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GC2030

Golf Course 2030

The Climate Impact of Golf Courses

Carbon Balances in Golf Course Landscapes

Contents.

This report primarily discusses carbon emissions of golf course turfgrass maintenance operations and the carbon sequestration value of golf course turfgrass. However, carbon emission estimations from golf courses could also include emissions from the clubhouse, event buildings, and even from the transport of golfers and employees to the facility. Conversely, carbon sequestration estimations could include the sequestration from non-turf areas of the golf course. Thus, when estimating carbon emissions and sequestration of a golf course, and the resulting carbon balance, it is critical to clearly defining which parts of the golf facility are included.

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An introduction to carbon and climate.

It is critical for the golf industry to contribute to mitigating climate change by reducing carbon emissions, and maximising carbon sequestration of courses.

Since the industrial revolution, human activity has caused the average surface temperature of Earth to rise by approximately 1°C.

Anthropogenic emissions of greenhouse gases, primarily carbon dioxide, methane, nitrous oxide, and fluorinated gases, which decrease the amount of heat Earth loses to space, are responsible for rising global average temperatures.

Throughout Earth's history, the climate has constantly, although slowly, changed. What is unprecedented today is the rate at which Earth's climate is changing. Human emissions of greenhouse gases are warming the climate so quickly, that life on earth is struggling to adapt to the rapidly changing conditions.

Global biodiversity is quickly declining, and we are under pressure to adapt to warmer temperatures, droughts, floods, and increasingly powerful and destructive storms. The golf industry is not immune to these pressures and is experiencing a range of challenges and threats, from water shortages to heavy rainfall and floods. It is critical for the golf industry to contribute to mitigating climate change by reducing carbon emissions and maximising the sequestration value of golf courses.

This report uses "carbon emissions" as a shorthand for the production of greenhouse gases (GHGs). Most greenhouse gases contain carbon (e.g., carbon dioxide, methane, fluorinated gases) but not all do (e.g., nitrous oxide).

The basics of carbon emission and sequestration

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

Oxygen + Hydrocarbon → Carbon dioxide + Water

Carbon emissions are the processes by which carbon is released to the atmosphere. Combustion of fossil fuels is the most common process that emits GHGs to the atmosphere and involves reacting oxygen and hydrocarbons (i.e., petrol, diesel, natural gas etc.) to produce carbon dioxide and water.

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

Carbon dioxide + Water → Sugar + Oxygen

Conversely, carbon sequestration is the process by which carbon is taken out of the atmosphere. Photosynthesis by plants removes carbon dioxide from the atmosphere and through a complex series of chemical reactions is able to produce sugars and oxygen. The plant retains the sugars and releases the oxygen back to the atmosphere.

The plant-soil system together are responsible for carbon sequestration in vegetated landscapes (i.e., forests, grasslands, and golf courses etc.). The sugars produced in photosynthesis are used by the plant as food and incorporated into their tissues (i.e., wood, leaves etc.). When plants die some of this plant material is consumed by microorganisms and other animals and the carbon in the plant tissue is returned to the atmosphere as CO_2. However, microorganisms cannot break down all plant tissue immediately, meaning that some of the plant tissue will slowly be transformed into what is called soil organic matter. Soil organic matter, which is present at some level in all soils, contains approximately 56% carbon and is one of the main repositories of carbon on Earth. Carbon sequestration by plants, largely happens through the combined processes of photosynthesis, eventual plant death, and the decomposition of plant material into soil organic matter.

Soil organic matter, which stores carbon in soils, is not a permanent repository or reservoir of carbon. Soil microorganisms can eventually break down soil organic matter under certain conditions, and in so doing return the carbon stored in soil organic matter to the atmosphere as CO_2.

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

Sugar + Oxygen → Carbon dioxide + Water

In much the same way as we eat food that contains carbon and breath out some of that carbon into the atmosphere as CO_2, soil microorganisms eat soil organic matter and release CO_2 back to the atmosphere. Scientists refer to this process performed by humans and microorganisms alike as respiration. Though the equation below is greatly simplified, respiration is the essentially opposite of photosynthesis.

Thus, carbon flows from the atmosphere into the soil and from the soil back to the atmosphere. The balance of these flows, which are always happening simultaneously, determines whether carbon accumulates in the soil or in the atmosphere. Soils can be a great repository of carbon, but they can also be large sources of carbon to the atmosphere if they are disturbed or managed incorrectly.

Golf course carbon cycling.

Golf courses both emit carbon to the atmosphere and sequester carbon from the atmosphere. The balance of emissions and sequestration determines the climate impact of a golf course.

The sum of direct, indirect, and associated emissions are equal to the total carbon emissions from a golf course.

Carbon emissions in golf course turfgrass maintenance

Carbon emissions can be broken down into different 'scopes' based on how closely associated the emissions are with an organisation or activity. Most carbon accounting strategies use a three scope system to categorise emissions, which is described below in the context of golf course maintenance.

Scope 1 Direct emissions

Golf course turfgrass maintenance operations emit carbon directly to the atmosphere through activities such as the combustion of fuel to power mowers and other maintenance equipment. These emissions are referred to as direct or Scope 1 emissions because they are directly controlled by the golf course itself.

Scope 2 Indirect emissions

Golf courses also emit carbon indirectly through the use of electricity, which are referred to as Scope 2 emissions. Emissions from using electricity are not generated on the golf course but are emitted at a power plant where the electricity is generated, which is why these emissions are labelled as indirect. The amount of carbon emitted per unit of electricity generated varies depending on the power source being use. Burning coal, for example, generates more carbon emissions per unit of electricity generated than hydroelectric power plants do.

Scope 3 Associated emissions

Golf courses not only emit carbon directly through burning fuels, and indirectly via consuming electricity but also through associated economic and supply chain related activities. The equipment (e.g., mowers, utility vehicles, tractors etc.) and materials (e.g., fertiliser, pesticide, sand etc.) that golf courses use all emits carbon in its production and transport to the facility. Emissions from these associated activities are referred to as Scope 3 emissions.

The sum of direct (Scope 1), indirect (Scope 2), and associated (Scope 3) emissions are equal to the total carbon emissions from a golf course.

Study of golf course maintenance emissions in US and Europe (Part 1)

Recent research conducted by turfgrass scientists at University of Wisconsin-Madison found that average carbon emissions on four US golf courses to be approximately 4,000 kg CO_2e ha^{-1} yr^{-1} (Bekken and Soldat, 2022). Scope 1, 2, and 3 emissions were all similar, approximately 1,300 kg CO_2e $ha^{-1} yr^{-1}$ (Figure 1A). On three European golf courses, overall emissions levels were similar, approximately 4,300 kg CO_2e ha^{-1} yr^{-1} (Figure 1B). Scope 1 emissions on European golf courses were 1,200 kg CO_2e ha^{-1} yr^{-1}, meaning they were approximately the same as in the US. Scope 2 emissions were much lower in Europe than in the US because of lower emissions from electricity generation in Europe. However, Scope 3 emissions on the European golf courses in the study were much higher because of sand topdressing use on fairways at the three golf courses in Europe that participated in the study. The authors of the study recognize that topdressing fairways is not a standard practice in golf course maintenance in Europe. The results of the study do highlight that if fairways are topdressed, the carbon cost to produce, transport, and apply that sand will be high.

Figure 1C and D show the same four US golf courses and three European golf courses, but instead of categorising the emissions by scope, the emissions are categorised into Electricity (production and transport), Electricity (use), Fertiliser (production and transport), Fuel (use), Machinery (production, transport, repair), Pesticide (production), and Sand (production and transport). For the four US golf courses Electricity (use) and Fuel (use) accounted for 63% of carbon emissions. For the three European golf courses, emissions were highest from Sand (production and transport) and Fuel (use).

The study revealed that if a golf course is not topdressing fairways, the most effective way to reduce carbon emissions is to transition to electric maintenance equipment and to source low carbon electricity.

Figure 1. A.

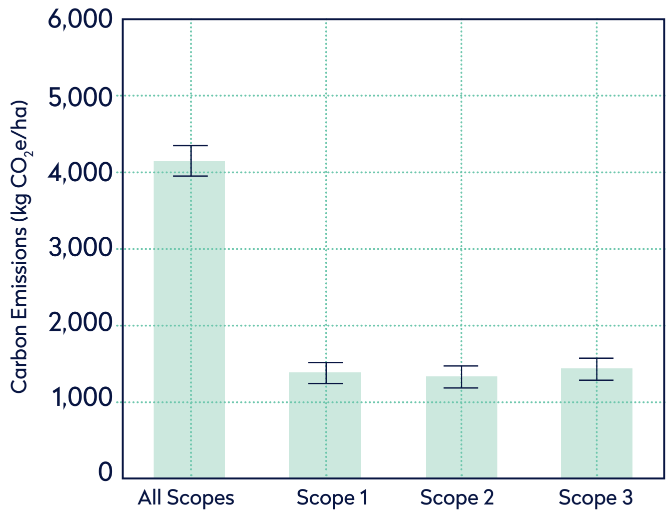


Figure 1. B.

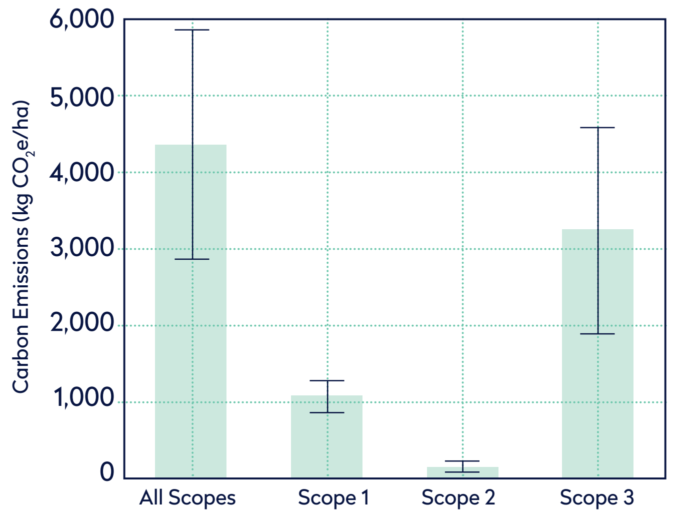


Figure 1. C.

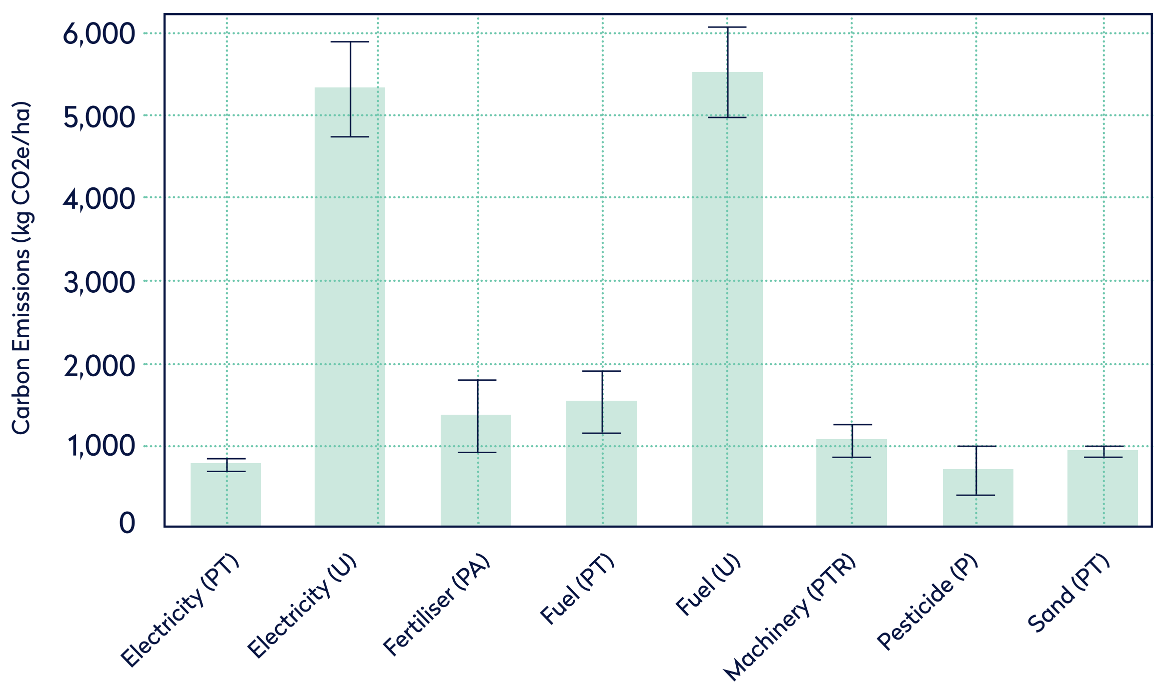


Figure 1. D.

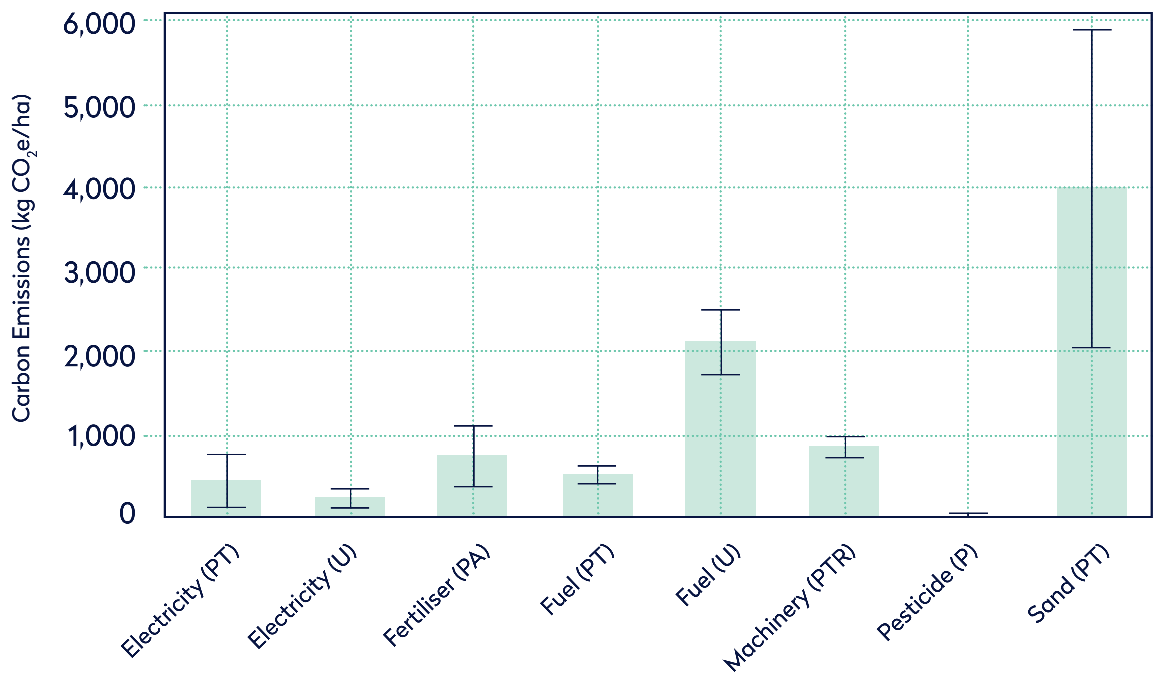


Figure 1. **Carbon emissions by scope on: A) four US golf courses, and B) three European golf courses. Carbon emissions across eight emission categories on: C) four US golf courses, and D) three European golf courses. P-Production, U-Use, A-Application (i.e., fertiliser identification), T-Transport, and R-Repair.**

The carbon balance of a golf course is equal to the weight of carbon emitted minus the weight of carbon sequestered.

Carbon sequestration of turf and non-turf areas on golf courses

Turfgrass sequestration

The turf-soil system on golf courses sequesters carbon in much the same way as natural vegetated landscapes. Golf courses are often converted from agricultural land and most forms of modern agriculture cause a decline in soil organic matter. When a golf course is constructed, on formerly agricultural land, several scientific studies indicate that the turfgrass-soil system quickly sequesters carbon (i.e., soil organic matter levels go up) for the first 20-30 years after the golf course is built. However, after 30 years, the rate of carbon sequestration (i.e., the rise in soil organic matter levels) starts to slow (Qian and Follet, 2002; Selhorst and Lal, 2011). After approximately 75 years, the rate of carbon sequestration becomes very low as soil organic matter levels stabilise and come to an equilibrium. At this point, most studies suggest that the turf-soil system on golf courses still sequesters carbon, but at a low rate.

Sequestration in non-turf areas

Approximately 20% of the average US golf course is natural or native vegetation (i.e., grassland, forest, or wetland) (GCSAA, 2017). Areas of native vegetation are important components of a golf course for the biodiversity and habitat value that they provide, especially in urban settings.

These vegetated native areas of the golf course can also sequester carbon. However, the rate of carbon sequestration in native areas depends on the type of vegetation and also how or if the native area is managed. The few scientific studies that attempt to account for carbon sequestration in native areas are mostly concerned in quantifying the effect carbon sequestration by forested areas on the golf course. The rate of forest carbon sequestration is heavily dependent on forest age and health, and so the estimates of carbon sequestration in forested areas on golf courses must be carefully conducted, if the estimates of sequestration are to be accurate. Unfortunately, there no studies to date which have directly measured carbon sequestration of forests and wider non-turf areas on golf courses, making this a possible area of future research.

There is some disagreement within the scientific community whether golf courses should take credit for carbon sequestration in non-turfgrass areas of the course, given that these areas are often not directly managed by golf course managers and sometimes are not entirely owned by the golf course either. Because the turfgrass system is most central to the operation of a golf course, many turfgrass scientists advocate that the turf system, the emissions of managing the turf and the sequestration that the turf provides, should be the main focus for golf course operators.

The carbon balance of golf courses

The carbon balance of a golf course is equal to the weight of carbon emitted minus the weight of carbon sequestered (Figure 2). A carbon balance is most typically calculated over a calendar year but can also be calculated over longer times scales as well. For example, one could calculate the carbon balance of a golf course over its entire lifetime.

Carbon positive (+)

If more carbon is emitted than sequestered over a given time period, the golf course is said to be "**carbon positive**".

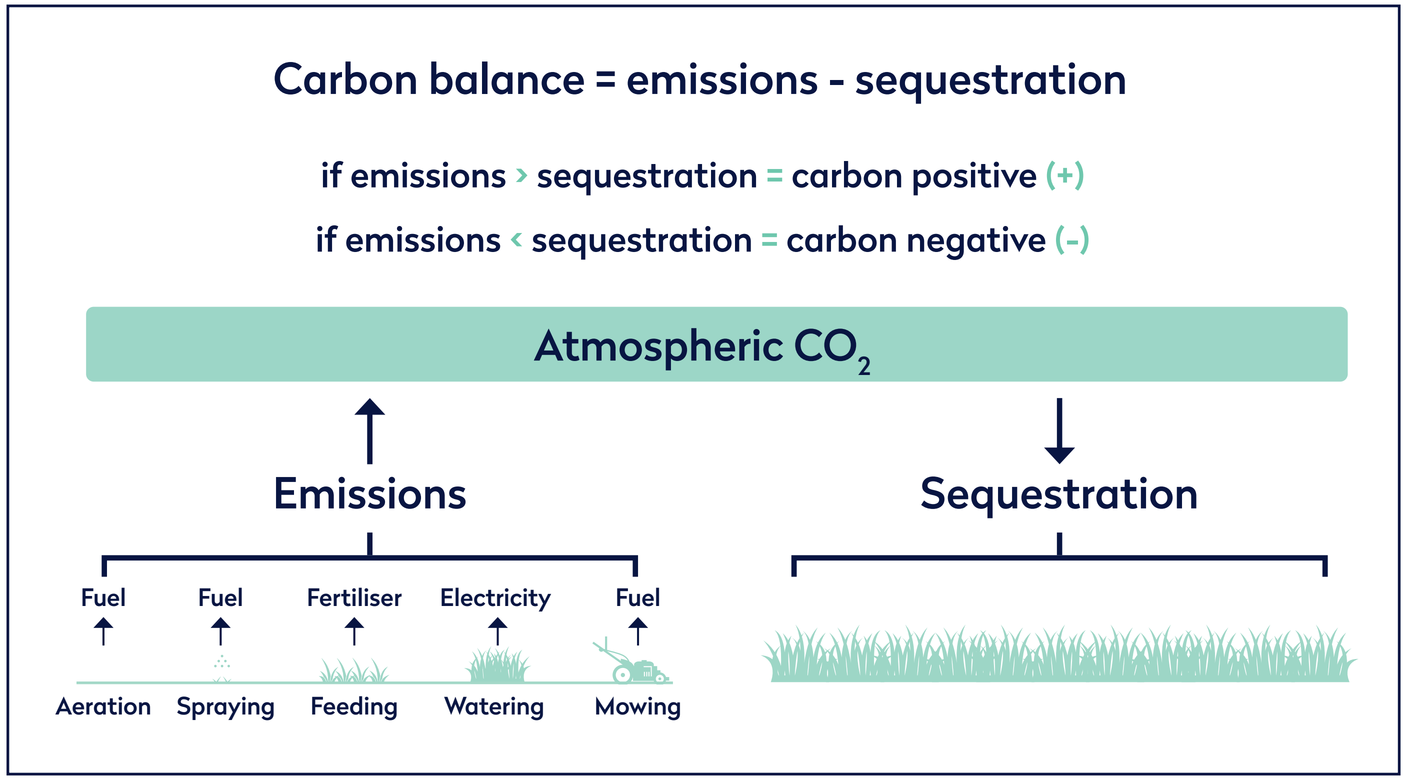
Carbon negative (-)

If more carbon is sequestered than emitted the golf course is said to be "**carbon negative**".

Carbon neutral

If emissions and sequestration are approximately equal, the golf course is said to be "**carbon neutral**". Net zero is another term that is synonymous with carbon neutrality.

Figure 2. **The carbon balance of a golf facility**



Study of golf course maintenance emissions in US and Europe (Part 2)

Figure 3 the cumulative carbon balance, emissions, and sequestration on four US golf courses over a 150 year period. Cumulative carbon emissions were assumed to increase linearly over the golf courses lifetime, meaning that the yearly emission rate stayed constant at approximately 160 Mg $CO_2e\ yr^{-1}$. Cumulative carbon sequestration was highest for the first 30 years after a golf course is built, but then level off almost completely after approximately 75 years.

The carbon balance of the golf courses in the study, was negative for the first 30 years of operation, but then became positive after 30 years. The average age of the four golf courses in the study was 65 years, at which point the golf courses were approximately 5,000 Mg CO_2e carbon positive. Unless emissions are greatly reduced, golf courses become increasingly carbon positive as they age.

For golf courses in the study to achieve carbon neutrality (i.e., net zero emissions) over an assumed 200 year life cycle, emission levels would need to be lowered from the current level of 160 Mg $CO_2e\ yr^{-1}$ to 30 Mg $CO_2e\ yr^{-1}$, a reduction of over 5 times.

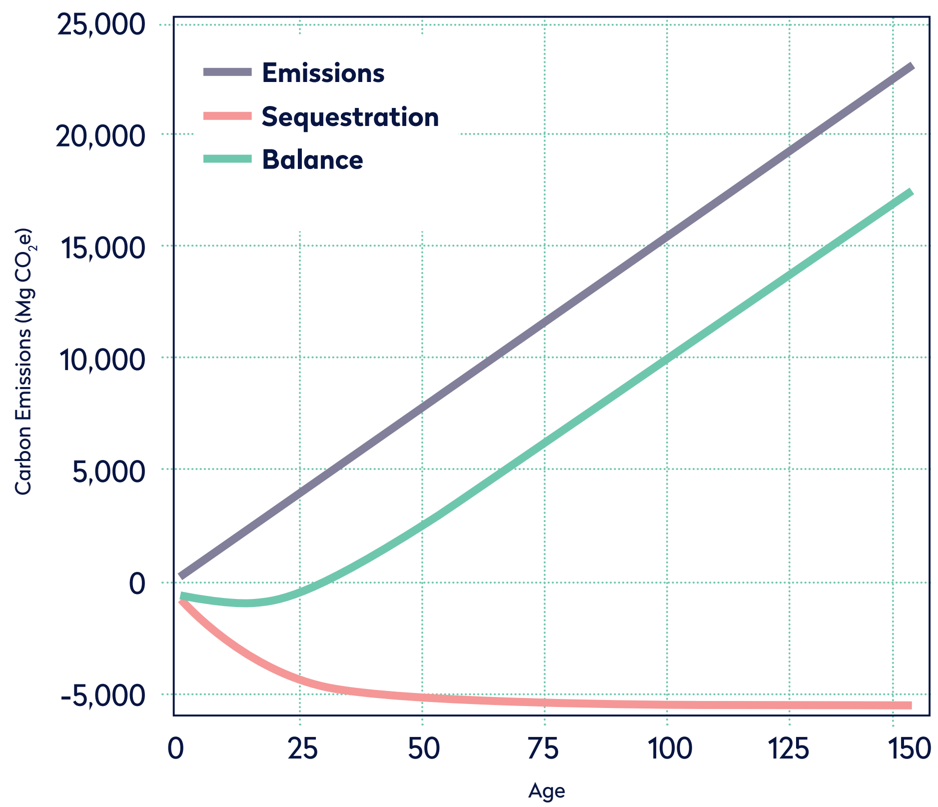


Figure 3. **Average cumulative carbon emissions, sequestration, and balance on four US golf courses. The grey line indicates the average age of the golf courses.**

Practical steps.

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Transitioning to electric maintenance equipment and sourcing electricity from a low carbon source are the most effective ways for most golf courses to reduce carbon emissions.

Minimising carbon emissions

Fortunately, the technology exists today to greatly reduce emission levels in golf course maintenance. Emissions in golf course maintenance operations primarily comes from fuel use for mowing and electricity use to power the maintenance building and irrigation pump. For golf courses that topdress fairways with sand, the emissions of mining, transporting, and applying sand to fairways is the primary emissions source at these golf courses, and nearly double the emissions from mowing or electricity use. However, if a golf course is only topdressing greens and tees, the most effective way to reduce emissions is to reduce fuel use by transitioning to electric maintenance equipment. Transitioning to electric maintenance equipment will reduce carbon emissions regardless of how the electricity is produced. However, the degree of emission reduction from electrification of maintenance equipment depends on the amount of carbon emitted per kWh of electricity generated.

Electrification of golf course maintenance equipment

Average emissions from electricity generation are displayed for 15 countries in Figure 4 below.

If a golf course is located in a country that emits more than 0.1 kg CO_2e kWh^{-1}, it is advisable to consider sourcing electricity from a lower carbon source other than the national electricity grid. This can be achieved by installing onsite solar panels, or by sourcing electricity from a low carbon source (i.e., hydroelectric, solar, or wind farm). Many electricity companies offer such a service, which is often referred to as a green tariff program.

A 2016 study found that 75-80% of mowing emissions are from mowing fairways and roughs (Tidåker et al., 2017). Thus, converting to electric mowers in these areas of the course is most important. While there are not currently any traditional fairway and rough golf mowers on the market that are electric, there are GPS guided antonymous electric mowers available that can mow fairways and roughs. Golf courses are strongly encouraged to consider adopting this technology to reduce emissions from mowing.

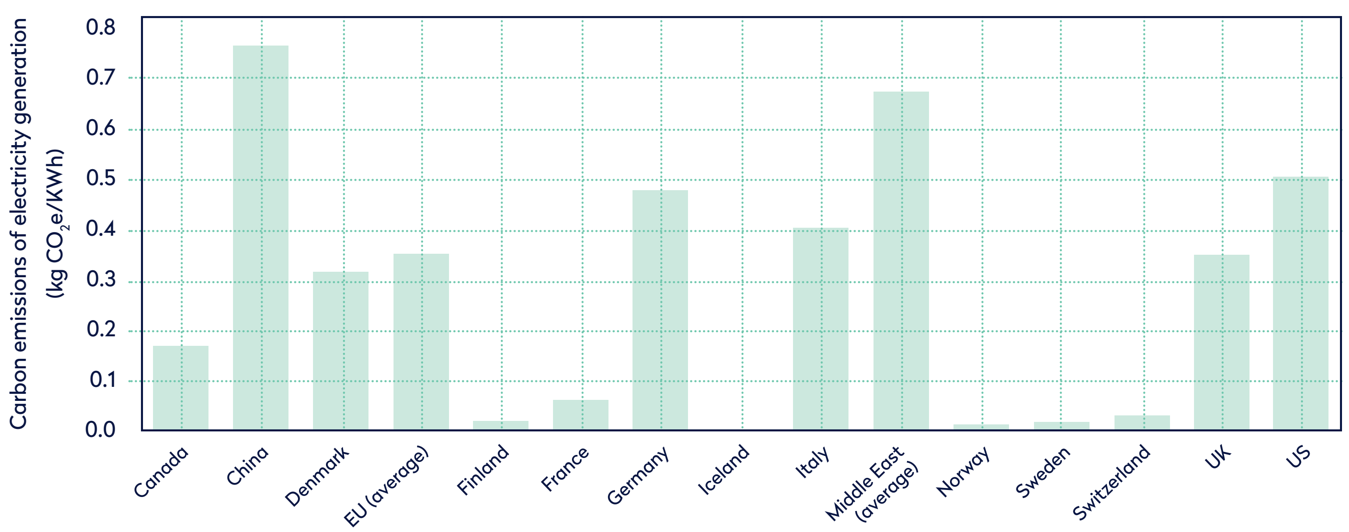

Figure 4. **Carbon emissions per kWh (kilowatt hour) of electricity generated in 13 countries and two regions (EU and Middle East).**

Reducing carbon emissions in golf course maintenance
1. Transition to electric machinery (e.g., mowers, utility vehicles etc.)
2. Source electricity from low carbon sources (onsite renewable or green tariff)
3. Install onsite solar panels on the roof of maintenance buildings
4. Reduce volume of topdressing and areas of topdressed if agronomically viable
5. Utilise N fertilisation in young turfgrass system (i.e., 0 to 10 years after planting) to develop a well-established turfgrass system with sufficient soil organic carbon and then begin with reduction of N inputs as the turfgrass system ages. After 50 years, N rates should be greatly reduced in most circumstances.

Golf course managers only have a limited ability to increase the sequestration capacity of a golf course.

Maximising carbon sequestration

Unlike carbon emissions, for which golf course managers have a high degree of control, managers only have a limited ability to increase the sequestration capacity of a golf course. Soil disturbances, like aeration, lead to a reduction in soil organic matter levels and carbon emissions. Greens and tees are a relatively small area of the average golf course (combined often less than 8-10% of the golf course). Aerating these areas is often agronomically important and will not significantly affect the golf courses carbon sequestration capacity. However, aerating fairways, which cover on average 30% of a golf course, will reduce a golf courses' ability to sequester carbon. In addition, tilling and renovating existing turf surfaces will also lead to a loss of soil organic carbon and carbon emissions. Practices such as returning clippings and increasing the turfgrass cutting height (especially in roughs) will also lead to a slightly higher carbon sequestration capacity.

Maximising 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 the existing turfgrass area, especially those less than 50 years old
4. Return grass clippings to the turfgrass surface
5. Increase turfgrass cutting height where possible

*This is a list of generalised recommendations that should only be applied where agronomically viable and may not be appropriate for all golf courses. Carbon sequestration should be one of many factors considered when making agronomic decisions on a golf course.

Summary.

Anthropogenic carbon emissions have caused the Earth's global average surface temperature to rise by approximately 1°C since the industrial revolution. This rapid rise in temperatures presents myriad challenges, including but not limited to more extreme and unpredictable weather, droughts, flooding, food shortages, sea level rise, and a decline in global biodiversity. All sectors of society, including the golf industry, must be engaged in mitigating the worst effects of climate change by reducing carbon emissions and increasing sequestration.

Carbon emissions in golf course maintenance primarily derives from burning fuels to power maintenance equipment and from the electricity used to power the maintenance facility and irrigation pump. Thus, the most effective way for golf courses to reduce emissions is to electrify maintenance equipment, and to source electricity from a low carbon source.

Golf course turfgrasses commonly sequester carbon from the atmosphere, but the rate of sequestration is heavily dependent on the historical land use and the age of the golf course. Some turfgrass species may sequester carbon more quickly than others, though this remains an active area of scientific research. Vegetation in non-turf areas of a golf course can also sequester carbon. However, the rate of sequestration in these areas is uncertain because of a lack of research, making this another possible direction for future investigation.

If considering the carbon balance of a golf course over its lifetime, recent research indicates that most golf courses are carbon negative in the first 30 years of operation. However, after 30 years of operation, most golf courses become carbon positive and become increasing carbon positive as they age.

This report outlines basic strategies for golf courses to reduce emissions and maximise sequestration. While it is important to employ both sets of strategies, for golf courses to be carbon negative or carbon neutral over their lifetime, carbon emissions must be greatly reduced from current levels. Increasing carbon sequestration on the golf course will help, but this alone will not turn a golf course from being carbon positive to carbon negative in most circumstances.

All sectors of society, including the golf industry, must be engaged in mitigating the worst effects of climate change by reducing carbon emissions and increasing sequestration.

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The R&A group of companies was formed in 2004 to take on The Royal and Ancient Golf Club of St Andrews' responsibilities for governing the Rules of Golf, staging The Open, golf's original championship, and developing the sport. The World Golf Museum in St Andrews is part of The R&A group.

Together The R&A and the USGA govern the sport of golf worldwide, operating in separate jurisdictions with a commitment to a single code for the Rules of Golf, Rules of Amateur Status and Equipment Standards. The R&A, through R&A Rules Ltd, governs the sport worldwide, outside of the United States and Mexico, on behalf of over 41 million golfers in 144 countries and with the consent of 159 organisations from amateur and professional golf.

The R&A has responsibility for running a series of world class amateur events and international matches in women's and girls' as well as men's and boys' golf. The R&A stages the AIG Women's Open and works with the DP World Tour to stage the Senior Open presented by Rolex.

The R&A is committed to investing £200 million over ten years in developing golf and supports the growth of the sport internationally, including the development and management of sustainable golf facilities. For more information, visit www.randa.org.

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