JPPIPA 11(5) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Using Life Cycle Assessment Approach to Support Environmental Science Education through Vegetation Maintenance Impact Control in City Park 1 Bumi Serpong Damai

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Received: March 26, 2025
Revised: April 29, 2025
Accepted: May 25, 2025
Published: May 31, 2025

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DOI: 10.29303/jppipa.v11i5.10981

Abstract: Maintaining vegetation can contribute to environmental impacts by producing exhaust gases and chemical residues. Therefore, to control it, it is necessary to trace impacts using the life cycle assessment approach. The aim of this research is to inventory inputs and outputs, calculate the magnitude of the impacts caused, and formulate recommendations scenarios for controlling environmental impacts from maintaining vegetation in City Park 1 BSD. Vegetation maintenance stages are identified based on the type of input and amount of output which is calculated using the basic formula: Emissions = activity data x emission factor. Vegetation maintenance has inputs in the form of petrol, diesel, electrical energy, manure, pearl fertilizer, curacron, furadan, dry leaves, and felled trees, while the output produced is CO_2, N_2O, CH_4, SO_2, NO_2, NO_3, NH_3, and PO_4^{3-}. Acidification emissions resulting have the highest value with hotspots in the form of electricity use and watering tankers. Impact control that can be done is reducing the use of watering tankers, reducing the use of blower machines, and composting dry leaves resulting from sweeping. The life cycle assessment approach can be used as a learning resource to strengthen environmental science education.

Keywords: Life cycle assessment; Maintenance; Vegetation

Introduction

Cities do not only contain physical components but must also be equipped with biotic components which are allocated as Green Open Space (GOS). GOS is an elongated/lane and/or clustered area whose use is more open, where plants grow, both naturally grown and deliberately planted, considering aspects of ecological function, water absorption, economics, social culture, and aesthetics (Peraturan Menteri ATR/BPN Republik Indonesia Nomor 14 Tahun 2022 Tentang Penyediaan Dan Pemanfaatan Ruang Terbuka Hijau, 2022; Suciyani, 2018). GOS that presents views of trees and flowers will make a person feel calmer, more relaxed, and increase positive human psychological well-being. In addition, these views will enhance the beauty of the city and become an attractive visual element (Wang et al., 2019). However, the phenomenon of increasing urbanization has resulted in a decrease in the number of GOS provisions in urban areas. The more urbanization increases, the worse the quality of the urban environment becomes (Hana & Pujiati, 2023). The decreasing number of GOS can cause various problems such as Urban Heat Island (UHI), flash floods, air pollution, and the extinction of urban wildlife due to habitat fragmentation (Idris, 2016; Nguyen et al., 2020). Apart from that, cities also play a role in the global carbon cycle which emits large amounts of CO_2 emissions due to energy consumption, transportation, and the conversion of natural land to built-up land (Strohbach et al., 2012).

How to Cite:
Hermawan, R., Rahma, L. A., & Rachmawati, E. (2025). Using Life Cycle Assessment Approach to Support Environmental Science Education through Vegetation Maintenance Impact Control in City Park 1 Bumi Serpong Damai. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 491–505. https://doi.org/10.29303/jppipa.v11i5.10981

The construction of GOS is an effort to improve environmental quality, especially air pollution and discomfort due to high air temperatures. The existence of vegetation in urban areas is very important for the environment by providing various ecosystem services. Urban vegetation supports the provision of habitat for urban biodiversity, regulates urban temperatures by providing shade and lowers temperatures through transpiration thereby helping reduce the risk of heat-related diseases for city residents, absorbs carbon dioxide from the atmosphere through photosynthesis, reduces noise, and improves atmospheric air quality (Ferrini et al., 2020; Ordóñez et al., 2023; Schueler & Oliveira, 2023). Apart from that, the presence of urban vegetation also has an effect on increasing water storage and reducing rainwater runoff, as well as an effect on urban aesthetics to increase pleasant visual quality (Gülgün et al., 2020; McGrath et al., 2021).

South Tangerang City has been a division of Tangerang Regency since 2008. The population of South Tangerang City in 2024, is 1,429,529 people with a population density of 8,672 people/km^2 (Badan Pusat Statistik Kota Tangerang Selatan, 2025). South Tangerang City has GOS that are widely used, including City Park 1 Bumi Serpong Damai (BSD). The area of GOS in South Tangerang City in 2010 was 6,070 ha, while in 2020 it was 4,224 ha. Changes in GOS are caused by land use for industrial development, residential areas, and other economic centers (Fitri et al., 2022).

The vegetation that makes up GOS needs to be maintained regularly so that it can live and develop well to produce maximum environmental services. Vegetation maintenance uses a lot of energy and chemicals, which will likely have implications for increasing exhaust gas emissions and chemical residues in the environment. Trees in urban areas experience various pressures due to increasing climate change, pests and diseases, drought, fires, and land conversion. This causes urban tree density and tree canopy cover to decline in many cities (Ordóñez et al., 2023). Excessive use of fertilizers, pesticides, herbicides, and other chemicals can cause indirect carbon emissions for the environment (Park & Jo, 2021). Excessive use of chemicals can cause hypoxia and anoxia, loss of biodiversity, and rapid algae growth (Bijay-Singh & Craswell, 2021). Dependence on the use of machines that consume fossil energy in vegetation maintenance emits dangerous emissions in the form of CO_2, NO_x, and CH_4 (Li & Liu, 2020).

Emission control from vegetation maintenance needs to be carried out because the quality of environmental conditions is increasingly declining. The Life Cycle Assessment (LCA) study is one approach to determine the type and magnitude of the impact of vegetation maintenance. LCA is a method for analyzing and quantifying the environmental impact of products or services in each stage of the cycle starting from material preparation to waste disposal for sustainable development (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2021; Suhariyanto et al., 2023). The aim of the research is to identify inputs and outputs, calculate the magnitude of the impact, and formulate impact control scenarios for vegetation maintenance in City Park 1 BSD, South Tangerang City.

Method

Location and Time

The research was conducted at City Park 1 BSD in February-May 2024. City Park 1 BSD has an area of 2.6 ha (Figure 1).

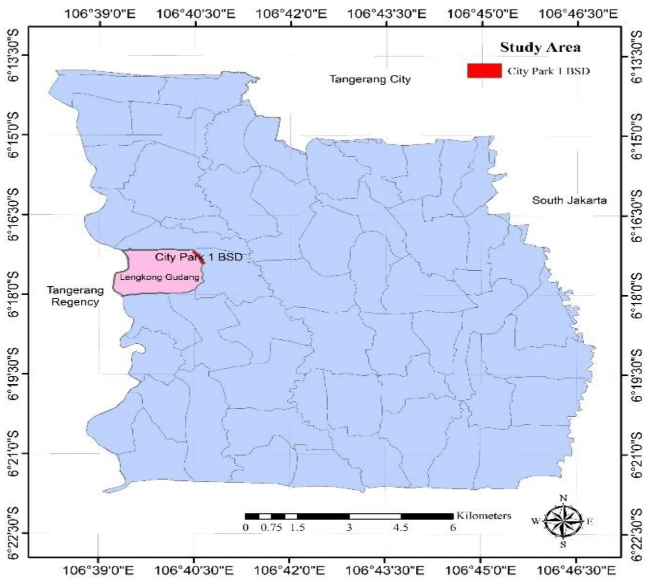

Figure 1. Map of research location

Data Collection Methods

Data collection was carried out by conducting interviews with managers from the Environmental Service of South Tangerang City. Interviews were conducted to obtain data regarding input and output from GOS management. Field observations were carried out by visiting GOS directly to find out the stages of the GOS management process, energy use and waste management. A literature study was carried out to obtain data and information regarding GOS based on supporting GOS documents.

Research Scope

The research only identifies the type of impact and calculates the magnitude of the impact that has occurred from vegetation maintenance activities. This research does not analyze the balance between the emissions produced and the ability of vegetation to control emissions. In addition, this study did not examine the effectiveness of emission control scenarios on vegetation maintenance performance.

Data Processing and Analysis Methods

1. Input and Output Inventory

The stages in inventorying input and output refer to ISO 14040: 2016 (Standar Nasional Indonesia, 2016).

2. Quantitative Environmental Impact Calculation

Calculation of the magnitude of environmental impacts resulting from GOS management was carried out by classifying input and output data into impact categories. The basic formula for calculating emissions is as follows:

$$\text{Emissions} = \text{activity data} \times \text{emission factor} \quad (1)$$

The types of emissions that have been calculated are characterized by modeling environmental impacts into impact categories using conversion factors. Impact categories are limited to Global Warming Potential (GWP), acidification, and eutrophication. The calculated emissions are the amount of emissions/year/ha.

a) *Global Warming Potential*

The types of pollutants that can cause GWP are CO_2, N_2O, and CH_4. Sources of pollution that cause GWP come from electricity, fuel, fertilizer, and organic solid waste. The number of emissions resulting from the GWP inventory refers to the IPCC (2006).

(1) Electricity

Electricity is used as energy for facilities such as jet pumps. Emissions produced by electrical energy are obtained by the following equation:

$$CO_2 \text{ emissions} = QL \times 0.84 \text{ kg } CO_2/\text{kWh} \quad (2)$$

Where:

QL : electricity consumption (kWh)

(2) Fuel

The use of fuel can produce CO_2, N_2O, and CH_4 emissions. The number of emissions resulting from transportation can be obtained from the following equation with emission factors according to the type of fuel (Table 1).

Table 1. Default emission factors for road transport

Emissions	Diesel	Gasoline*
CO_2	74,100 kg CO_2/TJ	69,300 kg CO_2/TJ
N_2O	3.9 kg N_2O /TJ	3.2 kg N_2O /TJ
CH_4	3.9 kg CH_4/TJ	33 kg CH_4/TJ
Calorific value	36 x 10^{-6} TJ/L	33 x 10^{-6} TJ/L

Note: *includes Pertamax and Pertalite

Source: (Intergovernmental Panel on Climate Change (IPCC), 2006)

$$CO_2 \text{ emissions} = QF \times NK \times FE \quad (3)$$

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L)

FE : emission factor (kg CO_2/TJ)

$$N_2O \text{ emissions} = QF \times NK \times FE \quad (4)$$

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L)

FE : emission factor (kg N_2O /TJ)

$$CH_4 \text{ emissions} = QF \times NK \times FE \quad (5)$$

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L)

FE : emission factor (kg CH_4/TJ)

(3) Fertilizer

Fertilizer is used in GOS management in the form of adding organic material, namely fertilizer to vegetation.

$$CO_2 \text{ emissions} = QP \times 0.2 \text{ kg } CO_2/\text{ton} \quad (6)$$

Where:

QP : fertilizer consumption (tons)

(4) Decomposition

Decomposition occurs in leaf and tree waste from vegetation maintenance. The emissions resulting from decomposition are CH_4 and N_2O. Efforts to recover or capture CH_4 gas are carried out when the gas is released during the waste processing process. The waste processing system is assumed to run naturally on open land so that no CH_4 emissions are captured, so the amount of CH_4 recovered (R) value is 0.

$$CH_4 \text{ emissions} = TOW \times 4 \text{ g/kg } CH_4 \times 10^{-3} - R \quad (7)$$

Where:

TOW : Total Organic Waste (tons)

10^{-3} : constant

R : amount of CH_4 recovered

$$N_2O \text{ emissions} = TOW \times 0.24 \text{ g/kg } N_2O \times 10^{-3} \quad (8)$$

Where:

TOW : Total Organic Waste (tons)

10^{-3} : constant

GWP emission values are obtained from the conversion of CO_2, N_2O, and CH_4 into CO_2eq with the following ratio: 1 kg CO_2 = 1 kg CO_2eq; 1 kg N_2O = 298 kg CO_2eq; 1 kg CH_4 = 25 kg CO_2eq (Intergovernmental Panel on Climate Change (IPCC), 2006).

b) Acidification

The types of pollutants that can cause acidification are SO_2 and NO_x. Sources of pollution that cause acidification come from the use of electricity and fuel.

(1) Electricity

SO_2 emissions = QL x 8.1 g SO_2 /kWh (9)

Where:

QL : electricity consumption (kWh)

NO_2 emissions = QL x 4.17 g NO_2/kWh (10)

Where:

QL : electricity consumption (kWh)

(2) Fuel

SO_2 emissions = QF x NK x 59.61 kg SO_2/TJ (11)

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L) (Table 1)

NO_2 emissions = QF x NK x 1.322 kg NO_2/TJ (12)

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L) (Table 1)

(3) Fertilizer

NO_3 emissions = QP x N x 0.005 kg NO_3/kg N (13)

Where:

QP : fertilizer consumption (kg)

N : N content in fertilizer (%)

The acidification emission value is obtained from the conversion of SO_2 and NO_x to SO_2eq with the ratio: 1 kg SO_2 = 1 kg SO_2eq; 1 kg NO_x = 0.7 kg SO_2eq (Heijungs et al., 1992).

c) Eutrophication

The types of pollutants that can cause eutrophication are NH_3, NO_x, and PO_4^{3-}. Sources of pollution that cause eutrophication come from the use of electricity, fuel, fertilizer, and pesticides.

(1) Electricity

NO_2 emissions = QL x 4.17 g NO_2/kWh (14)

Where:

QL : electricity consumption (kWh)

(2) Fuel

NO_2 emissions = QF x NK x 1.322 kg NO_2/TJ (15)

Where:

QF : fuel consumption (L)

NK : calorific value (TJ/L) (Table 1)

(3) Fertilizer

NO_3 emissions = QP x N x 0.005 kg NO_3/kg (16)

Where:

QP : fertilizer consumption (kg)

N : N content in fertilizer (%)

NH_3 emissions = QP x N x 0.1 kg NH_3/kg N (17)

Where:

QP : fertilizer consumption (kg)

N : N content in fertilizer (%)

PO_4^{3-} emissions = QP x P x 0.128 kg PO_4^{3-}/kg P (18)

Where:

QP : fertilizer consumption (kg)

P : P content (%)

(4) Pesticides

PO_4^{3-} emissions = QP_S x 0.015 kg PO_4^{3-}/kg pesticides(19)

Where:

QP_S : pesticides consumption (kg)

The eutrophication emission value is obtained from the conversion of NH_3, NO_x, and PO_4^{3-} to PO_4^{3-}eq with the ratio: 1 kg PO_4^{3-} = 1 kg PO_4^{3-}eq; 1 kg NO_x = 0.13 kg PO_4^{3-}eq; 1 kg NH_3 = 0.35 kg PO_4^{3-}eq (Heijungs et al., 1992).

3. Assumptions for estimating vegetation maintenance emissions

In calculating the magnitude of emissions resulting from vegetation maintenance, some data uses assumptions as in Table 2.

Table 2. Assumptions used for estimating vegetation maintenance emissions

Matters	Assumption
Weight of dry leaves for 1 sack	7.8 kg
Tree weight	722.44 kg
Pruning	1 year pruning is carried out once on 100 trees
Logging	Felling per year is carried out once on 1 fallen tree
Blower machine with gasoline	200 mL/hour
Chainsaw with gasoline	0.52 L/tree
Lawn mower with gasoline	1.2 L/hour
Watering tanker with diesel	5.67 L/hour

4. Interpretation of Results

The results interpretation stage is carried out to identify hotspots (activities that cause the greatest impact category) that are of concern to be controlled or reduced. Then formulate alternative scenarios/ recommendations for activities that can reduce the environmental impact of vegetation maintenance.

Result and Discussion

General Conditions

City Park 1 BSD is administratively located on Letnan Sutopo Street, Lengkong Gudang Village, Serpong District, South Tangerang City. Geographically, the location of City Park 1 BSD is 6°17'17" South Latitude and 106°40'34" East Longitude. The altitude of City Park 1 BSD is around 20-40 meters above sea level with a slope of around 0-5%. The constituent vegetation is dominated by vegetation gardens which function as shade with the most abundant tree species being the king palm (*Roystonea regia*) with 47 trees. Apart from that, there are also trees with aesthetic functions such as the beautiful violin (*Ficus lyrata*) and the resin-like tree (*Agathis dammara*). The planting patterns in City Park 1 BSD are single, grouped, and linear following the jogging track area (Isnaniyah, 2021).

Activity Scope

This research adopts and adapts the LCA approach to vegetation maintenance. The system boundary used in vegetation maintenance is "Gate to Grave" which includes the process of activity stages used to determine the environmental impact of an activity stage. This limitation only covers activities in GOS until final waste disposal. The vegetation maintenance studied is for mature plants, not starting from the beginning, such as preparing land and planting young plants. The activity scope of vegetation maintenance is depicted in a flow diagram (Figure 2).

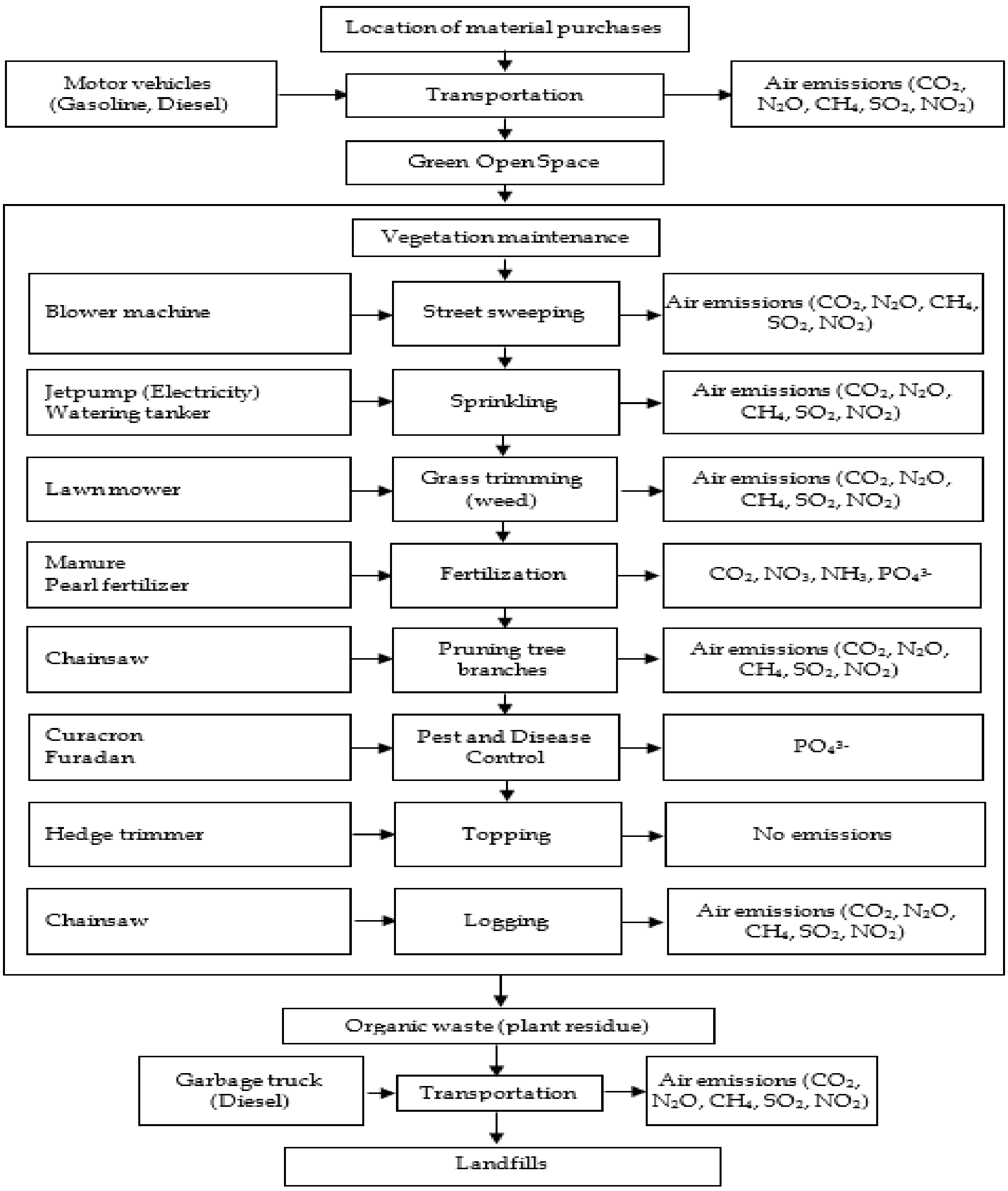

Figure 2. Activity scope

Inventory Analysis

Inventory analysis begins by taking an inventory of the materials and tools used in vegetation maintenance. Data of materials and tools are inventoried based on vegetation maintenance activities carried out in City Park 1 BSD as presented in Table 3.

Table 3. Data on materials and tools in vegetation maintenance in City Park 1 BSD

Activities	Materials		Tools		Intensity of use
	Type	Amount	Type	Amount	
Yard and road sweeping	Used sacks	1440 pcs/ year	Blower machine	1 unit	Every day
Sprinkling	Water (jetpump)	-	Electricity	kWh	1 time/day
			Watering tanker	1 unit	2 times/ week
Weed cutting (weeding)	-	-	Lawn mower	6 unit	1 time/month
Transportation in GOS	-	-	Wheelbarrow	1 unit	As needed
Soil tilling	-	-	Putty knife	5 pcs	As needed
Addition of organic materials and fertilization	Manure	120 sacks/ year	-	-	2 times/year
	Pearl fertilizer	10 kg/ year	-	-	3 times/year
Trimming tree branches	-	-	Chainsaw	1 unit	As needed
Planting flowers	-	-	Cutting scissors	5 pcs	As needed
Pest and disease control	Curacron	8 mL Curacron in 8 L water	Spray tube (8L)	1 unit	1 time/month
	Furadan	10 kg			3 times/year
Cavity treatment	-	-	Cutting scissors	5 pcs	As needed
Tree support	-	-	Machete	1 pcs	As needed
Topping treatment	-	-	Hedge trimmer	1 unit	As needed
Logging	-	-	Chainsaw	1 unit	As needed
Transportation	-	-	Wheelbarrow	1 unit	As needed
Composting	-	-	-	-	-

Input data was taken based on data on materials and tools in vegetation maintenance. The data analyzed are gasoline and diesel fuel, electrical energy, organic solid waste, fertilizer, and pesticides (Table 4).

Table 3. Amount of input for vegetation maintenance in City Park 1 BSD in 1 year

Activities	Input	Unit	Input quantity
Transportation			
Purchase of materials (shop-GOS)	Diesel	liter	1.13
Waste disposal (GOS -Final Disposal Site)	Diesel	liter	153.65
Vegetation maintenance			
Yard and road sweeping	Dry leaves	kg	11,232.00
	Blower machine		
	Gasoline	liter	189,80
Sprinkling	Jetpump		
	Electricity	kWh	6,920.40
	Water tanker		
	Diesel	liter	4,307.12
Weed cutting (weeding)	Lawn mower		
	Gasoline	liter	93.60
Transportation in GOS			-
Soil tilling			-
Addition of organic materials and fertilization	Manure	kg	1,200.00
	Pearl fertilizer	kg	10.00
Trimming tree branches	Chainsaw		
	Gasoline	liter	16.90

Activities	Input	Unit	Input quantity
Planting flowers			-
Pest and disease control	Curacron	kg	96.00
	Furadan	kg	10.00
Cavity treatment			-
Tree support			-
Topping treatment			-
Logging	Chainsaw		
	Gasoline	liter	0.52
	Trees felled	kg	722.44
Transport			-
Composting			-

The output produced is CO_2, N_2O, CH_4, SO_2, NO_2, NO_3, NH_3, and PO_4^{3-} (Table 5). Output data is inventoried, namely the use of materials and tools for a year.

Table 4. The magnitude of emissions from vegetation maintenance in City Park 1 BSD

Activities	Emission type	Unit	Amount of emission
Transportation			
Purchase of materials (shop-GOS)	CO_2	kg CO_2/year	3.00
	N_2O	kg N_2O/year	1.58×10^{-4}
	CH_4	kg CH_4/year	1.58×10^{-4}
	SO_2	kg SO_2/year	2.41×10^{-3}
	NO_2	kg NO_2/year	5.35×10^{-5}
Waste disposal (GOS-FDS)	CO_2	kg CO_2/year	409.87
	N_2O	kg N_2O/year	2.16×10^{-2}
	CH_4	kg CH_4/year	2.16×10^{-2}
	SO_2	kg SO_2/year	0.33
	NO_2	kg NO_2/year	7.31×10^{-3}
Vegetation maintenance			
Yard and road sweeping			
Dry leaves	N_2O	kg N_2O/year	2.70
	CH_4	kg CH_4/year	44.93
Blower machine	CO_2	kg CO_2/year	434.10
	N_2O	kg N_2O/year	2.00×10^{-2}
	CH_4	kg CH_4/year	0.21
	SO_2	kg SO_2/year	0.37
	NO_2	kg NO_2/year	8.28×10^{-3}
Sprinkling			
Electricity	CO_2	kg CO_2/year	5,813.14
	SO_2	kg SO_2/year	56,055.24
	NO_2	kg NO_2/year	28,858.07
Watering tanker	CO_2	kg CO_2/year	11,498.66
	N_2O	kg N_2O/year	0.60
	CH_4	kg CH_4/year	0.60
	SO_2	kg SO_2/year	9.24
	NO_2	kg NO_2/year	0.20
Weed cutting (weeding)			
Lawn mower	CO_2	kg CO_2/year	214.05
	N_2O	kg N_2O/year	9.88×10^{-3}
	CH_4	kg CH_4/year	0.10
	SO_2	kg SO_2/year	0.18
	NO_2	kg NO_2/year	4.08×10^{-3}
Transportation in GOS			-
Soil tilling			-
Fertilization			
Manure	CO_2	kg CO_2/year	240.00
	N_2O	kg N_2O/year	1.20×10^{-2}
	NO_3	kg NO_3/year	4.20×10^{-2}
	NH_3	kg NH_3/year	0.84

Activities	Emission type	Unit	Amount of emission
	PO_4^{3-}	kg PO_4^{3-}/year	0.61
Pearl fertilizer	CO_2	kg CO_2/year	2.00
	N_2O	kg N_2O/year	1.00 x 10^{-4}
	NO_3	kg NO_3/year	8.00 x 10^{-3}
	NH_3	kg NH_3/year	0.16
	PO_4^{3-}	kg PO_4^{3-}/year	0.20
Pruning			
Chainsaw	CO_2	kg CO_2/year	38.64
	N_2O	kg N_2O/year	1.78 x 10^{-3}
	CH_4	kg CH_4/year	1.84 x 10^{-2}
	SO_2	kg SO_2/year	3.32 x 10^{-2}
	NO_2	kg NO_2/year	7.37 x 10^{-4}
Planting flowers			-
Pest control			
Curacron	PO_4^{3-}	kg PO_4^{3-}/year	1.44
Furadan	PO_4^{3-}	kg PO_4^{3-}/year	0.15
Cavity treatment			-
Tree support			-
Topping			-
Logging			
Chainsaw	CO_2	kg CO_2/year	1.19
	N_2O	kg N_2O/year	5.49 x 10^{-5}
	CH_4	kg CH_4/year	5.66 x 10^{-4}
	SO_2	kg SO_2/year	1.02 x 10^{-3}
	NO_2	kg NO_2/year	2.27 x 10^{-5}
Tree felled	N_2O	kg N_2O/year	0.17
	CH_4	kg CH_4/year	2.89
Transport			-
Composting			-

Contribution of Vegetation Maintenance to Environmental Impacts

1. *Global Warming Potential*

Global Warming Potential is a relative measure of the amount of heat trapped by greenhouse gases. GWP is an indication of the number of tons of CO_2 emissions equivalent to one ton of each other greenhouse gas (Prayogi & Sugiono, 2022). GWP comes from Greenhouse Gases (GHG). Greenhouse gases include CO_2, CH_4, N_2O, HFC, CO, NOx, and others. GHG is caused by several activities, especially human activities such as agriculture, industry, energy, transportation, and household waste (Ain et al., 2022). The magnitude of emissions that cause GWP from vegetation maintenance in City Park 1 BSD as in Table 6.

Table 6. The magnitude of emissions causing GWP from vegetation maintenance in City Park 1 BSD

Emission type	Impact source	kg CO_2eq/year
CO_2	Transportation of material purchases	3.00
	Waste disposal transportation	409.87
	Manure	240.00
	Pearl fertilizer	2.00
	Blower machine	434.05
	Electricity	5,813.14
	Watering tanker	11,489.66
	Lawn mower	214.05
	Chainsaw for pruning	38.65
	Chainsaw for logging	1.19
N_2O	Transportation of material purchases	4.71 x 10^{-2}
	Waste disposal transportation	6.43
	Manure	3.58
	Pearl fertilizer	2.98 x 10^{-2}
	Blower machine	5.97
	Watering tanker	180.21
	Lawn mower	2.95

Emission type	Impact source	kg CO_2eq/year
	Chainsaw for pruning	0.53
	Chainsaw for logging	1.64×10^{-2}
	Natural decomposition of dry leaves	803.31
	Natural decomposition of trees	51.67
CH_4	Transportation of material purchases	3.95×10^{-3}
	Waste disposal transportation	0.54
	Blower machine	5.17
	Watering tanker	15.12
	Lawn mower	2.55
	Chainsaw for pruning	0.46
	Chainsaw for logging	1.42×10^{-2}
	Natural decomposition of dry leaves	1,123.20
	Natural decomposition of trees	72.24

Based on Table 6, the source of the highest emission value in City Park 1 BSD is the use of watering tanker. The largest GWP impact generators based on emission sources in City Park 1 BSD, respectively from the largest, are the use of watering tankers, electricity, natural decomposition of dry leaves, blower machines, waste disposal transportation, manure, grass cutting machines, natural decomposition trees, pruning chainsaw, material purchasing transportation, pearl fertilizer, and logging chainsaw.

2. Acidification

SO_2, NO_x, and NH_3 emissions when reacting with water will form H^+ ions in the environment causing acidification of the environment (Ula et al., 2021). Acidification is caused by the leaching of heavy metals in soil and water which increases the concentration of hydrogen ions, thereby lowering the pH. The negative impact is disruption of the food network between animals and plants both on land and in waters (Kim & Chae, 2016). The magnitude of emissions that cause acidification from vegetation maintenance in City Park 1 BSD as in Table 7.

Table 7. The magnitude of emissions that cause acidification from vegetation maintenance in City Park 1 BSD

Emission type	Impact source	kg SO_2eq/year
SO_2	Transportation of material purchases	2.41×10^{-3}
	Waste disposal transportation	0.33
	Blower machine	0.37
	Electricity	56,055.24
	Watering tanker	9.24
	Lawn mower	0.18
	Chainsaw for pruning	3.32×10^{-2}
	Chainsaw for logging	1.02×10^{-3}
NO_2	Transportation of material purchases	3.75×10^{-5}
	Waste disposal transportation	5.12×10^{-3}
	Blower machine	5.80×10^{-3}
	Electricity	20,200.65
	Watering tanker	0.14
	Lawn mower	2.86×10^{-3}
	Chainsaw for pruning	5.16×10^{-4}
	Chainsaw for logging	1.59×10^{-5}
NO_3	Manure	2.94×10^{-2}
	Pearl fertilizer	5.60×10^{-3}
NH_3	Manure	1.58
	Pearl fertilizer	0.30

Table 7 shows that the use of electricity has the highest acidification impact compared to other sources. This is because electricity is used for watering using tap water that comes from a jetpump. The jetpump is used to water once every day. The producers of the largest acidification impacts based on their emission sources are in City Park 1 BSD, respectively from the largest, namely electricity, watering tanker, manure, blower machines, waste disposal transportation, pearl fertilizer, grass cutting machines, pruning chainsaws, purchasing transportation materials, and logging chainsaws. Electricity usage in Indonesia until now still depends on fossil fuels, especially coal. In 2022, coal as a non renewable energy will be the main fuel for power plants up to 62.5% (Myllyvirta et al., 2023).

3. Eutrophication

Eutrophication is caused by high levels of PO_4^{3-}, NO_x, and NH_3 in water. This contaminant results from anthropogenic sources released into the environment (Meirinawati & Wahyudi, 2023). Eutrophication causes rapid growth of algae from nutrient enrichment. When algae die, it will be decomposed in the water by microorganisms. These microorganisms consume oxygen, resulting in a decrease in oxygen in the water. This anaerobic condition causes discoloration and an unpleasant odor. This causes aquatic biota to be unable to survive (Badamasi et al., 2019). The magnitude of emissions that cause eutrophication from vegetation maintenance in City Park 1 BSD as in Table 8.

Table 8. The magnitude of emissions that cause eutrophication from vegetation maintenance in City Park 1 BSD

Emission type	Impact source	kg PO_4^{3-}-eq/year
PO_4^{3-}	Manure	0.61
	Pearl fertilizer	0.20
	Curacron	1.44
	Furadan	0.15
NO_2	Transportation of material purchases	7.00×10^{-6}
	Waste disposal transportation	9.51×10^{-4}
	Blower machine	1.08×10^{-3}
	Electricity	3,751.55
	Watering tanker	2.66×10^{-2}
	Lawn mower	5.31×10^{-4}
	Chainsaw for pruning	9.58×10^{-5}
	Chainsaw for logging	2.90×10^{-6}
NO_3	Manure	5.46×10^{-3}
	Pearl fertilizer	1.04×10^{-3}
NH_3	Manure	0.29
	Pearl fertilizer	5.60×10^{-2}

Table 8 shows that the use of electricity also has a greater eutrophication impact than other sources of impact. The largest producers of eutrophication impacts based on their emission sources in City Park 1 BSD, respectively from the largest, are electricity, curacron, manure, pearl fertilizer, furadan, watering tanker, blower machines, waste disposal transportation, grass cutting machines, chainsaws. pruning, material purchasing transportation, and logging chainsaw.

Interpretation of Results

The results interpretation stage is the final stage in the LCA study of vegetation maintenance. Interpretation of the results is carried out to see the main sources of emissions (hotspots) that have the most influence on vegetation maintenance so that we can analyze improvement efforts that can be made. The total calculated value of vegetation maintenance impact categories per year is presented in Table 9.

Table 9. Total value of GWP emissions, acidification, and eutrophication from vegetation maintenance in City Park 1 BSD

Impact category	Unit	Emission value
GWP	kg CO_2eq/year	20,919.64
Acidification	kg SO_2eq/year	76,268.13
Eutrophication	kg PO_4^{3-}-eq/year	3,754.34

Vegetation maintenance in City Park 1 BSD contributes to higher acidification than GWP or eutrophication. The GWP impact is 20,919.64 kg CO_2eq/year, acidification is 76,268.13 kg SO_2eq/year, and eutrophication is 3,754.34 kg PO_4^{3-}-eq/year. The impact of acidification has the greatest value because of the high contribution to electricity use. Emission values/year/ha from vegetation maintenance are presented in Table 10.

Table 10. Emission/year/ha GWP, acidification, and eutrophication values from vegetation maintenance in City Park 1 BSD

Impact category	Unit	Emission value
GWP	kg CO_2eq/year/ha	8,046.02
Acidification	kg SO_2eq/year/ha	29,333.90
Eutrophication	kg PO_4^{3-}-eq/year/ha	1,443.98

The emission value/year/ha uses data on the total calculated value of vegetation maintenance impact categories per year divided by the area of the city park. In line with the total emission value, the acidification impact category on vegetation maintenance in City Park 1 BSD has a greater impact than GWP and eutrophication. The GWP impact contributed 8,046.02 kg CO_2eq/year/ha, acidification of 29,333.90 kg SO_2eq/year/ha, and eutrophication of 1,443.98 kg PO_4^{3-}-eq/year/ha.

Recommended Environmental Impact Control Scenarios

1. Scenario 1: Reducing the use of watering tankers for watering activities

Watering activities are a hotspot for vegetation maintenance. Frequent watering intensity is once a day using a jetpump and twice a week using a watering tanker. Reducing the use of watering tankers can be done during the peak of the rainy season or when the ground is still wet. Managers must be able to recognize soil conditions with water content that is still sufficiently utilized by vegetation. The aim of Scenario 1 is to reduce fuel emissions from the use watering tanker. During the rainy season, watering is carried out once a day every day without additional watering from a watering tanker. Reducing the use of watering tanker will reduce emissions from fuel use. Reducing the impact of GWP, acidification, and eutrophication from Scenario 1 vegetation maintenance in City Park 1 BSD is presented in Table 11.

Tabel 11. Reducing the impact of GWP, acidification, and eutrophication from Scenario 1 vegetation maintenance in City Park 1 BSD

Impact category	Data	Emission value
GWP (kg CO_2eq/year)	Calculation	17,498.12
	Scenario 1	14,801.58
	Reduced impact	2,696.53
	Percentage	15.41%
Acidification (kg SO_2eq/year)	Calculation	76,265.27
	Scenario 1	76,263.11
	Reduced impact	2.17
	Percentage	0.28%
Eutrophication (kg PO_4^{3-}-eq/year)	Calculation	3,751.58
	Scenario 1	3,751.57
	Reduced impact	6.15×10^{-3}
	Percentage	0.02%

Based on Table 11, vegetation maintenance emissions in City Park 1 BSD decreased by 15.41% for the GWP category, while acidification was 0.28% and eutrophication was 0.02%. The difference in the percentage of emission reduction is due to differences in the types of emissions for each impact.

2. Scenario 2: Reducing the use of machines in yard and road sweeping activities

The use of engines running on fossil fuels can have a negative impact on the environment. The greater use of machines in vegetation maintenance causes higher emission values. This is due to the use of fuel to start the engine. The practice carried out is that the blower machine is used every day at City Park 1 BSD. The aim of Scenario 2 is to reduce emissions from sweeping dry leaves in yards and roads, because the volume of dry leaves is relatively large, namely 120 sacks per month. Reducing the use of blower machines is an alternative for reducing emission values. The use of a blower machine can be done on weekends or national holidays with the aim of making sweeping work time more effective when city parks are busy with visitors. During working days, the use of blower machines can be replaced with manual sweeping by workers. Street sweeping has inputs in the form of dry leaves and a blower machine. Reducing the impact of GWP, acidification and eutrophication from Scenario 2 vegetation maintenance in City Park 1 BSD is presented in Table 12.

Tabel 12. Reducing the impact of GWP, acidification and eutrophication from Scenario 2 vegetation maintenance in City Park 1 BSD

Impact category	Data	Emission value
GWP (kg CO_2eq/year)	Calculation	2,371.71
	Scenario 2	2,078.98
	Reduced impact	292.73
	Percentage	12.34%
Acidification (kg SO_2eq/year)	Calculation	0.38
	Scenario 2	0.13
	Reduced impact	0.25
	Percentage	65.75%
Eutrophication (kg PO_4^{3-}-eq/year)	Calculation	1.08×10^{-3}
	Scenario 2	3.69×10^{-4}
	Reduced impact	7.08×10^{-4}
	Percentage	65.75%

Based on Table 12, vegetation maintenance emissions in City Park 1 BSD decreased by 12.34% for the GWP category, while acidification and eutrophication amounted to 65.75%. The reduction percentage differs greatly between the impact of GWP with acidification and eutrophication. This is because the emission source originating from sweeping dry leaves has a high emission value, whereas acidification and eutrophication of dry leaves are not one of the emission sources. Carbon storage in plants is also contained in dead organs such as dry leaves that fall to the ground. The carbon contained is the result of storage from the sequestration process in the form of capturing CO_2 from the atmosphere (A'la & Winarsih, 2021).

3. Scenario 3: Composting dry leaves resulting from sweeping yards and paths

Utilization of organic waste in the form of dry leaves from sweeping yards and roads can be reused for agricultural needs. The form of utilization of organic waste is in the form of making compost fertilizer. Compost contains nutrients in the form of nitrogen, phosphorus, and potassium. Organic material from plant products contains essential nutrients in the soil which accumulate to become a source of energy and food for plants (Hartatik et al., 2015). Disposal of dry leaf waste originating from City Park 1 BSD to the Final Disposal Site is carried out 3 times per month. The aim of Scenario 3 is that the use of dry leaves for compost can reduce the use of transportation in disposing of waste to landfill. The frequency of transportation can be reduced to once per month, so that the number of dry leaves that can be composted is 40 sacks. Reducing the impact of GWP, acidification and eutrophication from Scenario 3 of BSD City Park 1 vegetation maintenance is presented in Table 13.

Tabel 13. Reducing the impact of GWP, acidification and eutrophication from Scenario 3 vegetation maintenance in City Park 1 BSD

Impact category	Data	Emission value
GWP (kg CO_2eq/year)	Calculation	416.84
	Scenario 3	277.89
	Reduced impact	138.95
	Percentage	33.33%
Acidification (kg SO_2eq/year)	Calculation	0.33
	Scenario 3	0.22
	Reduced impact	0.11
	Percentage	33.33%
Eutrophication (kg PO_4^{3-}-eq/year)	Calculation	9.51×10^{-4}
	Scenario 3	6.34×10^{-4}
	Reduced impact	3.17×10^{-4}
	Percentage	33.33%

Based on Table 13, emissions resulting from vegetation maintenance activities in City Park 1 BSD experienced a decrease in the impact of GWP, acidification and eutrophication by 33.33%. Composting is a form of organic waste processing. Waste processing is part of a waste management system that is carried out in a comprehensive, systematic, and sustainable manner which includes reducing and handling waste (Peraturan Daerah Kota Tangerang Selatan Nomor 13 Tahun 2019 Tentang Perubahan Atas Peraturan Daerah Nomor 3 Tahun 2013 Tentang Pengelolaan Sampah, 2019). The development of a composting unit in City Park 1 BSD by utilizing relatively large amounts of dry leaf waste is a compromise step in controlling environmental impacts, namely reducing the accumulation of leaves that are less pleasing to the eye and providing an environmentally friendly source of organic fertilizer. Indirectly, composting reduces the use of fossil fuels which produce emissions due to transportation (Sunarto et al., 2014).

Implications of Research Results for Strengthening Environmental Science Literacy

Life Cycle Assessment is a method to track the impacts that have occurred from each stage of activity. The learning materials obtained from this study are the types and amounts of emissions from each stage of vegetation maintenance activities, their impacts on the environment, and control scenarios. Activities in vegetation maintenance including transportation, purchasing materials and waste disposal, as well as maintenance activities in green open spaces can contribute to GWP, acidification, and eutrophication.

Learning materials from LCA can be used to improve environmental science literacy for high school and college students with different learning methods and material scopes (Viere et al., 2021). LCA materials for high school students are introductory in nature which can be integrated into teaching materials in one of the subjects or special modules. The LCA learning method for college students is by analyzing case studies, starting from identifying stages of activity, types and amounts of emissions, determining hotspots, and control scenarios.

Public education can be aimed at managers and visitors of city parks. Educational content for managers can be outlined in guidelines or standard operating procedures, either in printed documents or attractive digital files. The main content is the stages of emission control according to the scenarios produced in the research. City parks for visitors can be used as educational parks that provide information on the function and management of environmentally friendly city parks. The strategy for implementing public education in city parks can be in the form of using information boards or smart education, for example using virtual reality smart explanation, smart service robots, and artificial intelligence (Xie et al., 2024). Understanding and awareness of the importance of quality environmental conditions will foster responsible attitudes and behaviors towards controlling negative environmental impacts (Miller et al., 2022). This can be implemented in vegetation maintenance through saving the use of water pumps, electricity for lighting, sweeping machines, using low-emission materials, and processing organic waste in-situ (on site).

Conclusion

Vegetation maintenance in green open spaces that produces an impact on the environment is transportation, purchasing materials and waste disposal, sweeping yards and paths, watering, cutting weeds, adding organic material, and fertilizing, pruning tree branches, controlling pests and diseases, and felling trees. The inputs (materials) inventoried are petrol and diesel fuel, electricity, manure and pearl fertilizer, curacron and furadan, as well as dry leaves and felled trees, while the output produced is CO_2, N_2O, CH_4, SO_2, NO_2, NO_3, NH_3, and PO_4^{3-}. Acidification emissions resulting from vegetation maintenance in City Park 1 BSD have a higher value than the impact of GWP and eutrophication. Hotspots for vegetation maintenance are the use of electricity and watering tankers. Impact control that can be carried out is reducing the use of watering tankers, reducing the use of blower machines, and composting dry leaves resulting from sweeping yards and road paths. The LCA-based environmental impact analysis can also serve as a contextual learning resource in science education related to environmental sustainability and urban ecology.

Acknowledgments
The author gives an appreciation to the management of City Park 1 BSD, Environmental Service of South Tangerang City, National and Political Unity Agency of South Tangerang City, and Tropical Biodiversity Conservation Study Program.

Author Contributions
RH: Conceptualization, Review & Editing; LAR: Writing & Editing; ER: Analysis, Review.

Conflicts of Interest
The authors declare no conflict of interest.

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