Turf Lifecycle Assessment

LCA Report

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Lifecycle Assessment modelling was conducted by Kyle O'Farrell of Envisage Consulting.

Report application

The study and modelling of processes is intended for use by the turf growing industry to support claims of environmental performance. The limitations of the study are evident in the variation in individual grower performance (see the benchmarking report). As such, it is not a claim that can be used by an individual grower without an individual study of their processes, but rather an indicative report on the industry's performance. It does not purport to show best practice in any aspect of the turf industry.

Executive Summary

The environmental impacts and benefits of turf grass are important as turf represents the largest area of horticultural land in Australia. Lawn is said to exceed the area of land put to crops in the United States of America and most likely in Australia as well.

Turf's environmental reputation has suffered from the impacts of fertiliser use and watering, together with energy used in mowing. These impacts have been studied here to gain sufficient information to provide an industry median environmental impact of turf over its lifecycle from the turf farm to the field or lawn.

The process of the turf lifecycle is described as a four stage lifecycle without a clear end of life point.

Raw materials → and energy	Turf growing → Stage 1	Packaging and → transport Stage 2	Installation at → site Stage 3	Maintenance at site Stage 4

Figure 1. Turf lifecycle stages

These four stages have been analysed in the lifecycle assessment (LCA) to determine the full lifecycle environmental impacts of turf for two applications: recreational and sports turf. Recreational turf has lower maintenance requirements than sports turf, however the stages to installation are basically the same.

The LCA is based on industry median figures from a study of 30 turf growing sites and five installations. Three lifetime scenarios were examined: one year life, five years life and ten years life. The LCA found the key environmental impacts of turf are water use, eutrophication potential, acidification potential and global warming potential. Other environmental impacts were relatively minor in terms of population norms.

The key positive impact of utilising turf to cover an outdoor area is the continuing sequestration of carbon dioxide over its life. The one, five and ten year scenarios yielded a sequestration rate per year per square meter of turf of 0.905, 0.375 and 0.308 kg CO_2 respectively for recreational turf. Due to the higher maintenance requirements of sports turf the only scenario with net CO_2 sequestration was the one year scenario at 0.01 kg $CO_2/m^2.y$.

Details of the environmental impacts and their interpretation are given in the results section of this report.

The industry can use this data to strongly indicate the benefits of using natural turf to environmentally sensitive markets. In order to utilise this, the LCA data and any declarations need to be independently verified to meet the requirements of the ISO 14040 standard.

Introduction

The turf industry is well established in all states of Australia with an estimated production area of 4,400 Ha spread over 250 growers (Turf Australia, 2018). Natural turf grass is produced from a variety of cultivars for home lawns, landscaping, recreational areas and sports fields. Turf growers cultivate the soil and grow turf, which is harvested as rolls or slabs for the various types of installations.

As an accountable industry the turf growers have commissioned the study: *An Environmental Assessment of the Australian Turf Industry*. Hort Innovation has funded this study using grower funds and support from the Australian government. This study includes a lifecycle assessment of turf.

Turf production requires sun water, soil and nutrients that are managed by the turf grower. There is a balance between inputs and outputs, both of which generate environmental impacts to be assessed in this study. The first two inputs from nature are variable from season to season and produce an inherent variability in the output of turf from a particular turf farm. As with all agricultural products there are good and poor seasons for growth. These have been taken into consideration by examining the turf farms over a two year period.

A two stage approach has been used where the growers have been assessed followed by an examination of installations to cover the full lifecycle of turf.

Goal and intended application of the study

The intent of this study is to quantify material movements and energy use over the lifecycle of turf and from this to determine the related environmental impacts of the lifecycle as defined herein. This data was then used to calculate the environmental impacts in a form suitable for publication as an Environmental Product Declaration.

Lifecycle assessment

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product or service by:

- compiling an inventory of relevant inputs and outputs of the product or service system
- evaluating the potential environmental impacts associated with those inputs and outputs
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA models the environmental impacts from each stage of a lifecycle across raw materials acquisition, manufacture, use and end-of-life. It incorporates the steps outlined in Figure 2.

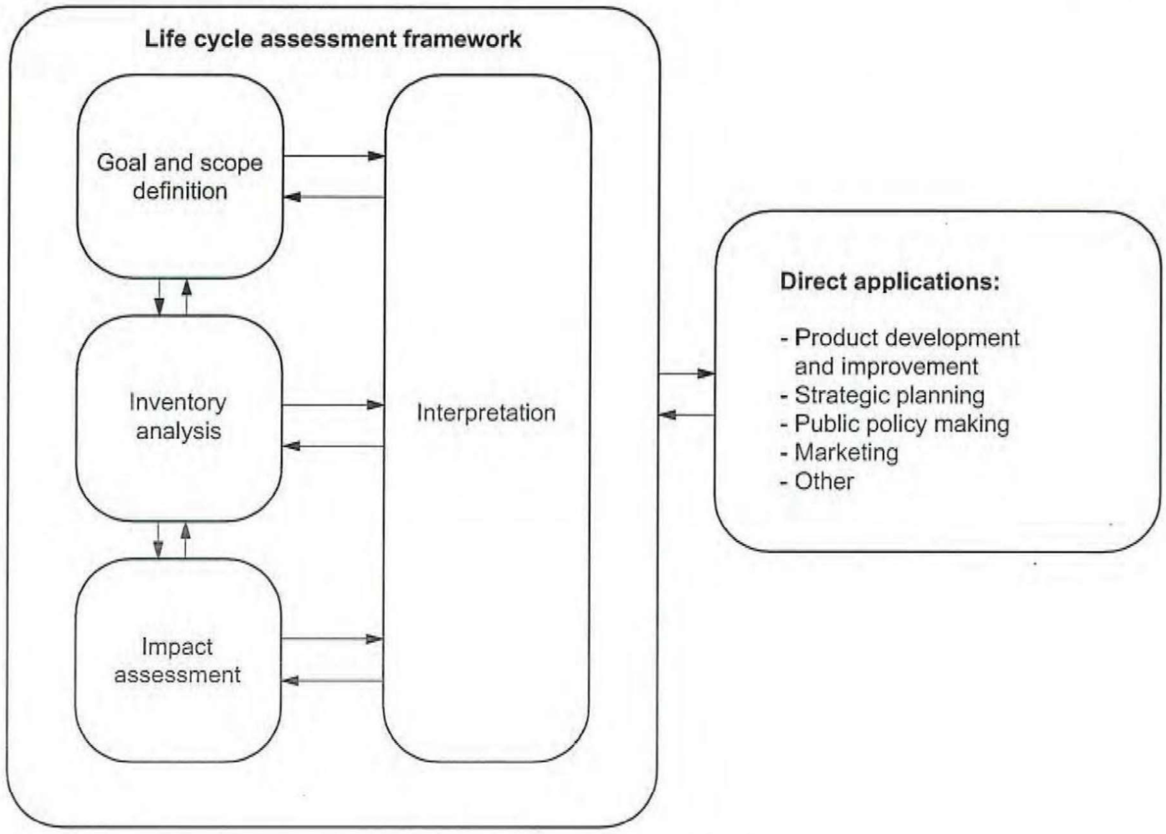

Figure 2. Stages in a lifecycle assessment

The key reference standards that are utilised in undertaking the LCA and Environmental Product Declaration (EPD) development are:

- International Standard ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework, Geneva: International Organization for Standardization.
- International Standard ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines, Geneva: International Organization for Standardization.
- ALCAS Best Practice Guide for Mid Point Lifecycle Assessment in Australia (M.A., 2018)
- International Standard ISO 14025:2006 – Environmental labels and declarations – Type III Environmental Declarations – Principles and Practice

Scope of the study

The data collected has been exclusively from the Australian turf industry for the application of the turf in Australia, under the various conditions encountered. Turf has a lifespan that is limited only by changes in the use of the land. This may occur after a few or many years, so the impacts of growing, transport, installation and maintenance are reported separately to allow users of the LCA to calculate the annual impact based on an assumed lifespan for a specific installation.

This assessment gains its primary data from a study of 30 growing sites and five installations across the major turf growing and installation areas across Australia. The data are expressed as median, or most likely values for the industry as at 2018. It should be understood that there is variability in the environmental conditions, growing and maintenance systems, as well as the function of the turf itself. The function of turf falls into two broad categories: ***recreational turf,*** which is the majority of turf applied to function as a lawn in residential and parkland areas and ***sports turf,*** which is applied to sporting fields and is more carefully installed and maintained.

Functional unit

The functional unit is the basis on which environmental impacts are calculated. Turf is sold by area of cover rather than weight of product, so the inputs are generally expressed and understood as the amount used per area of turf farm. In line with this practice the functional unit used is one square meter of finished product. The lifecycle inputs are expressed as those pertaining to the production of 1 m^2 of turf and its installation and maintenance over one year so the impacts are calculated as being per m^2 of turf per year.

FUNCTIONAL UNIT = 1 m^2 turf installed/year (1, 5 and 10 year default lifespans are used)

Process description

Turf lifecycle has been split into four stages:

1. Growing and harvesting
2. Packaging and transport
3. Installation on site and
4. Maintenance carried out each year

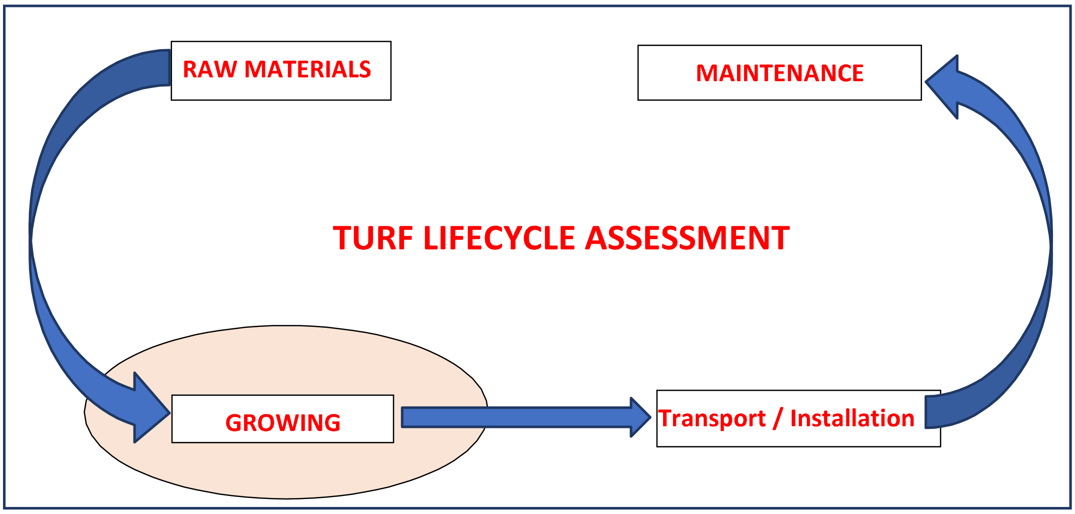

Figure 3. Lifecycle of turf

Stage 1. Growing

Turf grass may be grown from seed but is more commonly propagated from existing turf left remaining in the soil. The predominant varieties of Buffalo, Couch and Kikuyu are propagated in this way from strips of turf left after harvest or from turf grass roots left in the soil.

The diverse set of turf varieties have differing nutrition and water requirements. There was no attempt to split up the turf varieties as each farm produced a set of different products and differentiation of these was not practicable in this study.

Figure 4. Turf strips left for propagation after harvest

The process of propagation involves fertilisation and irrigation with due consideration of the season and growing patterns.

Growth rates are dependent on temperature, sunlight, nutrients and moisture in the soil. At temperate latitudes there is a growth season from Spring to Autumn and a dormant period over Winter. Subtropical regions can grow turf all year round.

During the growing period, water and nutrients have to be supplied for optimal growth and weeds and pests have to be controlled. Each grower has an irrigation program along with fertilisation and chemical addition schedules.

Growers use energy predominantly in the form of diesel fuel. Tractors are used across the farm for most activities, diesel may also be used for irrigation pumps. If not, electrical pumps are used for irrigation, which is the major use of electrical energy by turf growers.

Stage 2. Harvest and transport

Specialist equipment is used to harvest turf with most growers using automated harvesters that produce rolls or slabs. The rolls are placed on a pallet and wrapped to stabilise them. They are then loaded onto a truck (usually a flat bed truck) for transport to the installation site.

As a living product turf is harvested on market demand and transported within a day to the installation site.

Stage 3. Installation

The site is prepared for the turf by levelling the site, adding topsoil or sand if necessary. Fertiliser is added to aid the establishment of the turf. The turf is laid manually and watered in for the first week. A reticulated irrigation system may be used for larger installations. Smaller sites can use moveable sprinkler systems or can be hand watered.

Figure 5. Watering in a turf installation with a moveable sprinkler system

Stage 4. Maintenance

Once the turf is established a maintenance regime is employed. This involves mowing regularly over the growing season, fertilisation to maintain the required growth and watering as required by the turf grass.

It may be necessary to spot spray weeds and apply pesticides if they are having an adverse effect on the turf.

The end of life for a turf installation is dictated by land use rather than the lifespan of the turf, which can go on growing indefinitely if appropriately maintained. As such, there is no definite end of life scenario for turf grass and a one year period has been chosen for the installed lifespan.

The end of life scenario of turf is redevelopment of the site without the need to treat or dispose of any wastes. In most cases the topsoil with the turf will be stockpiled and reused. There are no environmental impacts considered in this analysis.

System boundaries

The examination of environmental impacts considers the operations on the turf farm and the various inputs on farm being: energy, water, fuels, chemicals and other consumables, such as netting. Farm infrastructure is not considered as it is not certain as to whether this was established with the purpose of turf growing in mind and may be utilised by other farming activities at the site. It is acceptable under the reference Product Category Rules[1] (PCR) to exclude infrastructure related inputs and outputs.

[1] Product Category Rules are an agreed set of rules governing the production of a lifecycle inventory and resultant environmental impacts that allows products and systems to be compared with the same "ruler" for measurement.

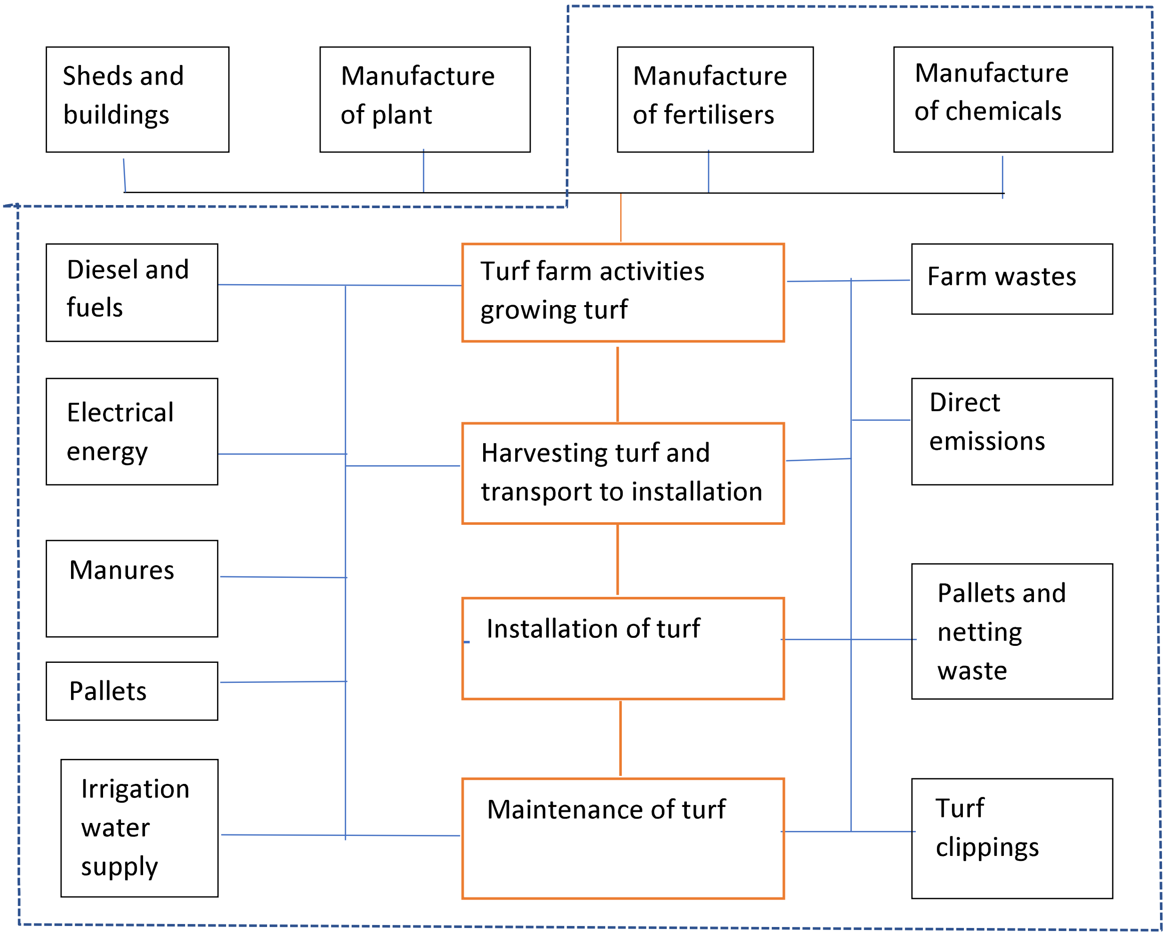

Figure 6. Boundaries of the life cycle assessment of turf (blue dotted line)

Geographical boundaries used were the limits of the Australian continent and Tasmania. The time boundaries used for the study are the financial years 2016-17 and 2017-18 for growing data. However, the installation data collection has been undertaken from January 2018 to March 2019.

The study was intended to cover all turf varieties together and growers in all sizes and Australian locations. Installation studies have been restricted to the Melbourne and Sydney regions.

System inventory data

The system inventory is the materials and energy used within the boundary of the lifecycle. All inputs are considered for inclusion in the lifecycle inventory (LCI), but in order to produce a manageable system decisions may be made to use particular inputs to represent a range of similar materials. For instance agricultural lime is used as the default input for all of the mineral inputs into turf growing and maintenance. Similarly representative chemicals are used for the wide range of chemicals used as pesticides and herbicides.

Growing

Studies of 30 growing sites across Australia, over two annual periods, and a series of five installations have produced data on material flows and energy consumption through the lifecycle of turf. This is presented as the industry mean with high and low limits to cover the performance of 80% of growers. As the application of turf varies from recreational to specialist sporting facilities these are split into categories.

Regional variation in growing conditions has been accounted for by the high and low limits of the data. For instance irrigation water use is considerably higher in the sand belt of Western Australia than it is in clay loam conditions encountered elsewhere.

As data has been collected for the turf growers over two years the data presented represents the average of the 2016-17 and 2017-18 financial years.

Turf grower data (n=30-40)			**Median**	**Average**	**Top 90%**	**Bottom 10%**
Land use	m^2 of land / m^2 turf produced per year		1.67	1.5	2.86	0.93
Electricity	kWh/m^2 turf produced		0.25	0.38	0.95	0.05
Diesel	L/m^2 turf produced		0.12	0.15	0.29	0.06
Energy used	MJ/m^2 turf produced		5.5	6.91	14.5	2.39
Greenhouse	Direct emissions kg CO_2/m^2		0.51	0.74	1.2	0.26
	Net emissions kg CO_2/m^2		-1.63[2]	-1.68	-2.31	-0.9
Water used	L/m^2 turf produced		1078	1497	3563	621
Nitrogen	kg(N)/m^2 turf produced		0.047	0.071	0.16	0.02
Phosphorus	kg(P)/m^2 turf produced		0.016	0.022	0.053	0.0023
Potassium	kg (K)/m^2 turf produced		0.021	0.027	0.061	0.00096
Ag chemicals	kg / m^2 turf produced		0.0019	0.0023	0.0061	0.00082
Lime +	kg / m^2 turf produced			0.092		

Table 1. Turf grower consumption data

Land use is an environmental impact category that may be considered in terms of its use over a set period of time. It also known as change of land use or biodiversity impact. The turf grower can use the same piece of land to produce turf for many years and it is commonly the case that the land has been used to produce turf for generations. The soil is incorporated into the turf product and hence soil is lost to the product. This may be replaced by manures and other additives used by the grower and the soil develops, through the plants, an increase in organic matter. The situation is complex and the soil is not lost to the environment, it is effectively transferred to another site, where it may also act to stabilise soil loss. For these reasons we believe that the impact of land use is simply to be taken as the area of the turf farm for the total production of turf from that farm, expressed in m^2 of land / m^2 turf produced per year.

Energy is used as electricity and diesel with a minor amount of LPG used in forklifts to load trucks. The LPG usage is less than 1% of the total and has not been included in the lifecycle assessment. The total diesel used on farm as well as electricity have been used to calculate the usage per m^2 of turf produced. Where diesel is also used on farm for transport purposes a factor has been applied based

[2] A negative emission of CO_2 represents capture of atmospheric CO_2 by the system commonly called carbon sequestration or a negative carbon footprint.

on the trucks and product distribution mileage to gain an estimate of the total diesel used on the farm only. In most cases the growers used different accounts for on-farm diesel to the trucks.

For each grower the diesel and electricity usage was used to calculate the greenhouse gas emissions for the farm, together with the greenhouse gas attribution of fertilisers and chemicals used. The net greenhouse gas emissions were calculated from a study of the carbon content of the product turf to gain a net Greenhouse emission per m^2 of turf. In all growers this was a net sequestration of carbon and negative Greenhouse emissions for turf products.

Turf growers use river water or bore water to irrigate turf. In some cases they collect run off from irrigation in dams and reuse this water. It was not possible to determine what the irrigation volume was recycled so the assumption is that all water is fresh. Some growers use waste water recycled from sewage treatment plants. While these growers can discount the water use impact for this wastewater reuse this has not be taken into account in this LCA.

Fertilisers and manures used by the growers were determined according to the NPK content (nitrogen, phosphorus and potassium) and these figures were used to estimate the environmental impact. The N, P and K were determined in the product turf of 6 growing sites and an average used to establish the amount of N, P and K held by the product turf and the remainder that is either held up in the soil or lost to groundwater or surface run off. The turf plant production was used to determine the quantity of carbon in the plant (at 50% of dry plant matter) and from photosynthesis the quantity of carbon dioxide absorbed by the plant from the atmosphere. This has a major implication in the net carbon dioxide emissions (the measure of climate change as $CO_{2(eq)}$) from the growing stage.

A single grower may have used up to 40 different chemical products in addition to the fertilisers in a year. Most of these chemicals are not registered in the lifecycle inventory used so it was assumed that they were a single common chemical and the total “Ag chemical” usage for the production of one m^2 of turf was calculated and used to determine the total environmental impacts.

The use of lime and other mineral soil additives is haphazard and in response to particular issues on the farm. Lime and dolomite are the most common additives used, but these are not added to the soil regularly by most growers. An average over the two years of the study was 0.092 kg per m^2 of turf produced.

Additional inputs come in the form of pallets and the netting used to stabilise the slabs or rolls of turf placed on them. The pallets are collected after installation and reused by the grower while netting wastes are assumed to be disposed to landfill through general waste bins at the point of installation. Each pallet holds about 80 to 100 m^2 of turf and is held by less than 10m^2 of netting (approx. 300g). Netting was a minor contribution of less than 1% of the material inputs (0.003 kg/m^2 of turf).

Transport and Installation

Typically a grower is involved in the marketing and delivery of product turf. Some growers are involved in installation and maintenance and others leave the whole marketing process to a third party.

Figure 7. A truck loaded with slabs of turf on pallets

Turf is palletised on the harvesting machine and dropped of at a storage location for truck loading and delivery.

Pallets are loaded and off-loaded from the truck using a forklift. Some were electric but most were either LPG or diesel forklifts.

Turf farms are scattered across the country positioned where irrigation water is available. The distance to market dictates the transport impacts in diesel fuel consumption. This was determined for 16 out of the 30 turf growing sites studied.

Transport to installation fuel use

Fuel	Mean consumption	Average consumption	
	Litre/m^2 produced	Litre/m^2 produced	
Diesel	0.088	0.096	
LPG	<0.001	<0.001	

Table 2. Fuel consumption in transport

The installation site is levelled either by mechanical or manual means, fertiliser pellets may be added to the site before the turf is installed or fertiliser can be added to the irrigation water.

In the case of sports fields drainage systems are in place and sand is laid over the substrate soil and levelled off. Manure or fertiliser is added prior to the turf installation.

Installation of the turf slabs or rolls is undertaken manually. The rolls are offloaded from the truck and set down by the installation from where they are rolled out or laid in position. When this has been accomplished the turf is watered in.

After installation the turf is watered in with an average daily application of 5mm of water for three weeks.

Input to installation	Quantity	Explanation
Top soil (sand) 150 mm	0.24 kg/m^2	Density assumed 1.6 kg/dm^3 -only applied for sports fields
Fertiliser	0.07 kg/m^2 total 0.05 kg N/m^2 0.06 kg P/m^2 0.006 kg K/m^2	Average usage rates from 5 installations studied of which two used no fertiliser
Water	0.047 m^3/m^2	Average of 5 installations studied watering in for three weeks in each case

Table 3. Inputs for turf installations

Maintenance of turf

The level of turf maintenance is dependent on the application. While recreational area turf or lawn provides a green and pleasant surface for human activities, sports field turf needs to function for the particular use(s) of the sports ground. Recreational turf surface smoothness and consistency is not critical for its use, so the maintenance activities are much reduced when compared to sports turf. For this reason we have split the lifecycle assessment into the two areas:

- Recreational turf and
- Sport turf.

Recreational turf maintenance

There is variation in recreational turf maintenance from just the occasional mowing to serious attempts to maintain the turf in a good condition. In most cases recreational turf is maintained with adequate fertilisation, weed management and watering followed by mowing at regular intervals during the growing period.

In our study of recreational turf maintenance examples of lawn at a tennis centre and lawn in a landscape for a new housing estate were examined. These sites were maintained appropriately and according to the industry regimes.

The activities and inputs expected are given in Table 4. These activities and inputs are expected for a well maintained turf lawn that may be the responsibility of a maintenance contractor. In many cases of domestic lawn maintenance the inputs will be less than is given and it is unlikely that the inputs will be greater.

Maintenance				**Recreational turf lawn**
Inputs	**per year**	**Expected**		**Comments**
Hand mowing	$MJ/m^2/y$	0.61		11.9 L of petrol per Ha (15 mows over the year – biweekly in Spring and monthly after 15 Dec)
Watering	$L/m^2/y$	50		Fortnightly watering to 5mm for 20 weeks per year
Fertilising	$kg/m^2/y$	0.024		4 kg All Purpose Fert per 500m2 = 0.008 kg/m^2 three times per year
Nitrogen	$kg/m^2/y$	0.0036		Nitrogen 15%
Phosphorus	$kg/m^2/y$	0.0012		Phosphorus 5%
Potassium	$kg/m^2/y$	0.0012		Potassium 5%
Mineral additives	$kg/m^2/y$	0.015		Assume ag lime or similar product addition at 150 kg/Ha (0.015 kg/m^2)
Ag chemicals	$kg/m^2/y$	0.00015		Weedicides at 150 g/Ha

Table 4. Inputs for recreational turf maintenance

Sports field maintenance

Sports fields require a clean cover of turf laid on top of a sand base to provide an even playing surface with sufficient resilience and consistency. The higher standard of surface requires an increased attention to the health of the turf and hence more inputs than for recreational turf

Maintenance activity	Sports fields			Data from maintenance schedule of a sports field
	per year			
Mowing fuel consumption	$L/m^2/y$	0.0128		Mowing 2x per week over growing season (32) at $0.4ml/m^2$/mow (diesel fuel)
Rolling, aerating	$L/m^2/y$	0.0064		Once per week equivalent energy use of mowing (diesel fuel)
Watering	$L/m^2/y$	140		23,300 L/Ha/day for 20 weeks over the growing period
Fertiliser	$kg/m^2/y$	0.50		Regular fortnightly fertilisation at 48 kg/Ha of 15:3:15 plus one off additions.
Nitrogen	$kg/m^2/y$	0.052		NPK 5-5-5 added
Phosphorus	$kg/m^2/y$	0.014		Super phosphate added
Potassium	$kg/m^2/y$	0.056		Granular slow release granular fertiliser
Mineral additives	$kg/m^2/y$	0.082		Gypsum, kieserite, trace elements
Ag chemicals	$kg/m^2/y$	0.00019		Weedicide, pesticides, fungicides, preventative herbicides

Table 5. Inputs for sports field turf maintenance

Assumptions

The LCA inputs rely on the use of industry mean data being representative of a particular case of growing conditions cultivar use and installation geography and climate conditions. The variations in growing conditions can be allowed for with particular data for growing conditions. The installation location of the turf is not known and may vary significantly.

It has been the intent of this study to be conservative in estimation of material and energy use across the lifecycle of turf, so that the environmental impacts provided are also conservative and reflect the potential for all significant material inputs.

The boundary conditions have excluded the impacts associated with infrastructure on the turf farm including the plant and equipment used. This avoids allocation issues as the farm and plant may well be used for functions other than turf growing. Farm infrastructure is likely to have a lifespan of 20–50 years or more and, other than land use, the impact associated with it is assumed to be minor.

Agricultural chemical use has been aggregated into the one of two categories: ag chemicals and mineral additives. The latter is likely to be a soil additive to correct for soil inadequacies such as pH or cation exchange capacity. Ag chemicals are many and varied and most of these have not been characterised in inventories so the impacts associated with their manufacture, transport and marketing have been consolidated into the few that have been characterised in the inventories used as a single chemical product.

Herbicides are the most common ag chemical applied to turf. These are synthetic chemicals generated from petrochemicals, one of the most common of these is MCPA (2-methyl-4-chlorophenoxyacetic acid), another is Simazine a triazine derivative. Nicotinoids are commonly used as pesticides on turf but the application rate is significantly lower than with herbicides.

Mineral additives are used in certain circumstances at a much greater application rate to improve the characteristics of the soils. Common minerals used are lime, dolomite and clay. As the use of minerals is sporadic the total minerals consumption was determined across the 30 growers studied and an average figure used.

	Total additions kg	Total additions / Total m^2 kg / m^2
Ag chemicals (n=17)	10,940	0.0012
Mineral additions (n=20)	329,324	0.071

Table 6. Other chemical additions

The fate of fertiliser additions is of concern as these present as nutrients for eutrophication of particular water bodies. Studies of installations for sports fields and grower sites in this project has given a figure of an average loss of nitrogen of 60% of the total amount of N applied. 40% of the N applied is taken up and incorporated into the turf plant while the remaining 60% is lost to the system predominantly by water movement to drains or groundwater bodies. Individual circumstances vary such as sandy sites, where the loss of water is rapid through the soil structure and clay based sites, where an effective barrier holds the water in the soil and the predominant mechanism is run-off to surface water bodies.

Phosphorus losses were also measured in this study as the difference between the applied amount and that taken up by the turf plants.

In either case the potential for eutrophication of the water body is similar and dependent on the nitrogen or phosphorus losses. These were measured at 59% loss of applied N and an 86% loss of applied P. In each stage of the turf lifecycle the applied N and P are assumed to be taken up and lost in these proportions (It could be argued that there are other loss mechanisms for nitrogen and that nitrogen can also be taken up by soil organisms.) Similarly phosphorus can be held up in the soil by biological and chemical adsorption mechanisms. As such this analysis presents a worst case scenario for eutrophication potential.

Outputs

Outputs come in the form of products and wastes. The product is turf: a mixture of the turf plant and topsoil from the growing stage and continuing production of turf, which also promotes the growth of organic matter in the soil. This organic matter consists of 50% carbon per unit of dry weight that accounts for further continuing absorption of CO^2 from the atmosphere. This absorption or carbon sequestration has been studied by a number of researchers from which an average rate of absorption of 0.096 kg C/m^2/y is used in this analysis to calculate the lifecycle Climate Change impact of -0.35 kg CO_2/m^2/y.

Literature source	Year	Ave Carbon Sequestration as soil organic matter kg Carbon/m^2/y	Sequestered kg CO2/m2/y
Bruce et.al. (J.Soil Water Conserv. 1999,54,PP382-390)	1999	0.06	0.22
Qian & Follett (Agronomy J. 2002, 94, PP930-935)	2002	0.09-0.1	0.35
Townsend-Small & Czimczik (Geophys Res. Lett. 2010, 37, L02707 PP1-5)	2010	0.14	0.51
Qian, Follet & Kimble (SSSAJ 2010, 74, PP366-371)	2010	0.032-0.078	0.20
Zirkle, Lal & Augustin (Hort. Sci. 2011, 46,5,PP808-814)	2011	0.05 -0.20	0.46
Average for turf urban			0.35

Table 7. Carbon sequestration measurements in turf soils

This organic matter build-up in recreational turf installations does not necessarily apply to sports turf applications, where the fields are turned over regularly and reconstituted. Some authors saw no organic carbon build-up in these soils.

Allocation rules

In cases where an input or an output can be used in other products there is an allocation required for the associated impacts between the different product lifecycles. With turf there is little allocation dilemma, as the inputs are directed solely for the production of turf as no significant by-products exist.

Any allocation issue was addressed through system expansion to include the alternative material uses within the system boundaries.

This approach is consistent with the ISO LCA standards.

Lifecycle inventory analysis outline

The lifecycle inventory analysis (LCI) involves the collation of all inputs and outputs associated with each of the modelled treatment pathways. Inputs and outputs that are included are the consumption of raw materials, energy and water and the environmental discharges to air, water and land.

The result of the analysis is an inventory of inputs and outputs for each lifecycle stage and aggregated across the full life cycle. The completion of the development of the inventory then leads into the life cycle impact assessment phase.

Lifecycle impact assessment

The lifecycle impact assessment (LCIA) phase of an LCA evaluates the environmental impacts associated with the inventory data, providing comparison of the different environmental impacts, which then provides information for the interpretation phase.

The LCIA phase is particularly important, and it is a requirement under ISO 14040:2006 to provide details on it in the scoping phase.

Methodology

The objective of the LCIA phase of this study is to provide comparative analysis around the environmental impacts resulting from the inventory results for each of the modelled material movement pathways. The aim is to provide comparison of the different environmental impacts for each stage and the overall lifecycle of turf.

The LCIA assigns the results of the inventory analysis to different impact categories. Impact categories represent the primary environmental issues of concern to which the life cycle inventory results can be assigned.

Impact categories selection

Selection of appropriate impact categories is an important step in an LCA, and should be selected to cover key environmental issues for the system under investigation.

Localised impacts such as dusts, noise and odour have been discounted in this study as they cannot be adequately accounted for in an industry wide study. In some cases these impacts may well be important.

The major impacts associated with energy inputs directly into the activities studied and indirectly through material inputs are given in table 8.

Environmental impact	Applicability to turf	Environmental significance	Risk to grower	Risk to environment	Included in LCA
Local air pollution	Unlikely	No		Unlikely	No
Energy resource use	Yes	Yes			Yes
Ozone depletion	Yes	Yes		Yes	Yes
Greenhouse emissions	Yes	No		Yes	Yes
Dust emissions	Unlikely	No	Yes	Unlikely	No
Odour emissions	Possible	Possible	Yes	Possible	No
Water resource use	Yes	Yes	Yes	Yes	Yes
Surface water pollution - ecotoxicity	Yes	Yes	Yes	Yes	Yes
Surface water eutrophication	Yes	Possible	Yes	Yes	Yes
Acidification	Yes	Yes		Yes	Yes
Ground water loss	Possible	Possible	Yes	Yes	No
Ground water pollution	Possible	Possible	Yes	Yes	No
Soil loss / erosion	Possible	Possible	Yes	Yes	No
Soil contamination	Possible	Yes	Yes	Yes	No
Land use / Biodiversity loss	Possible (Greenfield sites)	No		Yes	Yes
Land contamination	Possible	Yes		Yes	No
Noise pollution	Unlikely	No	Yes		No
Biodiversity	No	No		Yes	No
Human health impact	Possible	No			Yes

Table 8. Environmental impacts selection

While the environmental impacts of some risks to the environment may be present, it may not be possible to quantify these impacts for the turf industry in general. The impacts in some cases are particular to a micro-location and it is not possible to generalise particular impacts across the Australian turf industry.

The impacts that have been excluded based on this criterion are:

- Dusts
- Odour
- Groundwater pollution
- Soil/land contamination
- Noise

The other impacts have been examined in the LCA through mid-point analysis as described in Table 9.

Modelling software

The LCA modelling software used for this project was Open LCA, supplemented by the use of MS Excel as required. The LCA software was run in a series of modules covering: Greenhouse Gases, Ozone Layer depletion, human and ecotoxicity, water and air pollution impacts and resource depletion.

Inventory data was derived from the Australian AustLCI database and the EcoInvent database. Primary data was provided through this study and literature on the environmental impacts of turf.

Classification

The individual outputs of the processes studied are quantified and classified according to their environmental impacts. This is a function of the lifecycle inventory assessment system and is refined in the model development.

Characterisation models

Characterisation involves the calculation of impact category indicator results. This includes the conversion of LCI results to common units (often using characterisation / conversion factors) and the summation of the converted results to provide the numerical impact category indicator result.

LCI substances that contribute to an impact category are multiplied with a characterisation factor that expresses the relative contribution of the substance. For example, the characterisation factor for CO_2 in the impact category 'climate change' is equal to 1, while the characterisation factor of methane is 31 (across a timeframe of 100 years) and 85 (across a timeframe of 20 years). This means the release of 1 kg methane causes the same amount of climate change as 31 kg CO_2 when measured across a 100 year period.

As with classification, the characterisation factors incorporated into the listed characterisation models have not been modified from their published forms.

The chosen environmental impact categories have the following units and measurement systems.

Environmental Impact category	**Units**	**Explanation** (M.A., 2018)
Land use	m^2	Land area used for production of one square meter of turf. There is no change of land use as turf is produced on the same area of land continuously
Climate Change (Global Warming Potential)	kg ($CO_{2\text{-}eq}$)	This is a measure of the equivalent amount of carbon dioxide released into the atmosphere over a 100 year time period. A negative value indicates that there is a net loss of carbon dioxide in the atmosphere.
Ozone depletion	kg ($CFC\text{-}11_{eq}$)	Ozone depletion potential is measured as the equivalent amount of refrigerant CFC-11 emitted
Water consumption	m^3 (H_2O_{eq})	This is the amount of water consumed multiplied by the Water Stress Index averaged over Australia (WSI = 0.5)
Eutrophication	kg (PO_{4eq})	Eutrophication is taken as the sum of the nitrogen and phosphorus lost through run-off from the turf farm and installation that impinges on surface water systems. This is measured in phosphate equivalents
Acidification	kg (SO_{2eq})	Simply the acidification potential associated with turf from emissions to land water and air of acidic chemicals express as sulphur dioxide equivalents
Photochemical Ozone formation	kg $C_2H_{4\ eq}$	Predominantly air emissions with photochemical oxidation potential that can convert oxygen to ozone in the troposphere measured as ethylene equivalents
Aquatic Ecotoxicity	P.A.F.m^3.day	Potential Affected Fraction (of the ecosystem) for one cubic meter of water for one day
Toxicity Chronic (cancer) Acute (non-cancer)	cases	Toxicity to human health and the environment measured using USEtox methods for acute and chronic toxicity. This is measured simply as the number of cases potentially caused by the outputs
Resource depletion Abiotic depletion (minerals)	kg Sb_{eq}	Total mineral stock abiotic depletion allowing for current reserves and the rate of de-accumulation expressed as kg of antimony.
Resource depletion / Energy use	MJ	Fossil fuel abiotic use expressed as megajoules.

Table 9. Mid-Point Environmental Impacts and measures

Lifecycle Assessment Results

The lifecycle impact assessment split into the impact categories chosen was calculated under three scenarios for two product pathways:

1. A turf lifecycle of one year
2. A turf lifecycle of five years
3. A turf lifecycle of ten years

for recreational turf (lawn/parkland lawn) and sports turf.

In these scenarios the impacts associated with growing, transporting, installing and maintaining the turf are totalled and then calculated on an annual or per year basis. Consequently the impacts of growing, transporting and installing the turf are amortised over the full lifecycle chosen.

The outputs of the analysis are split between the four stages of the lifecycle for the three scenarios.

Recreational Turf LCA outputs

Impacts per m2 of finished turf product per year amortised over the lifecycle.

The impact numbers can be small and require scientific notation[3] to display them.

		1 year scenario					5 year scenario					10 year scenario				
Turf lifecycle stage	Units	Growing	Transport	Installation	Maintenance	**Total /Y**	Growing	Transport	Installation	Maintenance	**Total /Y**	Growing	Transport	Installation	Maintenance	**Total /Y**
Global warming potential	kg CO2eq	-1.0432	0.2802	0.09985	-0.24189	**-0.90504**	-0.20864	0.05604	0.01997	-0.24189	**-0.37451**	-0.10432	0.02802	0.009985	-0.24189	**-0.30821**
Ozone depletion potential	kg CFC11eq	6.65E-08	3.3778E-08	2.5297E-09	7.3906E-09	**1.1E-07**	1.33E-08	6.76E-09	5.06E-10	7.39E-09	**2.79E-08**	6.65E-09	3.38E-09	2.53E-10	7.39E-09	**1.77E-08**
Acidification potential	kg SO2eq	0.00275	0.00045922	0.00045082	0.00022	**0.00388**	0.00055	9.18E-05	9.02E-05	0.00022	**0.00095**	0.000275	4.59E-05	4.51E-05	0.00022	**0.000586**
Eutrophication potential	kg PO4 eq	0.04395	4.7931E-05	0.0000734	0.00226	**0.046331**	0.00879	9.59E-06	1.47E-05	0.00226	**0.01108**	0.004395	4.79E-06	7.34E-06	0.00226	**0.006667**
Photochemical ozone	kg C2H4eq	0.000114	2.6258E-05	1.7089E-05	1.0445E-05	**0.000168**	2.27E-05	5.25E-06	3.42E-06	1.04E-05	**4.19E-05**	1.14E-05	2.63E-06	1.71E-06	1.04E-05	**2.62E-05**
Resource Use																
Abiotic depletion of resources	kg Sbeq	2.75E-05	5.45E-07	7.11E-06	1.85E-06	**3.70E-05**	5.49E-06	1.09E-07	1.42E-06	1.85E-06	**8.87E-06**	2.75E-06	5.45E-08	7.11E-07	1.85E-06	**5.36E-06**
Water use	m3	5.39E-01		2.35E-02	5.00E-02	**6.13E-01**	0.1078		0.0047	0.05	**0.1625**	0.0539		0.00235	0.05	**0.10625**
Land use	m2	1.67E+00		1.00E+00		**2.67E+00**	0.334		0.2		**0.534**	0.167		0.1		**0.267**
Energy use	MJ	9.05E+00	4.60E+00	4.70E-01	1.27E+00	**1.54E+01**	1.81	0.92	0.094	1.27	**4.094**	0.905	0.46	0.047	1.27	**2.047**
Toxicity																
Fresh water toxicity	PAF.m3.day	7.50E-03	3.78E-04	1.69E-04	6.10E-04	**8.66E-03**	0.0015	7.57E-05	3.37E-05	0.00061	**0.00222**	0.00075	3.78E-05	1.69E-05	0.00061	**0.001415**
Human toxicity (cancer)	cases	2.48E-11	9.93E-13	4.14E-12	1.94E-12	**3.19E-11**	4.96E-12	1.99E-13	8.27E-13	1.94E-12	**7.93E-12**	2.48E-12	9.93E-14	4.14E-13	1.94E-12	**4.93E-12**
Human toxicity (non-cancer)	cases	1.29E-11	1.12E-12	5.78E-13	1.17E-12	**1.58E-11**	2.59E-12	2.24E-13	1.16E-13	1.17E-12	**4.10E-12**	1.29E-12	1.12E-13	5.78E-14	1.17E-12	**2.64E-12**

The 5 and 10 year lifespan scenarios generally show lower numerical impacts because the growing, transport and installation stage impacts are spread over the life of the turf. The exception is Global warming potential, which spreads the carbon dioxide absorption in growing over the lifespan of the turf, consequently dilutingit.

[3] Scientific notation provides a number as a decimal digit multiplied by a factor of 10 as such: 1.25E-6. This is the number $1.26/10^6$ (or 1.26 divided by one million) or 0.00000126.

Sports Turf LCA Outputs

Impacts per m2 of finished turf product per year amortised over the lifecycle.

		1 year scenario					5 year scenario					10 year scenario				
Turf lifecycle stage	Units	Growing	Transport	Installation	Maintenance	**Total /Y**	Growing	Transport	Installation	Maintenance	**Total /Y**	Growing	Transport	Installation	Maintenance	**Total /Y**
Global warming potential	kg CO2eq	-1.0432	0.2802	0.1017	0.65182	**-0.00948**	-0.20864	0.05604	0.02034	0.65182	**0.51956**	-0.10432	0.02802	0.01017	0.65182	**0.58569**
Ozone depletion potential	kg CFC11eq	6.6474E-08	3.38E-08	7.42E-05	2.56E-08	**7.44E-05**	1.33E-08	6.76E-09	1.48E-05	2.56E-08	**1.49E-05**	6.65E-09	3.38E-09	7.42E-06	2.56E-08	**7.46E-06**
Acidification potential	kg SO2eq	0.00275	4.59E-04	4.55E-04	0.00259	**0.006254**	0.00055	9.1844E-05	9.0984E-05	0.00259	**0.003322**	0.000275	4.59E-05	4.55E-05	0.00259	**0.002956**
Eutrophication potential	kg PO4 eq	0.04395	4.7931E-05	0.0000734	0.00226	**0.046331**	0.00879	9.59E-06	1.47E-05	0.00226	**0.01108**	0.004395	4.79E-06	7.34E-06	0.00226	**0.006667**
Photochemical ozone	kg C2H4eq	0.00011373	2.63E-05	1.72E-05	9.83E-05	**0.000255**	2.27E-05	5.25E-06	3.44E-06	9.83E-05	**1.30E-04**	1.14E-05	2.63E-06	1.72E-06	9.83E-05	**0.000114**
Abiotic depletion of resources	kg Sbeq	2.75E-05	5.45E-07	7.16E-06	2.63E-05	**6.15E-05**	5.49E-06	1.09E-07	1.43E-06	2.63E-05	**3.34E-05**	2.75E-06	5.45E-08	7.16E-07	2.63E-05	**2.98E-05**
Water use	m3	5.39E-01		2.35E-02	7.00E-02	**6.33E-01**	0.1078		0.0047	0.07	**0.1825**	0.0539		0.00235	0.07	**0.12625**
Land use	m2	1.67E+00		1.00E+00		**2.67E+00**	0.334		0.2		**0.534**	0.167		0.1		**0.267**
Energy use	MJ	9.05E+00	4.60E+00	4.70E-01	4.76E+00	**1.89E+01**	1.81	0.92	0.094	4.76	**7.584**	0.905	0.46	0.047	4.76	**3.792**
Fresh water toxicity	PAF.m3.day	7.50E-03	3.78E-04	1.69E-04	1.28E-03	**9.33E-03**	0.0015	7.57E-05	3.39E-05	0.00128	**0.00289**	0.00075	3.78E-05	1.69E-05	0.00128	**0.002085**
Human toxicity (cancer)	cases	2.48E-11	9.93E-13	4.16E-12	2.78E-11	**5.77E-11**	4.96E-12	1.99E-13	8.32E-13	2.78E-11	**3.38E-11**	2.48E-12	9.93E-14	4.16E-13	2.78E-11	**3.08E-11**
Human toxicity (non-cancer)	cases	1.29E-11	1.12E-12	5.94E-13	3.31E-12	**1.80E-11**	2.59E-12	2.24E-13	1.19E-13	3.31E-12	**6.24E-12**	1.29E-12	1.12E-13	5.94E-14	3.31E-12	**4.78E-12**

Sports turf impacts are generally greater as more materials and energy are used for the installation and maintenance stages. The carbon footprint of sports turf actually becomes positive due to a lack of organic carbon build-up in the soil structure.

Recreational turf impacts are dominated by the Global Warming Potential in numerical terms. The majority of the negative carbon footprint in the one year scenario is the sequestration of CO2 by the plant. In turf maintenance this sequestration is still through photosynthesis but it is stored in the soil carbon.

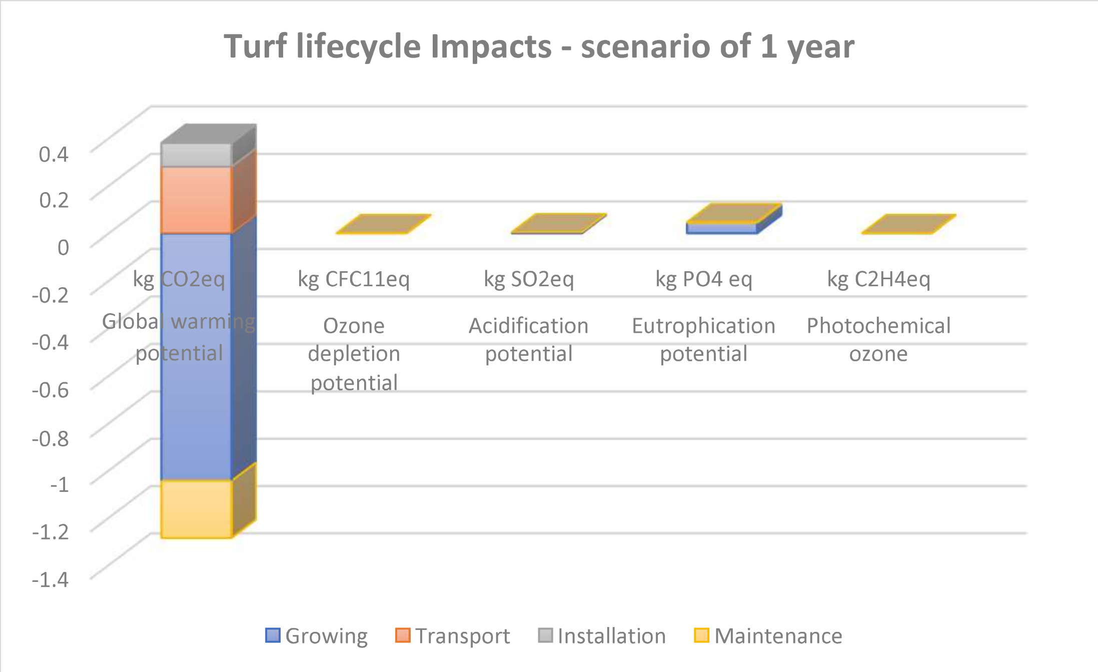

Figure 8. Recreational turf impacts

Eutrophication potential from fertiliser losses to water systems is the other impact that features here and is a cause for concern both from an environmental degradation viewpoint and an economic aspect to the turf farmer or the lawn owner.

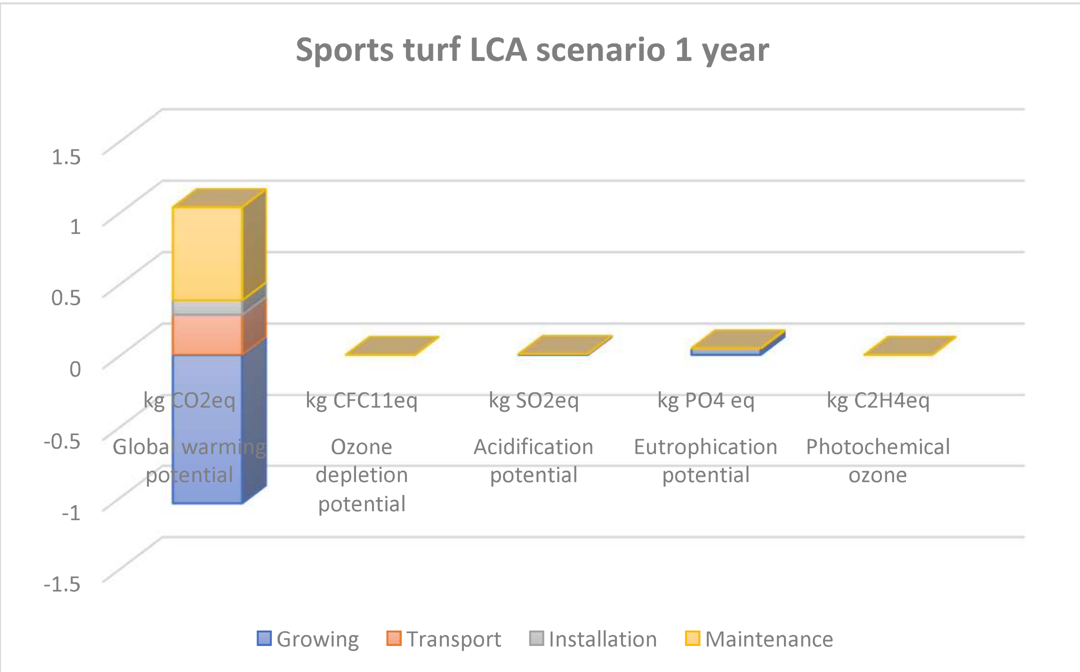

Figure 9. Sports turf impacts

Sports turf indicates a similar picture to recreational turf except that the Global Warming Potential for maintenance is positive rather than negative, due to the loss of the growth in soil carbon plus the higher energy and chemical use.

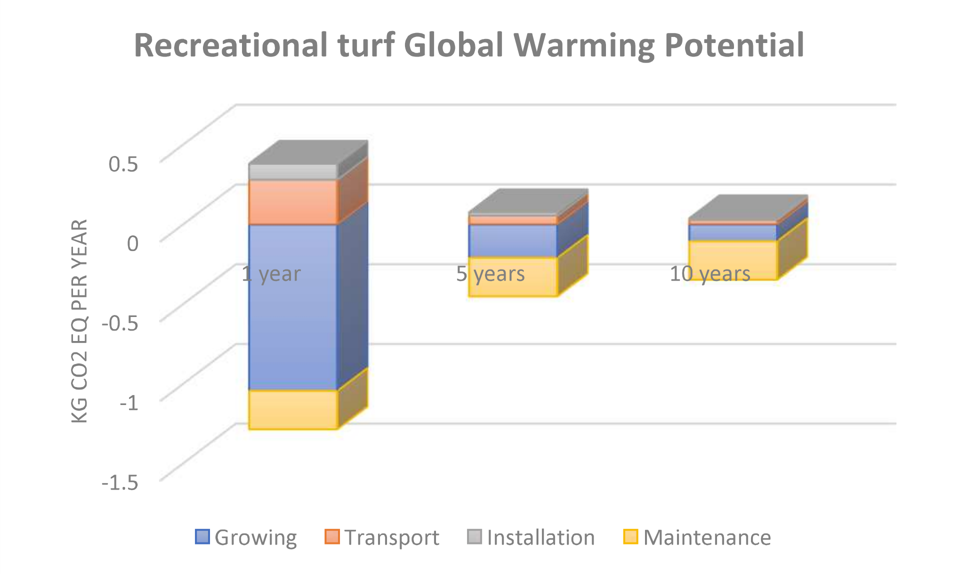

Figure 10. Recreational turf scenarios for global warming potential

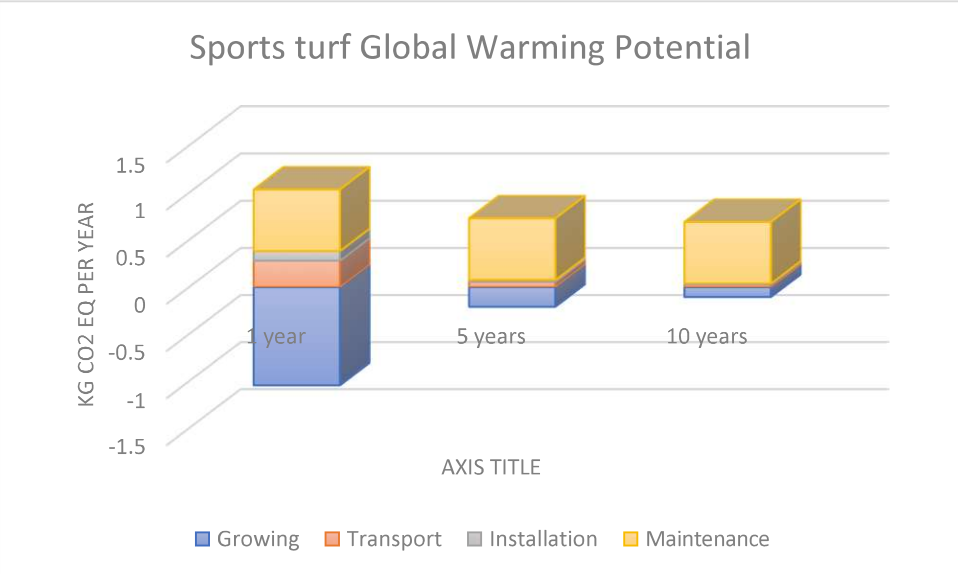

Figure 11. Sports turf scenarios for global warming potential

Sports turf does not provide a net benefit in negative carbon footprint after the first year of turf lifespan. In ten years the maintenance impacts predominate the full array of environmental impacts (not just global warming potential).

On the other hand recreational turf continues to sequester carbon through its lifespan and this impact outweighs the CO_2 emissions, due energy and fertiliser/chemical applications in this analysis. The interpretation here varies from other studies in which the energy use in park maintenance was calculated to outweigh the build-up of soil carbon. In the study in question (Czimczik, 2010) energy from council uses other than lawn maintenance appeared to be included.

Resource consumption

Resource usage was measured by examination of the materials purchased, water consumption metered, land employed for growing and installation and energy bills. The energy embodied in materials such as fertilisers was included in calculations.

Resource use	Units $/m^2/y$	1 year	5 years	10 years
Abiotic depletion of resources (minerals)	kg Sb_{eq}	3.70E-05	8.87E-06	5.36E-06
Water use	m^3	6.13E-01	0.1625	0.10625
Land use	m^2	2.67E+00	0.534	0.267
Energy use	MJ	1.54E+01	4.094	2.047

Table 10. Resource use scenarios for recreational turf

Mineral resource depletion is minor compared to the consumption of water at 613 litre per m^2 of turf in the first year. Energy consumption at 15.4 MJ in the first year is significant and sets a measure for process improvement.

Toxicity

Toxicity is calculated from material usage from the LCI (inventory data). Toxicity is due to the nature of the chemicals used and lost to the environment in air emissions, water pollution and to land. The toxicity in air emissions from burning fossil fuels for energy is included with the direct toxicity of chemicals used on the turf that are lost to the environment.

Toxicity	Units /m2/y	1 year	5 years	10 years
Fresh water toxicity	PAF.m3.day	8.66E-03	2.22E-3	1.42E-3
Human toxicity (cancer)	cases	3.19E-11	7.93E-12	4.93E-12
Human toxicity (non-cancer)	cases	1.58E-11	4.10E-12	2.64E-12

Table 11. Toxicity scenarios for recreational turf

The effect of turf on water ecotoxicity is significant while the human toxicity factors are more minor.

Lifecycle interpretation

The life cycle interpretation phase of the study is intended to analyse results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the study, and to report the results of the life cycle interpretation in a transparent manner (AS/NZS ISO 14044:2006).

The results of the LCA are generally conservative and err on the side of general industry performance rather than best practice. Nevertheless there is a wide range of variation in industry practice and environmental conditions that require this conservatism for the industry to be confident in putting forward this data.

Conclusions

Turf is a product that has the potential to provide a negative carbon footprint due to the sequestration of carbon dioxide from the atmosphere and also the build-up of carbon in the soils over many years of turf cover (G Zirkle, 2011). Turf growing exhibits a negative global warming potential calculated at 1.0 kg CO_2eq per m^2 of turf at the median grower performance. The net global warming potential per year in a 10 year scenario is 0.31 kg CO_2eq per m^2 of turf, or a total of 3.1kg CO_2eq per m^2 of turf over 10 years.

Resource depletion caused by material and energy use over the lifespan of turf is significant, particularly water use and energy consumption. This study sets a performance that can be used as a benchmark for industry improvement.

Ecotoxicity generated by the discharge of chemicals into waterways in particular and eutrophication of waterways from excess fertilisers is a concern that can be monitored by individual growers and lawn owners with the aim of impact reduction.

Identification of significant issues

While the study has been conservative in its claims there is a variation that is significant and can impact the confidence of claims made by individual growers.

Losses of fertiliser nitrogen as nitrate did not show build-up or losses of nitrate to the lower levels of the soil profile. This was unexpected and unexplained as the nitrogen loss to the soil and water systems was determined to be 60% at the mean grower performance.

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