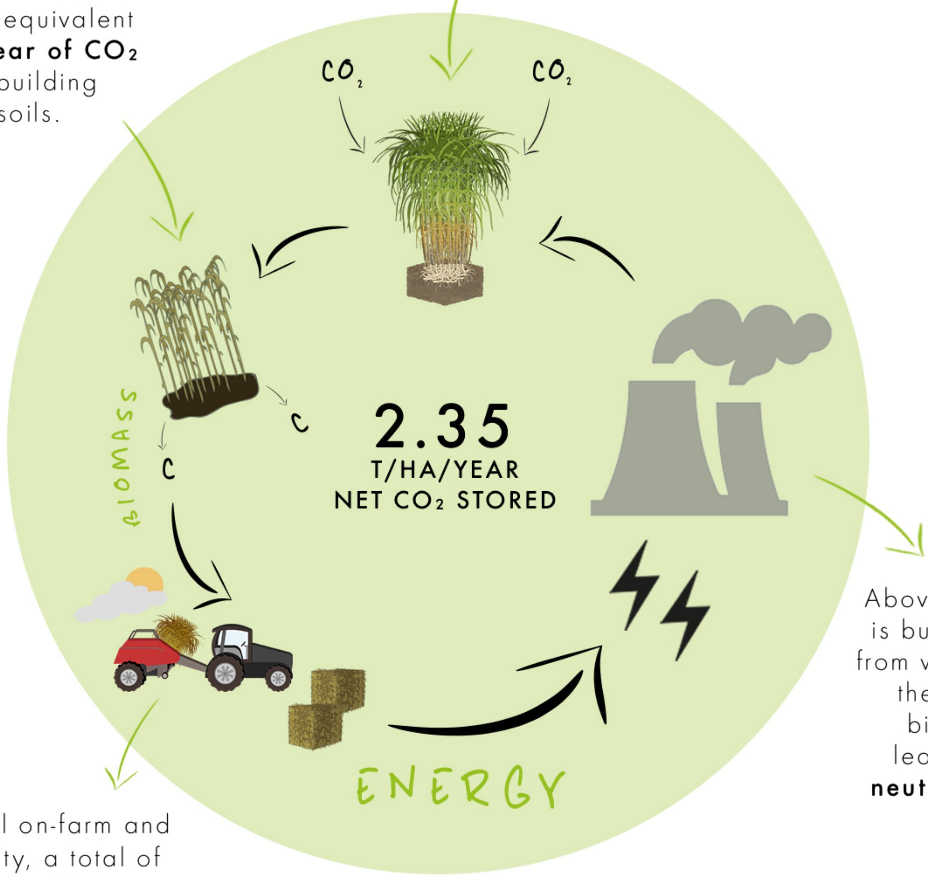
# Carbon Life Cycle

As Miscanthus grows, its above ground biomass will absorb the equivalent of **26 t/ha/year of $CO_2$**

The underground rhizome locks away the equivalent of **3.05 t/ha/year of $CO_2$** as it grows, building healthier soils.




Above ground biomass is burnt, the emissions from which are offset by the above ground biomass growth, leading to **carbon neutral** green energy.

Emissions of all on-farm and delivery activity, a total of **0.7 t/ha/year $CO_2$**, is offset by the underground biomass.

terravesta™

Growing Innovation

# Key Points

Miscanthus is a net carbon negative feedstock with the potential to capture net 0.64 tonnes of carbon (2.35 tonnes CO2e) per year in the ground, the amount being proportional to the biomass yield but excludes the actual biomass itself.

Miscanthus biomass is carbon neutral in bale form at the factory gate, with all previous production/logistics emissions accounted for in the net in-ground carbon capture calculation. The biomass contains the equivalent of c. 7 tonnes per ha (c. O.5t C/t biomass), or c. 26 t/ha CO2e.

Depending on use of biomass, the biomass carbon is either stored (eg. BECCS, building material) in addition to the below ground storage above, or released (eg. unabated power generation), in which case the use process is carbon neutral, with the released CO2e being reabsorbed by the crop for the next crop.

In terms of relative carbon efficiency, it performs well against alternative pre-2050 feedstocks such as imported wood pellet, natural gas and annual crops or crop residues.

Development of strategic Miscanthus crop area is complimentary to afforestation, rather than competitive against afforestation, as are the ultimate best end-uses. In particular, Miscanthus has the potential to supply substantial feedstocks to deliver 2050 and shorter strategic national carbon/climate objectives.

terravesta™
Growing Innovation

# Carbon

Even the most apparently simple question in relation to carbon involves a complex answer, because that question always has context, dependent upon both who is asking it and why.

This is because carbon lies at the heart of global climate strategy, and demands a fundamental change in almost every aspect of human activity, with knock-on consequences for our economy, society and the greater natural environment.

At the present time there is a lack of either international or even national (UK) understanding on how and where carbon is evaluated or to whom the benefit or detriment of that carbon or carbon flux accrues. Resolving this is fundamental to driving both the industrial/economic and societal changes necessary to deliver the new, non-exploitative path necessary for humankind and the future of life on our planet.

Such resolution will, of course, fall to our politicians who seek to match the correct science with actions that are necessarily deliverable now or in the short term across an all-encompassing activity spectrum from farming to space travel, and everything between.

In this period of policy flux, every possible interest is lobbying their case, and, as such, the simplest answer to that simplest question will be used to deliver massively different outcomes, depending on the context of the information user. What is certain is that the carbon element of the Miscanthus supply chain is likely to have high importance to the participants in different contexts, and "ownership" of that carbon will be a critical motivator between potential grower, potential off-taker and all in between.

For this reason, we consider separately the carbon relative to the growing crop in the field, attributable to the land, under Net Carbon Capture, and the carbon associated with the biomass and its uses, under Crop Biomass.

terravesta™
Growing Innovation

# Terravesta Miscanthus; Headline numbers.

- Net Carbon Capture up to 2.35 t$CO_2$e/ha/year, equivalent to 0.64 tC/ha/year. [15]
- Crop Biomass carbon content 45-60%. (Based on 50%, 7tC/ha/year, equivalent to 26t$CO_2$e/ha/year based on a yield of 14 ODT/ha). Based on multi study data.

# Net Carbon Capture

Miscanthus is a source of carbon capture on farmland removing up to 2.35 tonnes of $CO_2$e or 0.64 tonnes of carbon from the atmosphere annually, dependent on soil type and crop vigour (see Figure 1 and two below).

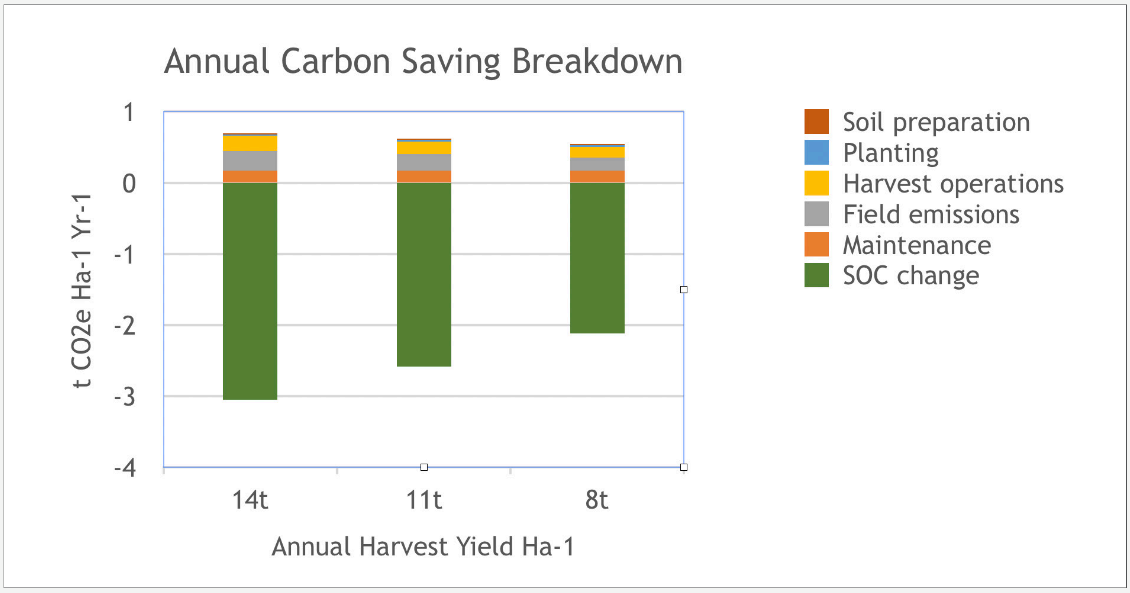



**Figure 1** Net Annual Atmospheric CO2e removal at different yield while crop remain in the field, accounting for planting material production, crop establishment, and farm operations through to bale delivery. (LCA Analyst; Jan Lask, University of Hohenheim)[1].

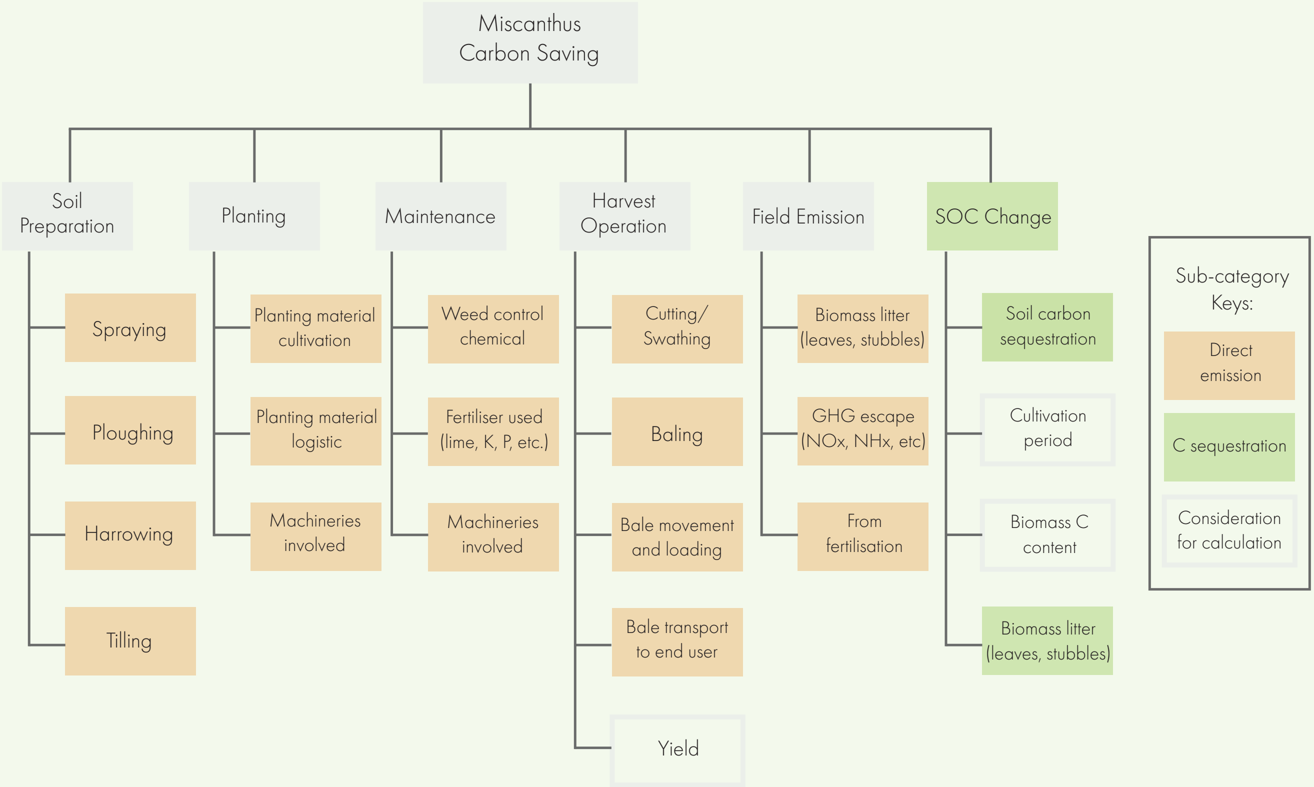



**Figure 2** Considerations made when calculating the carbon saving potential in cultivating Miscanthus.

Terravesta believes that the opportunity for Miscanthus in bio-energy and the broader bio-economy will require moving from rhizome propagation to higher performing seed based hybrids, for which plant breeding will be able to develop desirable traits for differing uses as well as wide variations in growing condition as in different geographical regions. They also offer much more efficient production ratios (1ha rhizome nursery = c.40ha new crop in 2 years; 1 ha seed production nursery = c.2,000ha new crop every year).

As part of the LCA study, the difference between seed and rhizome-based establishment was analysed, and showed material source to establishment emissions to be lower for seed (598kg$CO_2$e/ha established) than rhizome (675kg$CO_2$e/ha established). However, when considered over the potential 20 year life of the crop, the difference is not statistically significant. Commercial seed nursery and production systems for Miscanthus are still in early stages of development, so a comparison between this and the growing lifting and grading of rhizome has not been included at this stage, although we predict that seed production will show significantly lower emissions due to the lack of soil disturbance compared to rhizome.

This **Net Carbon Capture** calculation does **NOT** account for the carbon content of the harvested biomass, which is taken off farm for other uses.

terravesta™
Growing Innovation

# Crop Biomass

Miscanthus produces 8-14 tonnes of above ground biomass. Used in power generation or wet fermentation, the process CO2 emissions are assumed to be cancelled out by the CO2 absorbed during growing the crop, making these processes emissions net neutral. However, where the crop is used for long life products such as fibres, building materials, biochar etc., or bio energy with carbon capture and storage (BECCS), then it is possible to account for this carbon saving as additional, and separate to the Net Carbon Capture above. The effect of this is highlighted in the Climate Change Committee's 6th Carbon Budget - Methodology Report (2020) [2], where the graph in Figure 3 below demonstrates the effect of BECCS on total GHG capture.

Current literature [3 -12] puts carbon content in Miscanthus biomass between 45-60%. If one assumes 50% as the carbon stock, and 14 tonnes dry matter per Ha as the yield, the result is up to 26 tonnes of $CO_2$e taken out of the atmosphere each year per ha of Miscanthus harvested biomass. From this one would need to subtract the carbon emissions associated with the manufacturing process the crop is used for to get a net figure for Crop Biomass Carbon.

terravesta™
Growing Innovation

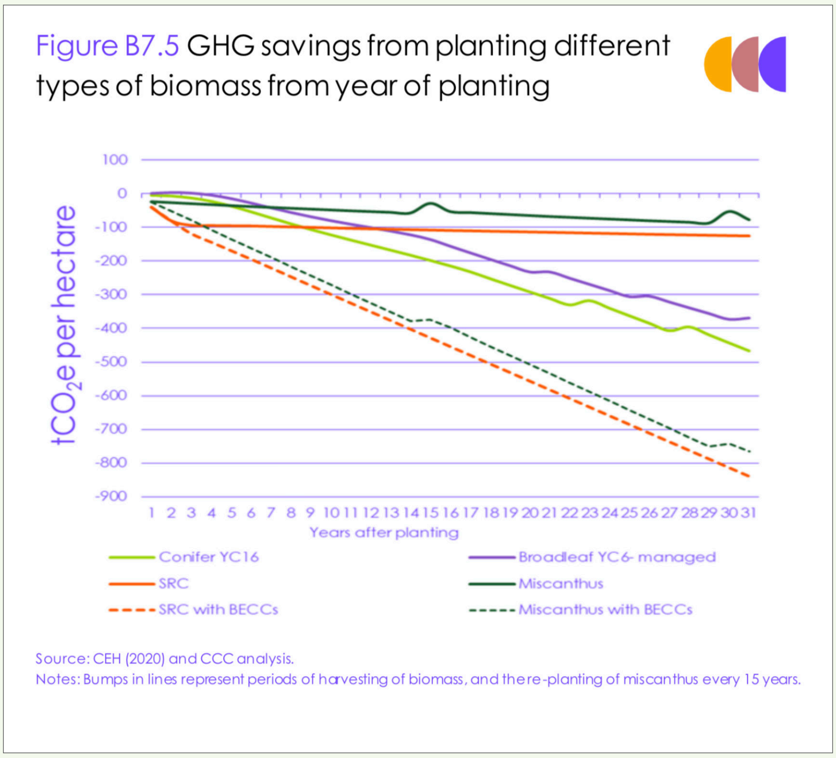



**Figure 3** CCC 6th Carbon Budget – Methodology Report (2020 Figure B7.5 in the report)[2] GHG savings from planting different types of biomass from year of planting. (Crop and biomass savings).

Figure 3 above assumes Miscanthus is grown on arable land, SRC both arable and grass, forestry on uplands (which are at considered high emissions source under current use). In considering crop biomass, it should also be noted from Figure 3 that that the conifer and broadleaf options do not yield any harvested biomass for 20 years, so there could be a counter factual if the consequence is that less carbon negative goods have to be utilised in the meantime. Equally, Figure 3 is based on home grown biomass sources. We consider imported feedstock emissions below.

**Validating Miscanthus Against Alternative Feedstocks**

**Relative Transport Emissions**

In the absence of significant UK grown timber biomass feedstocks, the alternative is imported wood feedstocks (in particular wood pellet from North America).

For Terravesta's UK Miscanthus, transport to off-taker facility is included within the LCA for NET Carbon Capture above, and therefore our Miscanthus bale is considered Carbon Neutral at the factory gate (www.BWSC.com/sustainability/minimising-emissions).

Emissions for importing wood pellets from overseas have been calculated at 122kg $CO_2$e per MWH of electricity produced [13].

terravesta™
Growing Innovation

# Relative to Natural Gas

Emissions associated with natural gas extraction and combustion are 14.2g C/MJ which, taking into account energy conversion efficiencies, translate to 33.73g C/MJ for gas heat and 23.61g C/MJ for gas CHP. Based on average household use of 3780 kWh per year (Ofgem stats) [14], Table 1 below shows the potential annual C emission per household, which could be a saving if they switched to electricity heat (e.g. GS/AS Heat pump) and power generated from Miscanthus.

| | Gas Fire | CHP | Miscanthus |
|---|---|---|---|
| g C MJ - 1 | 33.73 | 23.61 | 0 |
| Monthly average household demand (kWh) | | 315 | |
| Annual average household demand (kWh) | | 3780 | |
| Monthly average household demand (MJ) | | 1134 | |
| Annual average household demand (MJ) | | 13608 | |
| Monthly C emission per household (t C) | 0.038 | 0.027 | 0 |
| Annual C emission per household (t C) | 0.459 | 0.321 | 0 |

**Table 1** Natural gas carbon emissions per household from gas heat or CHP (Ofgem statistics)[14], compared to electric heat and power generated by Miscanthus.

Both natural gas and biomass are feedstocks for power generation. Unabated gas generation delivers net positive emissions, while by virtue of ground-based carbon capture Miscanthus biomass generated power is net emissions negative. Emerging carbon capture and storage technologies will have the effect of almost negating net emissions from natural gas power generation, while massively enhancing the level of carbon capture through Miscanthus fuelled power generation (Figure 3, above).

terravesta™
Growing Innovation

## Relative to Annual Crop Biomass

Biomass from annual crops fall into two categories; dedicated biomass crops, eg. maize, and crop residues, eg. straw. Because of their annual nature, both categories generate net annual land-based emissions through annual tillage and establishment and maintenance operations and the import of nutrition.

With crop residues, it can be argued as to where these emissions are allocated. Do they belong to the wheat, for example, which is the primary reason for the crop being grown? Even if the annual emissions are allocated against the primary crop, it should be borne in mind that the residue will contain both carbon and nutrients. If the residue is removed from the soil, increased levels of imported nutrients will be required to replace those carried off with the residue.

Therefore, however accounted, biomass from annual crops will almost certainly have net positive emissions at the same point of comparison as the net carbon capture of up to 2.35 t $CO_2$e/year for Miscanthus.

## Relative to Trees

There is much debate about the desirability of afforestation, it's benefits and landscape impact. It also raises expectations of delivery of conflicted outcomes in terms of access/leisure, nature/habitat/commercial production, and balancing such outcomes will be a challenge. Those same topics are the subject of debate around all existing forest abroad from which we draw our imported timber feedstocks. Whatever that outcome, there is no doubt that trees and afforestation offers an excellent carbon sink and source of GHG removal.

Additionally, the size of timber lends it to easy conversion for durable uses such as construction materials and furniture, where the carbon remains stored for the long-term in a very non-volatile way. On the basis of the Best C use principle, it must be the case that relatively little of the potential yield should be available for instant $CO_2$ release uses such as power generation.

In this sense dedicated perennial biomass crops offer a more single purpose feedstock solution that is very transparent and controllable, while offering net C negative supply chains.

In the context of the UK's mandated commitment to "Net Zero 2050,"[15] and in particular the necessity to decarbonise electricity with CCS as the core to that, afforestation is not anticipated to contribute any feedstocks within the 30-year 2050 window. With biomass availability from as little as two years after harvest Miscanthus offers the opportunity to fill the gap in a totally complimentary way that allows our future woodland resource to be planned in a way that best balances all of the societal, environmental and economic requirements from it.

terravesta™
Growing Innovation

# Conclusion

While Miscanthus may not be the only actor in the carbon story, it is playing an important role. Further, the existing farming infrastructure makes it accessible on most farm settings. The existing logistic chain means that both the carbon and financial cost can be clearly laid out in an expected manner allowing for a clear pathway to calculate returns.

terravesta™
Growing Innovation

# Reference:

[1] Lask J., Kam., Weik J., Kiesel A., Wagner M., Lewandowski, I. (2021) A simple parametric model for calculating the greenhouse gas emissions of miscanthus cultivation in Europe. GCB Bioenergy (Submitted for publication)
[2] Committee on Climate Change (2020) Sixth Carbon Budget – Methodology Report p. 228 https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-Methodology-Report.pdf
[3] Amougou N., Bertrand I., Machet J., Recous S. (2011) Quality and decomposition in soil of rhizome, root and senescent leaf from Miscanthus x giganteus, as affected by harvest date and N fertilization. Plant and Soil. 338(1) 83-97
https://link.springer.com/article/10.1007%2Fs11104-010-0443-x
[4] Anderson-Teixeira K., Masters M., Black C., Zeri M., Hussain M., Bernacchi C., Delucia E. (2013) Altered belowground carbon cycling following land-use change to perennial bioenergy crops. Ecosystems. 16(3): 508-520
https://link.springer.com/article/10.1007/s10021-012-9628-x
[5] Carvalho J., Hudiburg T., Franco H., Dulucia E. (2017) Contribution of above- and belowground bioenergy crop residues to soil carbon. GCB Bioenergy. 9(8): 1333-1343
https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/gcbb.12411
[6] Christensen B., Lærke P., Jørgensen U., Kandel P., Thomsen I. (2016) Storage of Miscanthus-derived carbon in rhizomes, roots, and soil. Canadian Journal of Soil Science. 96(4): 354-360
https://cdnsciencepub.com/doi/10.1139/cjss-2015-0135
[7] Clifton-Brown J., Breuer J., Jones M. (2007) Carbon mitigation by the energy crop Miscanthus. Global Change Biology. 13(11): 2296-2307
https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2007.01438.x
[8] Dohleman F., Heaton E., Arundale R., Long S. (2012) Seasonal dynamics of above- and below-ground biomass and nitrogen partitioning in Miscanthus x giganteus and Panicum virgatum across three growing seasons. GCB Bioenergy. 4(5): 534-544
https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-1707.2011.01153.x
[9] Holder A., Clifton-Brown J., Rowe R., Robson P., Elias D., Dondini M., McNamara N., Donnison I., McCalmont J. (2019) Measured and modelled effect of land-use change from temperate grassland to Miscanthus on soil carbon stocks after 12 years. GCB Bioenergy 11(10): 1173-1186
https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12624
[10] Ledo A., Heathcote R., Hastings A., Smith P., Hillier J. (2018) Perennial-GHG: A new generic allometric model to estimate biomass accumulation and greenhouse gas emissions in perennial food and bioenercy crops. Environmental modelling and Software. 102: 292-305
https://www.sciencedirect.com/science/article/abs/pii/S1364815217310496
[11] McCalmont J., Hastings A., McNamara N., Richter G., Robson P., Donnison I., Clifton-Brown H. (2017) Environmental costs and beenfits of growing Miscanthus for bioenergy in the UK. GCB Bioenergy 9(3): 489-507
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5340280/
[12] Rowe R., Keith A., Elias D., Dondini M., Smith P., Oxley J., McNamara N. (2016) Initial soil C and land-use history determine soil C sequestration under perennial bioenergy crops. GCB Bioenergy 8(6): 1046-1060
https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12311
[13] Speed R. (2017) Drax Biomass. Winchester Action on Climate Change (WinACC) University of Winchester. Winchester
https://www.winacc.org.uk/downloads/STAP/2017_Drax%20Biomass.pdf
[14] https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values
[15] Committee on Climate Change (2020) Land use: Policies for a Net Zero UK https://www.theccc.org.uk/wp-content/uploads/2020/01/Land-use-Policies-for-a-Net-Zero-UK.pdf

terravesta™
Growing Innovation