Hello, I´m Michael Bekken, a brief introduction…

The Golf Course Carbon Cycle

How to reduce emissions and maximize sequestration on golf courses

Michael Bekken

Since the industrial revolution, human activity has caused the average surface temperature of Earth to rise by approximately 1.3°C

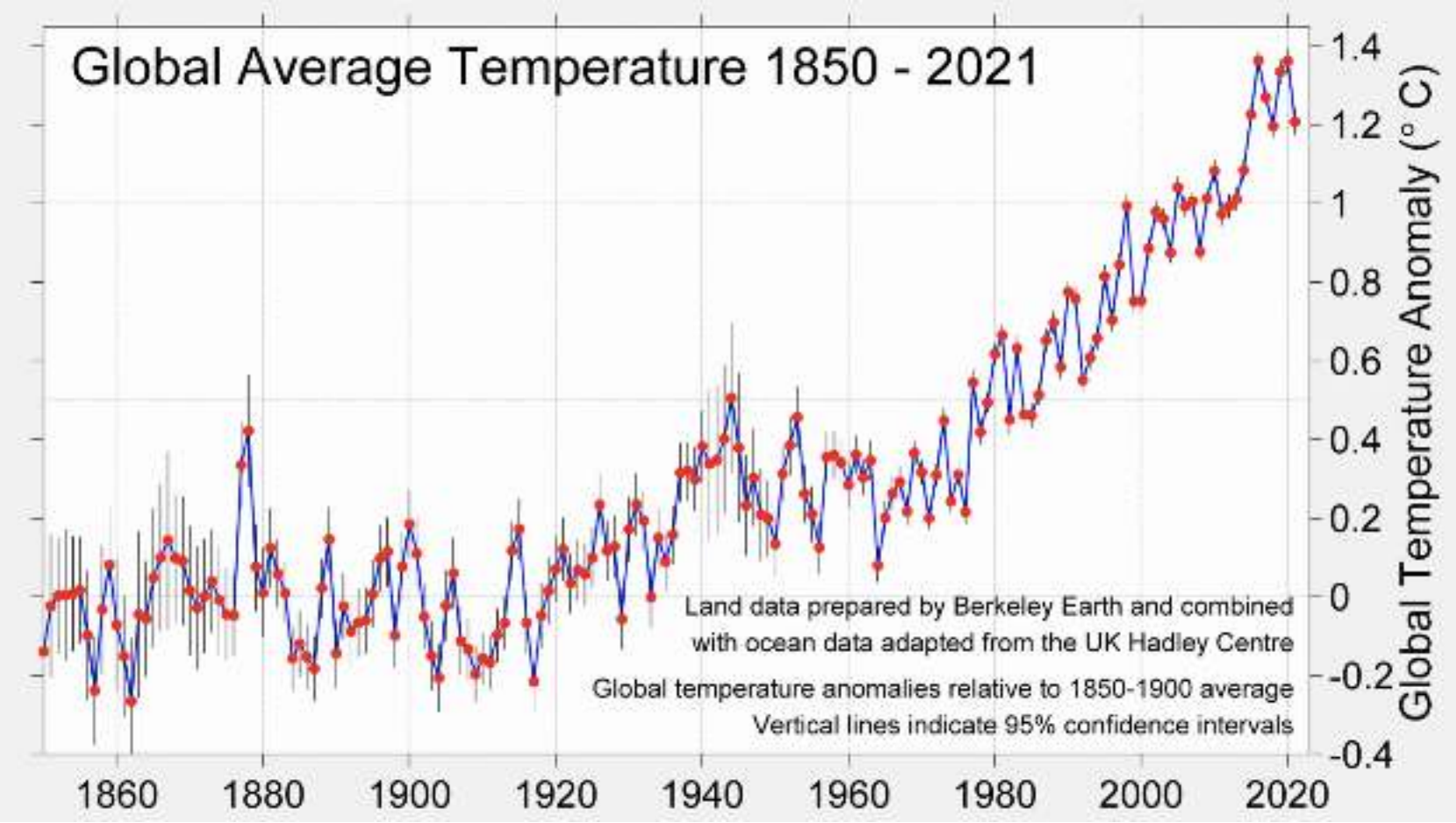
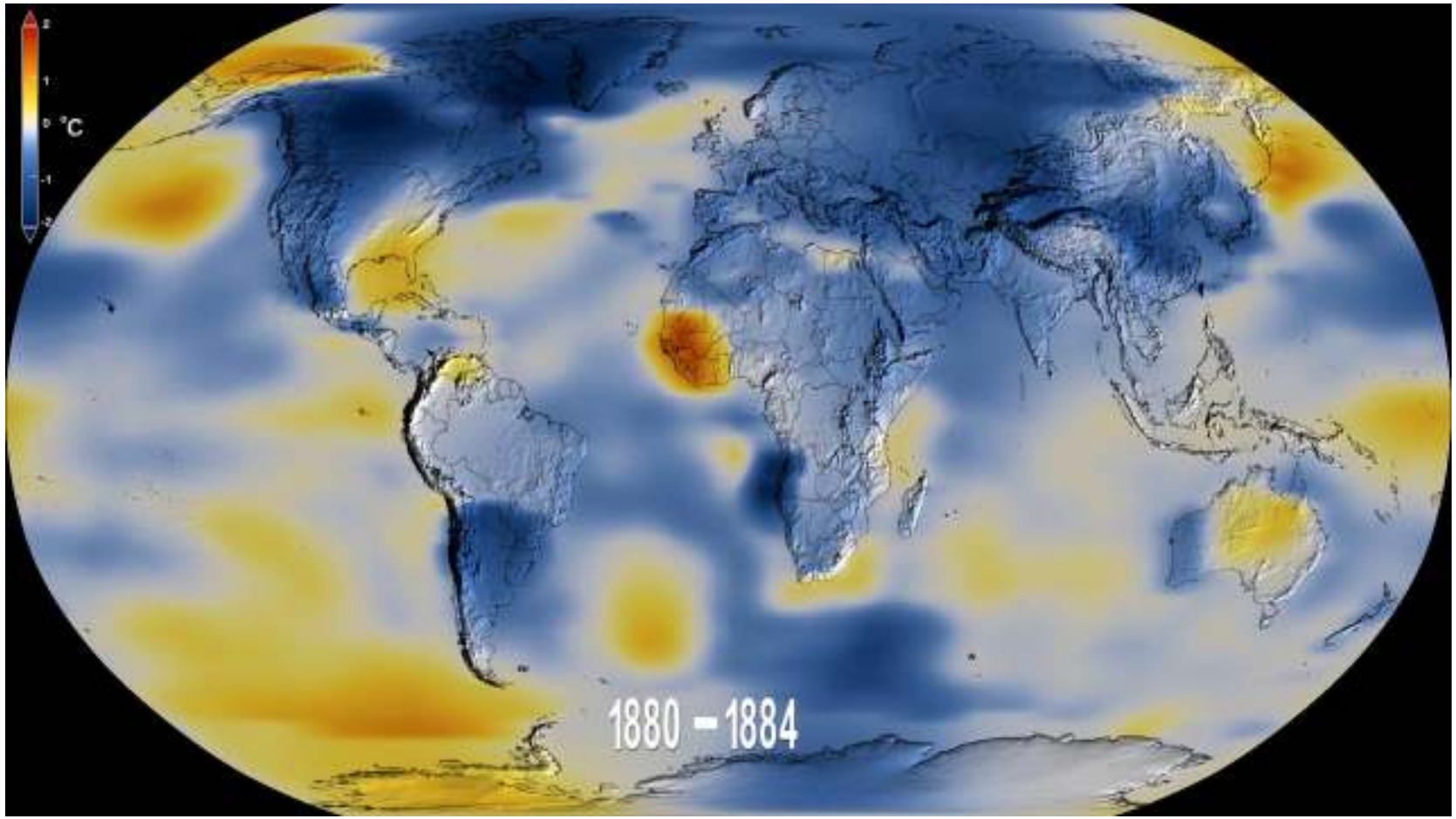


Figure Credit: Berkely Earth

$$Temperature\ anomoly = \overline{T_{5\ yr\ run\ avg}} - \overline{T_{1951-1980}}$$

Blue is colder than 1951-1980 average
Red is warmer than 1951-1980 average



Animation Credit: NASA

Increasing CO_2 concentrations strengthen the greenhouse effect

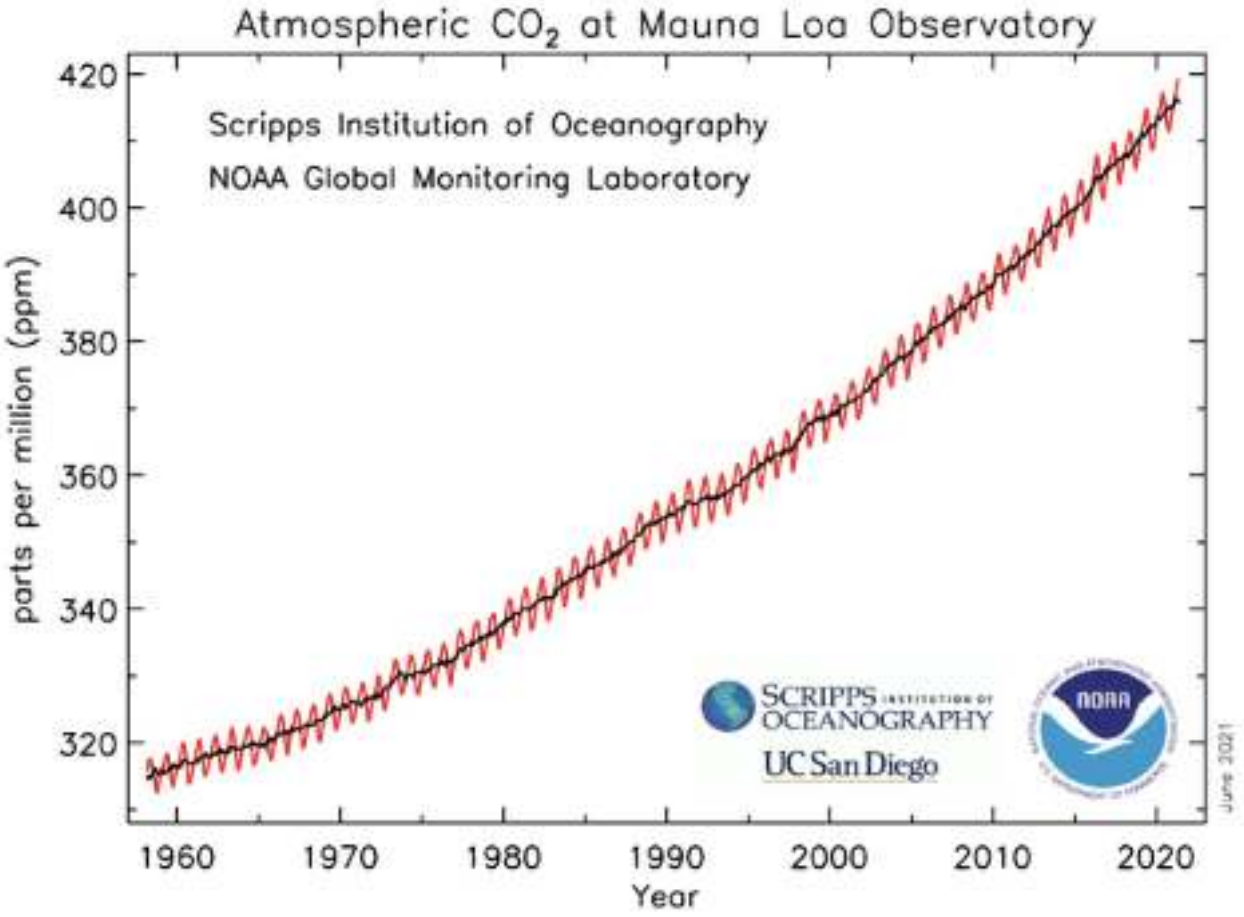


Figure Credit: NOAA

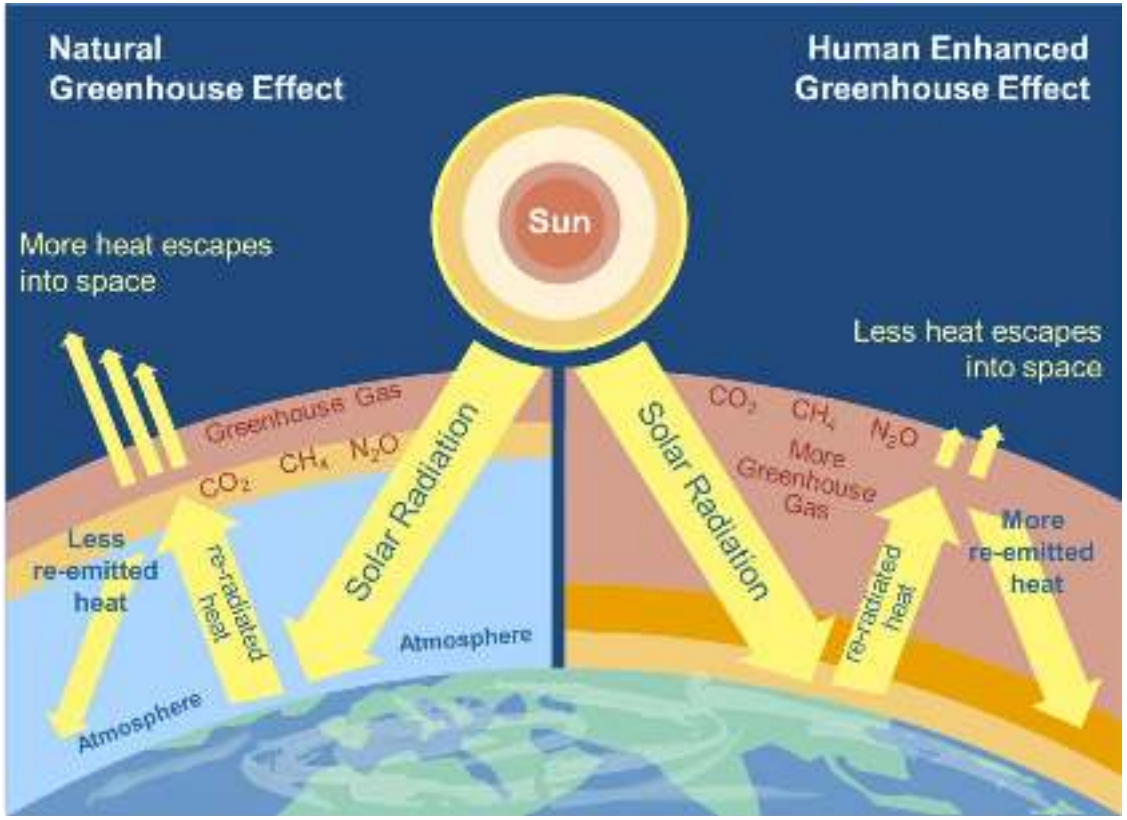
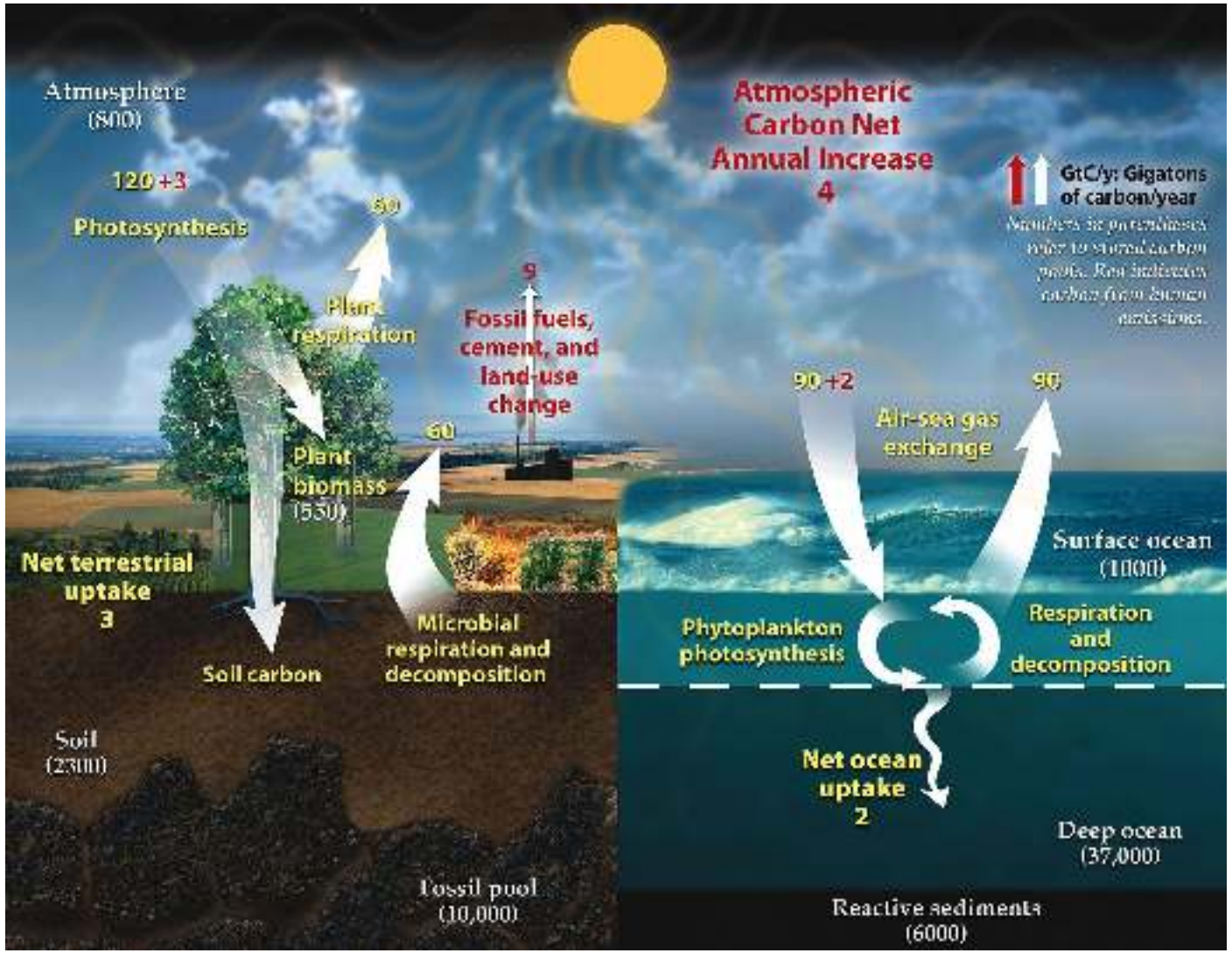


Figure Credit: The Physics Cafe

The carbon cycle is complex, but today we will break it down and highlight the most important components of this cycle for golf courses



Burning of fossil fuels emits carbon dioxide to the atmosphere (carbon emissions)

$$O_2 + C_2H_6 \rightarrow CO_2 + H_2O$$

Oxygen + Hydrocarbon → Carbon dioxide + Water

Photosynthesis removes carbon dioxide from the atmosphere (carbon sequestration)

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

Carbon dioxide | Water | Sugar | Oxygen

A simplified soil carbon cycle - carbon is both sequestered and emitted from soils

Respiration

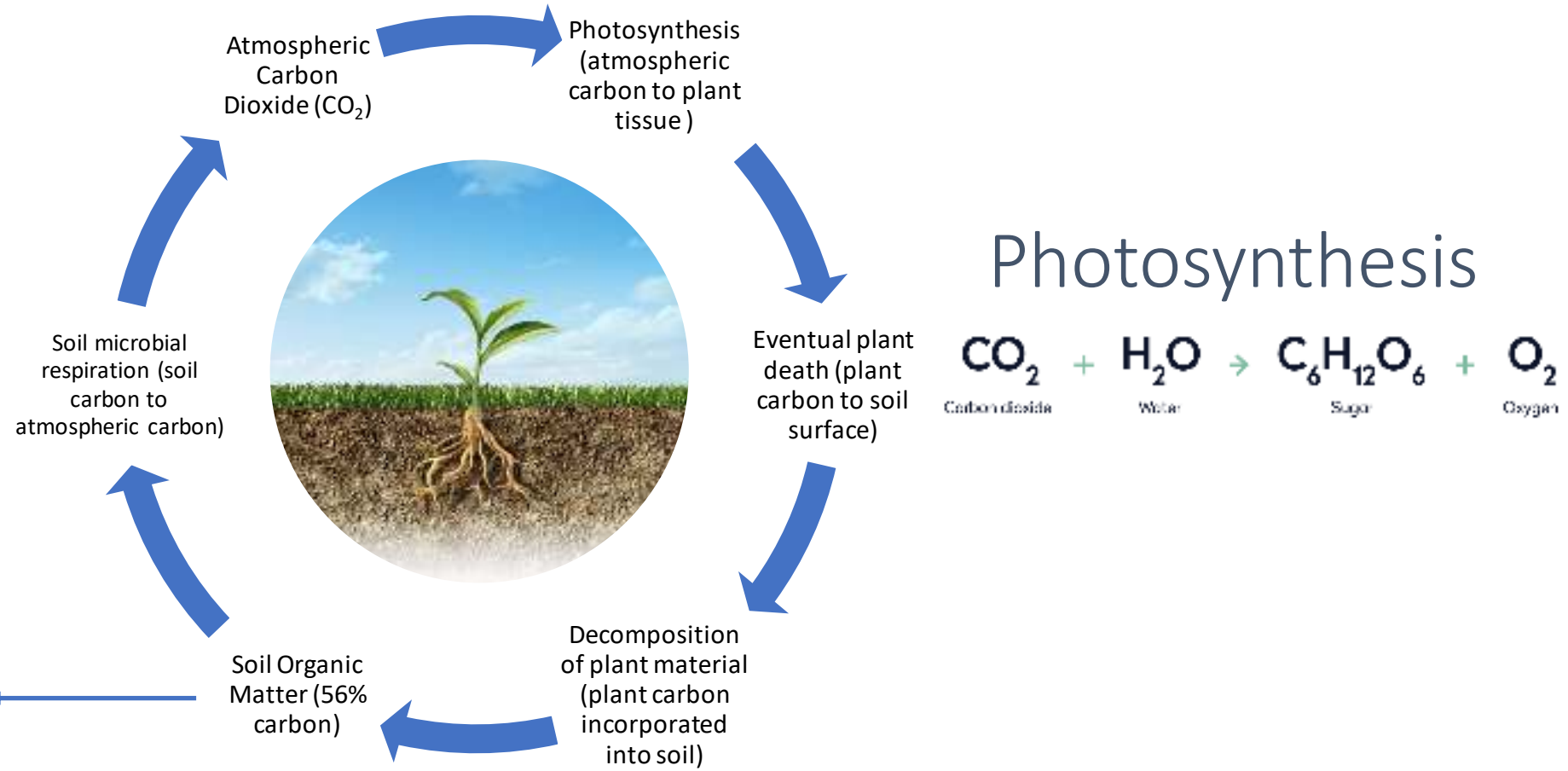
$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$

Sugar + Oxygen → Carbon dioxide + Water

Photosynthesis

$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$

Carbon dioxide + Water → Sugar + Oxygen

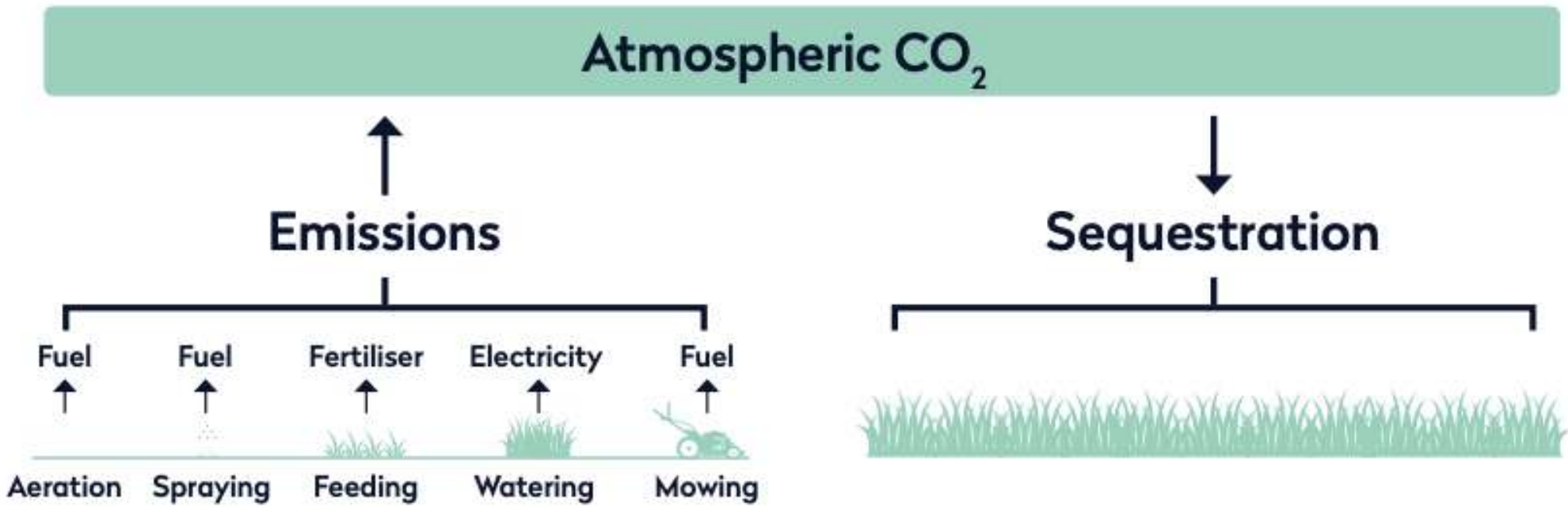


Soil organic matter (SOM)
Soil organic carbon (SOC)
SOC = SOM * 0.56
or SOM matter is ~56% SOC

Carbon balance = emissions - sequestration

if emissions > sequestration = carbon positive (+)

if emissions < sequestration = carbon negative (-)



We built a carbon balance model for golf courses which estimates emissions and sequestration directly related to turfgrass maintenance

Emissions

- Includes
  - Maintenance building
  - Irrigation pump
  - Maintenance equipment
- Does not include
  - Emissions from clubhouse or other golf facility buildings or operations

Sequestration

- Includes
  - Turfgrass sequestration

- Does not include
  - Sequestration in non-turf areas

Eight categories of carbon emissions

- Electricity (use)
- Electricity (production and transport)
- Fertilizer (production and denitrification)
- Fuel (use)
- Fuel (production and transport)
- Machinery (production, transport, and repair)
- Pesticide (production)
- Sand (production and transport)

GEO Foundation for Sustainable Golf

$$G_{Fuel\ (PT)} = Q_D C_{D(PT)} + Q_G C_{G(PT)} + Q_{NG} C_{NG(PT)} + Q_P C_{P(PT)} + Q_{HO} C_{HO(PT)}$$

$$G_{Fuel(U)} = Q_D\ C_{D(U)} + Q_G C_{G(U)} + Q_{NG} N_{NG(U)} + Q_P C_{P(U)} + Q_{HO} C_{HO(U)}$$

$$G_{Electricity\ (PT)} = Q_E\ C_{E(PT)}$$

$$G_{Electricity\ (U)} = Q_E C_{E(U)}$$

$$G_{Fertilizer(P)} = Q_N C_{N(P)} + Q_P C_{P(P)} + Q_K C_{K(P)}$$

$$G_{Fertilizer(A)} = Q_N\ C_{N(A)}$$

$$G_{Pesticide(P)} = Q_H\ C_{H(P)} + Q_F C_{F(P)} + Q_I C_{I(P)}$$

$$G_{Sand(MT)} = Q_S\ C_{S(M)} + Q_S C_{S(T)}$$

$$G_{Machinery(PTR)} = Q_{TM}\ C_{TM(PTR)} + Q_{TGM} C_{TGM(PTR)} + Q_{WBM} C_{WBM(PTR)} + Q_T C_{T(PTR)} + Q_{BRT} C_{BRT(PTR)} + Q_A C_{A(PTR)} + Q_{LUV} C_{LUV(PTR)} + Q_{HUV} C_{HUV(PTR)} + Q_{MSS} C_{MSS(PTR)} + Q_{FM} C_{FM(PTR)} + Q_{RM} C_{RM(PTR)} + Q_{SM} C_{SM(PTR)}$$

An example CO_2e calculation, simple!

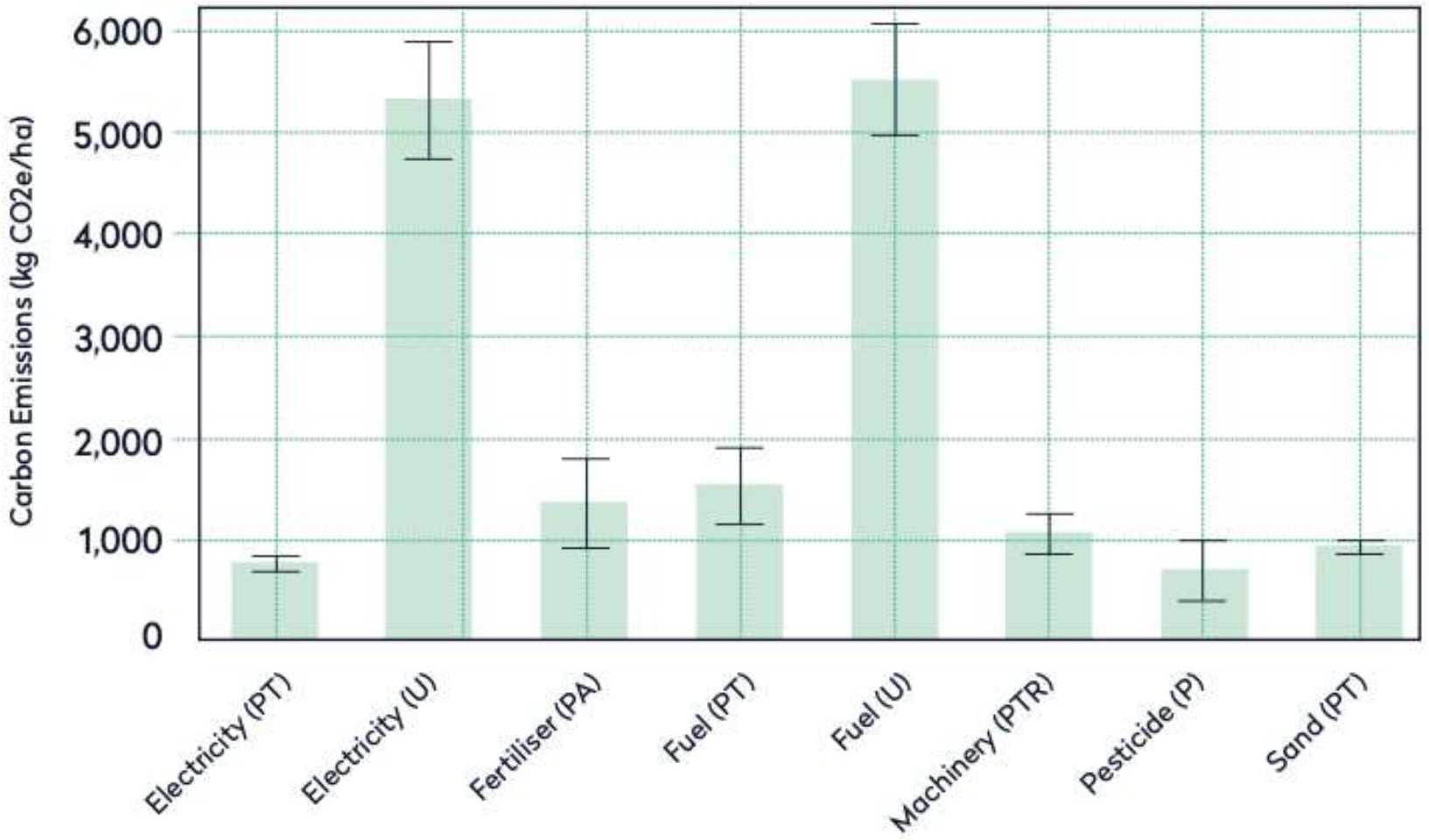
Fuel use * carbon emission coefficient = carbon emissions

Diesel use: 7000 L * 2.6 kg CO_2e /L = 18,200 kg CO_2e

Gasoline use: 5,600 L * 2.2 kg CO_2e /L = 12,230 kg CO_2e

Total fuel emissions = 30,420 kg CO_2e

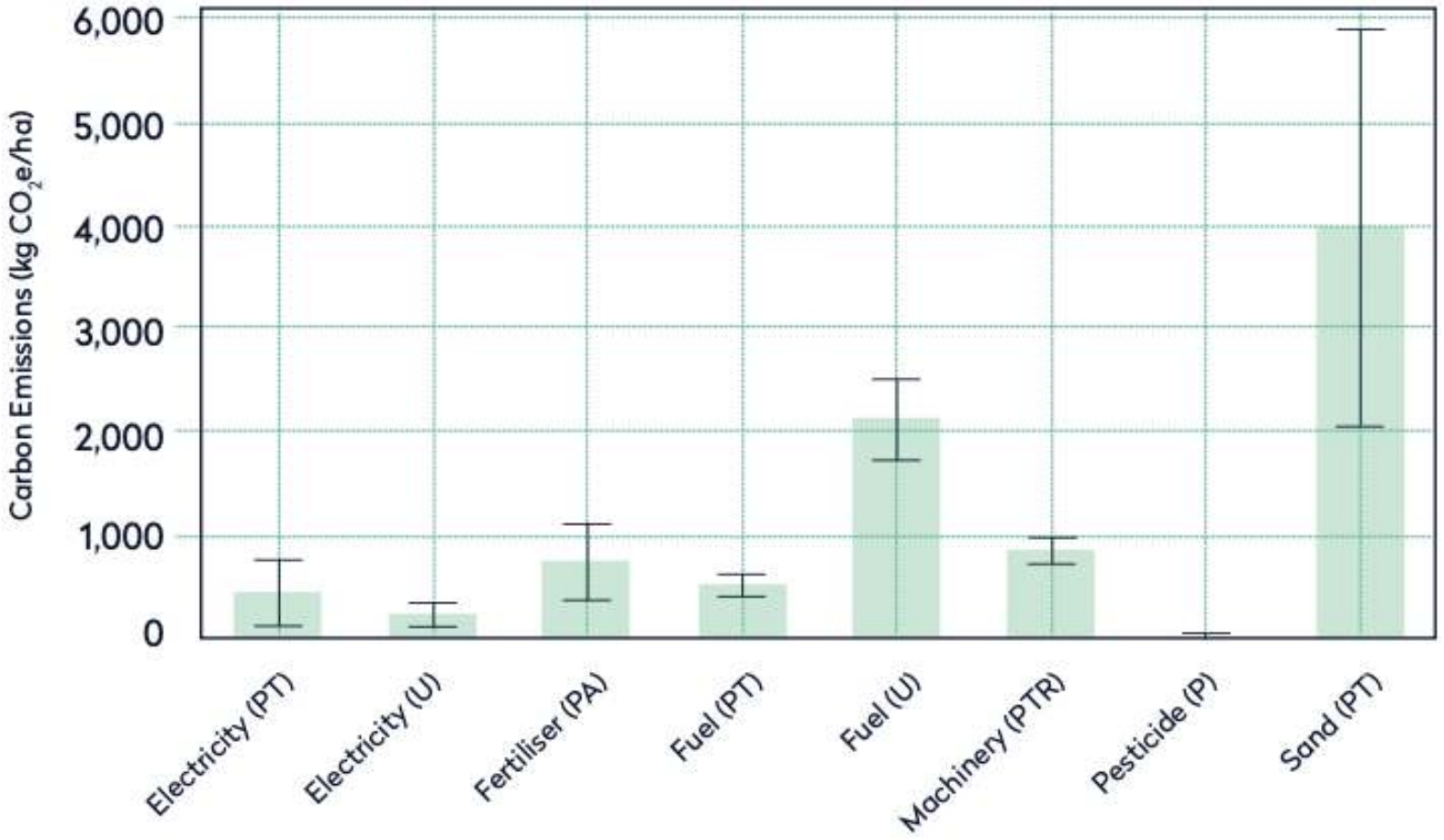
Greenhouse gas (GHG) emissions from 4 US golf courses



Legend
P – Production
T – Transport
R – Repair
U – Use
A – Application

Finding: Electricity and fuel use were the main sources of emissions from US golf courses

Greenhouse gas (GHG) emissions from 3 EU golf courses



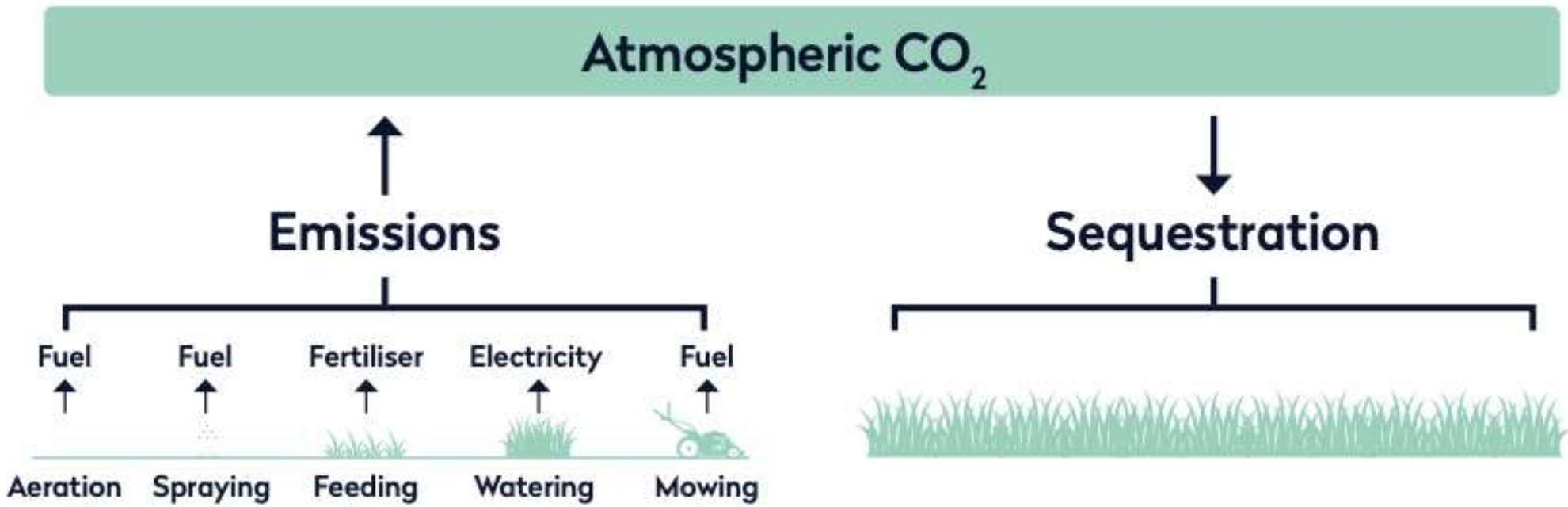
Legend
P – Production
T – Transport
R – Repair
U – Use
A – Application

Finding: Sand and fuel use were the main sources of emissions from EU golf courses

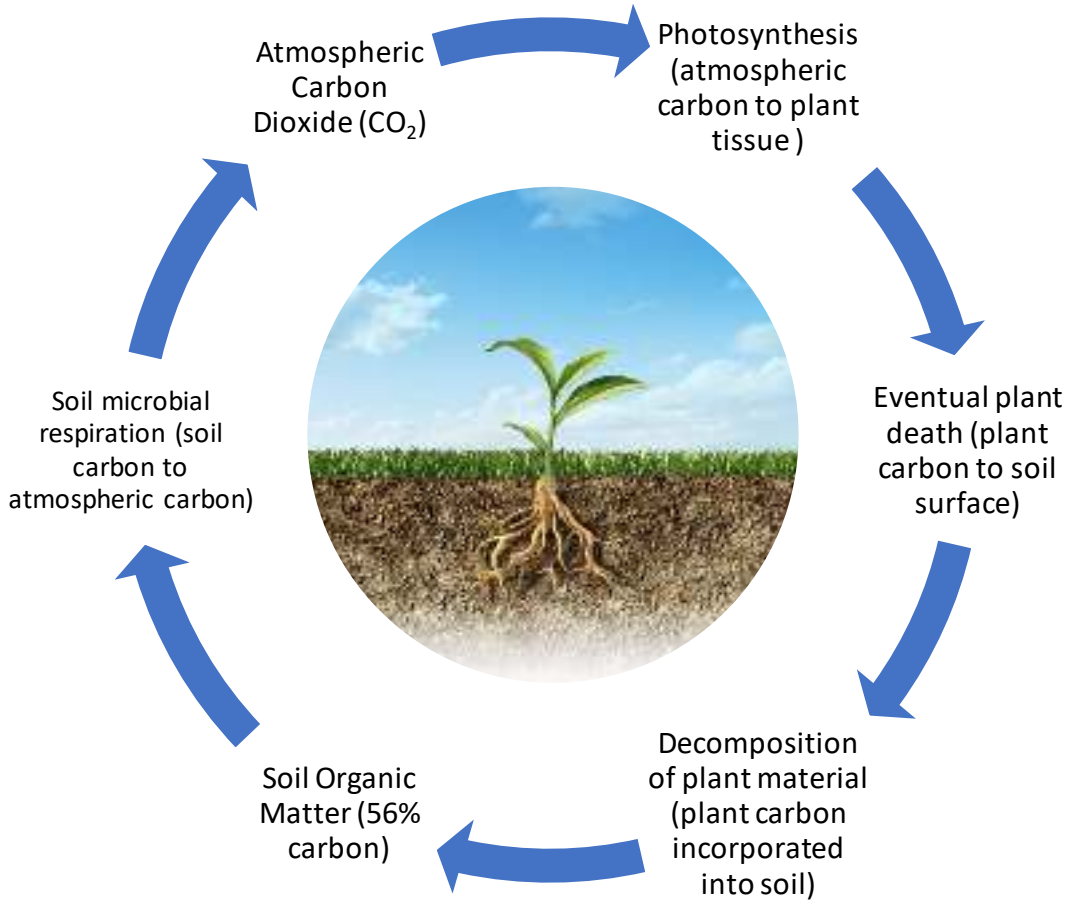
Carbon balance = emissions - sequestration

if emissions > sequestration = carbon positive (+)

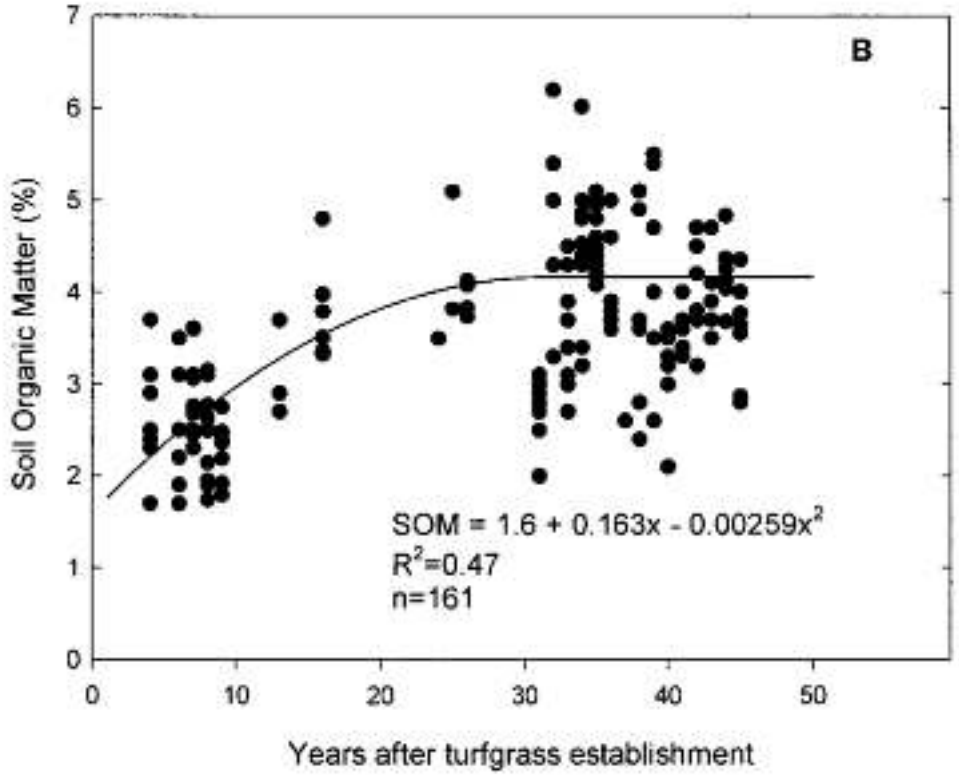
if emissions < sequestration = carbon negative (-)



Soil carbon sequestration on golf courses: soil carbon increases and then reaches a new equilibrium



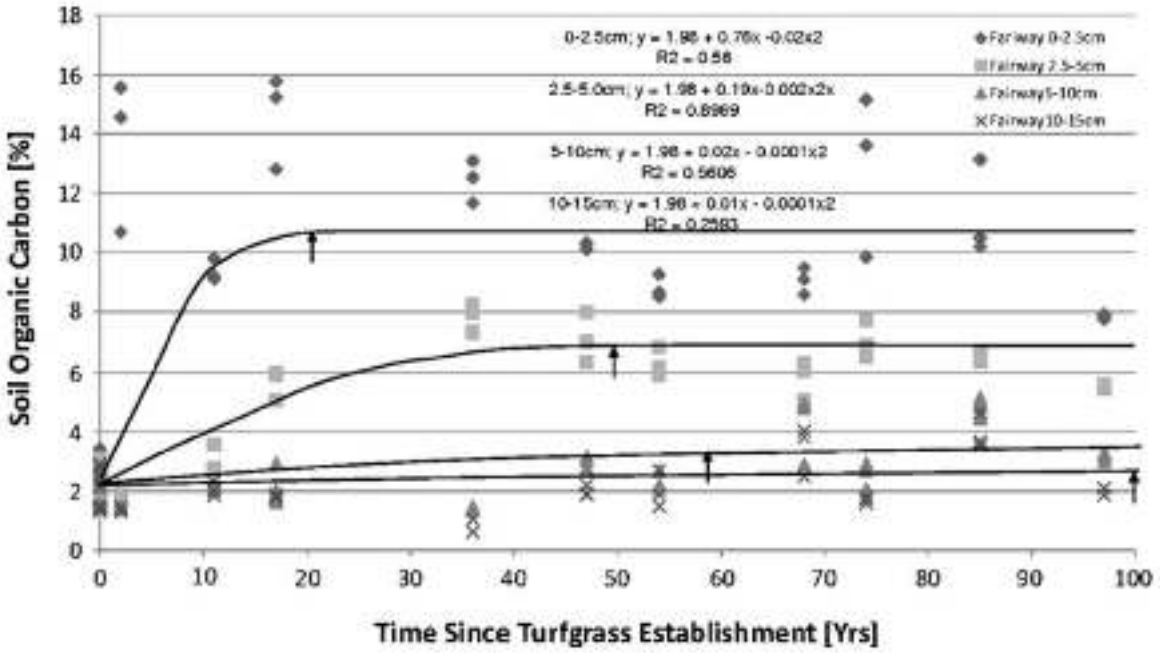
Golf course fairway in Colorado, USA



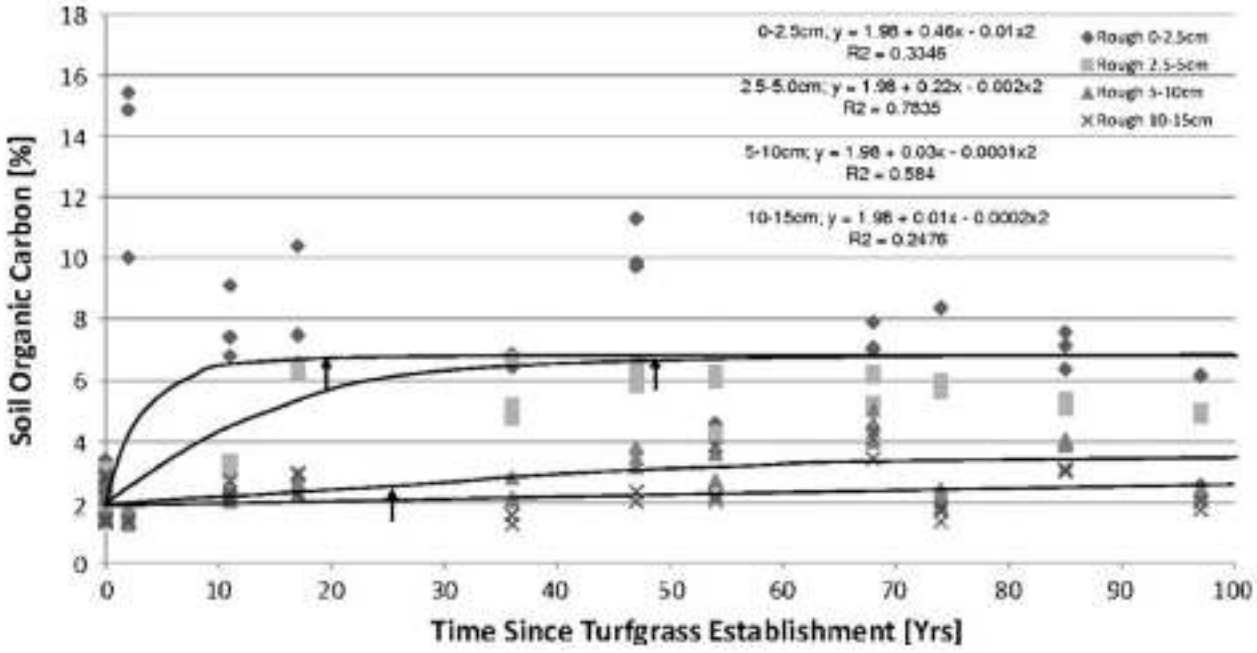
Qian and Follett, 2002

Golf course fairways and roughs in Ohio, USA also reached a SOC equilibrium

Fairways and Soil Organic Carbon (SOC)



Roughs and Soil Organic Carbon (SOC)

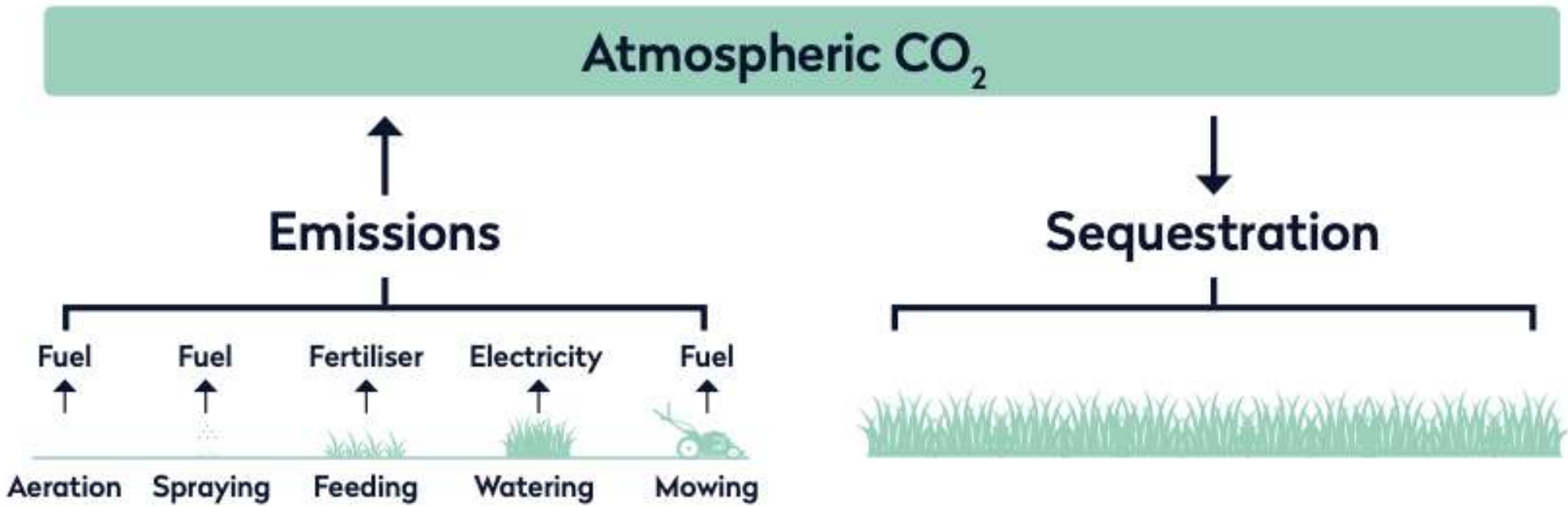


From Selhorst and Lal, 2011

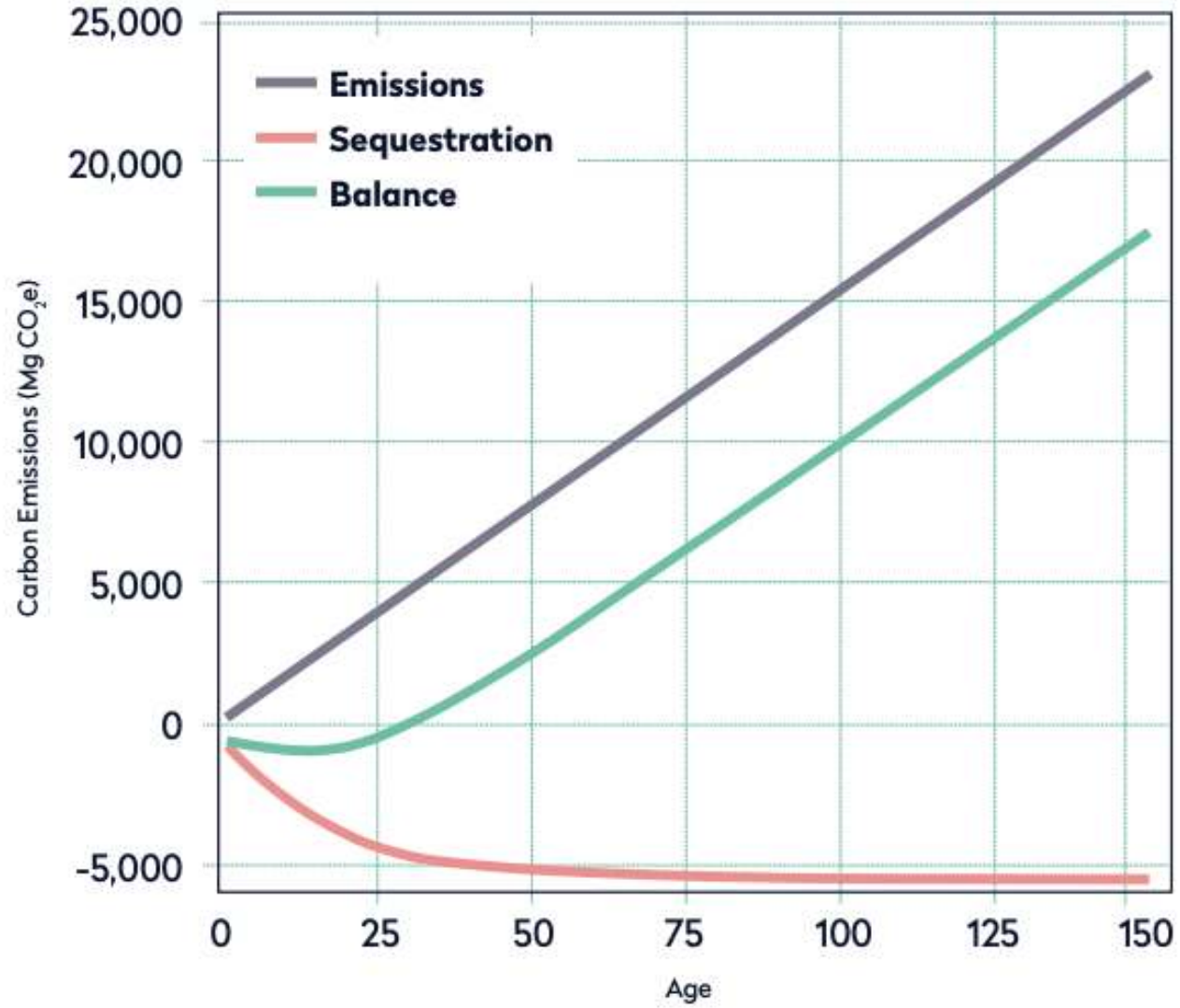
Carbon balance = emissions - sequestration

if emissions > sequestration = carbon positive (+)

if emissions < sequestration = carbon negative (-)

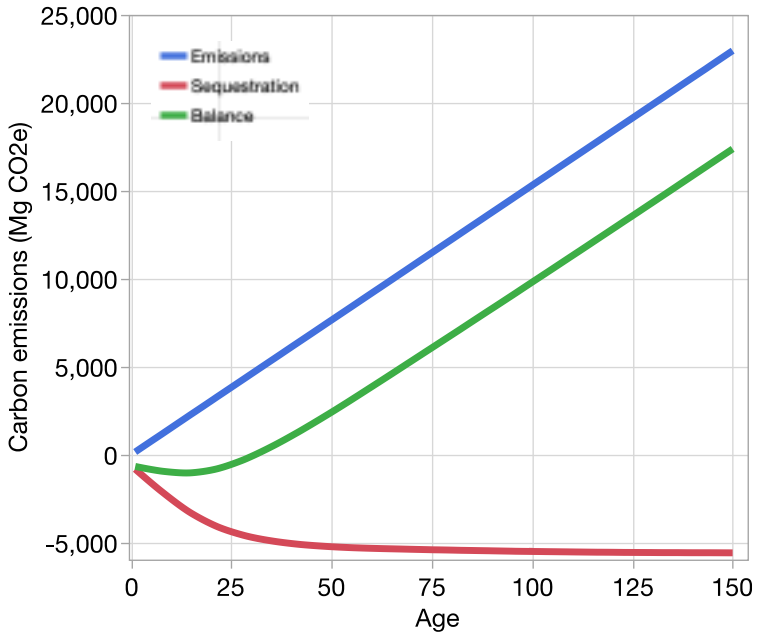


Average carbon balance of 4 US golf courses throughout their lifecycle

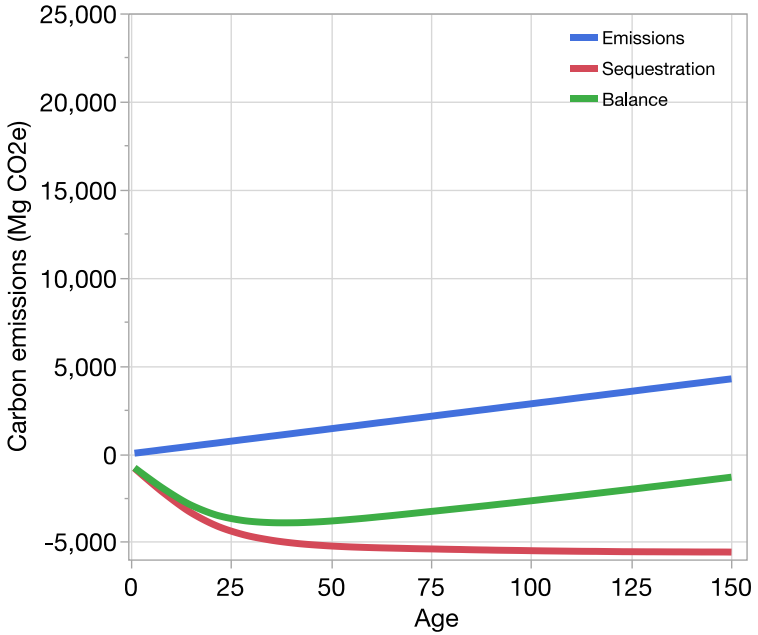


Emissions levels need to be reduced by over 5 times from current levels for golf courses to be carbon neutral over their lifecycle

Current trajectory



To be carbon neutral



What do emissions levels need to be for a golf course to be carbon neutral over its lifecycle?

Average golf course with 38 ha of turf

Assume 200-year golf course lifecycle

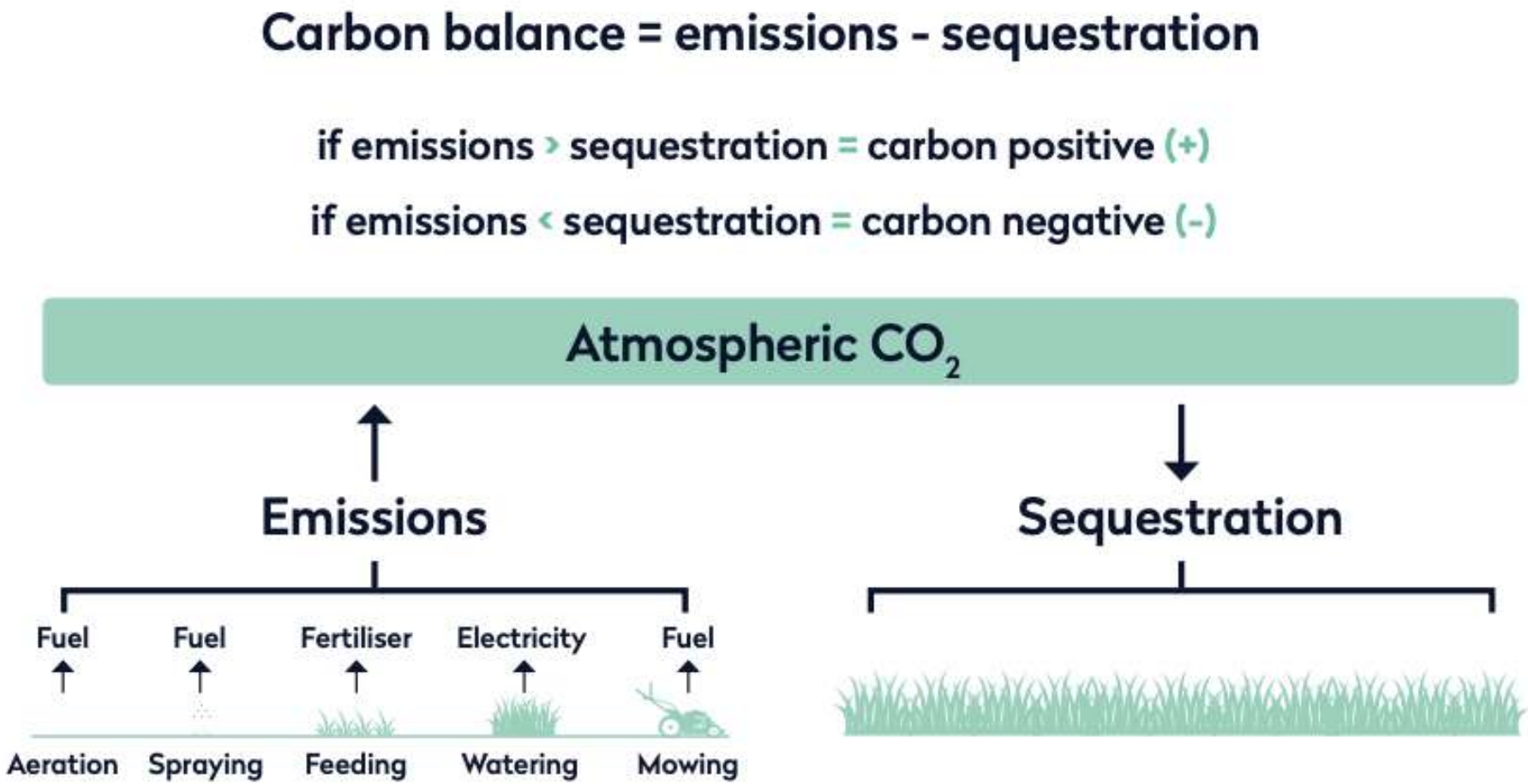
Sequestration capacity: 157,900 kg CO_2e ha^{-1}

Yearly emissions for carbon neutrality:
790 kg CO_2e $ha^{-1}yr^{-1}$

Average emissions levels in this study:
4,277 kg CO_2e $ha^{-1}yr^{-1}$

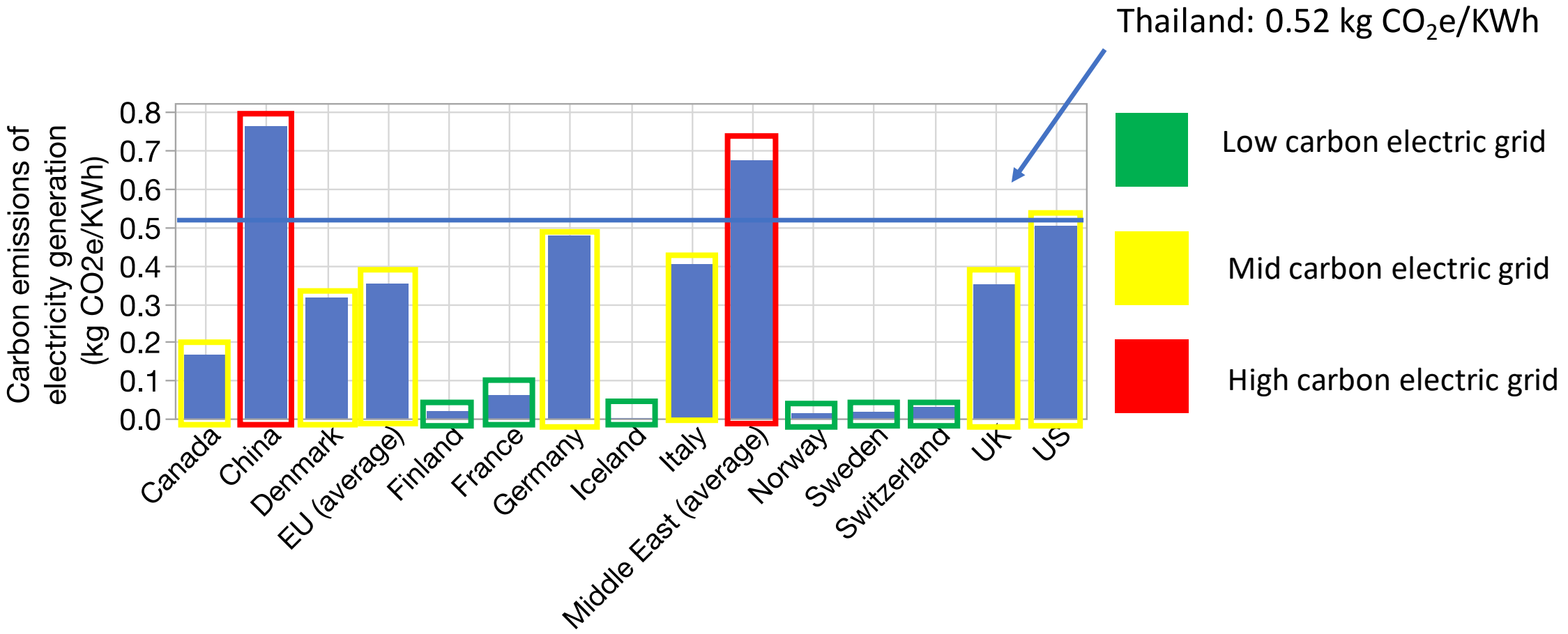
Emissions levels need to be reduced by 5.4 times from current levels for lifecycle carbon neutrality, more for a carbon negative lifecycle

5 practical actions for reducing carbon emissions in golf course maintenance



1) Transition to electric machinery

CO_2 emissions savings of electric maintenance equipment depends on carbon emissions of electricity generation



How much does electrification reduce carbon emissions?

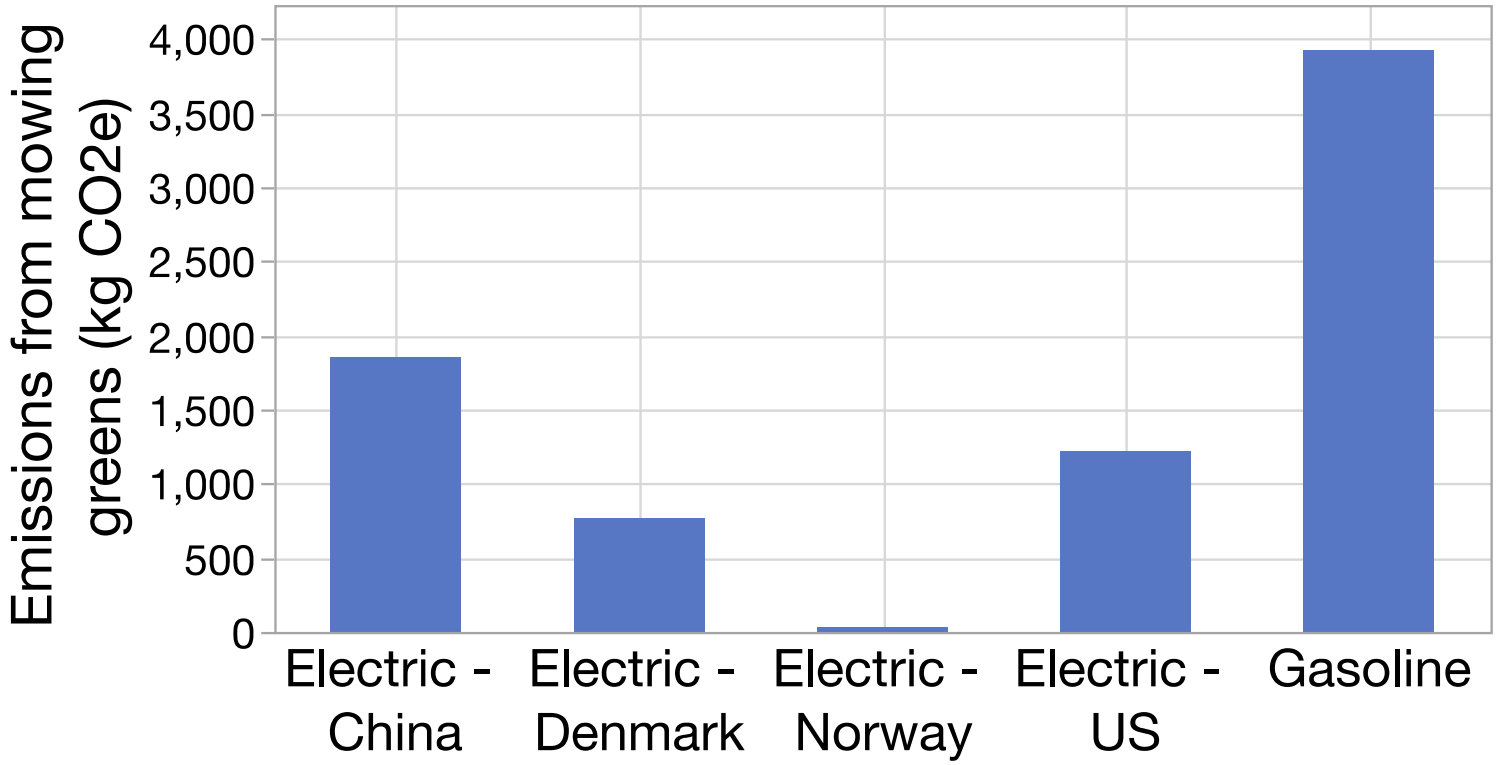
Hypothetical scenario

Gasoline vs electric triplex greens mower

Mowing greens for 1 year

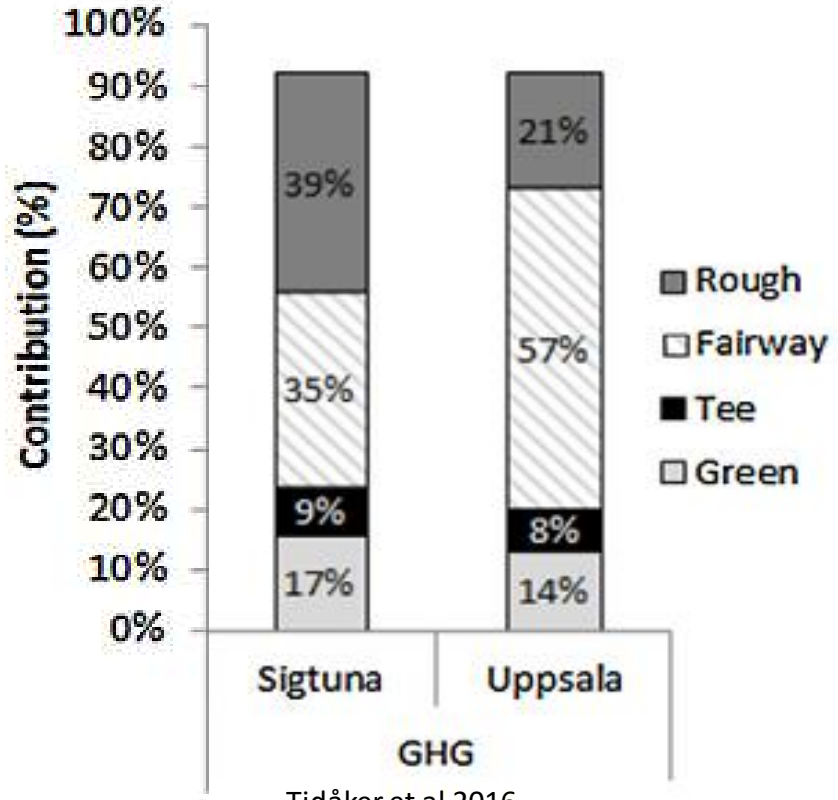
200 greens mowing events

1.2 ha of greens



Electric fairway and rough mowers are a critical next step to reducing carbon emissions in golf course maintenance

Fairways and roughs account for 75-80% of mowing GHG emissions



Tidåker et al 2016

Which machines are and are not currently electrified?

- Walk greens mower (yes)
- Triplex greens mowers (yes)
- Walk behind mower (yes)
- Bunker raking tractor (yes)
- Aerator (no)
- Utility vehicle (yes)
- Sprayer and spreader (no?)
- Fairway mower (yes, autonomous)
- Rough mower (yes, autonomous)
- Banks and surrounds mowers (no)

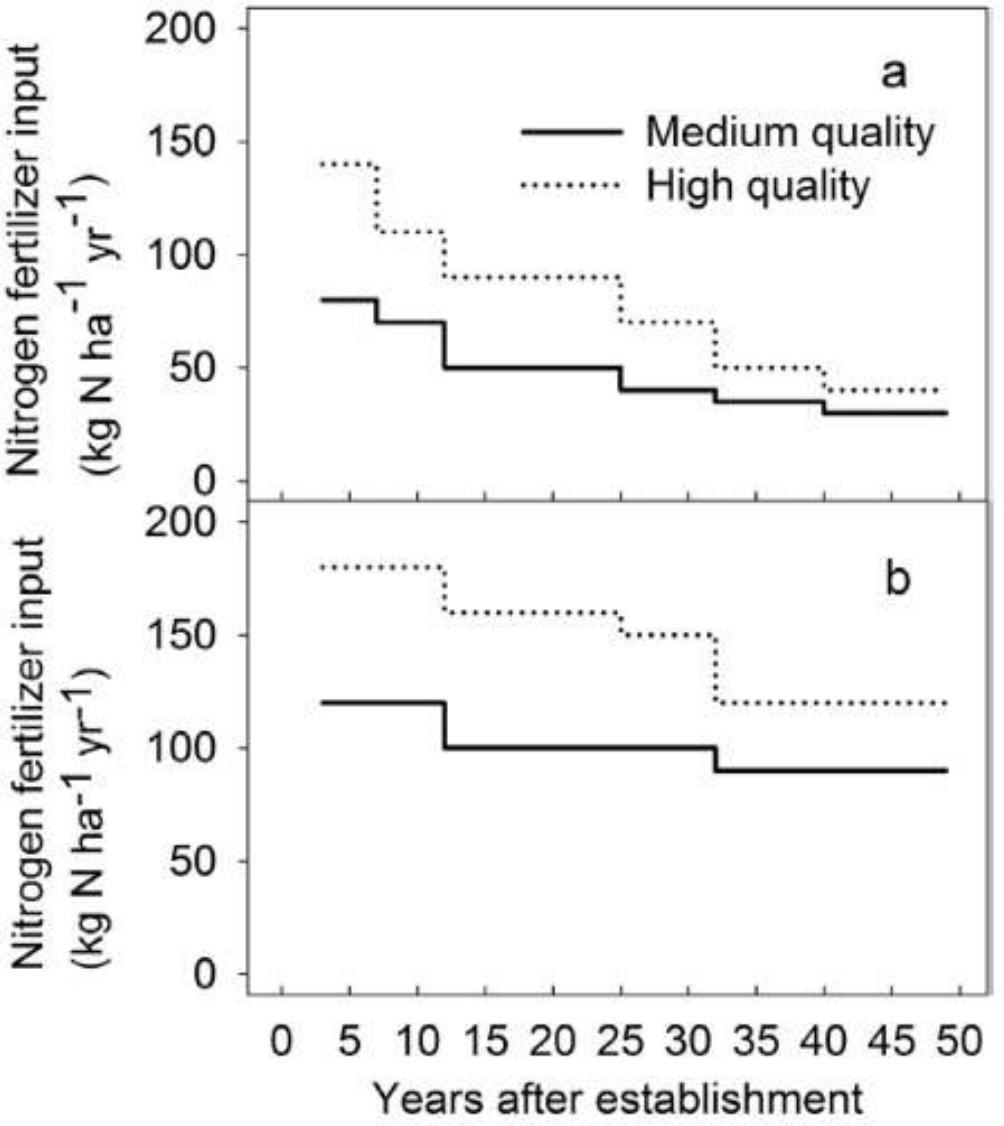
2) Source grid electricity from low carbon sources

3) Install onsite renewable energy

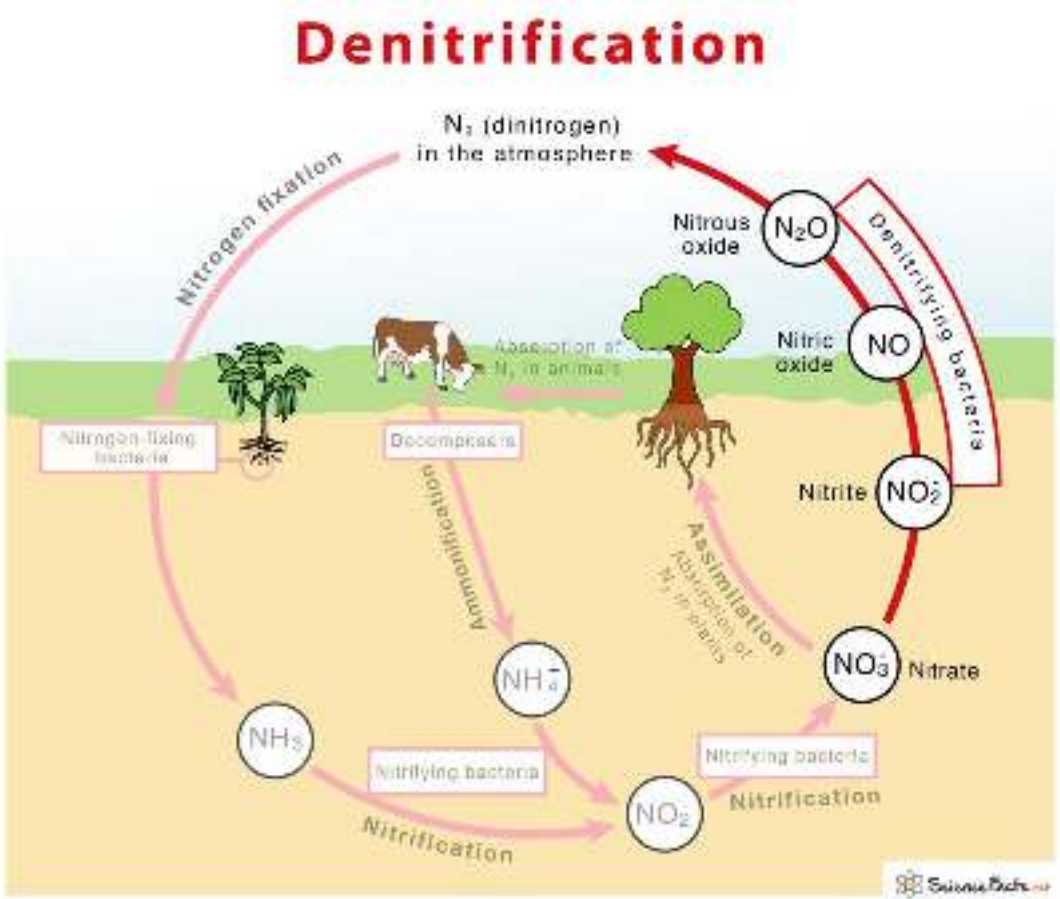
Photo credit: USGA

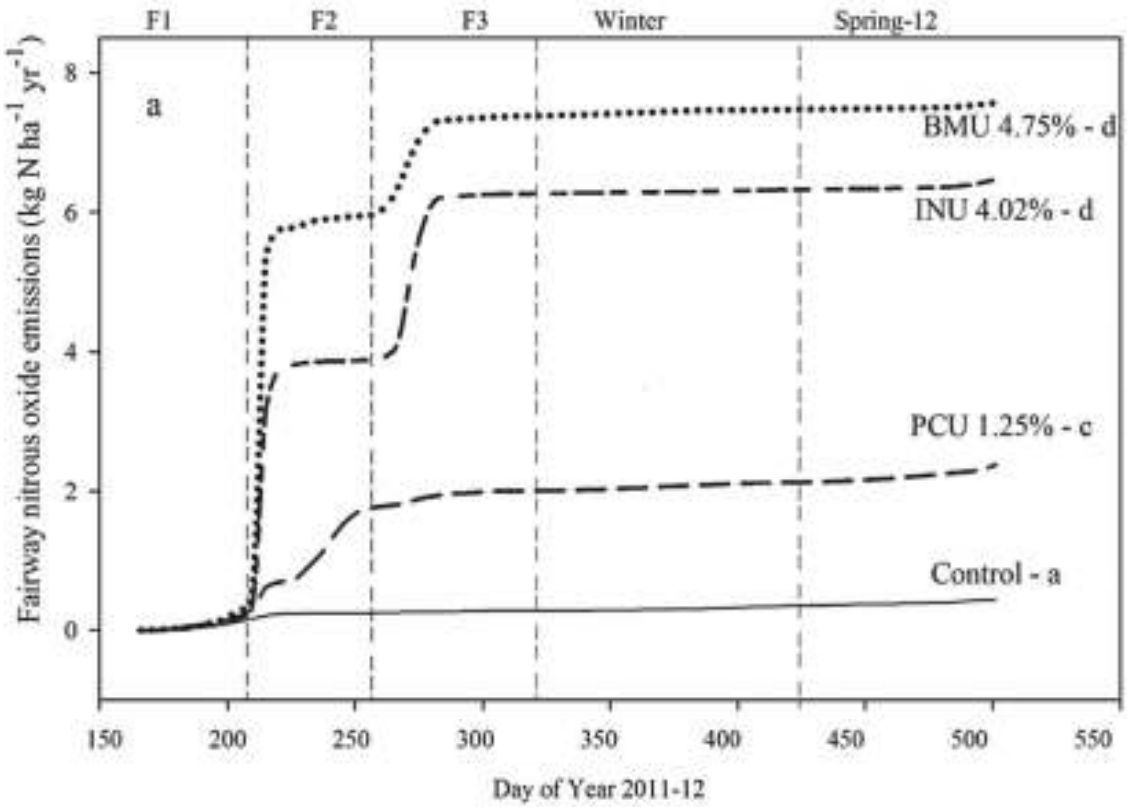
4) Reduce volume of topdressing and areas topdressed if agronomically viable

5) Reduce N fertilization rate as turf ages



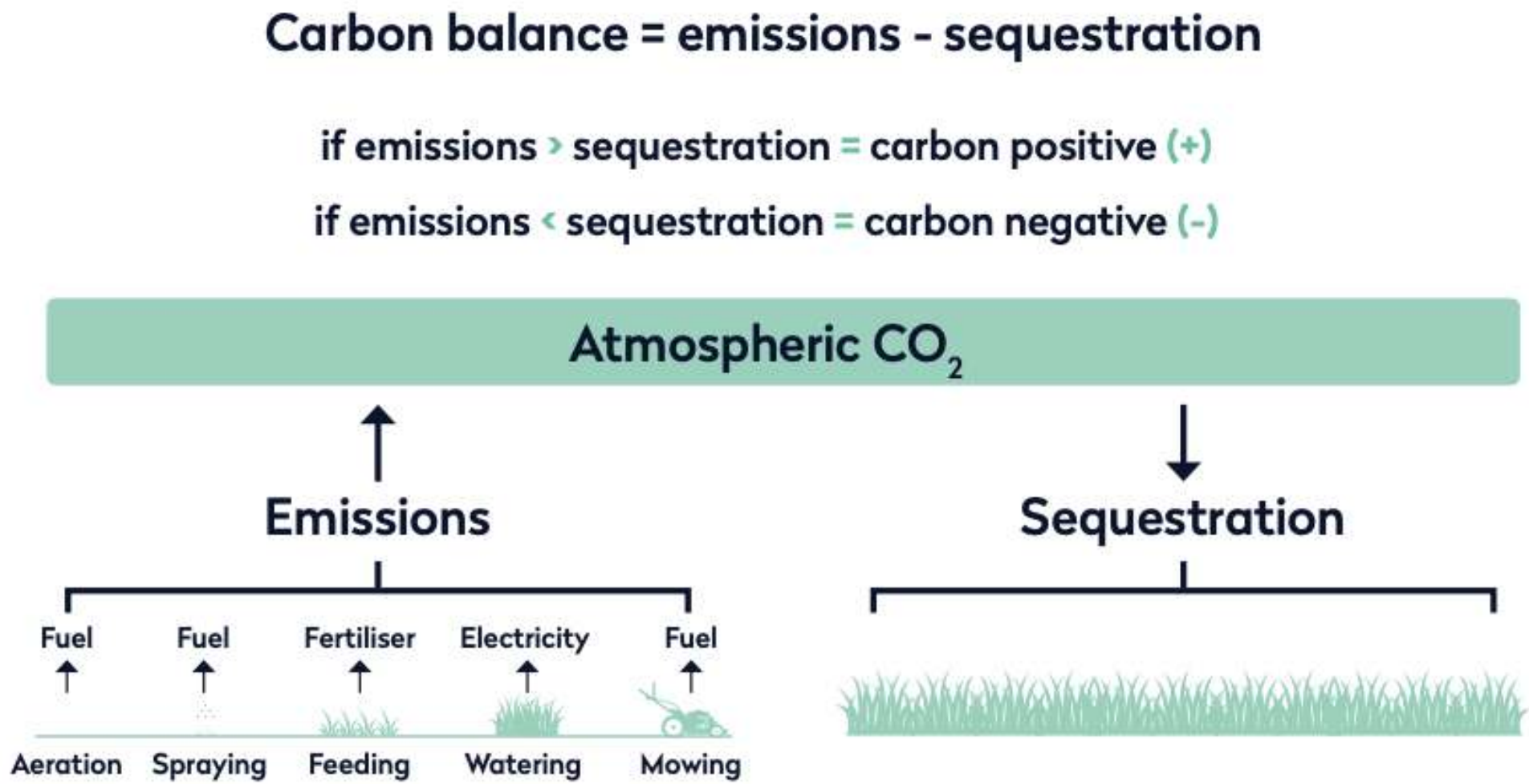
Nitrous oxide (N_2O) is powerful greenhouse gas that is emitted after N fertilizer applications





Gillette et al., 2016

5 practical actions for maximizing carbon sequestration of golf course maintenance



1) Maintain a healthy and actively growing perennial turfgrass system

2) Eliminate fairway aeration

3) Restrain from tilling and renovating existing turfgrass areas, especially those less than 50 years old

4) Return grass clippings to turfgrass surface

5) Increase turfgrass cutting height where possible

Sequestration capacity is hard to increase, reducing emission is much easier…transition to electric maintenance equipment and source low carbon electricity

Petrol maintenance equipment

Electric maintenance equipment

Low carbon electricity on site

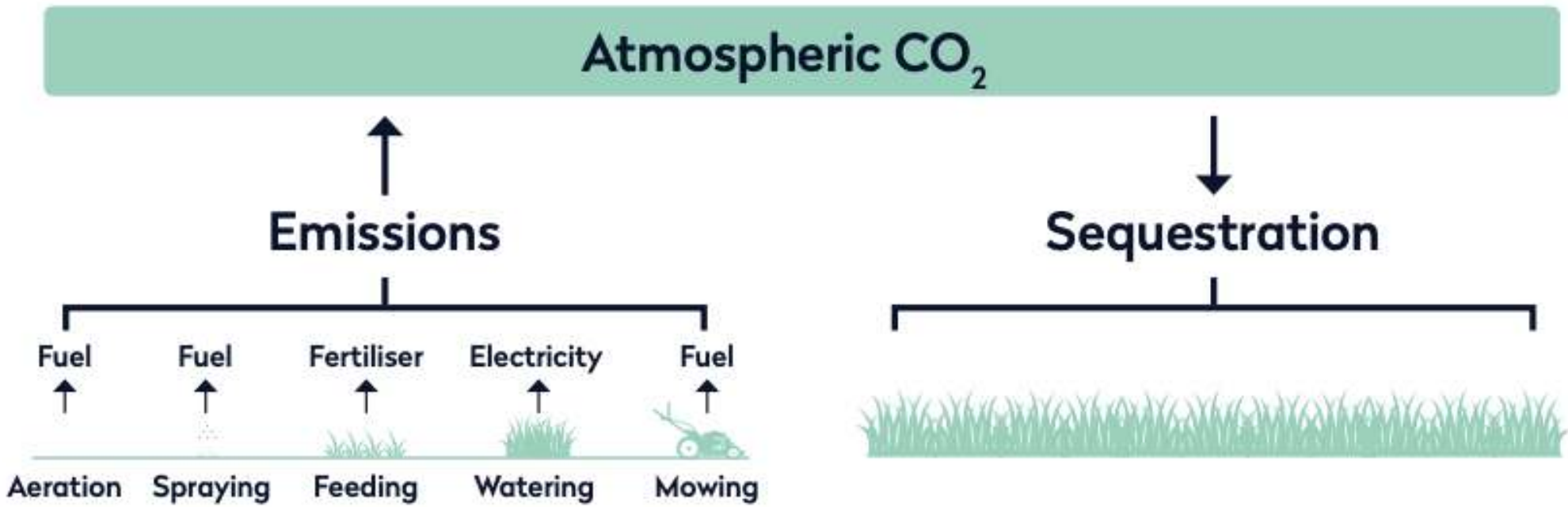
Low carbon grid electricity

Photo Credit: St Andrews Links and USGA

Carbon balance = emissions - sequestration

if emissions > sequestration = carbon positive (+)

if emissions < sequestration = carbon negative (-)



Climate change is perhaps the greatest societal challenge of our time: let´s do our part