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RESEARCH ARTICLE

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Carbon Footprint of Elephant Management in Ragunan Wildlife Park Using Life Cycle Assessment Approach

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ABSTRACT

Tourism significantly contributes to Indonesia's economy but poses environmental challenges, particularly climate change. Ragunan Wildlife Park, an urban tourism site, faces sustainability concerns, with elephant management identified as a key carbon emission source due to their high food intake. In its development, urban tourism needs to be controlled and well-designed to be sustainable. This study aimed to identify potential impacts and calculate the carbon emissions generated by elephant management. Elephants were chosen for this study because they consume more food and generate higher carbon emissions than other animals in the zoo. Life Cycle Assessment (LCA) was used to evaluate the environmental impact quantitatively. This research was conducted using LCA within a gate-to-gate boundary. The research began with the observation of Ragunan Wildlife Park to identify input-process-output components in elephant management. The results show that elephant management in Ragunan Wildlife Park generates a carbon footprint of 4.62 kg CO_2-eq per unit of elephant dung, with the hotspot of greenhouse gas emissions being elephant feed, particularly elephant grass. These findings emphasize the need for sustainable feed management to reduce emissions in urban zoo.

Introduction

Indonesia's tourism industry is a significant economic driver and ranks as the country's second-largest source of foreign exchange [1]. Urban tourism is increasingly popular among various tourism segments, especially for city residents seeking nearby, affordable, and time-efficient travel experiences [2]. One prominent urban tourist destination in Jakarta is Ragunan Wildlife Park. It is an ex-situ animal conservation area, conserving wildlife outside their natural habitats. Ragunan Wildlife Park mainly maintains the entire animal collection to avoid the extinction of scarce and protected animals. Ragunan Wildlife Park can accommodate 2,000 animals, has more than 50,000 trees, and is one of the destinations that families often visit because it is a tourist destination and one of the zoos in Indonesia. Ragunan Wildlife Park is one of the ex-situ conservation areas that serves as a place of maintenance and protection for mammalian animals, including the Sumatran elephant. Sumatran elephants (*Elephas maximus sumatranus*) are a subspecies of Asian elephants found along the island of Sumatra [3]. Sumatran elephants were declared animals listed on the IUCN (International Union for Conservation of Nature) Red List Book 2011 in the critically endangered category [4]. Sumatran elephants are megaherbivorous animals**,** a type of mammal that has a large body and eats many plants [5]. Besides eating, elephants also need a lot of water to drink, wallow, or spray on their bodies [6].

Elephant as mammals, can drink 20–50 liters of water daily and take in up to 9 litres in a single intake [7]. The management of elephant in Ragunan Wildlife Park should not have a negative impact on other land functions or the surrounding environment. Environmental impacts resulting from tourism development must be realized as early as possible so that Ragunan Wildlife Park does not develop into an uncontrolled tourist activity. The management of elephant in Ragunan Wildlife Park produces outputs in the form of emissions, feed residues, solid waste, and liquid waste, which, if not considered, will hurt the environment. Gases such

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as greenhouse gases, hydrogen sulphide, nitrogen, CO_2, and CH_4 are generated from animal feces [8]. In addition, animal wastes also cause unpleasant odors and interfere with human health. Animal waste can degrade soil quality, leading to pollution and reduced land productivity. In water, pathogenic (disease-causing) microorganisms derived from animal waste will pollute the aquatic environment [9].

Livestock sector emissions impact radiative forcing in several ways. Long-lived greenhouse gases, such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), are produced from fossil fuel use, land use, and land use changes [10]. The relationship between tourism and climate change, particularly its carbon footprint, has become a key research focus in sustainable tourism [11]. Carbon emissions contribute to climate change and ozone depletion, leading to more severe environmental effects [12]. Rising carbon emissions have resulted in a carbon levy or footprint tax, as outlined in Law No. 16 of 2016, which ratified the Paris Agreement to the UN Framework Convention on Climate Change [13]. National greenhouse gas accounting should reflect how countries' policies and behaviors affect global emissions, such as carbon footprints [14].

Global warming potential for 100 years (GWP 100) represents the amount of carbon dioxide emissions [15]. In this study, the global warming potential is calculated based on CO_2 emissions from elephant-rearing activities such as elephant feed, electricity for lighting and water supply, and transportation to deliver elephant feed from the feed supply place to the enclosure. Carbon emissions from events, products, and activities that impact the environment are called carbon footprints [16]. Carbon footprint measures human activities that impact the environment [17]. Carbon footprint (CF) is an acronym for a professional term used widely in the public sphere to address the threats posed by climate change [18]. The most efficient on-farm activity in reducing greenhouse gas emissions is full grazing, and excluding green crops from the diet in the case of keeping in stalls will reduce emissions [19]. Based on the reference search, no studies have quantified CO_2 emissions from elephant rearing, assessed the contribution of wild elephants to emissions, or focused on elephant dung processing. This discussion should be introduced at the beginning, following the CO_2 emissions calculations.

Many studies have examined CO_2 emissions from livestock, including their derivative products such as milk, cheese, meat, eggs, and manure [20,21]. So far, studies on elephants have focused more on conservation, interactions with the environment, other animals and humans, breeding, and protection [22,23]. As protected animals, Sumatran elephants require many resources, such as food and water, which impacts the environment. Several studies have researched elephant contributions to CO_2 emissions and the reduction in wild elephants [24]. This study contributes to calculating how much CO_2 emissions are from elephant-rearing activities. The amount of CO_2 emissions generated becomes a reference in developing elephant-rearing patterns. Based on this, the goal of elephant conservation in Ragunan Wildlife Park can be fulfilled, and possible environmental impacts can be anticipated.

Based on the reference search results, no research calculates CO_2 gas emissions from elephant rearing activities, the contribution of wild elephants in the forest, or the focus on elephant dung processing. Livestock production is a major contributor to greenhouse gas emissions and plays a crucial role in mitigation efforts [25]. Based on this, an analysis of the environmental impacts can be done using the life cycle assessment (LCA) method. The LCA method can identify and analyze the cumulative environmental impacts from all stages of the product/activity life cycle, so that it will be known which parts have the most significant environmental impact [26]. The carbon footprint was calculated using the 100-year Global Warming Potential (GWP100) metric, as recommended by ISO and key international LCA guidelines [27]. The LCA analysis results are expected to enhance elephant management, making it more efficient while reducing environmental impacts.

Methodology

Time and Study Location

This study was conducted at Ragunan Wildlife Park, located in South Jakarta, Indonesia (Figure 1). Ragunan Wildlife Park is an ex-situ conservation area established in 1966 and managed by the Jakarta Provincial Government. The zoo occupies approximately 147 hectares, accommodating more than 2,000 animals and over 50,000 trees, functioning both as a conservation site and a public recreation facility. The focus of this research was the management of Sumatran elephants (*Elephas maximus sumatranus*) in Ragunan Wildlife Park. As of January 2024, there were 14 elephants consisting of 5 males and 9 females, kept in three enclosures. The elephants vary in age, including both adult and younger individuals. Each enclosure is equipped with facilities such as water supply for drinking and bathing, daily feed distribution, and lighting. Primary and secondary data were collected during the period of January–June 2024, through field observations, interviews with keepers, and official documentation from Ragunan Wildlife Park management.

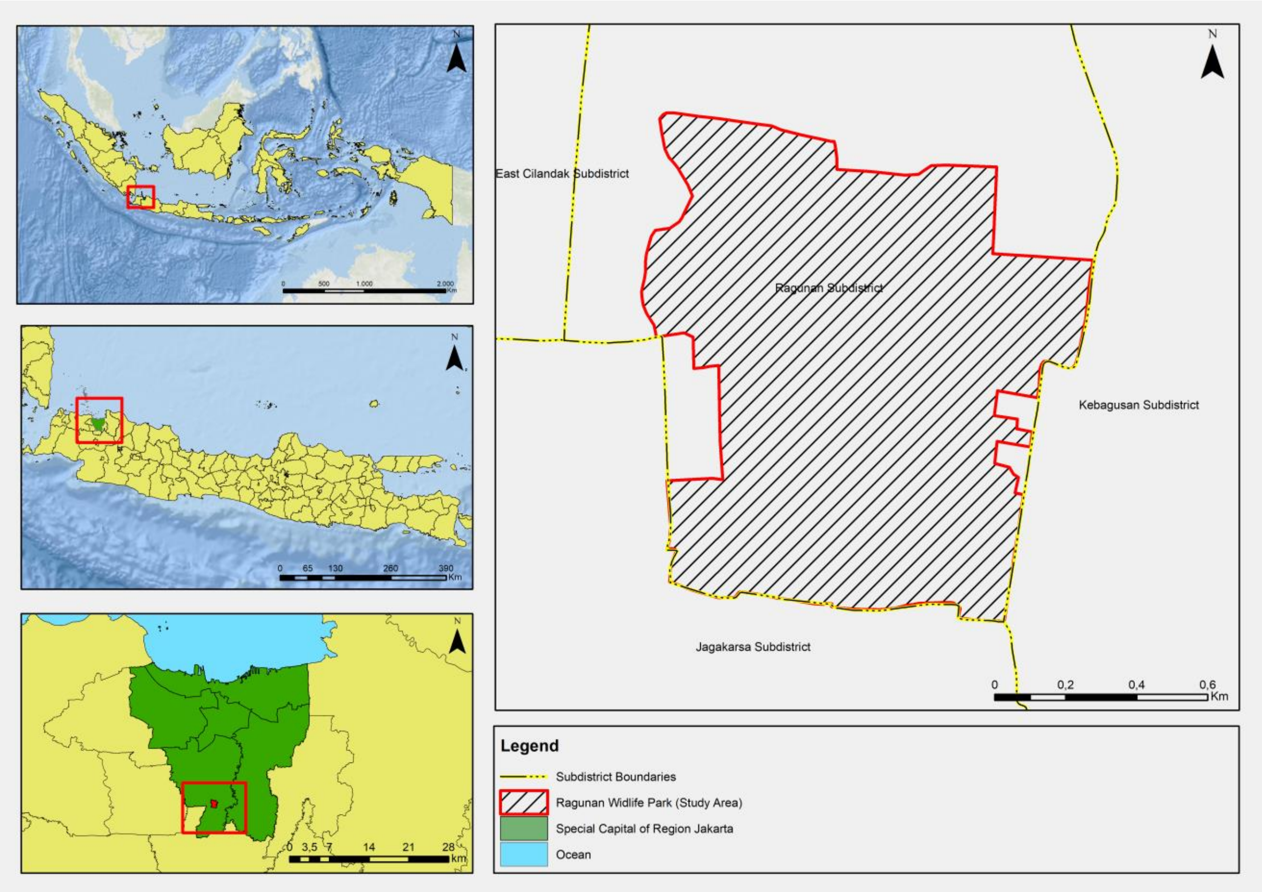

Figure 1. Study area: Ragunan Wildlife Park, Jakarta, Indonesia.

Data Collection and Analysis

The environmental impact analysis was carried out using the Life Cycle Assessment (LCA) approach to quantify the carbon footprint of elephant management. LCA is a technique for assessing the environmental aspects associated with the life cycle of a product [28]. Primary data were collected from direct observation of feeding, water use, waste generation, and energy consumption, supported by interviews with keepers. Secondary data were obtained from Ragunan Wildlife Park internal records, previous studies, and databases integrated into the LCA modeling. The analysis was performed using SimaPro® version 9.1.1.7 with the CML-IA baseline v3.06 method. Input and output data were entered based on the Ecoinvent 3 and Agrifootprint 5 databases. The selected impact category was Global Warming Potential (GWP100), expressed as CO_2-equivalent, as it represents the most relevant indicator for carbon footprint analysis.

Study Boundary

The Life Cycle Assessment (LCA) in this study was carried out using SimaPro software with a gate-to-gate scope, focusing specifically on the impacts of Sumatran elephant management activities in Ragunan Wildlife Park. The assessment followed the four stages defined in ISO 14040 [29]. The first stage was the goal and scope definition, where the study aimed to assess the environmental impacts of Sumatran elephant management in captivity. The system boundary was limited to the gate-to-gate stage, and the functional unit was defined as one Sumatran elephant. The second stage was the life cycle inventory (LCI) analysis, which involved collecting data on inputs such as resources, feed, and energy use, as well as outputs in the form of waste and emissions [30]. Primary data were obtained through direct field measurements, while secondary data were collected from Ragunan Wildlife Park management documents, the Ecoinvent 3, and Agrifootprint 5 databases in SimaPro. The inventory analysis modeled the flow of inputs and outputs across all sub-systems of elephant management. The third stage was the life cycle impact assessment (LCIA), in which the potential environmental impacts were evaluated using the CML-IA (baseline) method developed by the Institute of Environmental Sciences, Leiden University. This method was selected because it is widely applied in tourism-related LCA studies. The impact category chosen was Global Warming Potential (GWP), as it has the most significant effect on the environment, is widely used in LCA studies, and directly relates to carbon emissions. Finally, the interpretation stage involved identifying and evaluating significant sources of impact (hotspots) within the system, followed by the development of recommendations to minimize negative effects. Suggested improvements include process efficiency and waste utilization. Overall, the LCA results provide insights into the key processes that contribute most to carbon emissions and offer potential strategies for improving the sustainability of elephant management at Ragunan Wildlife Park [31]. The scope of the LCA study was gate-to-gate in the process of livestock in elephant enclosure. The management of elephant mammals in the enclosure has several activities that serve as process inputs, involve the transportation of animal feed from suppliers to boundaries, the provision of water for the bathing and drinking needs of elephants, the illumination of enclosures at night, and the production waste in the form of manure from livestock (elephant dung), which can be used as functional units in calculating the resultant carbon footprint. The scope of the LCA study conducted can be seen in Figure 2.

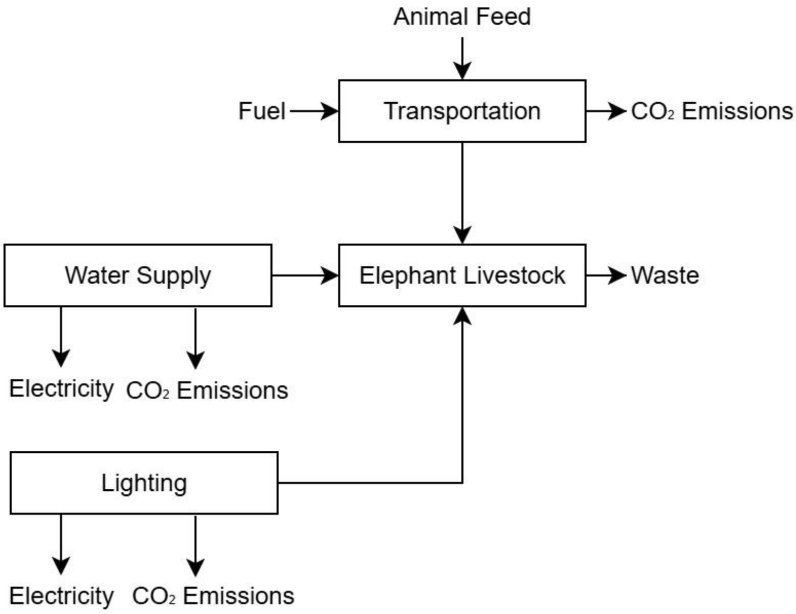

Figure 2. The research scope of the LCA study on elephant management in an enclosure.

Results and Discussion

Results

Sumatran elephants in Ragunan Wildlife Park are a subspecies of Asian elephants that only live on the island of Sumatra. Sumatran elephants are smaller in stature than the Indian elephant subspecies. Their population is declining, and they have become a highly threatened species. Sumatran elephants in Ragunan Wildlife Park are scientifically classified as a class of mammals and a subspecies of Asian elephants, so they are named *Elephas maximus sumatranus.*

Development Sumatran female elephants reach adulthood between 8 and 10 years of age. Their gestation period lasts 19 to 21 months, resulting in the birth of a single calf. The daily activities of Sumatran elephants in Ragunan Wildlife Park are the same as those of other Sumatran elephants, which are influenced by weather conditions and elephant health factors. Elephants are more likely to perform feeding activities in the morning when the weather is still cool compared to the afternoon when the weather is hot, elephants tend to forage and move. The number of Sumatran elephants in Ragunan Wildlife Park as of January 2024 is 14 (5 males, nine females).

The carbon footprint analysis showed that each elephant produces 4.62 kg CO_2-eq of greenhouse gas emissions daily, primarily from feed consumption. Inventory data revealed that elephants consume around

150 kg of elephant grass per day, in addition to supplementary feed such as bananas (7.5 kg/day), papayas (1 kg/day), sugarcane (every 2 weeks), and other local feed. Daily outputs include approximately 20 kg of solid waste (dung) and 4–5 m^3 of liquid waste per elephant. Energy consumption was recorded at 3.72 kWh for water pumping and 0.43 kWh for lighting, while transportation for feed distribution consumed 2.15 liters of gasoline daily. These quantitative findings provide measurable evidence of environmental impacts and strengthen the results by linking daily management activities to their corresponding carbon footprint values.

Discussion

Life Cycle Inventory Data Analysis

A life cycle inventory (LCI) analysis was conducted to track resource consumption such as feed, raw materials, and energy, and waste production, including emissions, throughout the elephant management process. The existence of elephants in an ecosystem was important. Reducing the carbon footprint was needed to minimize the negative impacts of domesticated elephants. At this stage, quantitative data were collected to determine the value of potential environmental impacts. Animal management impact data from animal feed and energy are taken from the SimaPro database, so that the impact of animal feed and energy can be calculated by the impact of animal feed with data on animal feed and energy requirements. Input and output data from the Sumatran elephant mammal management process inventory at Ragunan Wildlife Park have been converted based on the unit of function in the gate-to-gate cycle, namely the Sumatran elephant as seen in Table 1 below.

Table 1. Inventory data on one elephant activity in an enclosure.

Process	Input/output	Quantity	Units	Description
	Input			
Animal feed	Elephant grass	150	kg	Every day
	Siamese banana	7.5	kg	Every day
	Papaya	1	kg	Every day
	Yam	3	kg	Every day
	Corn husk	2.5	kg	Every day
	Coconut	1	pieces	Every day
	Carrot	1.5	pieces	Every day
	Sugarcane	3	stalks	Every 2 weeks
	Brown sugar	1.25	kg	Per month
Water supply	Water	20–30	litre	Every day
	Electricity	3.72	kWh	
Transportation	Gasoline	2.15	litre	Every day
Lighting	Electricity	4.29×10^{-1}	kWh	Every day
	Output			
Elephant activity in the enclosure	Elephant dung (solid waste)	20	kg	Every day
	Liquid waste	4–5	m^3	Every day

Ragunan Wildlife Park has three elephant enclosures. Based on Table 1, the largest input material in the management of elephant was from animal feed. Elephants consume large volumes of animal feed every day, especially elephant grass. In addition, the inventory data in Table 1 also showed that electrical energy is used in water pumps for water supply and lighting (lamps) in each enclosure. The inventory data also showed the use of gasoline as a transportation fuel for the distribution of elephant feed from the feed station to each enclosure. Elephant feed was prepared centrally in the animal feed unit. Feed ingredients were received by the animal feed unit for sorting before distribution to each enclosure. Feed distribution was done once a day for two meals and one snack. It can reduce vehicle emissions when distributing feed. The distance between the feed unit and the elephant enclosure averages 700 m. Based on the feed distribution pattern and the distance between the feed unit and the elephant's enclosure, which is not too far away, it contributes to controlling CO_2 emissions from internal transportation. The unit determined in this carbon footprint study was based on one elephant, which will be used as a reference in the life cycle impact assessment analysis and interpretation of results.

Life Cycle Impact Assessment Analysis

Life cycle impact analysis of several parameters or impact categories that cause carbon footprints using SimaPro ver. 9.0 software. Inventory data obtained at the inventory data analysis stage was processed with SimaPro software, which produced a total carbon footprint that will be generated while managing one elephant. Some processes that contribute to the most significant carbon footprint were animal feed in the form of elephant grass at 4.26 kg CO_2-eq, electricity use at 0.146 kg CO_2-eq, and gasoline use for transportation at 0.014 kg CO_2-eq (Figure 3).

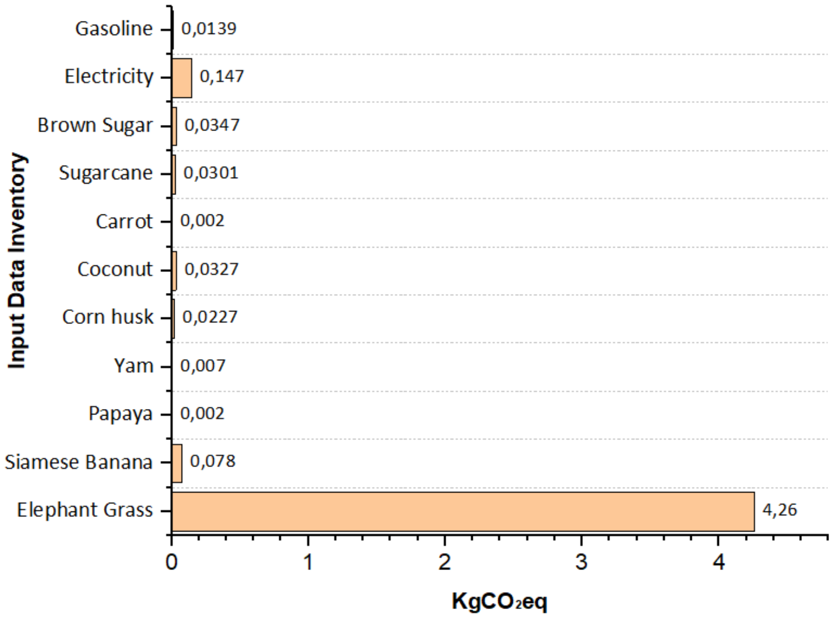

Figure 3. Distribution of carbon footprint emissions on elephant management in an enclosure.

The inventory analysis stage also determines the hotspots (primary sources) of the highest feed and energy use or the most significant sources of waste that produce environmental impacts. In elephant husbandry activities, the highest contribution to global warming potential through the formation of CO_2 was fed in the form of elephant grass. This was because each elephant consumes between 150–170 kg/day of vegetation for an adult elephant [32]. The main food for elephants in Ragunan Wildlife Park was elephant grass. This large feed requirement was one of the reasons for the high contribution of elephant grass feed to the animal's carbon footprint.

The carbon footprint analysis showed that each elephant produces 4.62 kg CO_2-eq of greenhouse gas emissions daily, primarily from its feeding cycle. The greenhouse gas emissions in a sector were closely linked to its carbon footprint. Research on biogas potential suggests that elephant dung can generate 0.020 L of methane (CH_4) per gram. With an average daily dung output of 100 kg, this equates to 37.4 kg CO_2-eq per day [33]. This discrepancy suggests that the 4.62 kg value may exclude methane released during anaerobic decomposition or focus on a specific management practice (e.g., controlled composting vs. natural decomposition). Greenhouse gases trap solar radiation in the Earth's atmosphere, leading to rising global temperatures and climate change [34]. Figure 4 illustrated the LCA results of elephant management.

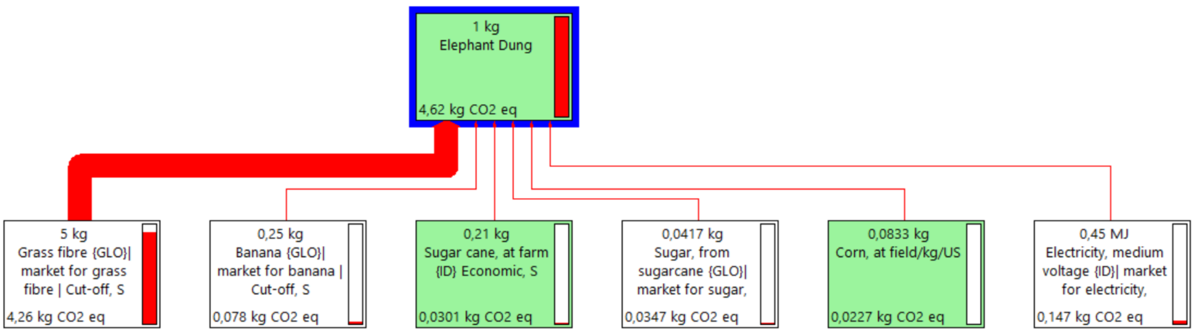

Figure 4. Distribution of impact sources on carbon footprint.

The livestock sector strongly focuses on reducing greenhouse gas emissions. Long-term emissions tracking will help determine whether the industry is meeting its reduction targets [35]. Sumatran elephants in

Ragunan Wildlife Park were mammals that consumed a large amount of elephant grass as their main food. An increasing elephant population requires larger amounts of elephant grass as its primary food source. Based on Figure 4, the hotspot of elephant management was the form of feed from procuring feed in elephant grass. Sumatran elephants in Ragunan Wildlife Park consume a large amount of feed daily. This high feed demand leads to increased carbon emissions from transportation and more livestock waste, contributing to a higher carbon footprint. Greenhouse gas emissions in livestock activities arise from concentrate feed production and transportation, fertilizer manufacturing for on-farm feed, and electricity usage, one of the largest contributors to off-farm emissions [36]. Livestock production contributed to the environmental carbon footprint through enteric fermentation, manure emissions, resource-intensive feed, and energy use [37]. Poor elephant health can lead to increased carbon emissions, as sick elephants require additional vitamins and medicines, contributing to their overall carbon footprint [38].

The process of transporting feed to the elephant's enclosure has an environmental impact. The magnitude of the environmental impact value on the transportation unit comes from the use of fuel. The magnitude of the environmental impact value on the transportation process unit is calculated using SimaPro software with units of tons.km (tkm) and the assumption of one trip by adjusting the scope of the research conducted. The livestock sector contributed to greenhouse gas emissions both directly, through animal digestion and manure, and indirectly via feed production, energy consumption, and transportation. Indirect emissions resulting from livestock management include emissions from feed crops, livestock operations, manure application, transportation, animal product processing, and land use allocation for animal production.

In contrast, direct emissions from livestock sources refer to livestock fermentation. Direct emissions from livestock sources refer to enteric fermentation, excretion, and respiration. Greenhouse gases are nitrous oxide and carbon dioxide. About 44% of animal emissions are CH_4, while N_2O represents 29% and CO_2 represents 27%. Livestock contributes to global greenhouse gas emissions. Global greenhouse gas emissions from the livestock sector are about 14.5% [39]. These percentages reflect the breakdown of emissions within the livestock sector, not the proportion of global emissions by each gas.

Elephants played a crucial role in maintaining ecosystem balance. Minimizing their carbon footprint was essential to reduce the environmental impact of domesticated populations. Calculation showed that the carbon emissions from animal feed, which were 4.26 kg CO_2-eq, similar to the emissions from driving a gasoline car for about 17 kilometres. Using electricity that produced 0.146 kg CO2-eq was equivalent to use 10-watt LED lamp for over 600 hours. Using gasoline for transportation with emissions of 0.014 kg CO_2-eq may be equivalent to driving about 50 meters with a gasoline-fuelled car. Therefore, from several hotspots of emission sources, a strategy was formulated that focused on carbon emission hotspots, including 1) sustainable feed management, namely in the form of utilizing local feed to reduce carbon emissions from the transportation side, and utilizing agroforestry programs by planting animal feed around Ragunan Wildlife Park for sustainable feed provision and increasing biodiversity in Ragunan Wildlife Park; 2) efficient use of energy, namely through the utilization of new renewable energy and evaluation of natural lighting levels to reduce electricity consumption for lighting; 3) waste reduction, namely through the process of recycling feces and feed waste so that it can be reused and increasing awareness of all officers to reduce waste in the form of feed that is wasted during the maintenance process; and 4) sustainable transportation in elephant maintenance, namely by minimizing elephant mobilization using vehicles and utilizing electrical energy for transportation that carries feed or is used for elephant mobilization. Therefore, proper care of elephants can help not only from a conservation aspect but also for the environment.

Strategies for reducing CO_2 emissions include 1) feed diversification, feed diversification to complement the main feed of elephant grass can reduce CO_2 emissions. The gas CO_2 emissions produced in the dung of elephants that consume only elephant grass were 7.41% higher than those of elephants that consume a combination of elephant grass with bananas or other feed [40]. 2) Utilization of elephant dung as an alternative energy source. Elephant feces generation was directly proportional to the amount of feed it consumes. Elephant faces weighing 50–100 kg can produce as much as 50 m^3 of biogas, or equivalent to 20–25 kWh of electrical energy [41]. Elephant faces produced comparable amounts of biogas to faces from other animals, such as pigs and cows [42]. Thus, the presence of domesticated elephants utilizing elephant dung can reduce CO_2 emissions into the environment. 3) Sustainable feed management, which includes the use of local feed to avoid additional carbon emissions from transportation and the use of agroforestry programs by planting fodder around Ragunan Wildlife Park to provide feed sustainably and increase biodiversity in Ragunan Wildlife Park. 4) Efficient feed procurement, proper sorting of elephant feed and good feed quality will increase the appetite of the elephants. This reduces the potential for feed to be left over, as elephants do not have the appetite to eat it. This contributes to carbon emissions from feed decay and risks elephant health. Impaired elephant health will increase CO_2 emissions from the use of medicines and vitamins. 5) Efficient in the use of energy, the use of environmentally friendly energy in the form of products from elephant dung processing can reduce the use of electricity. This can reduce CO_2 emissions from elephant care activities.

Conclusions

Management of elephant has the potential to produce a carbon footprint that will contribute to the concentration of global greenhouse gas values. The analysis using life cycle assessment results showed that one elephant unit produced a carbon footprint of 4.62 kg CO_2-eq/elephant dung. The greenhouse gas emission-contributing sector that become a hotspot was fed elephant grass. Therefore, to reduce the footprint of victims from elephant management activities, greenhouse gas emission mitigation efforts were more focused on providing elephant feed in the form of elephant grass with sustainable feed management, efficient energy use, reducing waste, and sustainable transportation during elephant rearing.

Author Contributions

NG: Conceptualization, Methodology, Investigation, Writing - Review & Editing; **SAZ:** Data Curation, Formal Analysis, Software, Investigation, Writing - Review & Editing, Project Administration, Funding Acquisition.

Conflicts of Interest

There are no conflicts to declare.

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