Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2021.27957

244 (2021) 55–62
December

Environmental impact of municipal wastewater management based on analysis of life cycle assessment in Denpasar City

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Received 20 April 2021; Accepted 30 October 2021

ABSTRACT

The municipal wastewater treatment in Denpasar City has a service target of 100%, which supports the Ministry of Public Works and Public Housing (PUPR), Indonesia. The total wastewater produced by Denpasar City is around 43,920 m^3/y. Currently, a centralized wastewater treatment plant treats only 3% of wastewater. In comparison, the rest of 96.8% is carried out by onsite treatment with septic tanks, and 0.2% is directly discharged into the environment (open defecation). This study examined the eutrophication impact generated by each wastewater management based on the analysis of the Life Cycle Assessment (LCA). The analysis was conducted using the Simapro ver. 9.1 software and observed the eutrophication impact potential generated for each wastewater management system. The inventory results showed that open defecation management was the largest pollution load, although the quantity of water contributed was very low (0.2%). The weighting of the impact of eutrophication, global warming potential, photochemical oxidation, and water scarcity on fecal management showed the same weight for open defecation behavior (346.8 pt). In comparison, the wastewater treatment plant (WWTP) and septic tanks were 2.1 and 52.1 pt, respectively. Open defecation behavior must be eliminated by formulating a right strategy. Treatment with septic tanks should be directed to centralized treatment by applying the tertiary treatment. Also, a sustainable development strategy needs to be applied in Denpasar City and more broadly throughout Indonesia and other developing countries where the population still applies open defecation.

Keywords: Denpasar City; Eutrophication; LCA; Municipal wastewater; Wastewater treatment

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1. Introduction

Bali Province is a national tourism icon and the main destination for international-scale tourism in Indonesia. The emergence of various environmental problems also follows the tourism growth sector and the development pace of Bali's tourism places. Pollution caused by rapid population growth, service industry, and tourism activities worsens the quality of environmental sanitation. One of the environmental problems that occur due to pollution caused by poor sanitation is eutrophication. Eutrophication can cause the blooms of algae and rooted aquatic plants to float because of the high nutrients contained in water bodies. Denpasar is the center of government in the Bali Province, showing the perception of households and businesses about wastewater management, which can cause water body pollution [1]. To prevent that, the effort that can be carried out is by using plants in wastewater treatment [2].

Not all generated wastewaters can be treated in the wastewater treatment plant (WWTP). The number of house connections in the Denpasar Sewerage Development Program (DSDP) in 2016 reached 8,500 house connections (HC) or equivalent to 3% of the population in Denpasar [3]. Domestic wastewater management in Denpasar is still dominated by the local system, with a value of 96.8% of the total population [3]. Based Total Sanitation Data (STBM) managed by the Indonesian Ministry of Health in 2017 showed that 0.2% of the Denpasar population still has open defecation (OD) behavior [4]. The results showed that open defecation behavior contained 12% positive feces of entering toxigenic *Escherichia coli*, 7.7% of *Giardia* sp., 3.8% of norovirus, and 3.8% of *Salmonella* sp. [5]. Epidemiological studies also showed an increasing risk of diarrheal diseases related to the use of communal sanitation facilities [6]. The practise of open defecation is influenced by demographic factors such as individual age, gender, place in the family hierarchy, time spent outside the home, and external factors such as personal security and privacy [7]. The behavior of open defecation is a daily habit in the open environment, commonly in water bodies, so that the dirt spreads and pollutes the environment [8].

One of the most important water bodies in Denpasar City is the Benoa Bay area. Previous research stated that the water quality index in the waters around Benoa Bay was polluted [9–12]. Benoa Bay waters estuary of six major rivers: Bualu, Sama, Mati, Badung, Buaji, and Loloan Rivers, potentially trigger the eutrophication process [11]. If eutrophication is left alone, it will affect marine meiofauna's biodiversity in Bali [13]. Besides causing health impacts, sanitation management also is potential to bring a number of environmental impacts. Public facilities such as wastewater treatment plants have contributed large amounts of greenhouse gases [14,15]. Another impact of the wastewater treatment process is photochemical oxidation [16]. The increase in photochemical oxidation is due to the emission of CH_4 from the degradation process of organic material in wastewater [17]. The most critical impact is water scarcity based on the number of water resources and water quality decline. Municipal water resources reliability and uncertainty are associated with financial sanitation management [18].

Fecal sanitation management in Indonesia still pays little attention to the environmental impacts arising from its production activities. The centrally improve water treatment services are often ignored because it requires high costs. This research aims to identify the impact of a series of fecal management processes in Denpasar City using a life cycle assessment (LCA) approach. LCA is a method used to produce information about environmental impacts occurred. It can analyze and can compare several processes or systems that contribute to environmental damage. In this study, the use of LCA is expected to identify and to evaluate the environmental performance of the process and to determine an essential idea for environmental improvement.

2. Materials and methods

This research's methodology was referenced to the LCA step as follows: goal and scope definition, inventory analysis, impact assessment, and interpretation. The LCA analysis was conducted by using Simapro ver. 9.1 software.

2.1. Goal and scope

This LCA study's scope is in fecal management activities with a centralized system, those with wastewater treatment plants, pesticides, and opens defecation. The scope of the LCA study is shown in Fig. 1.

2.2. Inventory analysis

At this stage, all boundary systems of product object complex were modeled as objects, For each process, all relevant inflows and outflows were collected. The inventory of the water quality can be determined by Eq. (1). The factors of water quality and water discharge were used based on the research of Abfertiawan et al. [3]. Water quality and water discharge data can be seen in Table 1.

$$\text{Mass}_{\text{in/out}} = \text{Flow rate (m}^3\text{/year) x Pollution Parameter Concentration (mg/m}^3\text{)} \quad (1)$$

To determine WWTP emissions, an emission calculation based on electricity usage was conducted. Previous research on DSDP showed electricity consumption reaching 0.5–0.7 kWh/1,000 m^3 wastewater for organic removal and 1.0–1.1 kWh/1,000 m^3 wastewater for nutrient removal [19]. This study used the existing condition of wastewater treatment with 5,238 kWh/d [20]. The equation used to determine electricity usage emissions was based on Table 2. However, to determine domestic waste emissions, the IPCC (2007) program with equation two was used.

$$CO_2 \text{ emissions} = \text{BOD or COD load (kg/year)} \times \text{BOD or COD emission factors} \quad (2)$$

2.3. Impact assessment

The resulting environmental impact was assessed using the Environmental Product Declarations (EPD) 2018 method. Simapro ver. 9.1 software was used to analyze the impacts, where the method used was EPD 2018, using a number of

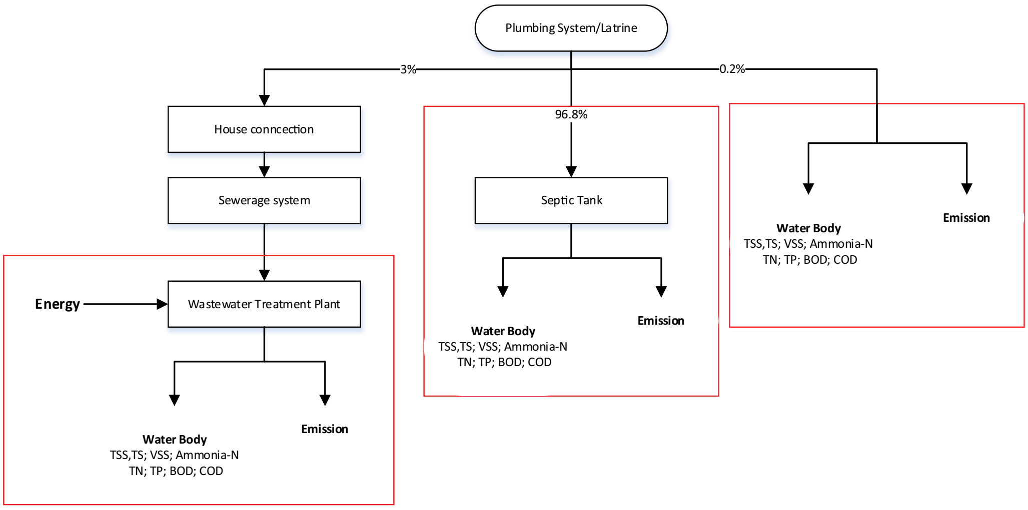

Fig. 1. Diagram of the process and scope of LCA feces management in Denpasar.

Table 1
The fecal sludge quality in each management in Denpasar [3]

Parameter	WWTP	Septic Tank	Open Defecation
Water discharge, m^3/y	1,099.85	35,488.48	7,332
Service percentage, %	3	96.8	0.2
Ammonia, mg/L	19.30 ± 8	40.15 ± 23	163.95 ± 147
Free ammonia (NH_3–N), mg/L	40.45 ± 32	86 ± 112	271.35 ± 263
Total Nitrogen (TN), mg/L	244.00 ± 100	3.63 ± 3	1.82 ± 0,5
Total Phosphate (TP), mg/L	19.99 ± 22	17.6 ± 17	60.45 ± 41
Biochemical oxygen demand (BOD), mg/L	1,041.00 ± 262	1,576 ± 1.001	31,913 ± 2,461
Chemical oxygen demand (COD, mg/L)	4,130.5 ± 1,900	30,005.5 ± 17,381	63,071 ± 42,750
Electricity, kWh/y	1,911.87 kWh		

parameters to measure environmental impacts. The measured environmental impacts here included eutrophication, global warming (GWP100), photochemical oxidation, and water scarcity.

2.4. Interpretation

The final stage of life cycle analysis provides an alternative to wastewater treatment. In this study, a review was carried out based on a literature study and strategic plans carried out by local and central governments [22]. This study also uses multi correlation analysis to make equations in estimating the magnitude of the impact. The dependent variable is the respective inventory data in Table 3. While the independent variable is each impact that will be predicted. Statistical calculations were performed with SPSS 26 software using linearity analysis.

3. Result and discussion

3.1. Determination of Goal and Scope

The inputting results of life inventory data obtained graphs for each process showing a priority impact assessment

Table 2
Emission factors based on wastewater quality

Parameter	Emission factor	Source
BOD, kg CH_4/kg BOD	0.6	[21]
COD, kg CH_4/kg COD	0.25	[21]

value. The impact assessment priority in this research was chosen based on the magnitude of the impact caused by water pollution. Feces waste generated from previous literature became the raw data in this research [3]. This research consists of three wastewater treatment schemes process studied in a gate-to-gate. The scheme consists of feces processing with a WWTP (Fig. 2), septic tank, and open defecation. The scheme consists of processing stool with a WWTP, septic tank, and open defecation. The inputs in this system were energy and water, while the outputs were emissions from electricity usage and organic material degradation from BOD and COD effluent of WWTP processing. The water quality was assessed from pollutant load based on Ammonia, free ammonia, TN, TP, BOD, and COD.

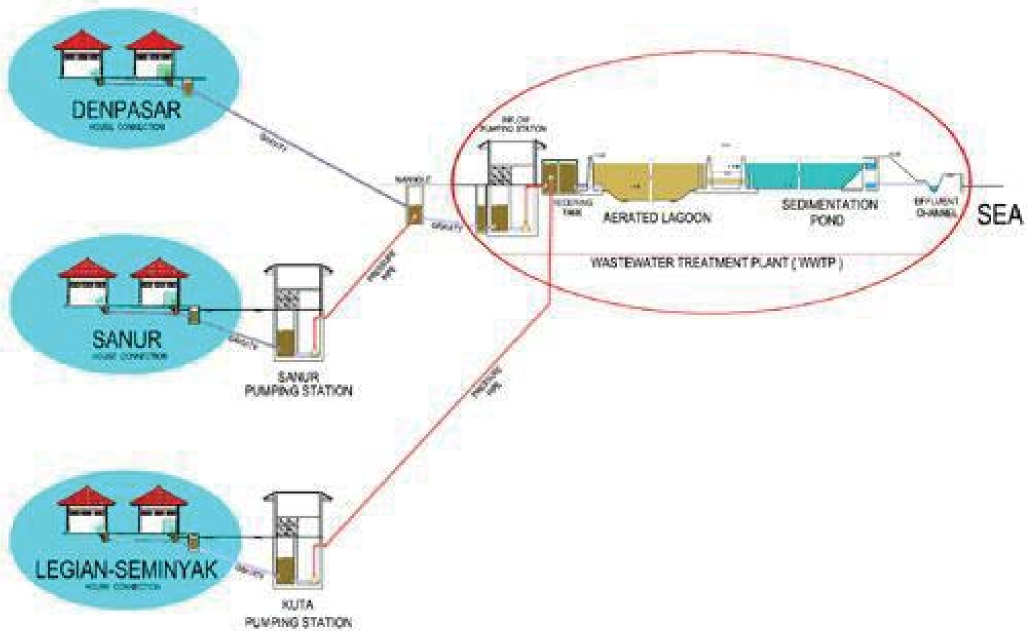

Fig. 2. WWTP flow diagram in Denpasar Sewerage Development Project [23].

In the feces treating with a septic tank, the input was the feces produced, and the output was the quality of feces in the form of pollutant load quality and emissions from BOD and COD degradation. The last scheme was open defecation, that is, activities without processing the feces where the feces were directly disposed of in water that could create pollutant and degradation results of CH_4 emissions load, and LCA studies in this research can be seen in Fig. 1.

3.2. Lifecycle cycle inventory (LCI)

LCI covers data collection and calculation of inputs and outputs to the environment of the evaluating system. It functions to inventory the use of resources, energy, and releases to the environment associated with the evaluating system. The LCI process requires important data used as a basis in data accuracy, so the collected data must be completed and come from the right source. The study results mentioned that the main problem is that all stakeholders need to consider ways in that the local citizen's conditioning process in Denpasar still do not follow the standard technology [3]. Based on Eq. (1), an inventory of pollutant load for each feces waste treatment is acquired and presented in Table 3.

3.3. Lifecycle impact assessment

Table 4 shows the impact analysis results by Simapro ver. 9.1 software with the EPD 2018 database. Overall, the open defecation process can have the most significant impact compared to other management. The impact analysis results on open defecation in Denpasar City were 2½ times higher than the low standard wastewater treatment (97.2 kg PO_4eq), as analyzed by Bai et al. (2018). Fig. 3 shows that open defecation gave an impact around 95.6% on eutrophication and around 97.6% on global warming and photochemical oxidation.

The impact analysis of water quality based on the eutrophication impact is due to the high nutrients' concentration in the feces. Nutrient concentration will significantly affect the quality of water bodies [9], [11,24]. Previous research mentioned that eutrophication were found in Buaji and Bualu Rivers, while other rivers were in oligotrophic conditions (nitrate level 0–1 mg/L) during the dry season [11]. Eutrophic status in the Second Transition Season in Badung and Mati Rivers needs a concern as they have constant water flow throughout the year [11]. The result in eutrophication becomes a significant impact analyzed by LCA.

One of the plants that get benefit from eutrophication is water hyacinth – a type of aquatic plant with a high growth rate, so it is considered a weed that can disrupt aquatic ecosystems [25]. Problems arising from the high population of water hyacinth are related to the decline of the number of diversity of aquatic animals, the occurrence of siltation, decreasing water quality due to reduced oxygen in view of a decreased intensity of sunlight entering water bodies, increasing disease vectors, irrigation disruption, pollutant transportation, and reducing aesthetic value in waters [25]. Besides, water hyacinth eutrophication will also cause an explosion of algae populations in the waters [26]. Algae growth is also influenced by the amount of substrate and light. A substrate in organic form can provide its environmental impact. Tabesh et al. [27] stated that processed wastewater from WWTP to surface water sources can cause a number of negative impacts such as eutrophication. However, without a proper wastewater treatment, the impact of eutrophication will be higher due to previous improper disposal such as open defecation. Septic tanks

Table 3
Inventory value of pollutant and emission loads from fecal management in Denpasar

Parameter	WWTP	Septic tank	Open defecation	Potential impact
Ammonia, kg/y	21.23	1202.08	1424.86	Eutrophication
Free ammonia (NH_3-N), kg/y	44.49	1989.54	3052.01	Eutrophication
TN, kg/y	268.36	13.34	128.65	Eutrophication
TP, kg/y	21.98	443.22	624.42	Eutrophication
BOD, kg/y	1144.94	233986.12	55929.84	Eutrophication
COD, kg/y	4542.93	462436.57	1064849.59	Eutrophication
CH_4 emissions from BOD parameter, kg/y	686.97	140391.67	33557.91	Global warming
CH_4 emissions from COD parameter, kg/y	1135.73	115609.14	266212.4	Global warming

Table 4
Results of the Environmental Impact Analysis of Feces Management in Denpasar City

Impact category	WWTP	Septic Tank	Open Defecation
Eutrophication, kg PO_4eq	0.439	11	246
Global warming (GWP 100a), kg CO_2eq	92.2	7170	83900
Photochemical oxidation, kg NMVOC	0.0422	2.59	30.3
Water scarcity, m^3eq	45.7	838	1730

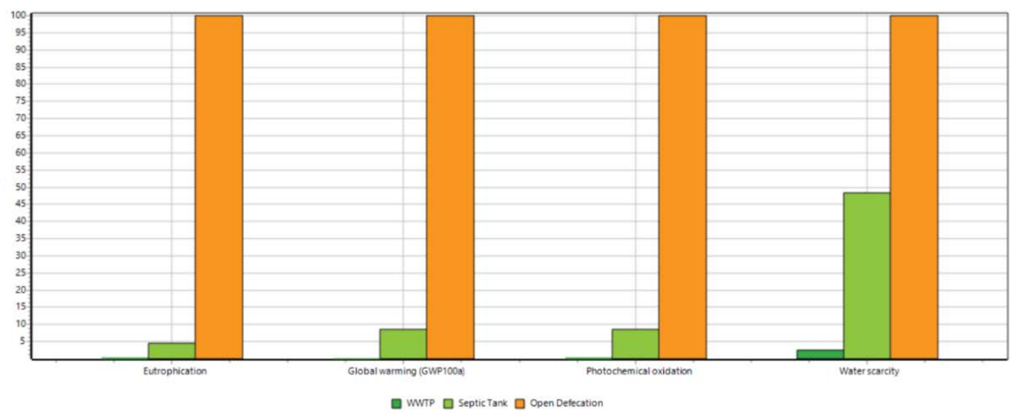

Fig. 3. Normalization of environmental impact data based on the EPD 2018 database in the feces management in Denpasar.

and seepage are widely used in various locations around the world to dispose of household wastewater, especially in the areas, which are not served by sewer systems [28]. Anaerobic decomposition wastewater will emit CH_4 emissions, thus, causing global warming. Methane production can contribute to the impact of global warming 25 times greater than CO_2 [29]. The formation process of CH_4 gas from this degradation process can occur quickly or slowly and then emitted to the ambient. CH_4 emissions not only causes global warming, but also causes photochemical oxidation, which is a chemical reaction that causes structural changes in electron release caused by light.

Normalization is a procedure needed to show the relative contribution of all impact categories to all environmental problems in an area. It is intended to create a uniform unit for all impact categories. The normalization value can be found by multiplying the standard value's characterization value so that all impact categories have used the same unit and can be compared. In this study, normalization was carried out by equating the unit into a percentage (%). The results of the normalization of all impacts can be seen in Fig. 3. It can be seen that the impact of eutrophication, global warming potential, along with photochemical oxidation, open defecation behavior contribute more than 95% of environmental impacts. It is followed by the use of septic tanks and WWTP. Other studies also mentioned that global warming potential and eutrophication potential are the most common impact categories in wastewater treatment [30]. The eutrophication impact caused by open defecation behavior is 560 times higher than that of WWTP processing.

Weighting is obtained by adding up the data normalization for each processing. Weighting impact for WWTP, septic tank, and open defecation are 2.1, 52.1, and 346.8, respectively. The weighting score showed that open defecation's environmental impact is very high compared to WWTP and septic tanks. The results of data weighting on the environmental impact and feces discharge can be seen in Fig. 4. Based on the weighting, the impact of open defecation is much more significant even though it only reduces feces by 0.2% (compared to the septic tank, which contributes 96.8%). It is proven that even though with the local treatment, the septic tank is able to reduce the environmental impact much more significantly. Although centralized treatment with WWTP cannot be applied quickly, people still conducting open defecation behavior must be served with a minimum of an individual or communal septic tank.

3.4. Interpretation analysis

The availability of a centralized domestic wastewater treatment system is expected to reduce the level of river water pollution and improve the environment's quality, which has implications for improving public health. However, this requires a relatively high cost and given the difficulty of changing citizen habits' behavior. Open defecation behavior is one of the citizen habits that very difficult to change [31]. Based on the considerations above, an appropriate and optimal treatment effort is needed by following the government's wastewater requirements.

A healthy environment is a condition of water and food contaminated-free. The open defecation free (ODF) activity or defecate only on the healthy toilet, is one of the efforts that can be made to achieve the government's goal of providing a healthy environment in residential areas through a total sanitation program. Changing people behavior to be more hygienically with ODF is not something simple to do as this behavior has become a habit which takes quite a long time to change, starting from the introductory stage, increasing the needs up to make citizens demands meeting the basic of sanitation needs [32,33]. The increasing needs of citizens for sanitation will run according to the objectives if there is a good facilitator. Within the framework of infrastructure enhancement grants (IEG), sanitation aims to boost the level of investment by local governments for infrastructure by rewarding the local governments who invest more in sanitation than their budgets [34]. For this reason, it is essential to do more careful planning to reduce open defecation behavior among the citizens, especially in Denpasar City. Based on the results of the study of strategies for improving sanitation management carried out by the Denpasar City government, five targets must be carried out [35] (Table 5).

Centralized processing with activated sludge system WWTP on the city's outskirts by implementing tertiary treatment is not recommended because more reclaimed water is discharged to the environment, creating a more massive negative effect [35]. This requires a strategic plan from the government to reuse wastewater. This can be applied to all countries that are currently developing. The space unavailability is also the problem of centralized wastewater treatment plant development directed to communal scale [36]. The location of the communal WWTP is chosen based on some careful considerations referring to several important things: long-term and medium-term city planning, availability and suitable land conditions (size, topography, and administration); flood water level; supporting road access for operation and maintenance; sufficient distance from the settlement to avoid odour and environmental, aesthetic disturbances; and no resistance from local community members.

The results of the calculation of the multi-linear analysis in determining the environmental impact of domestic wastewater management in Denpasar City only formed two dependent variables that significantly formed the environmental impact, namely the percentage of service and the concentration of COD in wastewater. Overall the equations formed can be seen in Table 5.

The municipal wastewater treatment system, mostly black water, must comply with healthy latrines [37]. The management/collection of feces must prevent fecal contamination into water bodies, prevent human contact with

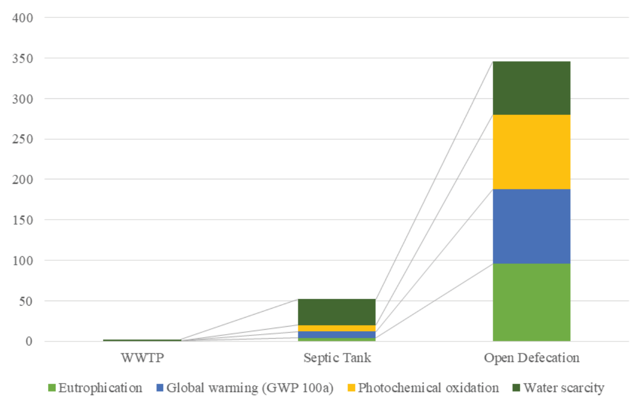

Fig. 4. The weighting of environmental impact data based on the EPD 2018 database on feces management in Denpasar.

Table 5
Multi-linearity equation determination of environmental impact of municipal wastewater management in Denpasar City

No	Equation	Information
1	$Y_1 = -13.499-(1.02X_1) + (0.004X_2)$	Y_1 = Eutrophication
2	$Y_2 = -4781.58-(312.68X_1) + (1.41X_2)$	Y_2 = Global warming (GWP 100a)
3	$Y_3 = -1.72\text{-}(0.113X_1) + (0.0005X_2)$	Y_3 = Photochemical oxidation
		Y_4 = Water scarcity
4	$Y_4 = -74.113 + (0.556X_1) + (0.028X_2)$	X_1 = Service percentage
		X_2 = COD concentration

Table 6
Denpasar City government strategy to fecal management [35]

No	Goal	Indicator	Strategy
1	Availability of planning for domestic wastewater management in densely populated areas and laws related to waste management	Accurate community sanitation development mapping is available, and waste management legislation is available.	Mapping densely populated areas for sanitation development and formulation of waste management legislation
2	Increased coverage of family latrine ownership through the use of septic tanks	Ownership of qualified latrines continues to increase	Optimizing and innovating the family toilet ownership program
3	Increasing the number and coverage of communal wastewater management services	Community Self-Help Groups can carry out their functions properly, and community sanitation in the form of communal WWTP can develop properly.	Optimization of communal WWTP both infrastructure and superstructure
4	Available and functional communal WWTP for home industries, livestock and slaughterhouses, markets, and Fecal Sludge Treatment Plant	Industrial communal WWTP can be utilized following the planning that has been made, both from the quality of the effluent and the target number served and the WWTP that is not yet optimal can be increased its performance	Building communal WWTP facilities and optimization
5	Increasing the effectiveness of municipal wastewater management services	Installations that are built can produce effluent according to predetermined quality standards.	Providing regional scale domestic wastewater treatment facilities & infrastructure

feces, make feces inaccessible to flies or insects, prevent odor generation, and adequately and safely constructed seats. Despite these challenges Denpasar City authorities are regularly develop improvement plans (Table 6). Environmental factors that influence sanitation technology selection include land availability, clean water sources, and groundwater level conditions. Meanwhile, social factors that affect the choice of technology are the behavior and culture of the community and economic factors (ability to build latrines). The condition of the community that has been triggered but there is not enough land to build a residential-scale WWTP, then technology options should be offered, such as a joint septic tank that can serve 2–10 households. It must be avoided forcing the construction of WWTP for a large number of users with insufficient land. Sometimes, interest in a site does not reach design capacity, while there is an interest in neighbouring areas, but pipelines will be more expensive if the systems are combined. There should be some flexibility to build a smaller system but with an optimal number of users.

After the open defecation service problem is resolved, it is necessary to plan more deeply for processing from the end of life to proactive. The provision of improving current conventional WWTPs in developing countries by adding tertiary treatment gives a positive impact to gain financial profits due to the value of the reusable produced water [17]. Besides, impact reduction can also use constructed wetlands that are the most environmentally friendly alternative than conventional systems such as activated sludge [38]. Previous LCA research showed that activated sludge technology's eutrophication impact is more significant than wetlands [39]. The use of new and renewable energy in biological processing systems needs to be used to reduce the impact of global warming [40].

4. Conclusion

Based on the LCA analysis of waste treatment with open defecation, it can cause the greatest environmental impact of eutrophication, global warming, photochemical oxidation, and water scarcity reached 246 kg PO_4eq, 83,900 kg CO_2eq, 30.3 kg C_2H_4eq, and 1730 m^3eq. Open defecation contributed 95.6% for the eutrophication effects and 97.6% for each global warming and photochemical oxidation effects. For this reason, the Denpasar Government is recommended to improve sanitation infrastructure services by conducting open defecation-free activities. The analysis of this study was only done by gate to gate; therefore, it is necessary to be more specific than cradle to grave. The calculation of LCA for certain areas with lower sanitation access than Denpasar City needs to be taken into account, not only in Indonesia but also in other developing countries with an expectation to realize a sustainable sanitation program.

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