The most striking feature of Table 4.1, is that there are no data on SRF. Whilst a few papers did present data, there was a lack of experimentation taking place of the effects of a conversion to bioenergy cropping in temperate climates. It was also observed from this analysis that the transition with the most data was that to SRC crops, reflecting the fact that this type of energy crop has a longer history, with its wide deployment across Scandinavian Europe and the USA for heat and power, from the 1970s.

The summary Table 4.1 has several caveats and limitations, of which the reader should be made aware. The most obvious is the limited field experimental research taking place into the effects of land-use change to bioenergy cropping systems. While an attempt has been made in this deliverable to quantify these effects it is very difficult to draw robust conclusions on such a limited dataset. Where possible original data, with error terms have been included and has no doubt been valuable to the analysis. Modelled data are more problematic, since although undoubtedly of value, they tend to be inappropriate for meta-analysis. The main problem being lack of error terms, which therefore leads to an over-use of bootstrapping that may lead to erroneous conclusions on size effects. Another problem with modelled data, in this case, is the effort and time required to elucidate underlying parameters which are entered to generate the model that may limit its interpretation significantly.

The sophistication of the meta-analysis was also limited due to availability of data. For example, soil sampling depth and bulk density are both important in understanding the storage of terrestrial carbon as both total soil carbon and soil organic carbon in this case, but due to lack of data their effects on the metrices, were ignored. Sampling depth will have a large effect on the amount of carbon stored as typically the deeper layers will contain more carbon compared to the shallow layers which undergo more disturbance, and the interaction of the vegetation type will affect how carbon is distributed along the profile. If in the analyses there was a bias towards a certain sampling depth, both total soil carbon and soil organic carbon could be under- or over- estimated. Bulk density is also important as it is in indicator of soil compaction and can influence the ability of soil to hold nutrients, water and carbon. When reporting stored carbon, studies will sometimes correct for the bulk density of their soil to give a more accurate estimate of soil carbon but other do not – this will affect the accuracy and continuity of the values in the meta-analysis.

In the general domain of meta-analytical technique there are further limitations in addition to those mentioned above. One potential limitation is publication bias: the phenomenon where authors will only tend to publish results which are statistically significant or there is a bias towards using studies that they are most aware of. This problem is likely less apparent in the natural sciences, compared to perhaps to the social sciences where meta-analyses are often applied to large qualitative data sets. To ensure that no bias is present here the analysed papers here are those from the systematic review conducted as part of D1.2.

The work conducted from all of Work Package 1 has been useful in informing the activities of other work packages. The work shown here emphasises the need to include sampling depth and bulk density – both of which are being considered in WP2 and WP3, where metre deep cores are being taken and the carbon assessed along this gradient. The database generated here will feed into the WP4 modelling work to help parameterise the model, uncovering data which may not have been previously known to the WP4 team.

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Appendix I: Full Methodology

A1.1 - Search Methodology

The initial search method was developed in 2010 by Mathew J Tallis and was adapted by Zoe M Harris in 2011 when the work began. Searches were conducted using three commonly used search engines, namely Google Scholar, Science Direct and Web of Science. The use of different search engines was to ensure that all publications that fall under the criteria of our search were captured and the search was truly exhaustive. For example, Google Scholar is able to capture grey literature, such as governmental reports, which the other search engines will not capture. Science Direct was used as papers in its databases, provided by Elsevier, were excluded from results in Google Scholar searches at the time of the original searches, although this has now changed and may be one reason why between 2010 and 2011 the numbers of hits from Google Scholar showed an increase. Web of Science was searched using two techniques, one with speech marks around the search terms and the other without, as differences were found in the papers retrieved from the search from using either method. This is shown in figures and in text using: "WOS" or WOS, for each search technique respectively. The ability of Google Scholar to act as a scholarly search engine has been called into question since its beta release in 2004 (Jacsó, 2005). An understanding of search engine algorithms is important, enabling users to have an idea of how searches are performed, to assess the reliability of any search for their own purpose. Google does not disclose what algorithm they use but from several studies it appears that it uses a combination of ranking factors (Beel & Gipp, 2009a; Beel and Gipp, 2009b), taking different weightings compared to other search engines which allow the user to select how the papers are ranked; for example Science Direct allows users to select between relevance and date (Beel & Gipp, 2009a). It is apparent now, 7 years after its release, that Google Scholar is a contender in the scholarly domain and is challenging the more conventionally used search engines, Science Direct and Web of Science (Yang & Meho, 2006).

Search terms were defined and searched in a standardised format across the search engines with slight modifications made to suit the searching preferences of the particular engine. The search string was made up of four tiers, which allowed filtering of the papers through the searches and also allowed us to highlight the difference in area of interest between crop species (Fig 1). The results from these search engines were uploaded into a database for systematic review, but in the first instance the number of hits from the search was recorded. Search terms were defined to capture all literature which would contribute to covering the assessment of the effects of LUC to bioenergy crops in a UK context. SRF was initially one of the species terms used in the ETI contract but it was agreed at a later date, following our consultation with the consortium, that the individual species under SRF would provide a more effective search term, as these individual species terms captured references not captured by applying the generic term "SRF".

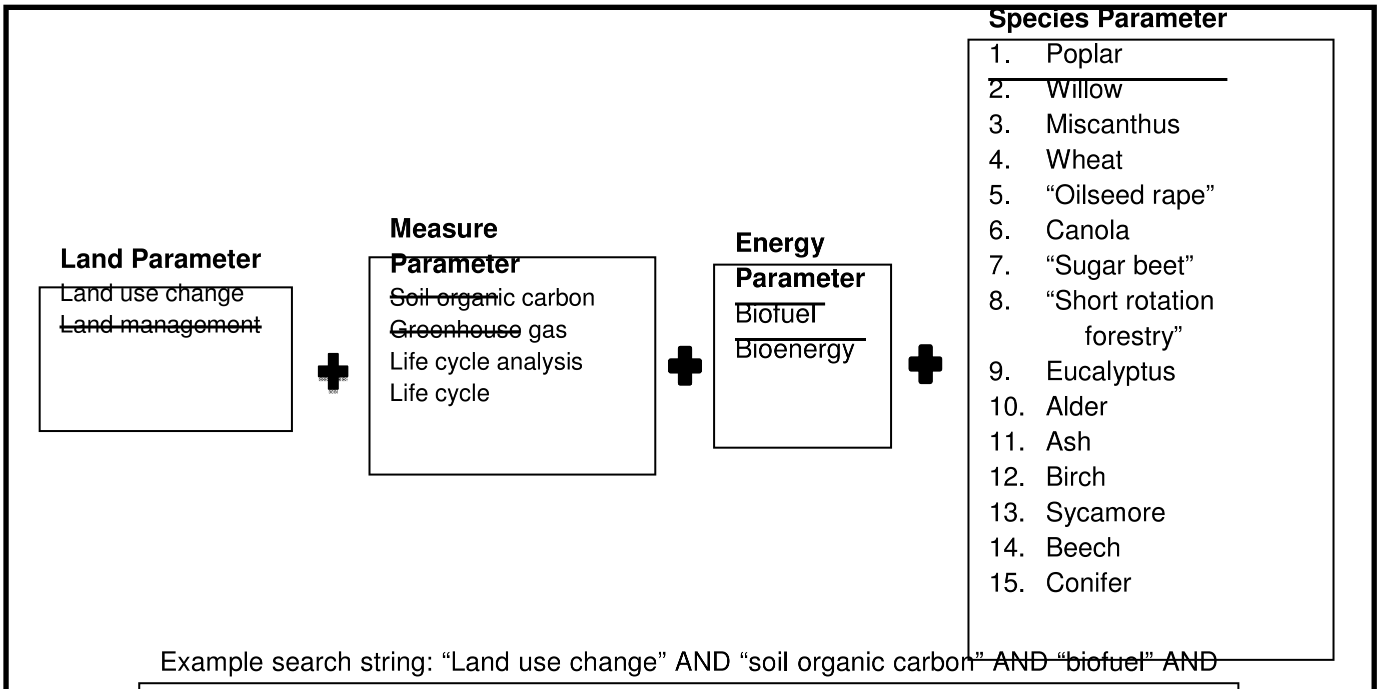

Figure ng consultation with the consortium at month 2 of the project.

This search stage was comprised of 1024 unique searches which resulted in a total of 5786 individual references once duplicates were removed. These papers were firstly ‘raw processed’ by assignment of the categories ‘useful’ and ‘not useful’ based on a pre-defined selection criteria as outlined in the ETI contract. The criteria for section were:

- the location (to be UK applicable)

- the species concerned (inclusive of first and second generation bioenergy crops)

- the mention of the metrics which we used in the meta-analysis

After this first round of processing, the papers were more carefully inspected to extract the data in pre-defined units for the meta-analysis, performing standard unit conversions if required. The metrics used for the extraction of data covered soil processes, GHG emissions and LCA are shown in Figure 2.

	Paramter	Unit
	Paper ID	
	Author	
	Year	
	Title	
	Transition from:	type or n/a
	Paper Type	Model/field/lab/database
	Measument year	
	Location	Latitude
		Longditude
	pH	
	Temp	°C
	Precipitation	mm yr^{-1}
	Yield	*t ha^{-1} yr^{-1}*
Different management Regimes	**Fertilization**	kg ha^{-1} yr^{-1}
	Tillage	Y/N
	Planting Density	*plants ha^{-1}*
	Crop Rotation	Crop & Length
	Irrigation	Y/N or n/a
	Residue	Y/N or n/a
Soil Texture	**Class**	
	Sand	%
	Silt	%
	Clay	%
	Bulk Density	g cm^{-3}

	Paramter	Unit
	Yrs after transition	*Yrs*
	Soil Organic Carbon	*kg C ha^{-1} yr^{-1}*
	Depth for SOC	*cm*
	Total Soil Carbon	*Kg C ha^{-1} yr^{-1}*
	Correction for bulk density	*Y/N*
GHG Net Emissions for crop life cycle	CO_2	*Kg CO_2 eq ha^{-1} yr^{-1}*
	N_2O	
	CH_4	
GHG for whole LCA	CO_2	*Kg CO_2 eq ha^{-1} yr^{-1}*
	N_2O	
	CH_4	
	Whole LCA for energy	*(MJ_{in} :MJ_{out})*
	Carbon Isotopic Soil Signature	*‰*
	Carbon Sequestration	*kg C ha^{-1} yr^{-1}*
	Dissolved Organic Carbon	*µg C g^{-1} soil*
	Below Ground Biomass	*Kg ha^{-1} yr^{-1}*
	Above Ground Biomass	*Kg ha^{-1} yr^{-2}*
	Litter Dry Matter	*g yr^{-1}*
	Litter Decomp Rate	*k*
	Root Decomp Rate	*k*
	Fine Root turnover	*yr^{-1} or % yr^{-1}*
	Conversions Made	
	Other Measurements	

Figure 2: Data extraction parameters for meta-analysis including standard units for measurements

The data extraction parameters, as seen in figure 2, were chosen with WP4 in mind as they will contribute to WP4's limited simulation input data for running the model. This is important as it will allow more accurate outputs to be generated for a wider range of bioenergy scenarios that may have been previously missed by modellers. Preliminary data sets were sent to Dr Marta Dondini at the University of Aberdeen to ensure all parameters were useful for model inputs before data extraction commenced. All the data from the papers in this deliverable will be passed onto Aberdeen to allow them periodically to enhance the model outputs.

A1.2 - Outline of CMA and FAQs

The statistical package used for deliverable D1.5 was Comprehensive Meta-Analysis (CMA), revised from the previously selected 'MIX 2'. The choice was made initially to use MIX 2 as it was relatively cheap and seemed relatively user-friendly. However, Zoe Harris completed an online meta-analysis course to aid her understanding and this course primarily used CMA for all its teaching. Due to the familiarity gained with the software on this course and the subsequent one-to-one support from the program developers it seemed the logical solution to adopt this software to complete the analysis. Referring back to D1.2 report (Management & Deliverable Reference: PM08.1.2) in the Appendix A1.2 it can be seen that there was the choice between CMA and MIX, both being appropriate for this purpose but MIX was chosen primarily based on price.

CMA is a statistical package which is designed specifically for the completion of meta-analyses, giving it a significant advantage over other more general statistical packages (such as SPSS, STATA etc.) which do not have sufficient processing depth and choice of processing options specific to meta-analytical techniques. CMA allows you to work with a spread sheet interface, compute the effect sizes automatically with the click of a button and produce high quality plots to visualise data. The software is extremely flexible in terms of data entry format which was extremely important in this case due to the varied formats in which the data and error terms were presented/acquired.

What is a meta-analysis?

A meta-analysis is a method to quantify the effect of a large set of data from a large set of studies in a way which can get a better overall picture of the changes occurring. A meta-analysis takes the data from many studies and presents a mean value and an upper and lower quartile limit, so the overall effects from these studies can be statically interpreted.

What is an effect size?

An effect size is a single number for each line of inputted data which takes into account the mean value, the standard deviation and the sample size. When all the effect sizes are considered together a 'summary effect size' is given which summarises all the individual effect sizes to give a mean effect.

What is Hedges g?

Hedges g is a way of presenting effect sizes, there are several matrixes available but this is the most commonly used in meta-analyses. It takes into account the before land use change mean and the after land use change mean (standardised across all samples) and then computes these against the pooled standard deviation of all the samples. This is done so the outputted *g* is corrected for when small sample sizes exist which is very appropriate in this case.

What is bootstrapping and why was it used?

Bootstrapping is a method of resampling a population to obtain information about that population, and in this case we are generating the mean, standard error and 95% confidence limits of the re-sampled population. The population is resampled many thousand times over to generate these numbers and is performed in the scripting program R. It was used in this case as there was often data presented in papers which did not have error terms and in order to allow their inclusion in the analysis bootstrapping was applied.

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