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QUANTITATIVE STUDY ON GHG EMISSIONS AND THE GWP INFLUENCE OF CEMETERY GREEN SPACE MAINTENANCE BASED ON LCA

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Highlights

- Reducing the application of maintenance materials such as pesticides, fossil energy, and irrigation water will efficiently reduce the GHG (Greenhouse gases) emissions in the maintenance cemetery green space.
- Establishing meadows to replace grasslands in dense cemetery facility areas can efficiently reduce the maintenance GWP (Global warming potential) impact of cemetery green spaces.
- In urban areas, the GWP influence of cemetery green space maintenance is relatively higher than that of the average of an urban public green space.
- Natural cemeteries have a lower GWP impact and contribute more ecological benefits than traditional cemeteries in considering the green space maintenance.

Abstract. Cemetery landscapes are austere and generally require maintenance. The materials and equipment used for maintenance emit greenhouse gases (GHGs). This research aimed to quantify the annual GHG emissions and global warming potential (GWP) indices of traditional and natural cemeteries for more environmentally friendly green and grey facility planning of cemetery areas. Based on life cycle assessment (LCA), in Yorkshire, UK, as an example, traditional cemeteries were found to be mostly established with landscaped cemetery facilities, and natural cemeteries were found to include mostly underground burials covered with wild plants. The average GHG emissions per hm^2 in traditional cemetery maintenance (1,552.88 kg/CO_2-e) were 1.8 times those in natural cemeteries (870.88 kg/CO_2-e). In the cemetery plant community, the mean GHG emissions for grassland maintenance (1,867.65 kg/CO_2-e) were 6.7, 2.8 and 2.3 times higher than the woodland, meadow and shrub maintenance values of 280.77, 673.03 and 821.00 kg/CO_2-e, respectively. The mean GWP indexes for traditional and natural cemetery green space maintenance were 0.027 and 0.015, respectively, which were generally higher than those for urban green space maintenance (0.010). This research recommends replacing grasslands with wild meadows, reducing the size of ground cemetery facilities and limiting the application of maintenance materials (i.e., irrigation water and pesticides) to reduce the environmental impact of green space in cemeteries.

Keywords: cemetery green space, global warming potential, greenhouse gas emissions, life cycle assessment, management and maintenance, plant community.

Introduction

As the world's population continues to grow, the area of cemeteries has continued to expand. In recent decades, some major countries with high population densities — such as China, the United States and Japan — have all advocated for cremation to efficiently use cemeteries and reduce the rate of cemetery expansion (Kato, 2001; Sloane, 2002). However, in most European countries, traditional ground burial remains the common funeral method (Colombo, 2016; Oestigaard, 1999; Rotar, 2011). Cemetery green space is a common type of green space in urban and rural residential areas in Europe. It is a comprehensive

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place that integrates functions such as memorial services, rest areas and biological habitats (Rugg, 2013b). To maintain the landscape effect of cemetery green space, long-term management and maintenance are required, including pruning/mowing, plant waste removal, irrigation, and pest control (Clayden et al., 2017; Hitchmough, 2008).

Rapid population growth after the industrial revolution led to increasing burial pressure in the United Kingdom before it was felt in the rest of the world (Philo, 2012). Cemeteries operated by private companies appeared in England for the first time in the 1820s, mainly in large cities. For example, the Chorlton Row Cemetery opened in Manchester in 1821, and the Low Hill Cemetery was built in Liverpool in 1825 (Darlington Historical Society, 2022). Since 1850, following the promulgation of the British Metropolitan Burial Act and other series of funeral laws, town councils have been granted autonomy over cemetery land establishment (Historic England, 2022). In the subsequent half century, public cemeteries arose in large numbers in urban and rural areas, and they are now widely called "traditional cemeteries" (Commission for Architecture and the Built Environment, 2007). The experience of British cemeteries in landscape patterns and funeral legislation provides a reference for the massive construction of public cemeteries worldwide since the 20th century (Beebeejaun et al., 2021; Clayden et al., 2014). Internal facilities in traditional cemeteries are regularly arranged, roads are staggered, and plants are neatly trimmed (Rugg, 2013a; Rugg et al., 2014). Natural cemeteries were established after 1990 and are divided into four categories: woodland, grassland, meadow and mixed burial grounds. The plant community of natural cemeteries exhibits high biodiversity, and the boundary of their burial facilities can be integrated with the external environment within 5–10 years (Clayden et al., 2014; Ministry of Justice, 2009). Recently, more than 20,000 public cemeteries with an overall burial land area of 2,400 hm^2 have been opened for service in England and Wales, which occupy a size of approximately 25% (Ministry of Justice, 2007; Secretary of State, 2001).

The maintenance of green space can directly cause energy consumption and greenhouse gas (GHG) emissions and lead to global warming potential (GWP) impacts. Green space maintenance relies on repeated plant trimming, mowing and waste removal, which requires fossil energy and releases GHG emissions, mainly as carbon dioxide (CO_2) (Tidåker et al., 2017). Additional plant maintenance practices, such as irrigation and pesticides, all have associated environmental impacts, such as N_2O leaching and CH_4 volatilisation (Gu et al., 2015; Li et al., 2013). Emissions of CO_2, N_2O and CH_4 are particularly worrisome since they are potent GHGs with high GWP impacts. The GWP of a certain gas is a measure of how much heat is trapped in the atmosphere relative to the amount of heat trapped by CO_2 over a specific time interval (The Intergovernmental Panel on Climate Change, 2007). GWP is used for a variety of different GHG indicators to obtain the total GWP for an entire system.

Energy consumption and GHG emissions are not only associated with the maintenance tasks performed on green spaces but are also indirect environmental burdens related to the production of purchased inputs, such as mineral fertilizers, fuel, machinery and transportation. A life cycle assessment (LCA) is a comprehensive methodology for studying the impact of human behaviour on the environment. Through the establishment of a life cycle inventory (LCI), an LCA analyses the environmental influence of a product or behaviour from production or occurrence to its retirement or end (Wang et al., 2016; Yang & Wang, 1998). Carbon foot-printing, a subset of a full LCA including only the GHG emissions caused by a product or a service during its life cycle and summarised as CO_2 equivalents, is attracting increasing interest in the context of GWP impact (Röös, 2013).

LCAs are widely used to evaluate the environmental impact of a product or production system and is considered an effective approach for defining and quantifying energy consumption and GHG emissions. Ingram (2012) used an LCA to study the carbon footprint components of red maple forests in the *US*. The system boundary included carbon sequestration and GHG emissions in the management of each plant across the 60-year life cycle (kg/CO_2-eq). The results showed that the GHG emissions from management were 113.47 kg, which accounted for approximately 13% of the plant carbon sequestration of 901 kg. Cao et al. (2014) mentioned that the annual GHG emissions for the rice production system were 11,810 kg/CO_2-e/hm^2 (1,232 kg/CO_2-e/t^{-1}) in agricultural fields in *Shanghai (China)*. Fertilisation emitted 204 kg/CO_2-e for each ton of rice produced, contributing 16.5% of the total maintenance GHG and acting as the major carbon contributor in rice production. Haas et al. (2001), in an LCA study of the carbon emissions of 18 pasture management practices in *Allgau (Germany)*, concluded that GHG emissions from fertilisation accounted for 57% of the total GHG released. GHG emissions produced through green space maintenance negatively impact the environment and are one of the main factors aggravating the GWP (Li, 2010). The territorially estimated GHG emissions from the maintenance of green space in the UK in 2019 were 5.9×10^6 t/CO_2-e, which accounted for 57% and 13% of industrial (10.4×10^6 t/CO_2-e) and agricultural production (46.3×10^6 t/CO_2-e), respectively (Waite, 2021). As a specific type of green space, cemetery green space has a high expansion rate and a high maintenance demand, and the estimated UK national annual GHG emissions in traditional and natural cemeteries are 1,560 and 900 kg/CO_2-e/hm^2, respectively, which are 5.2 and 2.9 times, respectively, that of the green space maintenance of 302 kg/CO_2-e/hm^2 (Brown et al., 2016). To better understand the environmental impact intensity of cemetery green space maintenance, this paper applies the LCA method to comparatively analyse the GHG emissions and GWP effects of the maintenance of traditional and natural cemetery green spaces in Yorkshire, England.

1. Materials and methods

1.1. Study sites

The study area of Yorkshire, UK has a temperate maritime climate with an average annual temperature of 13.2 °C and an average annual rainfall of 670 mm (Met Office, 2018). The first public cemetery and the largest natural burial ground in British history are located here. In this paper, the three largest traditional and natural cemetery green spaces in this area were selected as sample plots (Figure 1). Sample plots T1-T3 are traditional cemetery green spaces, all located in or around Sheffield: the City Road (T1), Burngreave (T2), and Shiregreen cemeteries (T3). Sample plots N1-N3 are natural cemetery green spaces, namely, the South Yorkshire woodland burial ground (N1), located on a farm in Ullry village between Sheffield and Rotherham (Peace Funerals, 2018); Brocklands natural burial ground (N2), located in Rathmell village, North Yorkshire, approximately 5 km south of Settle; and Golden Valley natural burial ground (N3), located in the Golden Valley, northwest of Nottingham, belonging to the Golden Valley National Park (Figure 2; Peace Funerals, 2018).

Area data of the plant community structure in the various plots were calculated using the facility layering tool in Digimap (Figure 3). The results are listed in Table 1.

1.2. LCI of maintenance supplies

Maintenance tasks in green spaces have the characteristics of annual repetition (Lindholst, 2008). The maintenance life cycle is defined as an annual process. The maintenance system includes the upstream, maintenance and recycling phases (Figure 4). The upstream phase consists of maintenance material production and transportation. In the maintenance phase, according to the difference in the maintenance tasks, the structure of the plant community can be divided into four layers: woodland, shrub, ground cover, and grassland. The recycling phase starts with plant waste being loaded into a site vehicle and then transferred out of the cemetery and combined onto a waste truck/van. Subsequently, the recycling phase ends when the plant waste is transferred to the recycling station (an average distance of 4 km). Simultaneously, the entire cemetery green space maintenance system is completed. The life

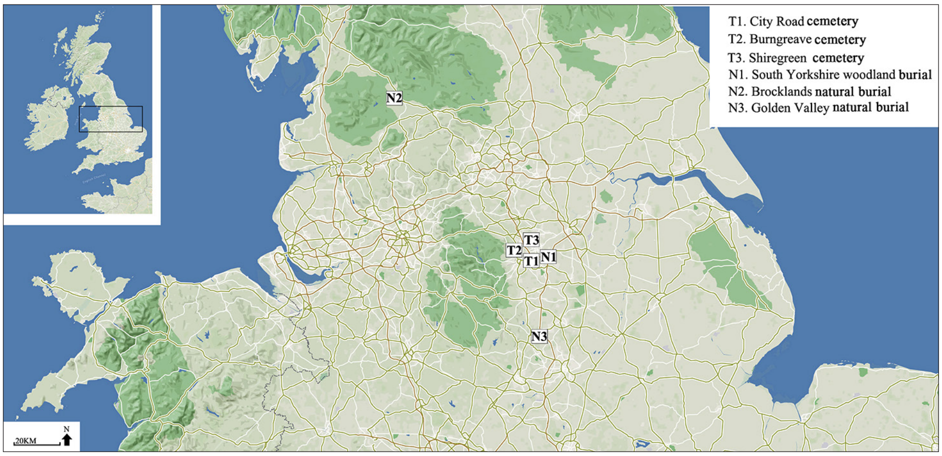


Figure 1. Study site locations (adapted from Mapbox, 2018)

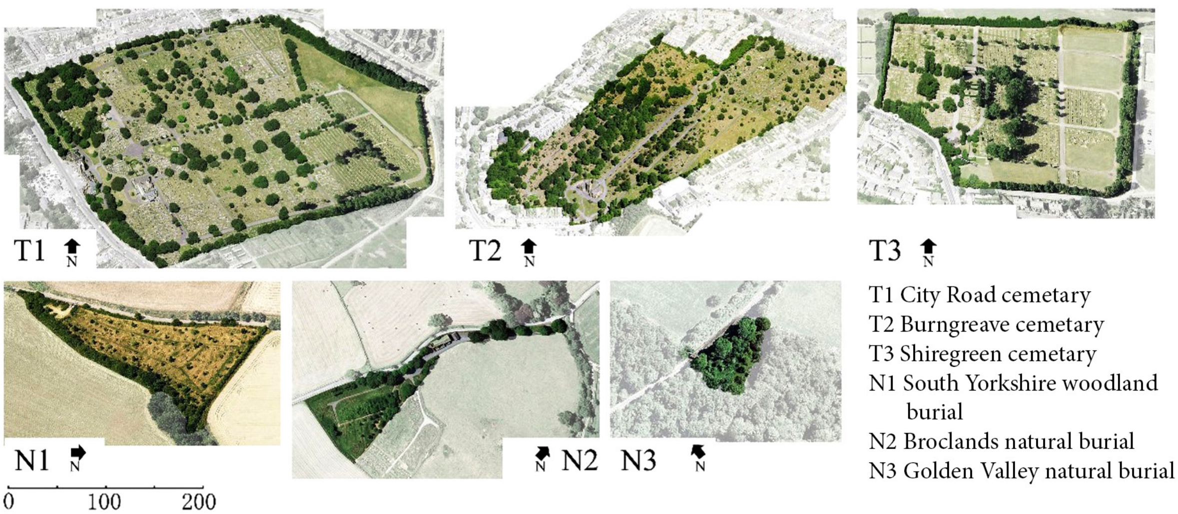


Figure 2. Aerial view of the study sites (adapted from Google Map, 2018)

Figure 3. Plant layer distribution at the study sites (EDINA, 2018)

Table 1. Basic information of each plant layer in the plots

Sample plot	Area (m^2)	Woodland (m^2)	Shrub (m^2)	Meadow (m^2)	Grassland (m^2)		Green space area (GS m^2)	Cemetery facilities area (CF m^2)	Ratio of GS/CF
					Open area	Memorial area			
T1	256,000	49,000	0	0	176,300	23,900	249,200	55,800	4.47
T2	148,400	78,700	0	0	800	76,500	156,000	71,100	2.19
T3	98,100	14,100	1,800	0	44,100	33,400	93,400	20,600	4.53
Total T	502,500	141,800	1,800	0	221,200	133,800	498,600	147,500	3.38
N1	11,600	9,400	0	8,400	2,600	0	20,400	9,000	2.27
N2	11,100	3,200	0	6,100	1,400	0	10,700	9,700	1.10
N3	3,600	2,600	0	3,500	0	0	6,100	3,600	1.69
Total N	26,300	15,200	0	18,000	4,000	0	37,200	22,300	1.67

Note: The grassland area includes the grass in the open and memorial areas; the green space area represents the total area of woodland shrub meadows and grasslands in one sample plot. GS = green space; CF = cemetery facilities.

cycle inventory (LCI) of the maintenance system allows the GHG emissions produced by the maintenance tasks in the cemetery green space to be quantified. Therefore, the system is recognised as a carbon source, as the CO_2 absorption function of plants and soil in the green space is not included in the LCI. In addition, because waste treatment belongs to the scope of municipal engineering rather than green space maintenance tasks, the LCI ends after the plant waste arrives at the recycling station. The goal and scope include the GHG environmental emissions and the GWP index of each plant layer in the maintenance system.

The major energy inputs in green space maintenance are fossil energy, electricity, municipal water and pesticides. Among these inputs, water and pesticides are direct energy (*DE*) inputs, while fossil fuels and electricity are indirect energy (*IDE*) inputs, which are consumed by maintenance equipment. *IDE* consumption can be calculated from the following equation:

$$IDE_a = \sum_{i}^{n} \frac{M_i}{E_i} \times \beta_i, \quad (1)$$

where IDE_a is the input amount of *IDE* material *a*, M_i is the workload of management device *i* within the system boundary, E_i is the working efficiency of device *i*, and β_i is the *IDE* consumption amount per unit time. Table 2 lists the onsite measurements of the main GHG emissions from the maintenance devices, which comply with BS ISO 8178-2:2008 (The British Standards Institution, 2008).

Table 2. Work efficiency and GHG emission inventories of the maintenance equipment

Equipment	Energy type	Unit	Work efficiency/unit	Energy consumption/unit	GHG emissions kg/unit		
					CO_2	CH_4	N_2O
Power chainsaw	Petrol	h	100 m^2	0.80 kg	1.55	9.28×10^{-3}	5.46×10^{-4}
Hedge trimmer	Petrol	h	300 m^2	0.60 kg	1.69	8.96×10^{-3}	3.20×10^{-4}
Strimmer	Petrol	h	300 m^2	0.80 kg	1.74	4.53×10^{-3}	3.90×10^{-4}
Push mower	Petrol	h	300 m^2	1.50 kg	1.80	9.10×10^{-2}	9.02×10^{-4}
Trail mower	Petrol	h	2,000 m^2	2.30 kg	2.68	3.74×10^{-3}	5.40×10^{-4}
Pesticide sprayer	Petrol	h	2,500 m^2	1.50 kg	1.86	4.78×10^{-3}	4.08×10^{-4}
Water pump	Electricity	h	12 m^3	2.20 kW	–	–	–
3-m^3 loading van	Diesel	h	20 km	1.00 kg	3.43	8.11×10^{-3}	5.22×10^{-4}
5-m^3 loading truck	Diesel	h	20 km	2.60 kg	6.20	1.81×10^{-3}	9.39×10^{-4}

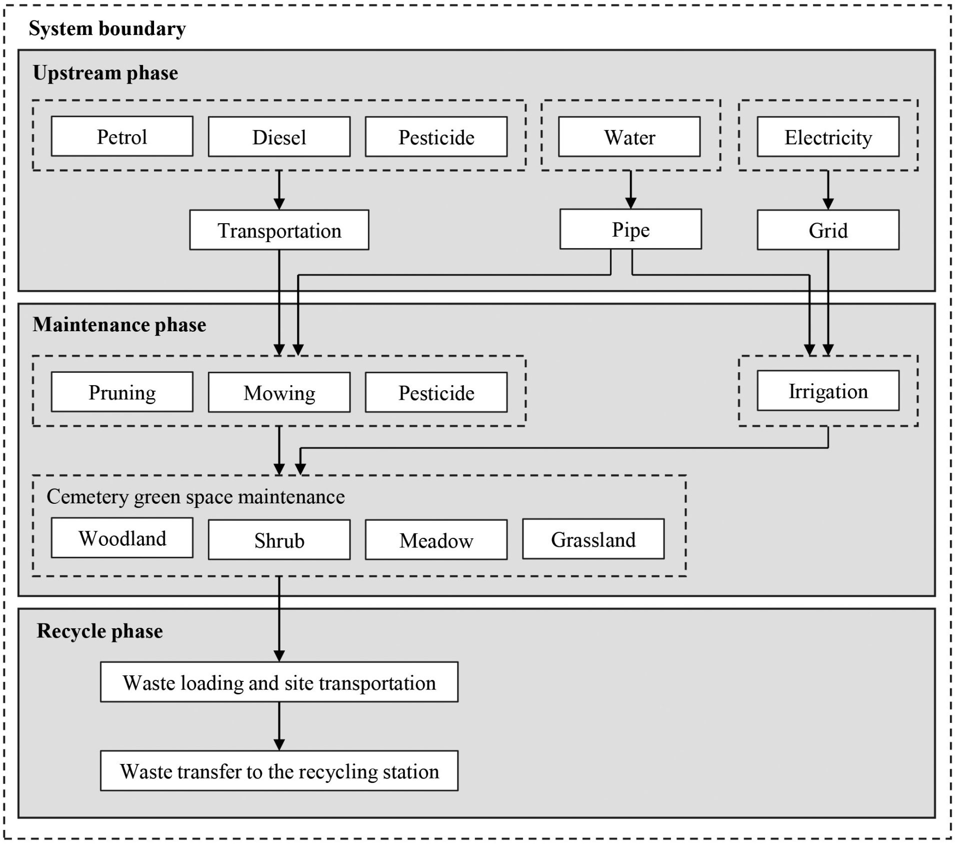


Figure 4. Life cycle flow chart of cemetery green space maintenance (source: Lindholst, 2008; Liu & Yang, 2019)

Table 3. Inventory of the material input for site maintenance

Sample site	Plant layer	Direct energy		Indirect energy		
		Water (m^3/hm^2)	Pesticides (kg/hm^2)	Petrol (kg/hm^2)	Diesel (kg/hm^2)	Electricity (kW/hm^2)
T1	Woodland	0	0	2.40×10^1	1.10×10^2	0
	Grassland	5.20×10^2	4.50×10^1	1.93×10^2	8.00×10^1	9.53×10^1
T2	Woodland	0	0	4.00×10^1	1.49×10^2	0
	Grassland	3.00×10^2	6.00×10^1	5.00×10^2	1.00×10^2	5.50×10^1
T3	Woodland	0	0	1.20×10^1	4.41×10^1	0
	Shrubs	0	6.50×10^1	2.40×10^1	2.00×10^1	0
	Grassland	6.00×10^2	4.20×10^1	4.08×10^2	1.50×10^2	1.10×10^2
N1	Woodland	0	0	2.00×10^1	9.00×10^1	0
	Meadow	4.50×10^2	3.00×10^1	3	1.33×10^1	8.25×10^1
	Grassland	5.00×10^2	5.00×10^1	5.00×10^2	5.33×10^1	9.17×10^1
N2	Woodland	0	0	8	2.49×10^1	0
	Meadow	3.20×10^2	2.60×10^1	2.40	1.20×10^1	5.87×10^1
	Grassland	3.90×10^2	3.20×10^1	1.04×10^2	5.33×10^1	7.15×10^1
N3	Woodland	0	0	2.24×10^1	8.32×10^1	0
	Meadow	4.80×10^2	4.30×10^1	3.60	1.43×10^1	3.30×10^1

Green space maintenance work has the characteristics of annual repetition (Hitchmough, 2008). Therefore, the maintenance life cycle defined in this study is a complete year. Table 3 summarises the inventory of the maintenance energy input of the sample plots (2017.06-2018.07). The data are derived from the work records of the respective maintenance units. The *IDE* was calculated by Equation (1).

1.3. GHG emissions and the GWP index

The quantitative equations for the environmental impact factor in waste emissions within the boundaries of the LCA system are shown below. Because the green space maintenance life cycle is defined annually, the quantification of maintenance GHG emissions and GWP impact factors refers to the annual value.

Table 4. GHG factors of the upstream energy inputs (National Standardization Administration, 2021; Integrated Knowledge for our Environment, 2021)

Type	Item	Unit	GHG factor γ ($kg/CO_2/Unit^{-1}$)	
			Domestic	Nondomestic
Direct energy	Water	m^3	5.10×10^{-1}	5.70×10^{-1}
	Pesticides	kg	6.73	7.49
Indirect energy	Petrol	kg	8.30×10^{-1}	1.73
	Diesel	kg	9.90×10^{-1}	1.88
	Electricity	Kw/h	5.60×10^{-1}	7.30×10^{-1}

Note: Domestic and nondomestic GHG factors were referenced from the ELCD in the region of Great Britain. According to the average domestic and imported ratios of raw materials used in domestic industrial production in the ELCD, 70%/30% was selected as the domestic/overseas ratio of upstream GHG emissions from energy inputs.

$$EL_s = \sum_i^n \gamma_i \times EC_i, \qquad (2) \text{ (West \& Marland, 2002)}$$

where EL_s is the calculated value of the GHG emissions, γ_i is the equivalent coefficient of the i-th GHG factor, and EC_i is the usage amount of the i-th GHG factor. The GHG quantitative data in this paper were calculated by eBalance software. Coefficient γ of the upstream process is provided by the built-in ELCD (European Reference Life Cycle Database) of eBalance (Table 4), and the site maintenance input materials and equipment are listed in Table 5.

Table 5. GHG factors of the site maintenance input materials and equipment

Type	Item	Unit	GHG factor γ ($kg/CO_2/Unit^{-1}$)	Reference
Input materials	Pesticides	kg	3.5×10^{-1}	(Solomon, 2007)
Equipment	CO_2	kg	1	(Boret, 2010)
	CH_4	kg	21	(Boret, 2010)
	N_2O	kg	310	(Boret, 2010)

After the weighted calculations of the GHG emissions are performed, the GWP index can be obtained as follows:

$$WE_s = W_i \times \left(EL_s / S_{2000} \right), \qquad (3)$$

where WE_s is the GWP index within the system boundary of the LCA; W_i is the climate warming weight coefficient of the GHG emissions, with a value of 1.2×10^{-1}; and S_i2000 is the standard worldwide GWP (year 2000) per capita reference value, which is 6.87×10^3 kg CO_2-e/person (Sleeswijk et al., 2008).

2. Results

2.1. GHG emissions from cemetery green space maintenance

Figures 5 and 6 show the GHG emissions from traditional and natural cemetery green space maintenance, respectively.

The main GHG emissions from cemetery green space maintenance are generated in the upstream stage, and the average GHG emissions of traditional and natural cemetery green space maintenance are 52% and 67%, respectively, of their total emissions. The upstream GHG emissions are predominantly due to water and pesticide (*DE*) consumption, while the GHGs generated at the site and in the recovery stage are dominated by the consumption of gasoline and diesel (*IDE*).

The GHG emissions from traditional cemetery green space maintenance are higher than those from natural cemetery green space maintenance. The average GHG emissions (per hm^2) from sample plots T1-T3 in the upstream, onsite and recovery stages were 38.2%, 198%, and 114%, respectively, higher than those from samples N1-N3. The largest GHG emission difference between the two different types of cemetery green space maintenance occurred at the field stage, indicating that different plant communities cause large differences in GHG emissions from maintenance activities.

2.2. GHG emissions of the various plant layers in the cemetery green space

Table 6 indicates that the average GHG emissions from traditional cemetery green space maintenance were 1,552.88 kg/CO_2-e, which was 58% higher than the average GHG emissions from natural cemetery green space maintenance (978.05 kg/CO_2-e). The reason is that the formally arranged burial facilities in the traditional cemetery green space fragment the grassland area, and multiple types of equipment are required to perform the mowing work (Figure 7). Approximately 30–50% more time is required to mow grass blocks than for the same continuous area of grassland, and the GHG emissions from mowing increase correspondingly. The average GHG emissions per unit area (100 m^2) from pruning trees in the traditional cemetery green space was 3.39 kg/CO_2-e, which was higher than that from tree pruning in the natural cemetery green space (2.11 kg/CO_2-e). Most of the trees in traditional cemeteries are located along the roadside as sidewalk trees, and the pruning frequency is significantly higher.

Figure 8 shows the relationship between the maintenance GHG emissions in each cemetery plot, the GS/CF value and the proportion of woodland, shrubs, meadows, and grassland in the green area. (GS/CF refers to the area ratio of green space to cemetery facilities in the cemetery

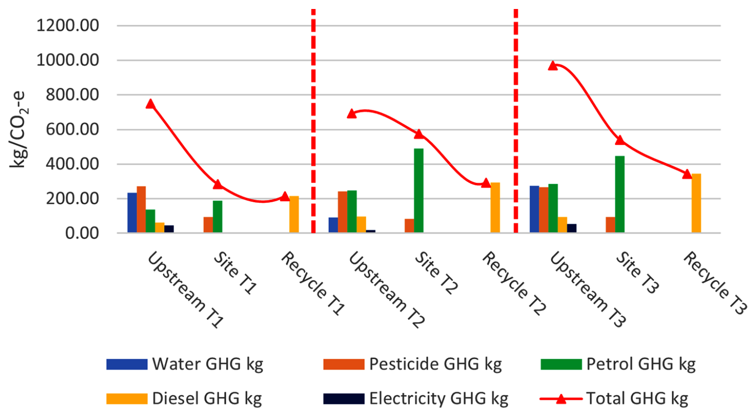


Figure 5. Life cycle of GHG emissions in traditional cemetery green space maintenance

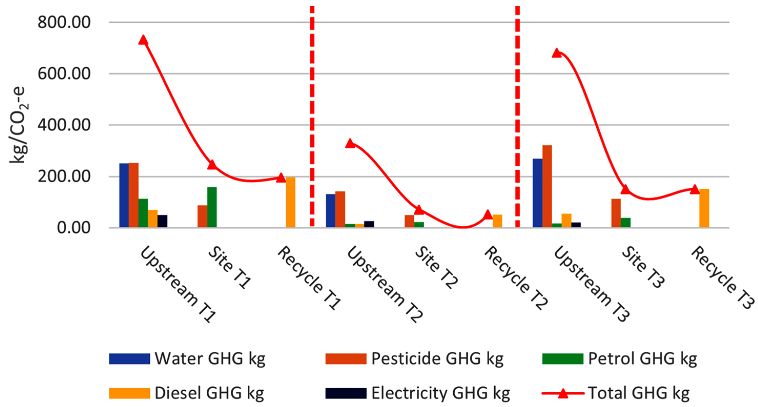


Figure 6. Life cycle of GHG emissions in natural cemetery green space maintenance

Table 6. GHG emissions of the various plant layers at the sample sites

Sample site	Green space area (hm^2)	Woodland		Shrubs		Meadow		Grassland		Total (kg/CO_2-e)
		Proportion (%)	GHG emissions (kg/CO_2-e)	Proportion (%)	GHG emissions (kg/CO_2-e)	Proportion (%)	GHG emissions (kg/CO_2-e)	Proportion (%)	GHG emissions (kg/CO_2-e)	
T1	1	19	68.34	0	–	0	–	78	1,178.01	1,246.36
T2	1	53	268.69	0	–	0	–	52	1,289.67	1,558.36
T3	1	14	21.12	2	16.42	0	–	79	1,816.40	1,853.93
N1	1	81	238.56	0	–	72	486.93	22	451.20	1,176.70
N2	1	29	25.73	0	–	55	296.49	13	129.70	451.92
N3	1	72	204.41	0	–	97	779.63	0	–	984.03

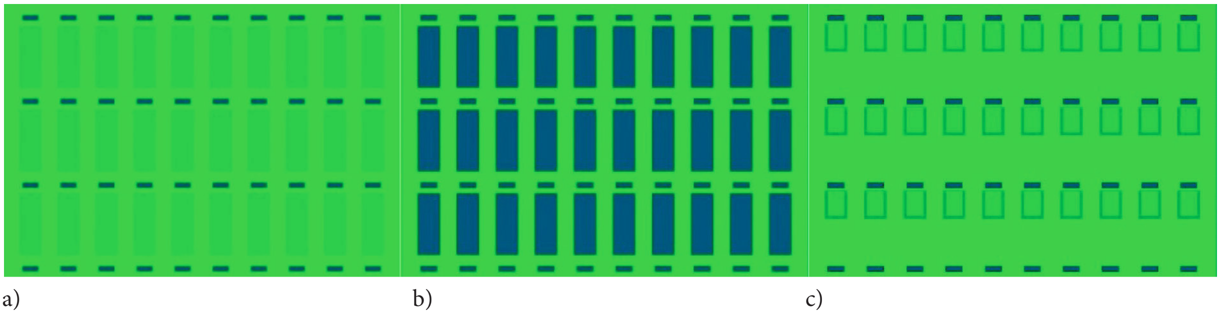


Figure 7. Common memorial facility layouts in a traditional cemetery:
a) Underground facilities with surface monument decorations, b) underground facilities with surface stone covers and monuments, c) sacred underground facilities with surface monuments

site). In general, the GS/CF ratio and GHG emissions per square metre of green space are negatively (positively) correlated in traditional (natural) cemeteries. Among the traditional cemetery plots, T2 had the lowest GS/CF (2.19), which was 49% and 48% of T1 (4.47) and T3 (4.53), respectively, and its GHG emission per square metre of green space reached 0.23 kg/CO_2-e, which was 1.5 times that of T1 (0.15 kg/CO_2-e). In contrast, although the GS/CF values of T1 and T3 were the same, the GHG emissions per square metre of green space in T3 were the same as those in T2, which was 1.5 times that in T1. These characteristics can be observed in the memorial area grassland ratio of T1 and T3: T3 (0.36) was 3.6 times that of T1 (0.10). The maintenance GHG emissions of traditional cemetery green space increased rapidly as the proportion of memorial area grassland increased. In natural cemetery green space, although the GHG emissions of green space maintenance increased with increasing GS/CF value, the increase was not obvious. For example, the GS/CF value of N1 (2.27) was 1.3 and 2.1 times that of N3 (1.69) and N2 (1.1), respectively, but the GHG emission value per square metre of green space of N1 (0.17 kg/CO_2-e) was only 1.1 and 1.9 times that of N3 (0.16 kg/CO_2-e) and N2 (0.09 kg/CO_2-e), respectively.

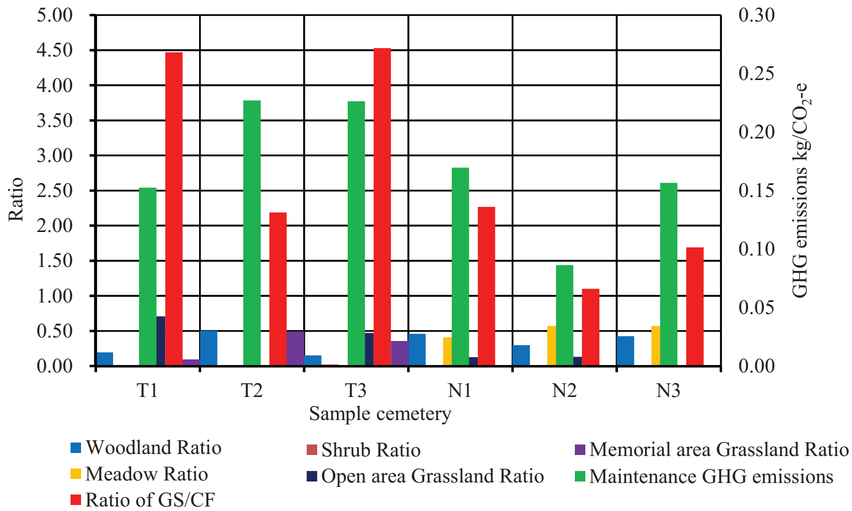


Figure 8. Relations of GHG emissions and GS/CF

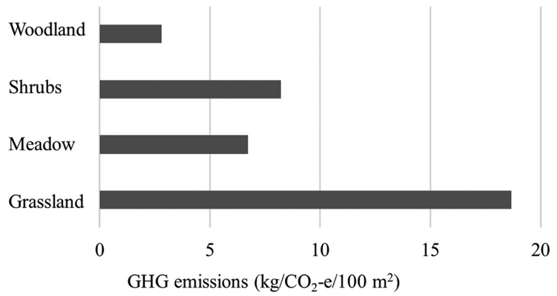


Figure 9. Average GHG emissions of the various plant layers in the cemetery green space maintenance

The woodland, shrub, meadow and grassland ratios represent the ratios of their areas to the total area of green space in one sample cemetery.

Figure 9 shows that the GHG emissions from grassland maintenance in the cemetery green space were the highest (18.68 kg/CO_2-e), which were 6.6, 2.3, and 2.8 times those from the maintenance of trees, shrubs, and ground cover, respectively. In sample plots T1-T3, the grassland layer occupied up to 70% of the area of the ground plant community, but it accounted for only 12% in sample plots N1-N3. This is the major reason why the unit area green space maintenance GHG emissions of the traditional cemeteries were higher than those of the natural cemeteries.

GHG emissions: This variable includes the annual GHG emissions generated by the plant maintenance tasks within the boundaries of the green space maintenance system, that is, pruning, irrigation, fertilization, pesticide application, and waste removal. The maintenance tasks of green space are a carbon source system, and carbon sinks, such as plant biomass and soil carbon sequestration, are not included in the system.

2.3. GHG emissions from the various maintenance tasks in the cemetery green space

Table 7 reveals that plant-trimming work (pruning/mowing) was the main source of the GHG emissions in traditional cemetery green space maintenance. The average value of the trimming work GHG emissions per hm^2 was 596.97 kg/CO_2-e, which was 2.5, 1.7, and 1.6 times the average value of the irrigation, pest control and waste removal GHG emissions per hm^2, respectively. This result was mainly due to the large number of high-intensity grasslands in traditional cemeteries.

Table 7. GHG emissions from the various maintenance tasks in the traditional cemetery green space

Sample site	Green space area (hm^2)	GHG emissions (kg/CO_2-e)			
		Irrigation	Pest control	Trimming	Waste removal
T1	1	279.45	366.29	324.82	275.81
T2	1	107.48	325.59	735.46	389.83
T3	1	326.57	359.82	730.64	436.90
Average	1	237.83	350.56	596.97	367.51

Table 8 indicates that pesticide application was the main source of the GHG emissions in natural cemetery green space maintenance (322.7 kg/CO_2-e per hm^2 on average), which was 1.3, 2.7, and 1.7 times the average value of irrigation, trimming, and waste removal, respectively.

Table 8. GHG emissions from the various maintenance tasks in the natural cemetery green space

Sample site	Green space area (hm^2)	GHG emissions (kg/CO_2-e)			
		Irrigation	Pest control	Trimming	Waste removal
N1	1	299.01	340.20	271.54	265.94
N2	1	156.19	192.64	36.32	66.77
N3	1	288.17	435.26	54.91	205.68
Average	1	247.79	322.70	120.93	179.46

2.4. GWP index of the cemetery green space maintenance

Table 9 shows the GWP indexes of the cemetery and other green areas during the maintenance lifetime of 100 years. The woodland replacement phase includes site preparation and transplanting, and the GHG emission bench values are 125.17 kg/CO_2-e and 1436.62 kg/CO_2-e per hm^2, respectively (Ingram, 2012). The replaced wood treatment phase includes wood removal and transportation (distance of 100 km), and the GHG emission bench values are 871.22 kg/CO_2-e and 1,690.91 kg/CO_2-e per hm^2, respectively (Yuan-Yuan et al., 2020). The GHG emission bench value of the deadwood disposal phase is 22,109 kg/CO_2-e per hm^2 (Yoshioka et al., 2015). Comparison with the LCAs of various other types of plant maintenance over the maintenance lifetime (Figure 10) show that the GWP indexes of the traditional and natural cemetery green space maintenance were at medium-high and medium-low levels, respectively.

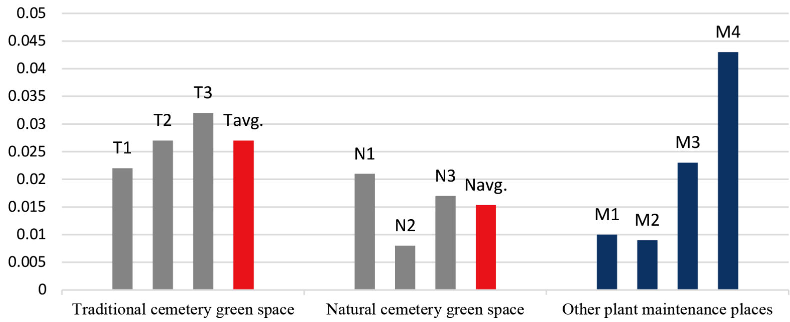
(a) In the cemetery green space (T1-N3), assuming that the density of burial facilities doubled during the maintenance lifetime, the replacement area of the woodlands is equal to the existing wood area. The deadwood rate in the woodland area is 30%, of which 30% is removed from the site, 70% is subjected to site disposal, and 10% is incinerated. (b) In the urban green space (M1), assume that the replacement rate of the woodlands is 40%. Seventy percent of the replaced wood is removed from the site, and 30% is disposed of at the site. Ten percent of the disposed wood is incinerated. (c) In the economic forest (M2) and orchard (M3), woodland replacement was assumed to be 3 and 5 times, respectively. All of the replaced wood was removed from the site.

The average GWP index of traditional cemetery green space maintenance was 2.732, which was 63% of that of farmland maintenance (4.300), approximately 2.7–3 times that of urban green space maintenance and slightly higher than that of orchard maintenance (2.675). The average GWP index of natural cemetery green space maintenance

Table 9. GWP indexes of cemetery green space and various types of plant site maintenance

Site	Green space maintenance	Woodland replacement		Replaced wood treatment		Deadwood disposal	Total
		Land preparation	Transplanting	Wood removal	Wood trans-portation		
T1	2.2000	4.0000×10^{-4}	4.8000×10^{-3}	2.9000×10^{-3}	1.9000×10^{-3}	5.1000×10^{-3}	2.2151
T2	2.7000	1.2000×10^{-3}	1.3300×10^{-2}	8.1000×10^{-3}	5.2000×10^{-3}	1.4300×10^{-2}	2.8030
T3	3.2000	3.0000×10^{-4}	3.5000×10^{-3}	2.1000×10^{-3}	1.4000×10^{-3}	3.8000×10^{-3}	3.2111
Tavg.	2.7000	6.0000×10^{-4}	7.2000×10^{-3}	4.4000×10^{-3}	2.8000×10^{-3}	7.7000×10^{-3}	2.7227
N1	2.1000	1.8000×10^{-3}	2.0300×10^{-2}	1.2300×10^{-2}	7.9000×10^{-3}	2.1900×10^{-2}	2.1642
N2	8.0000×10^{-1}	6.0000×10^{-4}	7.3000×10^{-3}	4.4000×10^{-3}	2.8000×10^{-3}	7.8000×10^{-3}	8.2290×10^{-1}
N3	1.7000	1.6000×10^{-3}	1.8100×10^{-2}	1.1000×10^{-2}	7.0000×10^{-3}	1.9500×10^{-2}	1.7572
Navg.	1.5330	1.3000×10^{-3}	1.5200×10^{-2}	9.2000×10^{-3}	5.9000×10^{-3}	1.6400×10^{-2}	1.5810
M1	1.0000	9.0000×10^{-4}	1.0000×10^{-2}	6.1000×10^{-3}	9.1000×10^{-3}	4.0000×10^{-4}	1.0265
M2	9.0000×10^{-1}	6.6000×10^{-3}	7.5300×10^{-2}	4.5700×10^{-2}	9.7500×10^{-2}	0.0000	1.1251
M3	2.3000	1.0900×10^{-2}	1.2550×10^{-1}	7.6100×10^{-2}	1.6250×10^{-1}	0.0000	2.6750
M4	4.3000	0.0000	0.0000	0.0000	0.0000	0.0000	4.3000

Notes: T1 = City Road cemetery, T2 = Burngreave cemetery, T3 = Shiregreen cemetery, Tavg. = Traditional cemetery green space average, N1 = South Yorkshire burial ground, N2 = Brocklands burial ground, N3 = Golden Valley burial ground, Navg. = Natural cemetery green space average, M1 = urban green space (Zheng Zhou, China), M2 = economic forest (Iran, Quran Province), M3 = orchard (California, USA), and M4 = farmland (Gerard, France).



T1 = City Road cemetery, T2 = Burngreave cemetery, T3 = Shiregreen cemetery, Tavg. = Traditional cemetery green space average, N1 = South Yorkshire burial ground, N2 = Brocklands burial ground, N3 Golden Valley burial ground, Navg. = Natural cemetery green space average, M1 = urban green space (Zheng Zhou, China), M2 = economic forest (Iran, Quran Province), M3 = orchard (California, USA), and M4 = farmland (Gerard, France)

Figure 10. Comparison of the GWP indexes of cemetery green space and the various types of plant site maintenance

was relatively low (1.581), only 35% of that of farmland maintenance and approximately 1.5 times that of urban green space maintenance.

3. Discussion

3.1. Reducing GHG emissions in the cemetery green space maintenance system

This article shows that the upstream phase of the maintenance system in cemetery green space contributed the maximum (more than 50%) GHG emissions. All of the maintenance materials produce GHG emissions during the upstream (production and transportation) phases, including irrigation water/pesticide/petrol and diesel energy/electricity power. However, water and electricity application during the site maintenance and waste recycling phase achieves a net GHG release. In contrast, the application of petrol and diesel energy produces GHG emissions in the total green space maintenance system (Bartlett & James, 2011). The standard coal combustion equivalent coefficients were 0.12 and 1.46 for electricity (per kW/h) and diesel (per kg) (National Standardization Administration, 2021), respectively. Thus, if diesel vehicles were replaced with electric vehicles in the waste-recycling phase of cemetery green space maintenance, the GHG emissions from traditional cemeteries could be reduced from 48,721 kg/CO_2-e to 16,162 kg/CO_2-e, and those from natural cemeteries could be reduced from 24,742 kg/CO_2-e to 9,175 kg/CO_2-e. GHG emissions from both cemetery types could thus be reduced by more than 60% during the 100-year maintenance lifetime per hm^2. Therefore, transforming the maintenance equipment from fossil- to electricity-powered can efficiently decrease the maintenance GHG emissions from the upstream and recycling phases. To reduce GHGs from the upstream phase, reducing the application of pesticides and saving irrigation water should be considered (Gu et al., 2015).

Changing the irrigation resources from city water to greywater and more intensively upgrading the irrigation system can reduce upstream GHG emissions in green space maintenance. The application of greywater to replace city water irrigation is a feasible way of reducing the GWP of green space maintenance (Dominguez et al., 2018; Jeong et al., 2018). Greywater is domestic wastewater originating in washing machines, kitchen sinks, baths, and hand basins (Fountoulakis et al., 2016; Gabarró et al., 2013). Hence, it is adequate for toilet flushing, irrigation, laundry, fire extinguishing, groundwater discharge or car and window washing (Abu-Ghunmi et al., 2011). The production of 1 m^3 reclaimed greywater releases approximately 0.60–0.80 kg CO_2-eq GHG emissions and can reduce GHG emissions by approximately 40–60% compared with the same amount of city tap water (1.30–1.50 kg CO_2-eq) (Hsien et al., 2019; Tidåker et al., 2017). Intensive irrigation systems have an approximately 10–20% water conservation opportunity compared with manual irrigation and can reduce upstream GHGs (Mukherjee et al., 2020). Modification of the water supply position from overhead spraying to root dripping can avoid unbalanced irrigation, soil surface leaching and partial water flooding (Davis & Dukes, 2014; McCready et al., 2009). Upgrading the supply method from manual to computing control can be used to collect environmental data, i.e., the surrounding temperature and soil and air moisture of maintenance green space, to automatically control the irrigation timing and frequency (McCready & Dukes, 2011). The cost of intensive irrigation systems is relatively high, and the alteration phase will involve GHG emissions (Wang et al., 2018). Therefore, general green areas can use greywater irrigation. Water shortage areas can consider both intensive irrigation and greywater supply systems.

The GHG emissions of maintenance tasks negatively impact the carbon sequestration of cemetery green space. According to Table 10, considering the carbon sink capacity of plants, woodlands can be recognized as carbon sink plants in the 100-year maintenance lifetime, and the storage capacity is 40,800 kg/CO_2-e per hm^2. Shrubs, meadows and grassland are all carbon source plants, with GHG emissions (CO_2-e) of 40,800 kg, 38,000 kg and 172,100 kg per hm^2, respectively. Grasslands have the highest GHG emissions among carbon source plants: more than 4 times those of shrubs and meadows. The increase in woodland areas can improve the carbon storage capacity of cemetery green spaces.

3.2. Limited application of grassland to reduce GHG maintenance in cemetery green spaces

Although the memorial facilities of different cemeteries may differ due to the different social features and customs in different countries and regions, the planting forms of cemetery green spaces are basically similar. Natural cemeteries dominated by naturally growing trees or meadows are considered a better way for humans to return to nature (Boret, 2010; Kaufman, 1999). The GWP indexes of two types of cemetery green space maintenance in Yorkshire reveal that natural cemetery green spaces have lower GHG emissions and exert a lower negative environmental pressure than do traditional cemetery green spaces.

The lower GWP impact of natural cemetery green space maintenance is due to the plant maintenance requirements being lower than those in traditional cemetery green space maintenance. The ecological advantages of trees in green spaces have been generally recognized, and their conservation requirements are low, while their ecological benefits are high (Li et al., 2016). Woodlands in green spaces have a direct effect on reducing air pollution, regulating microclimates, and increasing carbon storage (Nowak et al., 2018). According to Nowak et al. (2014), urban woodlands across the United States can save approximately $6.8 billion in health expenditures each year for community residents; in contrast, grasslands not only have high maintenance needs and consume large amounts of materials but also have higher GHG emissions (Jo & McPherson, 1995). The results of this study can further verify the ecological advantages of trees from the perspective of the negative environmental impact of plant maintenance, namely, the GHG emissions per unit area of woodland maintenance are only 1/6 of those per unit area of grassland maintenance.

The high plant-trimming requirements of traditional cemetery green spaces not only generate high GHG emissions but also increase the amount of plant waste removed and transported. This phenomenon results in increased GHG emissions during waste removal and transportation. Fragmented cemetery grasslands lead to mowing work that is almost entirely dependent on small equipment, and the unit workload of exhaust gas emissions is

Table 10. Carbon balancing between the GHG emissions and carbon sequestration of the plants over the 100-year maintenance lifetime of the cemetery green space

Carbon type	Woodland (kg/CO_2-e/hm^2)	Shrubs (kg/CO_2-e/hm^2)	Meadow (kg/CO_2-e/hm^2)	Grassland (kg/CO_2-e/hm^2)	Reference
GHG emissions	28,100	82,100	67,300	186,800	–
Carbon sequestration	68,900	41,300	29,300	14,700	(National Statistics, 2019)
Carbon balancing	40,800	–40,800	–38,000	–172,100	–

Note: Carbon balancing is the value of carbon sequestration minus the value of GHG emissions. In the carbon balancing row, positive values represent carbon sinks, and negative values represent carbon sources.

much higher than that of large maintenance equipment. The GHG emissions per kW/h of work of hedge trimmers, chainsaws, and push lawn mowers are 17.5, 8.4 and 1.3 times those of light trucks, respectively (McKenzie, 2018). In contrast to the low maintenance needs of meadows in natural cemetery green spaces, the average GHG emissions per unit area from lawn mowing and waste removal for the ground cover plants in the traditional cemeteries were 4.9 and 2 times, respectively, those for the plants in the natural cemeteries. In densely populated areas, the use of meadows to replace grasslands between commemorative facilities in cemetery green spaces can effectively reduce maintenance GHG emissions. During the 100-year maintenance lifetime, the GHG emissions per hectare of the meadows were 67,300 kg/CO_2-e, which was only 32% of those of the grasslands (209,600 kg/CO_2-e). The GHG emissions of meadow on-site maintenance were 16,800 kg/CO_2-e, which was only 18% of those of grassland maintenance at 91,100 kg/CO_2-e. The domestic and overseas GHG emissions (CO_2-e) from maintenance material production in meadows were 33,800 kg and 16,700 kg, which were 47% and 36% those of grasslands (72,300 kg domestically and 46,300 abroad), respectively. The difference between the GHG emissions of the two types of cemetery green spaces in terms of pesticide application and irrigation was less than 10%. To reduce GHG emissions from pesticide application and irrigation, it is necessary to start with the application of more intensive pesticides and irrigation equipment (Yuanyuan & Wei, 2016).

3.3. Applying meadows and improving the integrity of green spaces to reduce the maintenance GWP impacts

A large number of memorial facilities in cemeteries disrupt the integrity of their green spaces, especially that of ground cover plant spaces, and increases the manual intervention of maintenance tasks (Clayden et al., 2014; Dunnett & Hitchmough, 2014). Figure 8 shows that in traditional cemeteries, GHGs from green space maintenance significantly increase when high-density cemetery facilities frequently disrupt the integrity of grasslands. The GS/CF ratio of T2 was only 49% that of T1, i.e., the grassland of T2 that needed to be maintained in the same area of the cemetery was only approximately half that of T1. However, almost all the grassland in T2 is located in the memorial area (≥98%), so the grassland is fragmented by the cemetery facilities. This fragmentation increases the energy and time consumption of maintenance tasks, resulting in the GHG emissions per square metre of green space in T2 being 1.5 times that in T1. Meanwhile, the GS/CF values of T3 and T1 were the same, although the proportion of T3 grassland distributed in the memorial area was 3.6 times that of T1. The GHG emission per square metre of green space maintenance of T3 was 1.5 times that of T1, which was the same as that of T2. Therefore, reducing grassland usage in fragmented green areas and applying low-maintenance plants, such as meadows, as ground cover plants can effectively reduce GHG emissions from green space maintenance, thereby reducing the GWP impact.

This article references urban green areas in that the integrity and continuity of ground cover areas are essential factors that save maintenance resources and decrease the GWP impact. The working efficiency of a trail mower (2000 m^2/h) is approximately 6.5 times that of a push mower (300 m^2/h). Using a push mower to mow turf in curved and fragmented areas (0.53 kg/100 m^2) consumes approximately 4.6 times more petrol than does using a trail mower to mow large and open grass areas (0.12 kg/100 m^2). The GHG emissions generated by push mowers (1.33 kg CO_2-e/100 m^2) are approximately 9.1 times those generated by trail mowers (0.15 kg CO_2-e/100 m^2) for the same area. Furthermore, annual cut-backs of large meadows via trail tractors can save energy consumption and GHG emissions in comparison with strimmer cuts for continuous meadow areas of the same size (Hitchmough, 2008). Therefore, during the planting design phase for urban green spaces, adjusting plant community combinations to improve the integrity of ground cover plant layers can reserve space for the use of highly efficient maintenance devices to reduce future maintenance GHG emissions and GWP impacts (Liu et al., 2018).

Conclusions

Natural cemeteries have a lower GWP impact and contribute larger ecological benefits than do traditional cemeteries in terms of green space maintenance. The average GHG emissions from the maintenance of green spaces for traditional cemeteries were more than 50% higher than were those for natural cemeteries for the same unit area, mainly due to the high plant-trimming (pruning/mowing) and waste-removal requirements.

The GHG emissions from the maintenance of cemetery green spaces were mainly generated in the upstream stages of the production, transportation, and sales of maintenance materials, accounting for more than 50% of those of the entire maintenance system. Therefore, reducing the application of maintenance materials such as pesticides, fossil energy, and irrigation water will efficiently reduce GHG emissions in the maintenance of cemetery green spaces.

The majority of GHG emissions (≥50%) from the maintenance of cemetery plants were from grasslands, and the majority of these are from the fragmented grass of the cemetery facility area. Therefore, establishing meadows to replace grasslands in dense cemetery facility areas can efficiently reduce the maintenance GWP impact of cemetery green spaces.

In urban areas, the GWP influence of cemetery green space maintenance is relatively higher than that of the average of an urban public green space. Because it is an expanding type of urban green space, research on the maintenance of cemetery green spaces with low energy consumptions and low environmental impacts is beneficial to the ecological benefits and sustainable development of urban areas.

In terms of green space maintenance, natural cemeteries have a lower GWP impact and contribute more ecological benefits than do traditional cemeteries, mainly because more meadows than grasslands are used as ground cover and obvious ground cemetery facilities are limited. Regarding cemetery green space planning, replacing grasslands with wild meadows, reducing the size of ground cemetery facilities and limiting the application of maintenance materials (i.e., irrigation water and pesticides) can efficiently reduce the maintenance environmental impact.

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Implications and limitations

This article discusses the plant types and planting structure adjustment strategies in cemetery green spaces intended to reduce maintenance GHG emissions and GWP impacts. The differences between green space combinations space in cemeteries can reflect the differences in people's funeral concepts and sociocultural backgrounds. However, an in-depth discussion is required on the influence of the sociocultural factors on cemetery patterns. Carbon sources and sinks based on the physiological functions of plants and the soil also need to be considered as service functions of the cemetery ecosystem. Future research will consider how to quantify the impact of these factors on cemetery management to more comprehensively analyse how to increase the environmental benefits of cemetery green spaces.

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