ANNEX

1.1 GHG Equivalents calculator

This document is the short report to describe in detail the calculations of the GHG equivalent calculator as developed within the Nature4Cities[1] project.

[1] Increasing resilience through Nature based Solutions in Latin American cities (Nature4Cities Latam)

2 CO_2 EQUIVALENT CALCULATIONS

2.1 Solar, Avoided Emissions When Solar Power Replaces Fossil fuels

Indicator:
Number, or m^2 of Solar panels running for one year.

Assumptions:

A. Fossil fuel mix for the LAC region is assumed to be about 13% of coming from coal, about 21% from oil and about 67% from gas (https://ember-climate.org/countries-and-regions/regions/latin-america-and-caribbean/) An average coefficient per fuel type is calculated in order to provide the most accurate estimate possible. The contribution of each energy source to C02 emissions in the calculation is as follows (IPCC 2014).:
   - 0.820 t CO_2 eq /MWh for coal-fired plants (13%)
   - 0.777 t CO_2 eq /MWh for oil-fired plants (21%)
   - 0.490 t CO_2 eq /MWh for gas-fired plants (67%)

   This results in a 0.598 t CO_2 eq /MWh for the used Fossil fuel mix for the LAC-region

B. Life Cycle Greenhouse Gas Emissions from Rooftop Solar Photovoltaics is set in the calculation to a relative pessimistic value of 40 g CO_2 e/kWh (www.nrel.gov). The US-based National Renewable Energy Laboratory (NREL) estimated that solar power produces lifetime emissions of 40g CO2 equivalent per kilowatt-hour. A study published by Nature Energy was more optimistic, with estimated emissions below 21 g CO2 eq / kWh. In this equivalent calculator the 40g CO2 equivalent per kilowatt-hour is used as reference. This number is comparable to values used by IPCC 2014 (41g).

C. Practical power potential on average for the LAC region is set to: 4.16 kWh/kWp/day. This number taken from the calculation of the (PVOUT Level 1, kWh/kWp/day), long-term from the *Global Solar Atlas 2.0, using the Solar resource GIS data: Solargis* . 4.16 is the average value with 3.54 the minimum average value. (https://solargis.com/maps-and-gis-data/download/latin-america-and-caribbean).

D. Average Wp per solar panel is assumed to be 300 Wp with an average size of 1.93 square meter (99cm x 195 cm)

E. Calculation: Avoided CO2 = (A -B) * (C*D)

- **Known simplifications**: Average Practical power potential numbers will be varying significantly over the region as well as the real used fossil fuel mix per country/region/city. The given values are average proxies.

2.2 Wind, Avoided Emissions When Wind Power Replaces Fossil fuels

Indicator:
Number of wind turbines running for a year

Assumptions:

A. Calculation is based on an adaptation of the EPA.gov calculation of the potential reduction based on US numbers.
B. See for the Fossil fuel mix for the LAC region Paragraph 2.1.A
C. The capacity factor of a wind turbine is its average power output divided by its maximum power capability. Capacity factor of land based wind in the U.S. ranges from 24% to 56% and averages of 36%. Specific numbers for the LAC region can be extracted using the Global Wind Atlas . These range numbers are comparable for large parts of the LAC region, therefore the the US Average of 36% is used for comparison. Global wind Atlas numbers are in accordance with EU measured values at windeurope.org.
D. Life Cycle Greenhouse Gas Emissions from wind energy is set in the calculation to a value of 12 g CO_2 e/kWh (www.nrel.gov). The US-based National Renewable Energy Laboratory (NREL) estimated that wind energy produces lifetime emissions of 11g(onshore) to 12g (offshore) CO2 equivalent per kilowatt-hour. This number is comparable to values used by IPCC 2014 (12g).
E. For electricity generation an average wind turbine was determined to be 1.82 MW. The same number currently used in the EPA. The current US capacity already exceeds this number (2.75 MW for 2021), Higher capacity turbines mean that fewer turbines are needed to generate the same amount of energy across a wind plant which ultimately should lead to lower costs per MW. The conservative number of 1.82 MW is maintained in the calculation
F. Calculation is done by multiplying the average capacity of a wind turbine (1.82 MW) by the average capacity factor (0.356) and by the number of hours per year. It was assumed that the electricity generated from an installed wind turbine would replace marginal sources of grid electricity.

- **Known simplifications**: Average capacity factors and average wind turbine sizes currently varies steeply over the region (REN21). Same can be said about the real used fossil fuel mix per country/region/city. The given values are average proxies.

2.3 NbS assumptions

The calculations are made for Temperate and (Sub)Tropical zones. Consider:

- The regions in ALC are: (sub)tropical, Arid, Temperate and Other (Sub.Trop-Temp Highlands, Sub/artic Polar, and more). With the information and data base taken from geonames.org (considering cities with more than 50k of population) and with all spatial climate data extracted from chelsa-climate.org., we get the following statistics (RCP 8.5 used):

  - The (Sub)Tropical areas covers approximately 75% of all cities in The LAC region. This number is expected to remain 75% in 2050.
  - An 8% shift from subtropical to tropical.
  - The remaining cities can be classified as being Arid 12% (19% in 2050), Temperate 6.5% (3.1% in in 2050), Other 6.5% (3% in 2050).

- Despite this distribution, there is no reliable information available for Arid Regions yet.

  - In conclusion, with this tool we are covering 89,5% of the ALC region (86,1% in 2050). However, it is likely that in majority of the Arid-steppe cities, water is the main growth limiting factor. If sufficient water can/will be provided to the (planted) trees, these Arid-steppe regions can change to the (sub) tropical and temperate region. These cities are predominantly located in Mexico (hot Steppe region) or at high altitude in the Bolivian Andes (cold Steppe region).

- Species type choice: it was chosen a generic one. The CO2 sequestration per tree species differs, but the greater importance is behind which circumstances the tree is growing (soil type, water management, climate change conditions).

2.3.1 Roadside Trees

Indicator:
KM of roads planted with trees on both sides for 40 years

Assumptions:

A. Calculation is based on the forest climate adaptation factsheet with specific CO2-effects of forestry related nature based solutions of WENR (in Dutch) with a conversion to (sub-)tropical numbers by Laura Blok WUR/MetaMeta:

Type of plantation	Carbon sequestration <10 years	Carbon sequestration 10-50 years	Total carbon sequestration after 40 years
Boreal regions			
1 row of trees – 1 roadside	2.0 ton CO_2-eq/km/yr	4.2 ton CO_2-eq/km/yr	145 ton CO_2-eq/km
1 row of trees 2 roadsides	4.1 ton CO_2-eq/km/yr	8.3 ton CO_2-eq/km/yr	290 ton CO_2-eq/km
2 rows of trees 2 roadsides	8.2 ton CO_2-eq/km/yr	16.6 ton CO_2-eq/km/yr	581 ton CO_2-eq/km
10 rows of trees 2 roadsides	41 ton CO_2-eq/km/yr	83 ton CO_2-eq/km/yr	2904 ton CO_2/eq/km
Wooden bank	3.0 ton CO_2-eq/ha/yr	6.0 ton CO_2-eq/ha/yr	211 ton CO_2-eq/km
Forest			100 ton CO_2-eq/ha
Temperate regions			
1 row of trees 1 roadside	3.1 ton CO_2-eq/km/yr	6.2 ton CO_2-eq/km/yr	220 ton CO_2-eq/km
1 row of trees 2 roadsides	6.2 ton CO_2-eq/km/yr	12.6 ton CO2-eq/km/yr	440 ton CO_2-eq/km
2 rows of trees 2 roadsides	12.4 ton CO_2-eq/km/yr	25.2 ton CO2-eq/km/yr	880 ton CO_2-eq/km
Wooden bank	4.6 ton CO_2-eq/ha/yr	9.1 ton CO2-eq/ha/yr	319 ton CO_2-eq/km
Forest			320 ton CO_2-eq/ha
Tropical regions			
1 row of trees 1 roadside	3.9 ton CO_2-eq/km/yr	7.9 ton CO_2-eq/km/yr	275 ton CO_2-eq/km
1 row of trees 2 roadsides	7.8 ton CO_2-eq/km/yr	15.8 ton CO_2-eq/km/yr	550 ton CO_2-eq/km
2 rows of trees 2 roadsides	15.5 ton CO_2-eq/km/yr	31.5 ton CO_2-eq/km/yr	110 ton CO_2-eq/km
10 rows of trees 2 roadsides	77.5 ton CO_2-eq/km/yr	157 ton CO_2-eq/km/yr	5500 ton CO_2/eq/km
Wooden bank	5.8 ton CO_2-eq/ha/yr	11.4 ton CO_2-eq/ha/yr	399 ton CO_2-eq/km
Forest tropical climate			400 ton CO_2-eq/ha

B. Comparable numbers differentiating for (Sub-)Tropical versus Temperate GHG emissions related to forest and forestry can be found in Harris et al 2021 in their Nature article.
C. The site conditions are sufficiently guaranteed (water, light, nutrients) for the given climate conditions. This can be due to natural conditions, or active management (e.g. watering the trees).
D. The basic principle is that the trees on both sides receive sufficient light so that they can fully develop.

2.3.2 Forest preserved from conversion to cropland

Indicator:
Hectares of forest preserved from conversion to cropland
Assumptions:

A. Calculation is based on an adaptation of the EPA.gov calculation of the potential reduction based on US numbers and the IPCC guidelines for conversion of forest to cropland.
B. A lot of carbon is stored in forests, especially in living biomass and in the soil, and to a lesser extent in litter and dead wood. When converting forest to land use, (almost) all biomass is generally generalized, and at least part of the soil material is lost. All this carbon is released in the form of CO2 in a short time. These emission factors are strongly related to the standing stock and the type of tree species.
C. When calculating carbon stock changes in biomass due to conversion from forestland to cropland, the IPCC guidelines indicate that the average carbon stock change is equal to the carbon stock change due to removal of biomass from the outgoing land use (i.e., forestland) plus the carbon stocks from one year of growth in the incoming land use (i.e., cropland), or the carbon in biomass immediately after the conversion minus the carbon in biomass prior to the conversion plus the carbon stocks from one year of growth in the incoming land use (i.e., cropland) (IPCC 2006).

D. The carbon stock in annual cropland biomass after one year is 5 metric tons C per hectare, and the carbon content of dry aboveground biomass (AGB) is 45 percent (IPCC 2006). Therefore, the carbon stock in cropland after one year of growth is estimated to be 2.25 metric tons C per hectare. This equals the original EPA.org calculations.
E. The stock density in aboveground, belowground, dead wood, and litter biomass of U.S. forests in 2019 was 200 metric tons of carbon per hectare. For the LAC region this is considered to be comparable on average, but with huge variations over the region and its biomes. Lowland tropical forests globally reach average AGB values of 423 metric tons per hectare. However more montane tropical forest in Ecuador and Peru have an average of 270 metric tons per hectare. Tropical dry forest sees values in the range of 100-150 metric tons per hectare, or in more extreme values lower than 50 tons per hectare for dry open fragmented forest in Mexico, showing the range of value which can be found in the LAC region.
F. The number of 200 metric tons for the stock density for all the LAC region forest is a conservative number. Large tropical forest areas in the region, with the Amazon basin dominating the average values, shows values >= 250-300 metric tons per hectare. Therefore for the (sub) tropical LAC-region a conversion factor of 125% is used (see roadside trees).
G. For the Annual Change in Organic Carbon Stocks in Mineral and Organic Soils a multiplication factor for temperate and (sub)tropical LAC region is used based on the relative Soigrids SOC-content in topsoil US copared to LAC (114% (sub)tropical, 127% temperate). This factor has a relative small effect in the total calculation
H. The site conditions are sufficiently guaranteed (water, light, nutrients) for the given climate conditions. This can be due to natural conditions, or active management (e.g. watering the trees)

Known simplifications: Average carbon stock of forest will vary considerably over the region. The given numbers are average proxies for the region.

2.3.3 Planted forest sequestering CO_2

Indicator:
Hectares of tropical forest plantations sequestering CO2 for one year

Assumptions:

A. An average tropical tree sequesters 22.6 kg carbon /yr. Much higher number can be found under optimal conditions, but the 22.6 kg carbon/tree/year can be considered a conservative average for tropical planted trees
B. Using the Industry standard of 1250 trees planted per hectare (later culled back to 600 trees per hectare) is asumed giving a sequestration 13.56 metric tons carbon stored / hectare / yr (= 49.72 metric ton CO_2 /ha/year) over a 10 years planting cycle.
C. For natural regrowth e.g. lower numbers are given by different sources: 243 - 512 metric ton CO2/ha for regrowth of secondary forest in 50 years time (resulting in a maximum of 5-10 metric ton CO2/ha/yr) . While IPCC gives comparable values of 4-8 t / ha / yr of carbon (C) sequestered in tropical regions for natural regrowth.

Managed plantations generally can produce 20 to 30 times more wood than do natural (regrowth/secondary) forests, resulting in higher carbon sequestration rates per hectare. So, the here used value of 13.56 t / ha / yr for plantations can be considered conservative.

D. IPCC gives 1.5-4.5 t ha^{-1} yr^{-1} in temperate regions, and 4-8 t ha^{-1} yr^{-1} in tropical regions, showing slightly overlapping ranges. In this calculator a conservative number of 125% for tropical vs temperate tree plantations is used resulting in a sequesters number of 18 kg (temperate) versus 22.6 kg (tropical) carbon /yr / tree. Braakhekker et al. 2019 shows higher numbers for the maximum C-capture, based on extensive use of global samples for forest plantations, so both values can be considered conservative
E. A 10 year planting cycle is used to maximize woody biomass growth and carbon sequestration is supported. Once tropical trees reach maturity their effectiveness for carbon sequestration purposes declines. That means that using a 10 year cycle maximizes the carbon sequestration efficiency of their tropical tree plantations, with every cycle ending in harvest and followed by replanting.
F. The site conditions are sufficiently guaranteed (water, light, nutrients) for the given climate conditions. This can be due to natural conditions, or active management (e.g. watering the trees).

Known simplifications: Average (potential) carbon stock of planted forest will vary considerably over the region. The given numbers are average proxies.

2.3.4 Planting of urban tree seedlings

Indicator:

Number of urban tree seedlings grown for 10 years

Assumptions:

A. Calculation is based on an adaptation of the EPA.gov calculation of the “Number of urban tree seedlings grown for 10 years”
B. Deciduous trees forms 89 percent of trees in US. This is assumed to be correct for the temperate region, but assumed 100% in (the sub)tropical LAC region.
C. For the (sub) tropical LAC-region a conversion factor of 125% is used (see roadside trees and Planted Forest sequestering CO2)
D. The site conditions are sufficiently guaranteed (water, light, nutrients) for the given climate conditions. This can be due to natural conditions, or active management (e.g. watering the trees)

Known simplifications: Average (potential) carbon stock of planted trees will vary considerably over the region. The given numbers are average proxies.