Landscape Carbon Calculator / Pathfinder

Methodology, Data Sources and Metrics Summary

July 31, 2020

Contents

Introduction

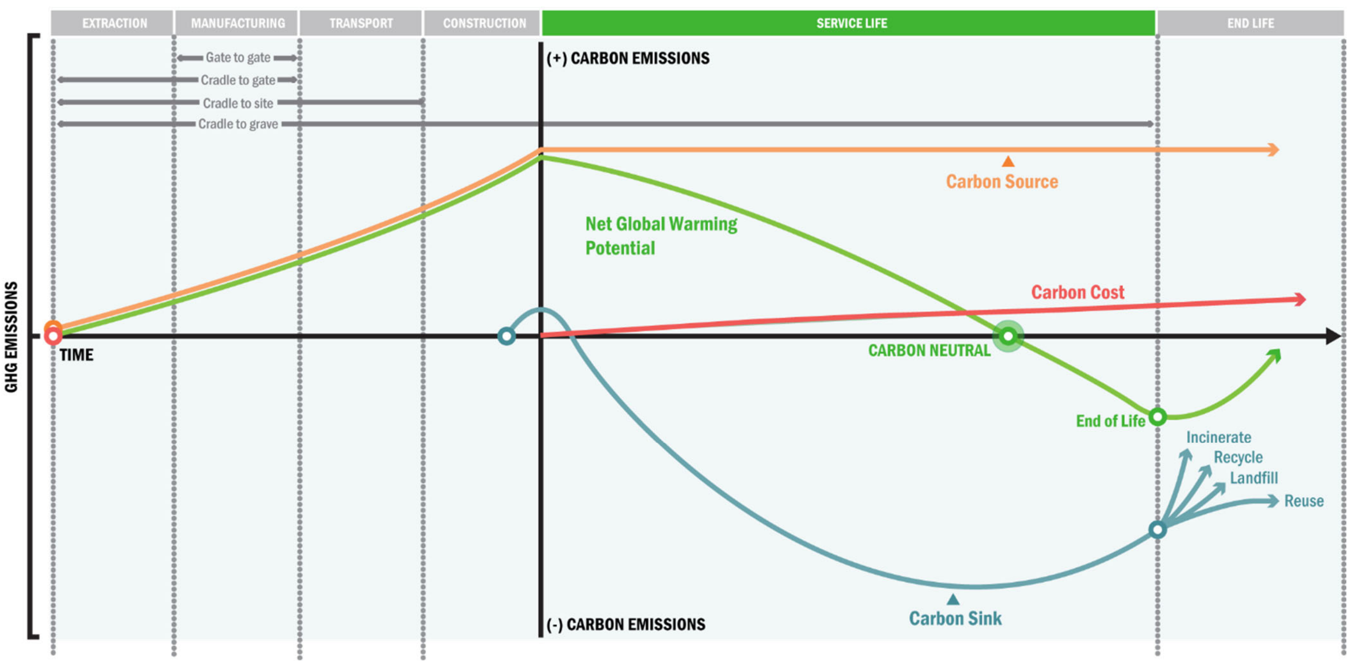
CMG Landscape Architecture and Atelier Ten collaborated through the Climate Positive Design initiative to develop a back-end calculation tool that computes greenhouse gas (GHG) emissions and sequestration associated with landscape projects. This calculation tool is the basis for the front-end web-based Pathfinder app, which is intended as an early-stage design tool with simple inputs, and enables users to compare design alternatives from a 'contribution to climate change' lens by accounting for the following:

- **Carbon Sources (Embodied Carbon from "Materials" as shown in the V2 app)**: GHG emissions associated with the production of construction materials installed on-site. For the project, these are 'upfront emissions' that have occurred in Year 0 of its lifespan.
- **Carbon Costs (Operational Carbon from "Operations" as shown in the V2 app)**: GHG emissions associated with fertilizers and maintenance of vegetation. These are fairly constant every year, apart from the heavier fertilizer use associated with the establishment of vegetation.
- **Carbon Sinks**: CO_2 sequestration by trees, shrubs, lawn and wetlands for photosynthesis (**as shown as "Plants" in the V2 app**). As trees and shrubs grow faster, they pull out more CO_2 from the atmosphere, resulting in an increasing rate of sequestration every year which peaks as they reach maturity.

These are elaborated further in subsequent sections of the report.

***Note:** "GWP" and "carbon/carbon emissions/GHG emissions" have been used interchangeably in this report.*

Users can see the variables listed above change over the lifespan of a project, as shown below.



The tool characterizes emissions and sequestration during the service life of the project but does not account for en-masse removal and disposal of vegetation and hardscaping when the project is replaced.

How To Use The Tool

The tool is intended for relative comparisons to inform early design decisions. For instance, the user can see in real-time the carbon impact of changing the following design variables and how important each of them is to the project's overall carbon story:

- ratio of deciduous and evergreen trees/shrubs
- ratio of large trees vs small trees
- amount of vegetation vs hardscaping materials
- different materials for paving, walls, sub-surface fill, site elements

- electric vs gas-powered maintenance equipment
- low-mow fescue vs lush-green lawns requirement intensive care
- establishing wetlands
- fate of existing trees on-site
- regrading soil vs no-till
- importing and off-hauling soil

The tool, however, is not intended for performing a greenhouse gas inventory of projects. If the user wants to perform a more accurate inventory of the project, they are pointed to the GHG Planting Calculator available on itreetools.org for computing sequestration at the species-level, and encouraged to use a dedicated LCA tool like Athena, Tally, Gabi or SimaPro for computing embodied carbon from material installation.

Comparison Metrics

1. Net Global Warming Potential (GWP) in Year X:

Source + Cost Emissions – Sink Sequestration (cumulative up to Year X)

The Net GWP metric represents how many cumulative metric tons of CO_2-equivalent have been emitted or sequestered by a given year. A negative value indicated that the project as sequestered more than it has emitted. Most projects would start as 'emitters' in Year 0 and have a positive Net GWP value. As vegetation sequesters CO_2 from the atmosphere, the Net GWP drops every year.

2. Years to Neutral (YTN): The year in which Net GWP first equals zero, i.e.

Project Year in which cumulative Sink Seq. = (Source + Cost Emissions)

This metric tells the user how long it will take the project sequester as much as it has emitted or become carbon neutral/'net zero carbon'. After this year, the project's net impact on the planet is *climate positive,* and it acts as an asset to reversing climate change. For many projects this year might be beyond 80 years, in which case the tool calculates the YTN by extrapolating a best-fit line for the Net GWP curve to a zero value. However, for this extrapolation, the tool does not account for embodied carbon associated with material replacement during that time.

3. Offset in Year X:

Sink Seq/(Source + Cost Emissions)

The Offset metric is a point-in-time cumulative metric similar to Net GWP, which tells the user the % of emissions that have been sequestered or 'offset' by a given year.

Time-Value of Carbon

The time-aspect of these variables is crucial in considering the overall carbon profile of a project, because a ton of CO_2 emitted today is worse for the planet than a ton of CO_2 emitted after a decade. This concept stems from a broadly held scientific consensus that the accumulation of GHGs in the atmosphere must be halted before they reach a *tipping point*, i.e. a point of no-return for global warming. However, the tool does not discount the value of a ton of CO_2 over time, so the user is encouraged to qualitatively make this consideration, that the first step to a low-carbon project is reducing embodied carbon (emitted earliest) and then increasing sequestration.

Carbon Sources

Embodied carbon

Greenhouse gas emissions associated with the extraction, manufacturing, transportation, installation, use/maintenance and replacement of construction materials (see Figure 1 below) are referred to as the 'embodied carbon' of the project. The bulk of these emissions do not occur during the lifetime of the project, but have actually occurred prior, and are thus attributed to the project as an upfront emissions penalty in Year 0.

The tool accounts for all life-cycle stages below. Stages B6 and B7 are included the "Carbon Costs" section. The tool also includes emissions associated with demolishing existing paving before the installation of new landscape.

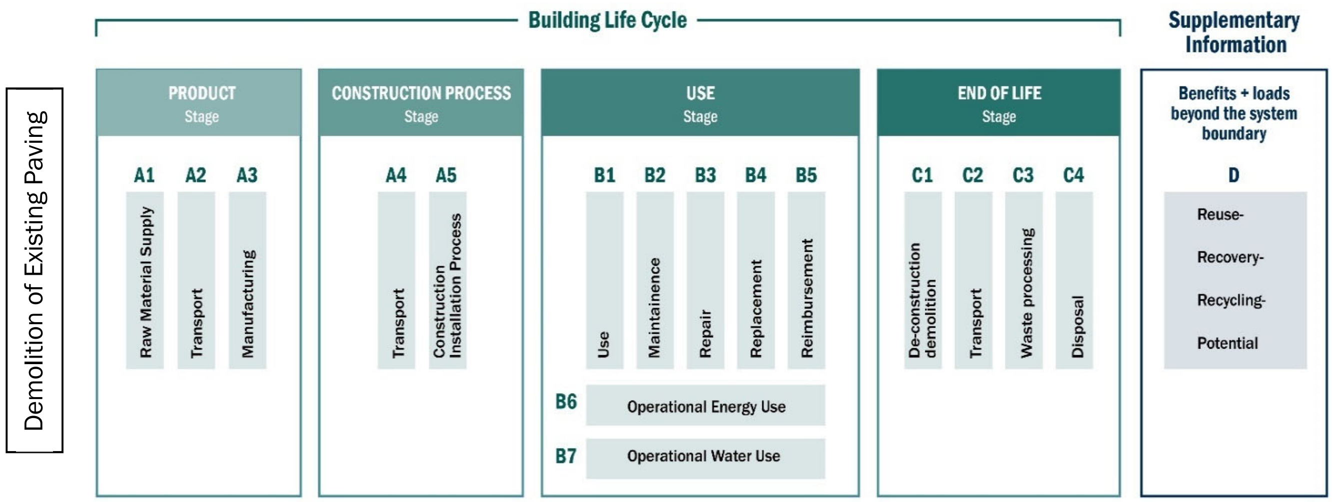


Figure 1 Life Cycle Stages

In addition to accounting for emissions associated with materials and construction, as explained above, the tool accounts for emissions associated with installation of landscape vegetation and soil. These are explained subsequently.

Data Sources and Calculation

A variety of LCA databases exist that can quantify environmental impacts associated with construction materials. Often this information comes directly from manufacturers in the form of 'Environmental Product Declarations' – a standard way of communicating an industrial product's environmental impacts. Data from manufacturer supplied EPDs and the Athena database[1] have been built into the calculator for the user to quantify the Global Warming Potential (GWP) of their product selections. Data for emissions associated with vegetation and soil has been obtained from academic studies as referenced. All these emissions and sequestration credits discussed below are recorded as upfront GWP numbers in Year 0 of the project.

HARDSCAPE - PRODUCT STAGE EMISSIONS

The calculation works as follows:

1. The user ascertains hardscaping materials being installed in the project under the following categories – paving, wall, curbs and headers, fences and gates, site elements, drainage/irrigation, subsurface elements, and planting/soil.
2. The user enters quantities of each material expected to be installed, performing unit conversions if necessary, to get data in the units accepted by the calculator.
3. The calculator has in-built values for GWP-per-unit of different materials, which are multiplied by the quantity of materials to get that product's GWP impact in kg CO_2-eq.

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[1] "ATHENA® Impact Estimator for Buildings V5.2 Software and Database Overview." (2017). Athena Sustainable Materials Institute, Ontario, Canada

HARDSCAPE - TRANSPORTATION, CONSTRUCTION, USE AND END-OF-LIFE STAGE EMISSIONS

GWP impact data associated with the transportation, construction (including site work) and end-of-life stages is beyond the scope boundary of EPDs, and is dependent on project characteristics. The development team conducted test studies using Athena to estimate these impacts as a percentage of product-stage emissions. Based on these results, the impacts of transportation, construction and end-of-life processes are assumed to be 30% of product-stage emissions.

For computing use-stage emissions, the development team made assumptions about the number of times each material would be replaced during the life of the project. These assumptions are based on the 2011 Architectural Manual published by the DCA Office of Affordable Housing and modified by the team based on project experience and extent of replacement.

TREES AND SHRUBS – INSTALLATION EMISSIONS

Emissions associated with the production of trees are based on the number of trees, and do not vary with tree type or region. Location-averaged data is used from the USDA study referenced in the Carbon Sink section. For smaller shrubs, the number has been scaled down by a factor of three, in line with the assumptions for sequestration in shrubs.

SOIL DISTURBANCE

Emissions associated with regrading or tilling soil are based the area of soil disturbed. Data is used from a study[2] of tillage impacts on soil carbon storage in a cornfield in Ohio. It is understood that this number can vary between different soil types and their existing vegetation, as well as regions. However, a single value is used in the tool as an order-of-magnitude estimate.

SOIL IMPORT AND OFF-HAUL

Emissions associated with the transportation of soil – both import and off-haul – are based on the volume of soil being moved. Data is used from Athena IE4B, from which transportation impacts were averaged for a variety of aggregate products with similar characteristics to soil.

REMOVAL OF EXISTING PAVING

Emissions associated with the demolition, disposal and waste processing of concrete and asphalt paving are based on the volume of paving removed. Data is used from Athena IE4B.

FATE OF EXISTING TREES

The following end-of-life scenarios are presented to the user to evaluate emissions or sequestration credit associated with the action taken for existing trees on-site. The user needs to provide the number and type of trees subjected to the respective end-of-life scenarios.

- Harvest Wood Product - Trees that are converted to wood products are able to lock up the carbon stored in their biomass for 50+ years, as opposed to it being released back to the atmosphere through decomposition. Thus, the user's project is credited with the amount of carbon dioxide that was sequestered (in 40 years) by the existing trees that are chosen to be harvested.
- Mulch – When a tree is cut down and mulched, it begins to decompose. Over time, all the CO2 stored in the tree biomass will be released to the atmosphere. Thus, the user's project is penalized with emissions equal to the amount of carbon dioxide that was sequestered by existing trees that are chosen to be mulched. The user is, however, encouraged to utilize the same to reduce the need for chemical fertilizer.

[2] Ussiri, D. A., & Lal, R. (2009). Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio. *Soil and Tillage Research*, *104*(1), 39-47.

- Biochar – Removed trees can also be used as feedstock to produce biochar, which is a long-term store of carbon. For this choice, the user's project is credited with the amount of carbon dioxide that was sequestered (in 40 years) by the existing trees that are chosen to be used as biochar feedstock.
- Retain Onsite – If existing trees are left undisturbed, or simply relocated onsite, the user can add the number of such trees to the input of new trees being planted.

Best Practices for Reducing Embodied Carbon

The following is a non-exhaustive list of strategies that the project designer can consider to reduce the project's embodied carbon:

- Reduce concrete, stone, steel and foam (carbon-intensive materials)
- Reuse/salvage materials from other projects
- Substitute cement with fly-ash, slag, glass pozzolan or other cementitious materials in the concrete mixes
- Use more wood as a substitute for concrete or metals
- Consider gravel, terrazzo, asphalt or other aggregate-based paving (tradeoff with heat island reduction)

Carbon Costs

Operational Carbon

Carbon costs represent GHG emissions associated with mowing/pruning performed using machinery and fertilizer use for trees and shrubs. (Note that fertilizer use for lawns is already accounted for in the Carbon Sink – Lawn calculation.) These emissions occur regularly over the lifespan of the project and are often referred to as 'operational carbon'.

Mowing/pruning using machinery consumes either gasoline or electricity as fuel, both of which result in emissions. Fertilizer production results in CO_2 emissions due to consumption of resources, and its application also results in N2O emissions as the applied nitrogen is fixed and released to the atmosphere.

Data Sources and Calculation

MACHINERY

Four categories of plant-care equipment are available in the calculator – 1) trimmers/edgers/cutters; 2) leaf blowers/vacuums; 3) chainsaws; and 4) lawn-mowers. The user needs to enter the cumulative hours of usage annually for these types of equipment.

For gas-powered equipment, emissions are calculated as follows:

Emissions = HP * EF * Runtime * LF

Where:

HP: Rated horsepower of the equipment [in hp] – ***user input or default present in calculator***
EF: Emissions factor for the pollutant, from the equipment [in g/hp-hr] – ***obtained from an EPA publication***[3]
Runtime: Number of hours that the equipment was functioning [in hr] – ***user input***
LF: Load factor - fraction of time equipment is used at rated HP [unitless] – ***obtained from an EPA publication***[4]

For electric-powered equipment, emissions are calculated as follows:

Emissions = Power * EF * Runtime * LF

[3] US Environmental Protection Agency (2010). Exhaust Emission Factors for Nonroad Engine-Modeling – Spark-Ignition.
[4] Banks, J. L., & McConnell, R. (2015, April). National Emissions from Lawn and Garden Equipment. In *International Emissions Inventory Conference, San Diego*.

Where:

Power: Rated power of the equipment [in W] – ***user input for voltage/current rating or default present in calculator***
EF: Emissions factor for US average electricity [in kgCO2eq] – ***obtained from an EPA publication***[5]
Runtime: Number of hours that the equipment was functioning [in hr] – ***user input***
LF: Load factor - fraction of time equipment is used at rated HP [unitless] – ***same as gas-powered***

FERTILIZER

Emission factors associated with fertilizer production are obtained from Dr Gu's (reference 3) interpretation of a 2004 study[6].
For NPK, these are 4.76 kg CO2/kg N; 0.73 kg CO2/kg P; 0.55 kg CO2/kg K.

The emission factor associated with fertilizer application is obtained from Table 11.1 of the IPCC report referenced.[7] It is 0.01 kg N_2O/kg N applied.

Users can either input amounts of N, P and K applied every year (can be varied in each year) to obtain fertilizer emissions or input number of Agriform tablets applied per tree/shrub, which has an emission factor of 0.0385 kgCO_2eq/tablet calculated using the numbers above.

Best Practices for Reducing Operational Carbon

The following is a non-exhaustive list of strategies that the project designer can consider to reduce the project's operational carbon:

- Use electric-powered equipment instead of gas-powered
- Ensure that electricity is coming from clean sources
- Limit the use of fertilizer; reuse mulch produced from pruning and trimming
- Select vegetation that does not require extensive maintenance and fertilization

Carbon Sinks

Science Behind Sequestration[8]

- **Process** - Plants 'sequester' carbon dioxide from the air through the process of photosynthesis, during which CO_2 is converted to cellulose, sugars and other materials in a chemical reaction catalyzed by sunlight. These are then mostly stored as biomass – wood, roots and leaves, while some CO_2 is respired back.
- **Factors affecting Sequestration Rate** – Amount and rate of CO_2 storage is directly related to how big and how fast a plant is growing. This in turn depends on species, geographic location (can affect length of growing season) and age of the plant. Warmer regions with more sun exposure have longer growing seasons and thus trees/shrubs in those regions sequester more CO_2.
- **Decomposition and Mortality –** Storage of CO_2 in trees and shrubs is not permanent; as trees die, most of the CO_2 stored in above-ground biomass is released back to the atmosphere through decomposition when the wood is chipped and mulched. A small percentage of the CO_2 sequestered by the tree/shrub is fixed into the soil for the long term, unless the wood itself is converted to a wood product. This storage of carbon dioxide in the soil is not counted explicitly in the tool; however, the 'net sequestration' at a given point in time during does account for the CO_2 stored in the undecomposed biomass of dead trees. Since dead trees are assumed to decompose slowly, projects are still able to claim significant sequestration during the project lifespan.

[5] US Environmental Protection Agency - Greenhouse gas equivalencies calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. Last accessed on 04/18/2019.
[6] Lal, R. (2004). Carbon emissions from farm operations. *Environ. Int. 30 (7),* 981-990.
[7] 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
[8] McPherson, EG.; Simpson, JR. (1999). Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSWGTR-171. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture

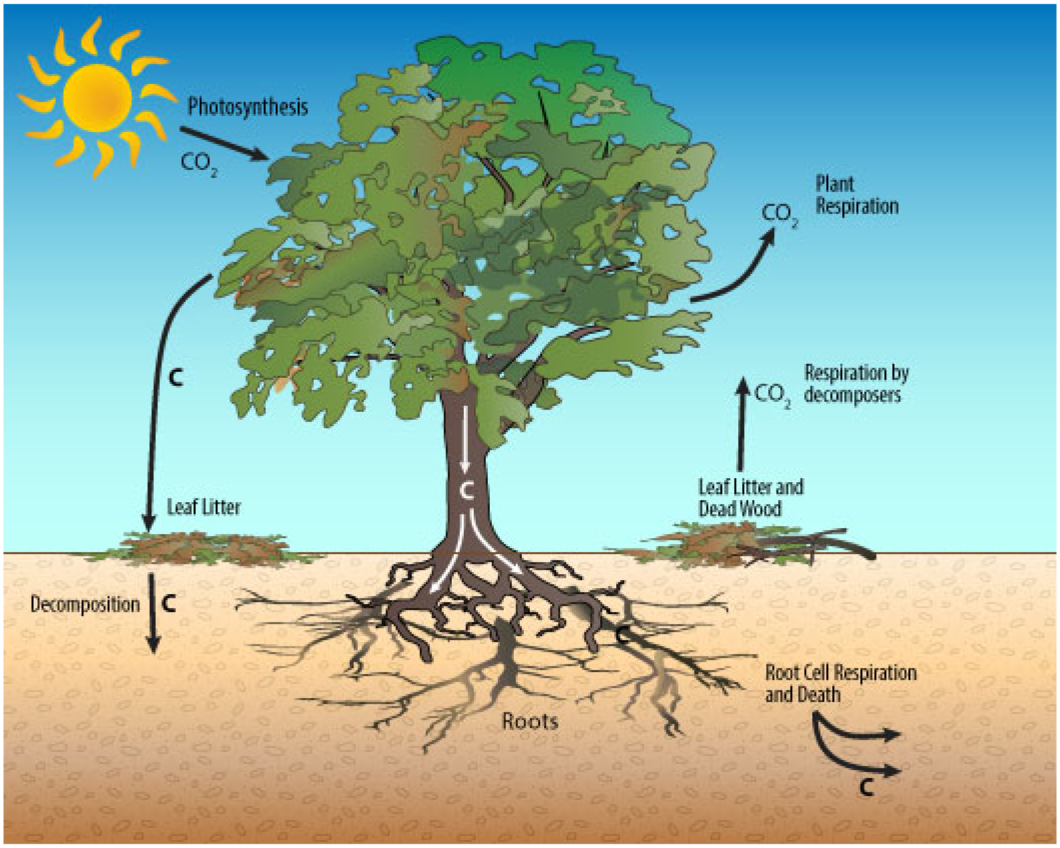

Figure 2: Carbon Cycle in Trees[9]

Data Sources and Calculation

TREES AND SHRUBS

All data used for calculating sequestration and decomposition for trees and shrubs is obtained (and modified as noted) from EG McPherson's seminal publication (hereon, "Pub1") listed in the footnotes, produced by the USDA Forest Service. The calculation works in the following manner:

1. The user selects the geographical region in which the project is located as North, South or Central based on the map in Figure 3.

[9] Obtained from https://serc.carleton.edu/eslabs/carbon/1a.html. Last accessed 04/17/2019

Tree Growth Zones of The United States

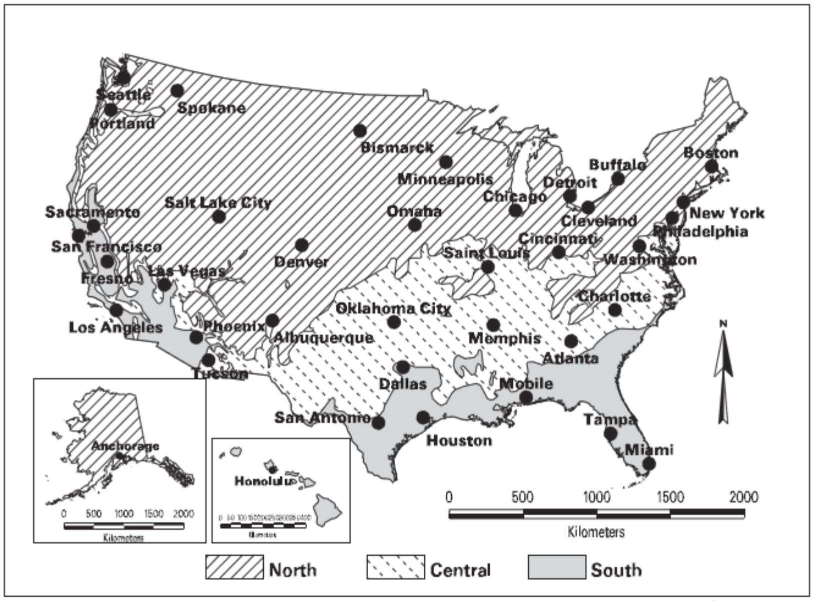

Figure 18—Tree growth zones for the United States correspond with mean number of freeze-free days per year (North = < 180, Central = 180-240, South = > 240) (Repeated as figure 25 in Appendix D).

Figure 3 Growth Zones Map

2. The user enters the number of each of the six type of trees being planted:

Dec-Large	19	Definitions:
Dec-Med	14	• Deciduous—foliation period generally matches the duration of the cooling season
Dec-Small	1	• Evergreen—year-round foliation (includes conifers and broad leaf evergreens)
Evr-Large	28	• Large—mature height greater than 15 m (50+ ft)
Evr-Med	21	• Medium—mature height 10-15 m (35-50 ft)
Evr-Small	2	• Small—mature height <10 m (<35 ft)

Figure 4 Tree Number Input

3. Gross sequestration is calculated for each tree group (Dec-Large, Dec-Med, etc.) for 5-year age periods by multiplying the following
   a. Number of trees in that tree group
   b. Mature sequestration rate (annual) for that tree group and region, obtained from Appendix A, Pub1
      These were determined empirically during the USDA study
   c. Tree Age/Survival Factors (annual) for that age period and region, obtained from Appendix H, Pub1
      This is the product of a tree age factor (what % of Mature sequestration/decomposition rate is the tree going to experience in the given age period) and survival factor (what % of originally planted trees are expected to be alive in the given age period) – both determined empirically
   d. 5 (since above factors are annual, and we are calculating for a 5-year period)
4. Gross decomposition is calculated the same way as described above, by replacing the mature sequestration rate (b) by the mature decomposition rate.
5. Gross sequestration and gross decomposition numbers for each tree group and each age period are summed together, and the latter is subtracted from the former to obtain net sequestration for the project over 80 years.

MODIFICATIONS FOR SHRUBS

To account for the smaller size of shrubs, the mature sequestration and decomposition rates are obtained by doing the following:

- Large shrubs: Dividing rates for ‘Dec-small’ and ‘Evr-small’ tree groups for all regions by 3
- Medium shrubs: Dividing Large shrub rates by 2

- Small shrubs: Dividing Medium shrub rates by 2

Shrubs also have shorter lifespans – assumed to be 10 years, and the tree age/survival factors have been modified as follows:

- For Age Period 1-5, factors from the 11-15 age period for equivalent tree groups have been used to reflect a fast-growth period
- For Age Period 6-10, factors from the 31-35 age period for equivalent tree groups have been used to reflect a growth period closer to maturity

REPLANTING

The following assumptions have been made about replacement of dead trees and shrubs:

- 15% of the number of original planted trees are replanted every 20 years
- 100% of the number of originally planted shrubs are replaced every 10 years

LAWN

Lawns can be either net sources or sinks depending the interplay of the soil N_2O flux and carbon sequestration[10]. N_2O is a greenhouse gas with about 298 times the GWP of CO_2 (GWP of CO_2 is 1) and is released when microbes act on excess nitrate available in saturated soil after application of fertilizer. Intensively managed soils (those that are regularly irrigated, mowed and fertilized) have higher carbon sequestration but also a higher N_2O flux, which can overpower the former.

The calculation for lawn emissions/sequestration is straightforward: the user enters the area in sf covered by lawn for each of the following types:

Low-mow fescue/meadow	0	No fertilizer, no mowing, no irrigation
Minimal management	0	Mowing to 6 inches, no irrigation/fertilizer
Moderate management	0	Mowing to 6 inches, moderate application of fertilizer and irrigation
Intensive management	42532	Manicured lawns - mowing to 6 inches, intensive use of fertilizer and irrigation

These areas are then multiplied by emissions/sequestration factors obtained from Dr Gu's study (reference 3 in the footnotes) which studied urban turfgrass systems in Nashville, TN to obtain annual emission/sequestration numbers in kg-CO_2eq for lawn planting.

WETLANDS

Like lawns, wetlands can also be either net sources or sinks depending on the complex interplay of GHGs besides CO_2, particularly methane, which has a GWP of 28 and N_2O[11]. The calculator uses an annual per-unit-area sequestration rate obtained through the study (reference 4) of a constructed wetland in the Netherlands. It is important to note that due to the specificity of this data source, generalization to constructed wetlands in the USA carries significant uncertainty.

In the calculator, the user has to simply input the area of constructed wetland to obtain annual sequestration.

Best Practices for Increasing Sequestration

The following is a non-exhaustive list of strategies that the project designer can consider to increase the project's sequestration capability:

- Planting more trees that can grow to taller heights (35+ ft)

[10] Gu, C., Crane, J., Hornberger, G., & Carrico, A. (2015). The effects of household management practices on the global warming potential of urban lawns. *Journal of environmental management, 151*, 233-242.

[11] de Klein, J. J., & van der Werf, A. K. (2014). Balancing carbon sequestration and GHG emissions in a constructed wetland. *Ecological engineering*, *66*, 36-42

- Selecting species that have longer growing seasons in that region
- Planting woody shrubs
- Ensuring proper care during establishment periods to increase survival rates
- Selecting trees with known long lifespans
- Salvaging wood from fallen trees
- Selecting lawn types that require lesser fertilizer application and maintenance
- Constructing wetlands

Case Study Findings and Metrics

CMG analyzed a wide range of project types using the Landscape Carbon Calculator. These case studies allowed for a better understanding of potential changes that one could make to reduce the project's embodied carbon and ongoing costs while increasing sequestration.

- **Project Type and Quantity:** A range of project types were studied. Below are the type and quantity.
  - (3) Parks
  - (2) Gardens
  - (2) Plazas
  - (1) Streetscape
  - (3) Campus (For the purposes of this report, campus also includes mixed-use developments.)
  - (2) On-Structure (For the purposes of this report, Green Roofs are classified under On-Structure.)

- **Region:** The projects evaluated are all located within the South Tree Growth Zone as shown in the Landscape Carbon Calculator Methodology, Data Sources and Best Practices: Figure 3.

- **Scale:** The case study projects ranged in size from .03 acres to 13.76 acres.

To reduce the overall Global Warming Potential (GWP) of a project, the sources and costs must be reduced while sequestration is increased. Those three impacts are synonymous with reducing the YTN for a project. Therefore, YTN was established as the primary driver for data comparison and metrics.

For the analysis, YTN data was collected at three different scenarios: 1) the project as currently designed/built, 2) the project with minor changes (modified), and 3) projects alterations required to meet (forthcoming) targets.

Metrics

To estimate the approximate global impact of landscape architecture projects, data was extrapolated from the case study findings and is based on the following:

Global Application Potential: According to the International Federation of Landscape Architects[12], there are approximately 75,000 landscape architects in the world.

Sample Data: Based on sample firm data from CMG, an average size (forty person) landscape architecture practice in the United States, there are approximately five landscape architects (LAs) per project team, average size of project is five acres, and approximately three projects per year are constructed.

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[12] "Hayter, James, (2005, June). International Federation of Landscape Architects. *IFLA News, No. 60*. 6

Global Projects Designed Annually:
75,000 total LAs / 5 LAs per team * 3 Projects per year per team = 45,000 projects annually.
A 15% contingency was applied bringing the total down to 38,250 projects per year

From 2020-2030 = 420,750 projects
From 2031-2050 = 1,147,500 projects

Application:
Two methods were evaluated to quantify the potential collective impact of the landscape architecture profession.

Method One: Landscape Carbon Footprint % Improvement

The CMG case study modified median project carbon footprint was reduced by 51% and sequestration was increased by 58%, based on the feasibility of improvements made to the case study projects. The average footprint and sequestration rates were then applied to the global total number of projects, which led to the following total quantity of carbon removal beyond project emission by the following timeframes:

By Year 2030 .064 gigaton (GT)
By Year 2050 1.059 GT

Method Two: YTN % Improvement

As discussed above, lowering the YTN represents the reduction of embodied carbon and cost along with increasing sequestration. The modified case study average YTN across all project types was compared to the target YTN resulting in the average percentage improvement of 296%. The modified case study projects global carbon impact was multiplied by the 296% improvement of the targets to yield the following contributions:

By Year 2030 .511 GT
By Year 2050 1.513 GT

Summary
Based on the two methodology evaluations, the estimated impacts of landscape architecture projects for the purposes of the Climate Positive Design Challenge are:

By 2030, Get to Positive (Beyond neutral. Beyond project emissions.)
By 2050, remove 1GT CO2 (Beyond project emissions.)

Additional project data collected with further confirm and/or allow the targets and overall impact metrics to be updated over time. Data will be reviewed on an annual basis to inform the initiative.

Next Steps and Further Areas of Research

The following items have been identified as areas for further refinement and expansion of the tool's knowledge base:

- Capture sequestration rates at the species level
- Research more comprehensive sources for plant ecosystems (forests, wetlands, perennials, grasslands, mangroves etc.) to offer more options to the user
- Use region-specific electricity emissions factor for electric-powered equipment
- Expand the list of hardscaping construction materials with GWP-per-unit data
- Incorporate lighting and related energy usage
- Factor carbon impacts of water usage from different sources (potable, reclaimed etc.) and benefits of minimizing use