Evaluation of Existing And Future Zero Waste Approach in Municipal Solid Waste Management Utilizing the Zero Waste Index: Bali Province, Indonesia

I Made Wahyu Widyarsana (imww.research@gmail.com)
Institut Teknologi Bandung https://orcid.org/0000-0003-2337-8500
Radhitiya Al Furqan
Bandung Institute of Technology: Institut Teknologi Bandung
Moehammad Budhicahyanto
Bandung Institute of Technology: Institut Teknologi Bandung
Dianisti Saraswati
Bandung Institute of Technology: Institut Teknologi Bandung
Nabila Nurfajri
Bandung Institute of Technology: Institut Teknologi Bandung

Research Article

Keywords: Bali, Municipal Solid Waste, Zero Waste Index, Indonesia

Posted Date: October 13th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-909598/v1

Abstract

The World Bank reported that around 1.3 billion tonnes of municipal waste were generated in 2011, and this amount is expected to increase to 2.2 billion tonnes by 2025. Zero Waste Index (ZWI) is a breakthrough for measuring and evaluating waste management's performance based on the concept of zero waste, where recycling is the key to determining this value. This study was conducted in a province in a developing country, namely Bali Province, Indonesia. The calculation of ZWI and energy substitution from waste management is carried out on two schemes, an optimistic scheme (basic data and percentage of waste management targets referring to the regional policy and strategy documents) and a pessimistic scheme (basic data refers to material flow analysis of waste with no increase in the percentage of waste management) from 2020 to 2025. Energy substitution is calculated on two conditions of use, namely through incinerator technology (listed in Indonesia Presidential Regulation No. 35 of 2018) and without incinerators at the Sarbagita Regional Landfill. Analysis indicated that the pessimistic scheme provides a higher ZWI value of Bali Province in 2020 than the optimistic scheme, but there is no increase in the ZWI value until 2025 (the ZWI value ranges from 0.02 to 0.2) due to no increase in the percentage of solid waste management. Meanwhile, the optimistic scheme provides a lower ZWI value for Bali's Province in 2020 than the pessimistic scheme, but there is an increase in the ZWI value every year until 2025 (the ZWI value ranges from 0.004 to 0.22). In terms of energy substitution, an optimistic scheme provides energy substitution values 2-5 times greater than pessimistic schemes, with and without incinerators. However, in terms of the incinerator efficiency, the pessimistic scheme provides greater efficiency (2-6% efficiency when using an incinerator) than the optimistic scheme (1-2% efficiency when using an incinerator). The 3R (Reuse, Reduce, Recycle)-based waste management and high energy substitution potential in Bali Province can be an effective waste management solution if the stakeholders are committed to achieve the *Jakstrada* targets by 2025.

1. Introduction

Waste is the symbol of inefficiency in modern society and a representation of misallocated resources (Zaman & Lehmann, 2013). The presence of waste often creates problems in geographic attractiveness and the health of people living in an environment. Based on The World Bank, the cities around the world generate about 1.3 billion tonnes of solid waste per year. And this continues to increase to 2.2 billion tonnes by 2025 (Hoornweg & Bhada-Tata, 2012). It is approximately 84% of waste is collected in around the world, and only 15% is recycled, with most global waste still managed by landfills (Zaman, 2016). Increased population, urbanization, and economic development raised people's concerns about waste management (Levis et al., 2013).

Zero Waste (ZW) has become the alternative solution in waste management system for handling waste problems in recent decades. Policymakers have embraced the ZW concept because it encourages sustainable production and consumption, optimum recycling and resource recovery, and bans mass incineration and landfilling (Zaman, 2015). Zero-waste is the conservation of all resources through responsible production, consumption, reuse, and recovery of all products, packaging, and materials without burning and discharging them to land, water, or air that threaten the environment or human health. Zero waste is different from the concept of waste as an 'end of life' product, yet, it conveys the comprehension of 'waste' as a 'resource' which produces during the intermediate phases of production and consumption activities, and thus, should be recirculated to production processes through reuse, recycle, reassemble, resell, redesign or reprocess (Zaman, 2016).

Three countries that have implemented zero waste on their waste management which are Adelaide (Australia), San Francisco (USA), and Stockholm (Swedia). Adelaide applied zero-waste by banning plastic bags and facilitating containers for recycling which have been implemented for three decades (Zaman & Lehmann, 2013). In San Francisco, the zero waste challenge that supports solid waste systems is implemented by minimizing consumption, maximizing diversion and encouraging reuse, repair, and eco-friendly purchases of products, banning troublesome items such as plastic bags and redundant packaging to achieve zero-waste goals. One of the most important waste management policies in Stockholm, Sweden, is the ban on disposing of combustible waste and organic waste to the landfill.

Zero Waste Index (ZWI) can also be a tool to evaluate the implementation of zero waste programs based on quantitative values developed. ZWI is a tool to measure the potential of virgin materials to be balanced by zero waste management system (Zaman & Lehmann, 2013). A high ZWI value indicates a high substitution of virgin materials, energy, and water-saving, that means higher achievement (Zaman, 2014). The previous study found that the ZWI of Adelaide, San Francisco, and Stockholm were 0.23, 0.51, and 0.17, which means that the current waste management system in those cities potentially offset 23%, 51%, and 17%, respectively. Furthermore, the same research calculation found 0.07 as the global ZWI, and in another study, the ZWI of the world is calculated to be 0.12 (Zaman & Swapan, 2016), means that the current waste management system only compensates for 12% of the total potential for substituting virgin materials from waste (Zaman, 2016). However, conditions and activities relating to zero-waste will vary in several countries in the world. Developing countries are still conducting trial and error to find a suitable solution to solve this solid-waste management problem. As one of the developing countries, Indonesia is the second-highest country contributing to plastic disposal to the sea after China (Asfar & Asfar, 2020). Illegal waste disposal still occurs in Indonesia, both on vacant land and in waters, which will produce pollution and negative impacts on the environment. Waste disposal to waterways will eventually damage the sea and marine life.

The waste management systems in Indonesia still apply "collect-transport-landfill disposal" methods. This method involves accumulating waste in the landfill and reducing its capacity every day (Prihatin, 2020). The landfill capacity is disproportionate to the generated waste, resulting in landfills becoming full quickly and shortening their useful life. To anticipate landfill problems, the Indonesian Government passed Law No. 18/2008 concerning Solid Waste Management. This law explains that waste management is an activity that is systematic, comprehensive, and sustainable, including waste reduction and handling. Waste reduction is applied by reusing or recycling, and waste handling is carried out from sources to the final processing facilities until the waste can safely return to the environment. Based on Governor of Bali Regulation No. 95 of 2014 concerning Policies and Strategies for Management of Household Waste and Household-like Waste in Bali Province, local governments must convert open dumping landfills within a maximum of 5 (five) years into a sanitary landfill system. Almost all provinces in Indonesia use landfills as the final location for dumping their waste, including Bali province.

As one of Indonesia's most desirable tourist destinations, Bali Province is surrounded by the sea and has a big impact on the sea and the aquatic environment. Increasing local and foreign tourists will also affect the amount of waste generated. Most of Bali’s waste management activity still uses the old-paradigm: waste collection–transporting–disposing. Waste management in Bali Province still relies on landfills, leading to the shorter lifespan of the landfill. Most landfills are operated by an open dumping method, which results in high polluting potential towards the environment. Nowadays, the Sarbagita Regional landfill only serves the operational areas of Denpasar City, Badung Regency, Gianyar Regency, and Tabanan Regency in poor condition as it still implies the open-dumping method. Based on the Integrated Risk-Based Approach (IRBA), Sarbagita Regional landfill has the highest risk index (664.8), which implies it has the highest risk of environmental pollution, hence needing further action, either by closing or rehabilitating the landfill. Therefore, Bali needs to implement the ZW concept to tackle those waste management problems, especially in the Sarbagita region.

Currently, Bali Province has started to apply zero waste to improve its waste management. Some examples of zero waste activities are establishing a waste bank, 3R (Reuse, Reduce, Recycle) Temporary Disposal Site, and socializing the 3R program supported by the informal sector. Bali Province uses landfills as a waste final processing technology for residual waste or those not handled by zero waste activities. There are ten landfills in Bali Province, with Sarbagita as the regional landfill. This study aims to evaluate the performance of zero waste activities in the integrated waste management system in Bali Province, starting from the generation of waste at sources to landfills by calculating the zero-waste index under two possible schemes; the scheme without any improvement in waste management and the scheme following the Regional Policy and Strategies on Municipal Solid Waste Management (from this point forward will be mention as *Jakstrada*). This research is expected to become a scientific base for the government to evaluate the currently implemented waste management policies and help determine future steps to be taken, ensuring that the government and community can implement the zero-waste concept in Bali’s waste management system with better performance.

2. Material And Methods

Initially, the ZWI value will be calculated for Bali Province and Regency/City in Bali Province. ZWI value is calculated using the equation from previous research conducted by Zaman & Lehmann (2013); the equation is:

$$ZWI = \frac{\sum_1^n MSW_{ij} \ x \ SF_{ij}}{\sum_1^n MSWi} \quad \text{Eq. (1)}$$

Where:

MSWij = amount of waste in stream i (i = 1,2,3… n = paper, plastic, metal, etc.) which are managed by the system/institution j (j = 1,2,3… n = amount of waste reduced, recycled, managed, etc.)

SFij = substitution factor for waste in stream i (i = 1,2,3,… n = n = paper, plastic, metal, etc.) which are managed by the system/institution j (j = 1,2,3… n = amount of waste reduced, recycled, managed, etc.)

MSWi = total amount of waste managed (i = 1,2,3,… n = n = paper, plastic, metal, etc.)

The amount of waste flow and the total amount of waste managed in Bali Province will use data from a previous study for the pessimistic scheme and modify it for the optimistic scheme. Meanwhile, the performance of the material recovery rate is calculated using the efficiency of the substitution factor for virgin material (Zaman and Lehmann, 2013), shown in Table 1.

Table 1
Substitution factor in different waste streams and management options

Waste management system	Waste category	Virgin material substitution efficiency	Energy substitution efficiency (GJLHV/tonnes)	GHG emissions reduction (CO_2e/tonnes)	Water saving (kL/tonnes)
Recycling	Paper	0.84–1.00	6.33–10.76	0.60–3.20	2.91
	Glass	0.90–0.99	6.07–6.85	0.18–0.62	2.30
	Metal	0.79–0.96	36.09–191.42	1.40–17.8	5.97–181.77
	Plastic	0.90–0.97	38.81–64.08	0.95–1.88	−11.37
	Mixed	0.25–0.45	5.00–15.0	1.15	2.0–10
Composting	Organic	0.60–0.65	0.18–0.47	0.25–0.75	0.44
Incineration	Mixed MW[a]	0.00	0.972–2.995[b]	0.12–0.55	0.00
Landfill	Mixed MW[a]	0.00	0.00–0.84[c]	(−)0.42–1.2	0.00

[a]Average composition of municipal waste (MW).

[b]Heat capture efficiency of waste to energy (WTE) technology 15–30%

[c]Energy from the landfill facility. A positive value represents the savings, and a negative value the demand or depletion.

Considering the performance of waste management and the low level of waste purity in Indonesia due to mixed conditions, the substitution factor will use the lowest value on the range. Apart from ZWI, energy substitution efficiency is also crucial because there will be construction and operation of incinerators at the Sarbagita Regional landfill with 1000 tonnes d^{-1} capacity. This construction and operation plan is listed in Presidential Regulation No. 35 of 2018 concerning the Acceleration of the Development of Waste Processing Installation into Electrical Energy based on Green Technology. However, it is still uncertain whether this facility can operate in 2025 as targeted. Therefore, the calculation of energy substitution efficiency for the Bali Provinces and its regencies/cities will also be carried out, both when the incinerator is implemented and not implemented. In the case without an incinerator, the energy substitution sources only come from recycled materials, composting, and landfills. However, in the case of the operation incinerator facility, the energy substitution comes from recycled materials, compost, landfills, and incinerators. Therefore, the potential for energy substitution still exists even if the incinerator is not used.

The ZWI calculation methodology and energy substitution are carried out in two schemes: the optimistic and pessimistic schemes. The optimistic scheme refers to data and targets of the *Jakstrada* documents in 2025, with the percentage of waste handling increasing every year according to the documents. Meanwhile, the pessimistic scheme refers to existing data from a previous study projected until 2025, assuming there is no change in the percentage of waste management. The ZWI value in 2020 and 2025 of the two schemes will be compared.

2.1 ZWI for pessimistic schemes

In the pessimistic condition scheme, ZWI in Bali Province will be calculated using the material flow analysis (MFA) of waste from Bali Province, as shown in Fig. 1.

This data describes the flow of existing waste management in Bali Province. The amount of waste generation used in the 2020 ZWI calculation is the generation shown by the recycler section, which is 109,896.80 tonnes yr^{-1}, with 13.36% of the total generation. Based on Bali Province's MFA, a projection of waste generation is carried out until 2025, but the percentage of waste management is assumed to remain the same every year. The results of ZWI calculations will be displayed in the form of a time series to see the pattern of ZWI value for an area each year until 2025.

2.2 ZWI optimistic scheme

The second scheme uses an optimistic scheme with the management target referring to the *Jakstrada* documents for regencies/city in Bali Province. Each regency and city in Bali Province have already established their own *Jakstrada* as guidance on municipal solid waste management with targets at 2025. The targets are: reducing waste by 30% of total waste generation and waste handling by 70% of total waste generation. ZWI in this scheme is calculated following the planned annual waste generation rate as stated in the *Jakstrada* documents at the regency/city level. Like the pessimistic scheme, the optimistic scheme also calculates and analyzes the energy substitution efficiency, with and without incinerator.

3. Result And Discussion

3.1 ZWI of Bali Province and its regencies/cities on pessimistic scheme

The ZWI of Bali Province and regencies/cities in Bali Province is calculated according to Eq. (1). The amount of waste generated that will be used in the calculation is equal to the "recycler" sector, as shown in Fig. 1, which is 128,087.48 tonnes yr^{-1}. The data regarding waste composition, both at sources and landfills, shown in Fig. 2 & Fig. 3.

The amount of recycled waste from the material flow analysis is used to calculate the ZWI in 2020. The waste generation is then projected according to population growth to calculate the ZWI in 2025. Under the pessimistic scheme, it is assumed that the percentage of recycled waste from managed generated waste is stagnant and constant at 24.53%. Efficiencies of virgin material substitution used in this calculation are the lowest in the range (Table 1) as Indonesia is categorized low in virgin material substitution management. The ZWI of Bali Province on pessimistic scheme year 2020 and year 2025 shown in Table 2 and Table 3.

Table 2
Zero Waste Index of Bali Province on Pessimistic Scheme (2020)

Waste management system	Waste category	Total waste managed (tonnes yr^{-1})	Virgin Material Substitution		Energy substitution (GJLHV/tonnes)		GHG emission reduction (CO2e/tonnes)		Water saving (kL/tonnes)	
			Efficiency	Potential	Efficiency	Potential	Efficiency	Potential	Efficiency	Potential
Recycle	Paper	11,425.40	0.84	9,597.34	6.33	72,322.80	0.6	6,855.24	2.91	33,247.92
	Glass	1,537.05	0.9	1,383.34	6.07	9,329.89	0.18	276.67	2.3	3,535.21
	Metal	1,152.79	0.79	910.70	36.09	41,604.09	1.4	1,613.90	5.97	6,882.14
	Plastic	20,109.73	0.9	18,098.76	38.81	780,458.79	0.95	19,104.25	-11.36	-228,446.58
	Mixed waste	10,605.64	0.25	2,651.41	5	53,028.22	1.15	12,196.49	2	21,211.29
Composting	Organic	83,256.86	0.6	49,954.12	0.18	14,986.24	0.25	20,814.2155	0.44	36,633.02
Thermal process	Mixed waste	0.00	0	0.00						
Landfill	Mixed waste	292,430.94	0	0	0	0	-0.42	-122,820.995	0	0
Total		822,542.84		70,865.63		833,727.24		-130,960.25		-108,909.71
ZWI		0.09								

Table 3
Zero Waste Index of Bali Province on Pessimistic Scheme (2025)

Waste management system	Waste category	Total waste managed (tonnes yr^{-1})	Virgin Material Substitution		Energy substitution (GJLHV/tonnes)		GHG emission reduction (CO2e/tonnes)		Water saving (kL/tonnes)	
			Efficiency	Potential	Efficiency	Potential	Efficiency	Potential	Efficiency	Potential
Recycle	Paper	11,425.40	0.84	9,597.34	6.33	72,322.80	0.6	6,855.24	2.91	33,247.92
	Glass	1,537.05	0.9	1,383.34	6.07	9,329.89	0.18	276.67	2.3	3,535.21
	Metal	1,152.79	0.79	910.70	36.09	41,604.09	1.4	1,613.90	5.97	6,882.14
	Plastic	20,109.73	0.9	18,098.76	38.81	780,458.79	0.95	19,104.25	-11.36	-228,446.58
	Mixed waste	10,605.64	0.25	2,651.41	5	53,028.22	1.15	12,196.49	2	21,211.29
Composting	Organic	83,256.86	0.6	49,954.12	0.18	14,986.24	0.25	20,814.2155	0.44	36,633.02
Thermal process	Mixed waste	0.00	0	0.00	0.0972	0	0.12	0		0
Landfill	Mixed waste	511,802.47	0	0	0	0	-0.42	-214,957.039	0	0
Total		914,259.51		82,595.67		971,730.03		-154,096.27		-126,937.00
ZWI		0.09								

According to the material flow analysis, recycled waste comes from 3R transfer stations, informal collectors, and waste banks, with the percentage of collected recyclable waste being 2%, 8.44%, 8.36%, and 5.72%, respectively. It is logical to use the waste from recyclers to calculate the ZWI of Bali Province since the ZWI is calculated based on the waste category, which can be utilized as an alternative raw/ virgin material.

The ZWI value of Bali province in the existing condition scheme is obtained at 0.09 or 9%, meaning that from 100% of handled waste in Bali province, 9% of waste can be recycled and can be used as alternative virgin material. According to the ZWI value prediction in previous studies conducted by Zaman & Swapan (2016), Indonesia is estimated to be in the low ZWI category (0.06–0.10). Compared with the results obtained from the calculation, which is 0.09, this figure is in the range estimated by Zaman (2016). The predicted figure is the ZWI for Indonesia as a whole nation; in other words, this figure is the average index for all regions in Indonesia. As one of the provinces with a proper and developing waste management level, Bali Province is reasonable to have the ZWI slightly under the highest number in Indonesia's projected average ZWI.

Meanwhile, the ZWI of Bali Province based on the projection of 2025 is still the same as 2020. It means that, in 2025, the amount of substitute virgin materials recovered is still the same as in 2020. This result is expected as the percentage of recycled waste stays stagnant year to year, while the amount of generated waste increases each year.

There are 8 (eight) regencies and 1 (one) city in Bali Province: Denpasar City, Badung Regency, Gianyar Regency, Tabanan Regency, Jembrana Regency, Buleleng Regency, Klungkung Regency, Bangli Regency, and Karangasem Regency. Using a similar method with the Bali Province, the ZWI of each regency and city is calculated from 2020 and 2025, as shown in Table 4.

Table 4
Zero Waste Index of city/regencies in Bali Province on Existing Scheme

Location	Year 2020	Year 2025
Jembrana Regency	0.20	0.19
Karangasem Regency	0.13	0.12
Bangli Regency	0.13	0.13
Klungkung Regency	0.05	0.05
Buleleng Regency	0.02	0.02
Gianyar Regency	0.09	0.09
Tabanan Regency	0.10	0.09
Denpasar City	0.04	0.03
Badung Regency	0.10	0.09
Average	0.10	0.09
Bali Province	0.09	0.09

Calculations show that the ZWI of regencies/cities in Bali Province ranges from 0.02 to 0.2 in 2020 and 0.02 to 0.19 in 2025. There is no significant change in ZWI from 2020 to 2025. The Jembrana Regency holds the highest ZWI for both years, and the Buleleng regency holds the lowest ZWI for both years. The Jembrana regency has the highest percentage of recovered substitute virgin material and sold recyclables compared to other locations, which is 30.65% from the total waste generated, resulting in Jembrana Regency holding the highest ZWI in Bali Province. On the contrary, Buleleng Regency's substitute virgin material recovery and sold recyclables percentage is only 3.23%, the lowest compared to other locations, making it have the lowest ZWI among the regencies. The percentage of recovered substitute virgin materials is shown in Table 5.

Table 5
Recapitulation of solid waste data and zero waste index of regencies/city in Bali Province by 2020

No	Location	Waste generated (tonnes yr^{-1})	Recovered substitute virgin materials (tonnes yr^{-1})	Percentage of recovery (%)	ZWI
1	Jembrana	46,318.5	14,195.95	30.65	0.20
2	Karangasem	56,502	10,622.60	18.8	0.13
3	Bangli	30,399.755	6,478.02	21.31	0.13
4	Klungkung	32,371.485	2,682.40	8.29	0.05
5	Buleleng	113,252.565	3,655.84	3.23	0.02
6	Gianyar	65,846	9,283.90	14.1	0.09
7	Tabanan	64,751	8,789.57	13.57	0.10
8	Denpasar	270,311.7	15,708.50	5.81	0.04
9	Badung	142,802.6	23,090.27	16.17	0.10
10	Bali Province	822,542.84	109,896.80	13.36	0.09

In 2020, the average ZWI of regencies/cities in Bali Province was 0.1, similar to the ZWI of the Bali Province, which was 0.09. This similarity is expected as the waste data from Bali Province is the total of each regency/city. Aside from a similar value, ZWI figures for regencies/city and Bali Province on the pessimistic scheme stay the same, either stagnant or decreasing compared to the initial year.

Classified nations around the world according to each nation's respective ZWI. This study follows the same classification to classify each regency/city in Bali Province according to the ZWI in 2020 and 2025 (Fig. 4 and Fig. 5). According to the classification, regencies/cities in Bali Province are classified in very low ZWI (i.e., Denpasar City, Klungkung Regency, and Buleleng Regency), low ZWI (i.e., Gianyar Regency, Tabanan Regency, dan Badung Regency), and medium ZWI (i.e., Jembrana Regency, Karangasem Regency, and Bangli Regency). By using the ZWI value of each regencies/cities, some of the regencies in Bali Province is classified as low class and some other is classified as high class. However, it shows a different result if the ZWI from the Bali Province data is used, which is 0.09, which classifies the Bali Province as low class. This discrepancy shows a data gap between the government's level, which affects the region's classification into two different classifications.

The Sarbagita Regional landfill (also known as Suwung Landfill) is a landfill that serves four regions: Denpasar City, Badung Regency, Gianyar Regency, and Tabanan Regency. Waste generated from those four regions will be transported to the Suwung Landfill and reduces the possibility of collecting recyclable materials from the source. Although the recyclable collection is performed on the landfill by scavengers, it is not as easy as the collection performed from the lower level (e.g., transfer station, households, etc.) as the landfill waste is heavily mixed in enormous mass and volume. This issue affects the recycling performance in 4 (four) regions as it becomes harder to perform the collection for recyclable materials (only performed by waste banks and 3R transfer stations with low rate). In the end, it also lowered the value of ZWI, as shown in the ZWI classification; those four regions are classified as very low and low.

Besides ZWI, the energy substitution efficiency is also calculated on the scheme. The primary difference between ZWI and energy substitution is that ZWI sees waste as an alternative for raw/virgin materials to make products; meanwhile, the energy substitution calculation views waste as a potential source to produce energy. This is why thermal processes do not contribute to the ZWI calculation but contribute to determining the energy substitution efficiency (Table 1). There are 2 (two) applied cases for calculating energy substitution efficiency; (1) incinerator facilities are implemented in certain landfills in Bali Province, and (2) incinerator facilities are not implemented.

Incinerator facilities are planned to be implemented in Suwung Landfill following the Presidential Regulation no. 35/2018 regarding Acceleration of the Development of Waste Processing Installation into Electrical Energy based on Green Technology. The Suwung Landfill covers the area of Sarbagita (Denpasar City, Badung Regency, Gianyar Regency, and Tabanan Regency); therefore, it is assumed that the waste which the incinerator will process comes from the 4 (four) regions. Table 6 shows the value of energy substitute for 4 (four) regions or Suwung Landfill, with and without incinerator facilities.

Table 6
Comparison of energy efficiency substitution value in the pessimistic scheme

Location	Energy substitution value (GJLHV/tonnes)		Percentage of increase
	Without incinerator	With incinerator	
Denpasar City	154,302.35	164,812.07	6%
Badung Regency	226,812.30	232,364.47	2%
Gianyar Regency	77,288.20	79,848.29	3%
Tabanan Regency	100,320.09	102,837.61	2%
Average	139,680.73	144,965.61	4%
Bali Province	971,730.03	1007,208.03	4%

The result shows energy substitution from 4 (four) regions without an incinerator, ranging from 77,288.20 to 226,812.30 GJLHV/tonnes with an average value of 139,680.73 GJLHV/tonnes. Projection with incinerator shows a range increase and becomes 79,848.29 to 232,364.47 GJLHV/tonnes with an average value of 144,965.61 GJLHV/tonnes. The values show a significant increase in energy substitution by implementing the incinerator in this scheme—the percentage of increase ranging from 2% to 6% with an average value of 4%. As the highest percentage of increase, Denpasar city has promise for incinerator implementation. This is supported by the fact that Denpasar city is Bali's capital that generates a larger amount of combustible waste than other locations. Meanwhile, the recycling activities are not as potential in Denpasar City as most generated waste is transported to the Suwung Landfill. This makes the ZWI value of these regions low, but the energy substitution value high as there is a large amount of input waste and could be utilized in the landfill. The value of energy substitution will be discussed further on the comparison between the two schemes.

3.2 ZWI of Bali Province and its regencies using optimistic scheme

The optimistic scheme is a scheme based on the waste management targets in *Jakstrada* documents by 2025. The existing and projected data of waste generation in *Jakstrada* from each regency/city in Bali Province is used, assuming there is no change in data composition, both at sources and landfills. ZWI calculation is the same as the pessimistic scheme from 2020 to 2025 and compared between 2020 and 2025 shown in Table 7 and Table 8.

Table 7
Zero Waste Index of Bali Province on Optimistic Scheme (2020)

Waste management system	Waste category	Total waste managed (tonnes yr^{-1})	Virgin Material Substitution		Energy substitution (GJLHV/tonnes)		GHG emission reduction (CO2e/tonnes)		Water saving (kL/tonnes)	
			Efficiency	Potential	Efficiency	Potential	Efficiency	Potential	Efficiency	Potential
Recycle	Paper	9,880.62	0.84	8,299.72	6.33	62,544.31	0.6	5,928.37	2.91	28,752.60
	Glass	1,329.23	0.9	1,196.31	6.07	8,068.43	0.18	239.26	2.3	3,057.23
	Metal	996.92	0.79	787.57	36.09	35,978.96	1.4	1,395.69	5.97	5,951.63
	Plastic	17,390.77	0.9	15,651.70	38.81	674,935.90	0.95	16,521.23	-11.36	-197,559.18
	Mixed waste	9,171.69	0.25	2,292.92	5	45,858.47	1.15	10,547.45	2	18,343.39
Composting	Organic	30,040.43	0.6	18,024.26	0.18	5,407.28	0.25	7,510.11	0.44	13,217.79
Thermal process	Mixed waste	985.50	0	0.00						
Landfill	Mixed waste	372,188	0	0	0	0	-0.42	-156,319.15	0	0
Total		962,475		46,252.47		832,793.35		-114,177.03		-128,236.54
ZWI		0.05								

Table 8
Zero Waste Index of Bali Province on Optimistic Scheme (2025)

Waste management system	Waste category	Total waste managed (tonnes yr^{-1})	Virgin Material Substitution		Energy substitution (GJLHV/tonnes)		GHG emission reduction (CO2e/tonnes)		Water saving (kL/tonnes)	
			Efficiency	Potential	Efficiency	Potential	Efficiency	Potential	Efficiency	Potential
Recycle	Paper	17,796.80	0.84	14,949.32	6.33	112,653.77	0.6	10,678.08	2.91	51,788.70
	Glass	2,394.19	0.9	2,154.77	6.07	14,532.73	0.18	430.95	2.3	5,506.63
	Metal	1,795.64	0.79	1,418.56	36.09	64,804.71	1.4	2,513.90	5.97	10,719.98
	Plastic	31,323.97	0.9	28,191.57	38.81	1,215,683.3	0.95	29,757.77	-11.36	-355,840.31
	Mixed waste	16,519.90	0.25	4,129.98	5	82,599.52	1.15	18,997.89	2	33,039.81
Composting	Organic	30,040.43	0.6	18,024.26	0.18	5,407.28	0.25	7,510.11	0.44	13,217.79
Thermal process	Mixed waste	985.50	0	0.00						
Landfill	Mixed waste	28,0663	0	0	0	0	-0.42	-117,878.7	0	0
Total		1,042,941	Total	68,868.45		1,495,681.30		-47,989.95		-241,567.40
ZWI		0.07								

The ZWI calculation in 2020 is 0.05 or 5% and 0.07 or 7% in 2025. With this scheme, there is an increase of 2% for ZWI in Bali Province in 5 (five) years. This increase follows the assumption that the targets of *Jakstrada* are achieved (30% reduction and 70% handling). It is also assumed that 30% of total waste generation is successfully recycled to be virgin material in 2025. Thus, there is an increase in the value of ZWI. Same as Bali Province, ZWI for each regency/city also increases, as shown in Table 9.

Table 9
Yearly Zero Waste Index of Bali Province

Location	Yearly Zero Waste Index					
	Year 2020	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025
Denpasar City	0.02	0.01	0.03	0.03	0.03	0.03
Badung Regency	0.04	0.11	0.06	0.07	0.07	0.18
Gianyar Regency	0.06	0.11	0.08	0.08	0.09	0.10
Tabanan Regency	0.20	0.22	0.19	0.18	0.19	0.18
Klungkung Regency	0.11	0.14	0.13	0.13	0.13	0.11
Bangli Regency	0.004	0.01	0.005	0.01	0.01	0.01
Karangasem Regency	0.01	0.01	0.01	0.01	0.01	0.01
Jembrana Regency	0.07	0.09	0.06	0.10	0.11	0.13
Buleleng Regency	0.04	0.04	0.04	0.05	0.05	0.07
Average	0.06	0.08	0.07	0.07	0.08	0.09
Bali Province	0.05	0.05	0.05	0.06	0.06	0.07

The ZWI average of the regencies/cities is not too different from the ZWI in Bali Province, which is still in the very low ZWI class and low ZWI class. Table 9 also shows a decrease in ZWI value in certain years in each location (i.e., Denpasar city from 2020 to 2021, Badung Regency from 2021 to 2022, Gianyar Regency from 2021 to 2022, etc.). The ZWI value decrease is caused by the increasing amount of waste generation but not followed by an increase in waste management capacity for reduction or recycling. Therefore, instead of reduction or recycling, the increased waste will enter the landfill.

The calculations and time series graphs in Fig. 6 show that Bali's regencies/cities' ZWI value in the optimistic scheme ranges from 0.004 to 0.22. Tabanan Regency held the highest ZWI value, and Bangli Regency had the lowest ZWI value. In this scheme, Tabanan Regency has a high ZWI value because, based on *Jakstrada* data, this regency is making great use of existing recycling facilities, such as 3R transfer station, unit waste Bank, main waste bank, and even the waste recovered by scavengers at final processing is the highest compared to other regencies/cities. Waste composting in Tabanan Regency is also the highest in final processing compared to other regencies.

Meanwhile, Bangli Regency has a low ZWI value due to very few recycling and composting facilities based on *Jakstrada* data. Figure 7 and Fig. 8 also shows that Badung Regency has experienced an increase in ZWI's value from 2024 to 2025. This increase is very rapid compared to other districts due to a large increase in the amount of waste recycled by the unit's waste bank sector. In 2024, it is targeted that the unit waste bank can manage 25.51 tonnes d^{-1} of waste, but in 2025 the targeted amount of waste that can be recycled by the unit's waste bank sector is 110.2 tonnes d^{-1} - a 4.32 times increase in just one year. Thus, the ZWI value of Badung Regency increased rapidly from 0.07 to 0.18 in just one year.

Referring to the ZWI value classification reported by Zaman and Swapan (2016), this scheme in the year 2025, the regencies/cities in Bali Province can be categorized into very low ZWI value (i.e., Denpasar City, Bangli Regency, Karangasem Regency), low ZWI value (Gianyar Regency and Buleleng Regency), and ZWI medium (i.e., Badung Regency, Klungkung Regency, Tabanan Regency, and Jembrana Regency). Based on the average ZWI value of regencies/cities in Bali Province, the ZWI value for Bali Province is in the low ZWI value. This scheme also shows the calculations of energy substitutions obtained from the two conditions, such as implementing and not implementing incinerator as shown in Table 10.

Table 10
Comparison of energy efficiency substitution value in the optimistic scheme

Location	Energy Substitution (GJLHV/tonnes)		Percentage of increase
	With incinerator	Without incinerator	
Denpasar City	889,338.658	877,757.7665	1%
Badung Regency	474,118.1727	467,944.2466	1%
Gianyar Regency	175,723.2949	173,029.6707	2%
Tabanan Regency	239,798.7215	239,798.7215	0%
Average	444,744.7118	439,632.6013	1%
Bali Province	2,116,274.862	2,080,796.862	2%

Incinerator usage contributes a higher energy substitution value than the condition without incinerator usage. However, the increase in value is not high, with only a maximum of 2%. This result was obtained because for the pessimistic scheme, the 3R approach is preferable to a thermal process like incineration. Thus, it causes less efficiency in incineration as the waste is expected to be successfully recovered into virgin materials through the 3R activities.

3.3 Comparison between ZWI of Bali Province on two schemes

The pattern of municipal waste management in Bali Province for both schemes is obtained after the ZWI calculation. The ZWI value between optimistic and pessimistic scheme from 2020 to 2025 will be compared to identify the changing pattern and achievement of the 3R based waste management in regencies/cities of Bali Province as shown in Fig. 9.

From the comparison, the average ZWI value of 2020 in pessimistic schemes is higher than the optimistic scheme. It happens because the data used for the pessimistic scheme is data from a previous study regarding material flow analysis in Bali Province; hence the data is closer to the actual practice done on the sites. Meanwhile, the data used for the optimistic scheme is data from *Jakstrada* documents which use a standardized per capita waste generation approach. Therefore, the data are less likely to represent the actual condition and more of a projection.

The average ZWI value of Bali Province in 2025 is the same for both schemes; however, further analysis shows a difference in the ZWI development pattern. Even though the initial ZWI is high in a pessimistic scheme, there is no improvement in ZWI value to 2025. This scheme assumes that there will be no change in waste management and recycling percentage for every location, hence no change in ZWI despite an annual increase in waste generation. On the other hand, optimistic schemes give a lower value of initial ZWI with a changing pattern from year to year for every location. According to the *Jakstrada* documents, the generated waste will be reduced to 30% by 2025 using 3R activities. This target affects the value of ZWI as it changes following the target of waste reduction by 3R activities in 2025. Therefore, the ZWI value is not affected by the initial data and waste generation rate used for the calculation, but it is affected by the increase of waste management utilizing the 3R or zero-waste-based activities. Nevertheless, it is still imperative to have a reliable and valid database to determine and evaluate the current condition of waste management.

Additionally, the energy substitution values between the two schemes are also compared. Both comparisons consider the case where the incinerator is applied and not applied in Sarbagita Regional Landfill/Suwung Landfill as shown in Table 11.

Table 11
Energy substitution between two schemes

Location	Energy Substitution (GJLHV/tonnes)			
	Optimistic scheme		Pessimistic scheme	
	With incinerator	Without incinerator	With incinerator	Without incinerator
Denpasar City	889,338.66	877,757.77	164,812.07	154,302.3512
Badung Regency	474,118.17	467,944.25	232,364.47	226,812.3019
Gianyar Regency	175,723.29	173,029.67	79,848.29	77,288.19743
Tabanan Regency	239,798.72	239,798.72	102,837.61	100,320.0869
Average	444,744.71	439,632.60	144,965.61	139,680.73
Bali Province	2,116,274.86	2,080,796.86	1,007,208.03	971,730.0312

The difference in energy values between the optimistic and pessimistic schemes occurs due to differences in the basic data used. In total, the optimistic scheme provides energy substitution values 2–5 times greater than the pessimistic scheme, but in terms of the efficiency of using incinerator technology, the pessimistic scheme provides a higher percentage than the optimistic scheme.

On the optimistic scheme with an increase in waste handling by recycling every year, incinerator technology contributes an increase of 1–2% compared to when not using an incinerator. Meanwhile, the use of technology in the pessimistic scheme contributes an increase of 2–6% compared to when not using an incinerator. Based on alternative energy use, the optimistic scheme is a better priority than the pessimistic scheme, but incinerator technology does not make a significant difference; therefore, the usage of more efficient alternatives needs to be considered.

4. Conclusion

According to the analysis, the pessimistic scheme shows a higher value of initial ZWI than the optimistic scheme in 2020, but the value is stagnant and does not increase by 2025 (ZWI value ranges from 0.02 to 0.2) because there is no improvement in recycling and waste management percentage. On the other hand, the optimistic scheme gives a lower value of initial ZWI than the pessimistic scheme, but the value keeps increasing until 2025 following the target in *Jakstrada* documents (ZWI value ranges from 0.004 to 0.22).

For energy substitution, an optimistic scheme gives an energy substitution value 2–5 times higher than the pessimistic scheme, both with and without an incinerator. However, if the incinerator is to be implemented, the pessimistic scheme gives better efficiency (2–6% higher than without the incinerator) compared to the optimistic scheme (only 1–2% higher than without the incinerator).

From an optimistic scheme, the waste management utilizing the 3R approach gives significant results, as shown by ZWI improvement from year to year. The optimistic scheme also gives a relatively higher energy substitution value from the energy substitution variable and can be utilized further. The 3R based waste management and energy substitution potential in Bali Province may become the solution for effective municipal solid waste management under the condition that every stakeholder is committed to achieve the *Jakstrada* targets by 2025.

Declarations

Availability of data and materials

All data generated or analyzed during this study are available upon request. Data will not be shared due to privacy and policy of the place from which data was taken.

Competing interests

The authors declare they have no competing interests.

Funding

This work was supported by and funded by the P3MI Program from Bandung Institute of Technology.

Authors' contributions

I Made Wahyu Widyarsana proposed the research, conceived and designed the analysis, contributed data or analysis tools, collected the data, performed the analysis, and wrote the paper. Raditya Al Furqan performed the analysis and wrote the paper. Moehammad Budhicahyanto processed the data, performed the analysis, and wrote the paper. Nabila Nurfajri Surbakti collected the data, performed the analysis, and wrote the paper. Dianisti Saraswati performed the analysis and wrote the paper. All authors read and approved the final manuscript.

Acknowledgment

Not applicable.

Supplementary Information

Additional information that accompanies this paper is the author's previous paper which has been published at http://dx.doi.org/10.25105/urbanenvirotech.v0i0.4365 (Evaluation of Waste Management Achievement in Padangtegal Pekraman Village, Ubud Sub District, Gianyar District, Bali); https://doi.org/10.1051/e3sconf/202014805005 (A Preliminary Study: Identification of Stream Waste Quantity and Composition in Bali Province, Indonesia); https://doi.org/10.1007/s10163-020-00989-5 (Municipal solid waste material flow in Bali Province, Indonesia); https://doi.org/10.21660/2019.63.39057 (Risk Assessment and Rehabilitation Potential of Municipal Solid Waste Landfills in Bali Province, Indonesia).

References

1. Asfar AIT, Asfar A (2020) I. A. Unique Chair Cushions from Sent Plastic Waste. Media Science Indonesia
2. Hoornweg D, Bhada-Tata P What a waste: a global review of solid waste management; 2012
3. Levis JW, Barlaz MA, DeCarolis JF, Ranjithan S (2013) R. A generalized multistage optimization modeling framework for life cycle assessment-based integrated solid waste management. Environmental modelling software 50:51–65
4. Prihatin RB Waste Management in Medium Type Cities: Case Studies in Cirebon City and Surakarta City. Aspirations: Journal of Social Issues. 2020; 11(1):1–16
5. Zaman AU, Lehmann S (2013) The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city'. J Clean Prod 50:123–132
6. Zaman AU, Swapan MSH (2016) Performance evaluation and benchmarking of global waste management systems. Resour Conserv Recycl 114:32–41
7. Zaman A (2015) U. A comprehensive review of the development of zero waste management: lessons learned and guidelines. J Clean Prod 91:12–25
8. Zaman A (2016) U. A comprehensive study of the environmental and economic benefits of resource recovery from global waste management systems. Journal of cleaner production 124:41–50
9. Zaman AU (2014) Measuring waste management performance using the 'Zero Waste Index': the case of Adelaide, Australia. J Clean Prod 66:407–419

Figures

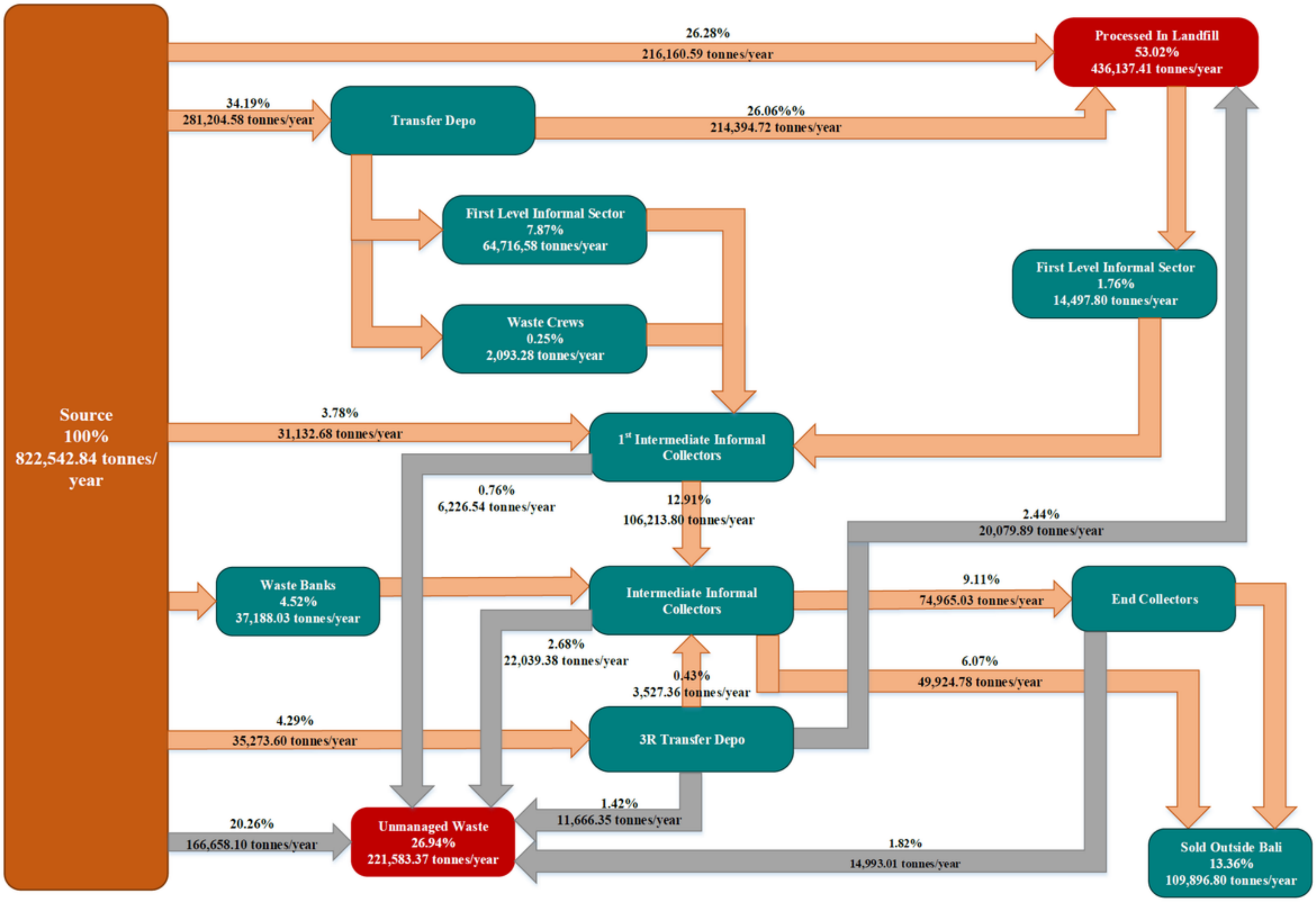

Figure 1

Material flow analysis of Bali Province in 2020

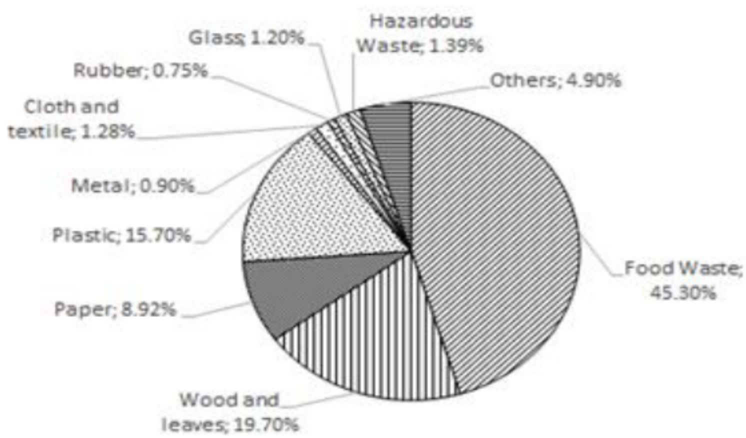

Figure 2

Average waste percentage composition in landfills

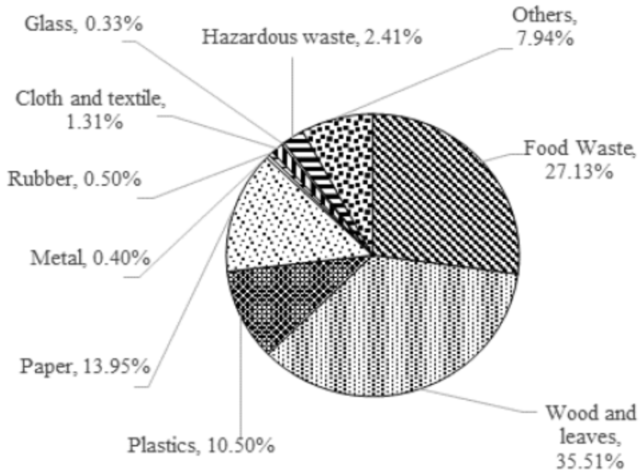

Figure 3

Average waste percentage composition at the source

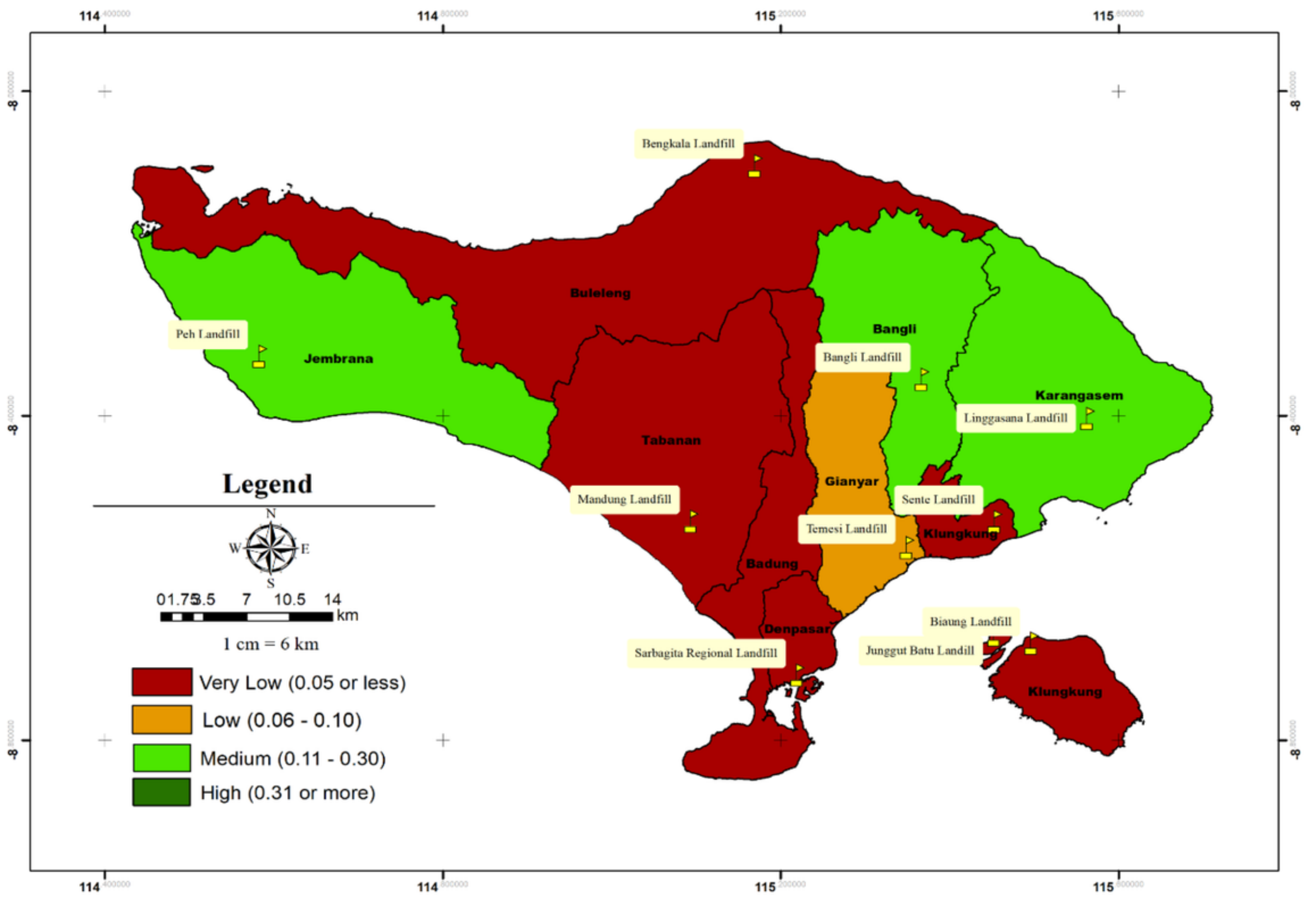

Figure 4

Zero Waste Index of Regencies/Cities in Bali Province by 2020 on Pessimistic Scheme

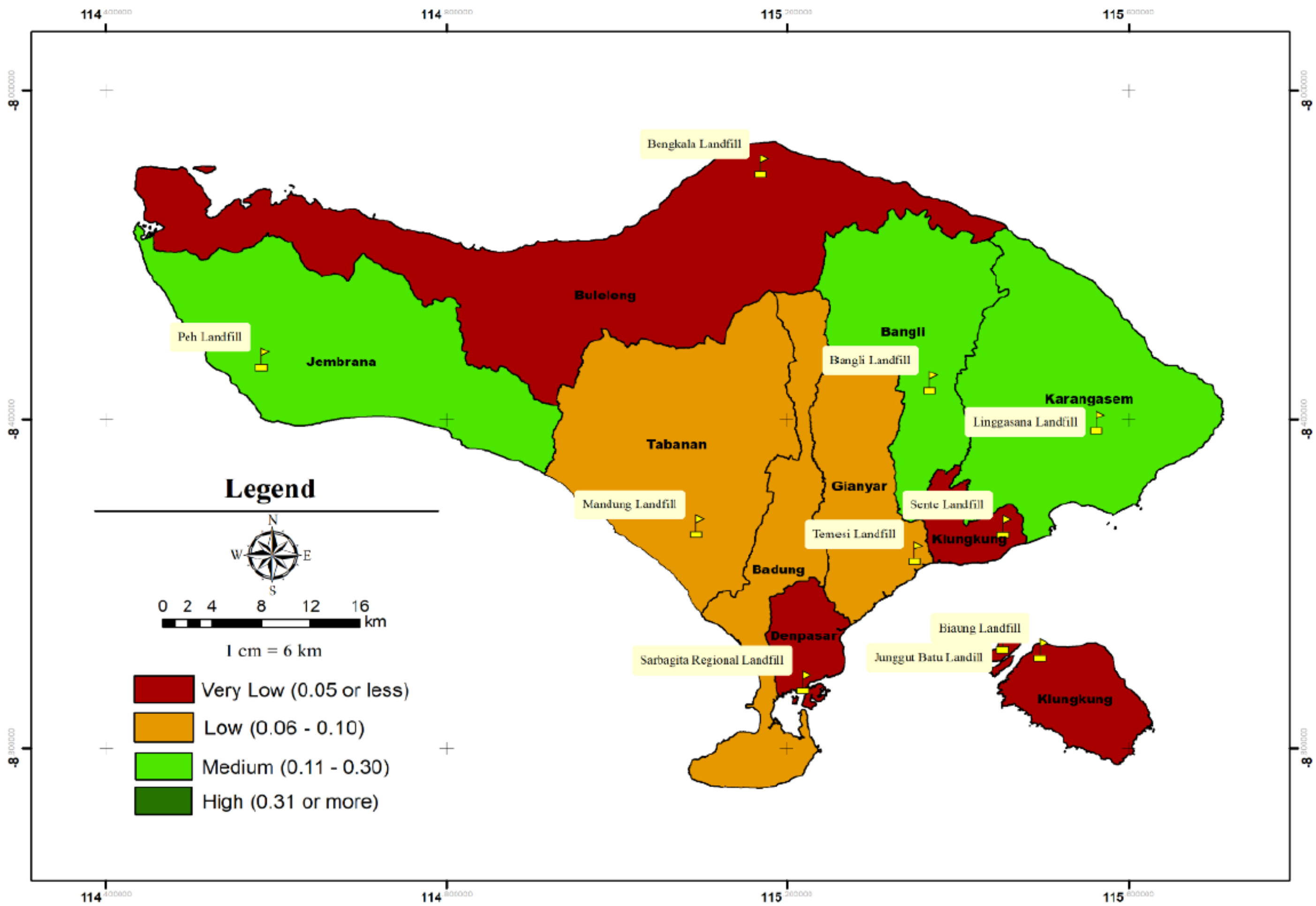

Figure 5

Prediction of Zero Waste Index of Regencies/Cities in Bali Province by 2025 on Pessimistic Scheme

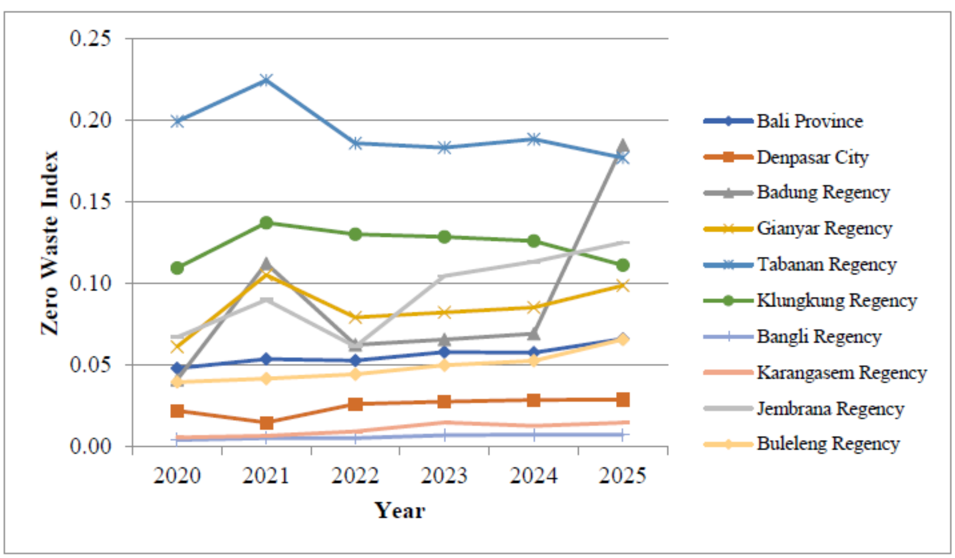

Figure 6

Time series of ZWI from each regency/city of Bali Province

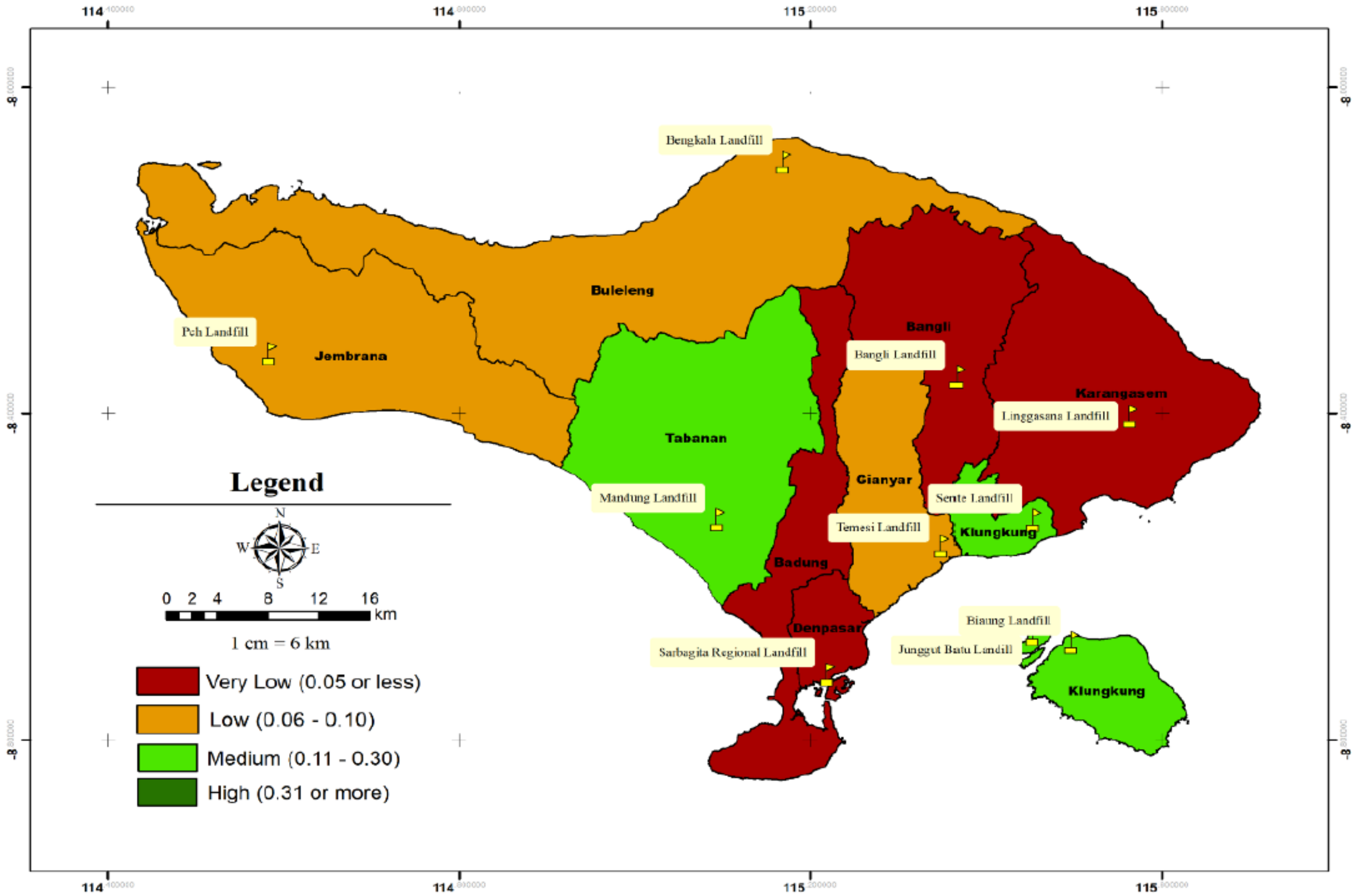

Figure 7

Zero Waste Index of Regencies/Cities in Bali Province by 2020 on Optimistic Scheme

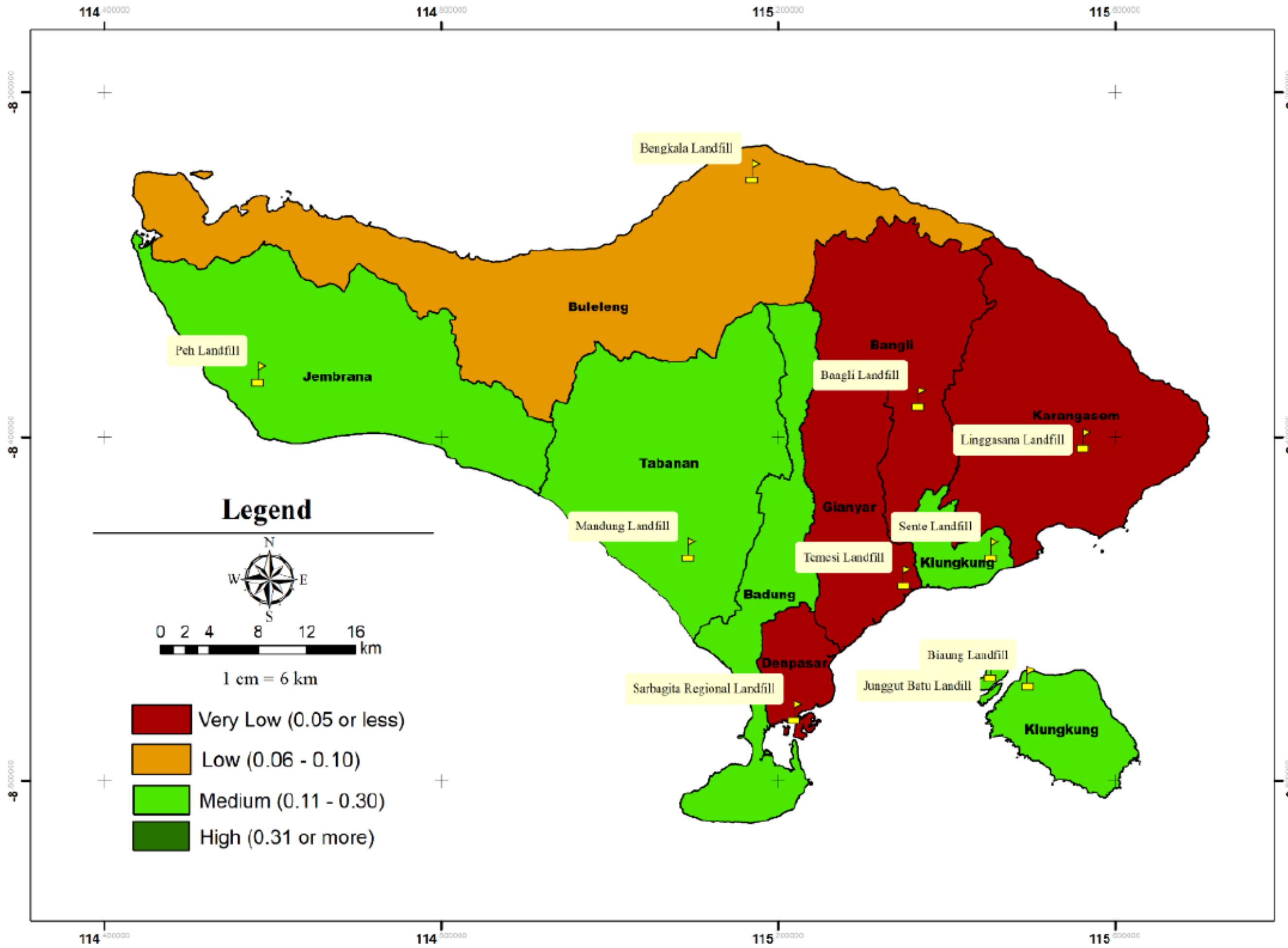

Figure 8

Prediction of Zero Waste Index of Regencies/Cities in Bali Province by 2025 on Optimistic Scheme

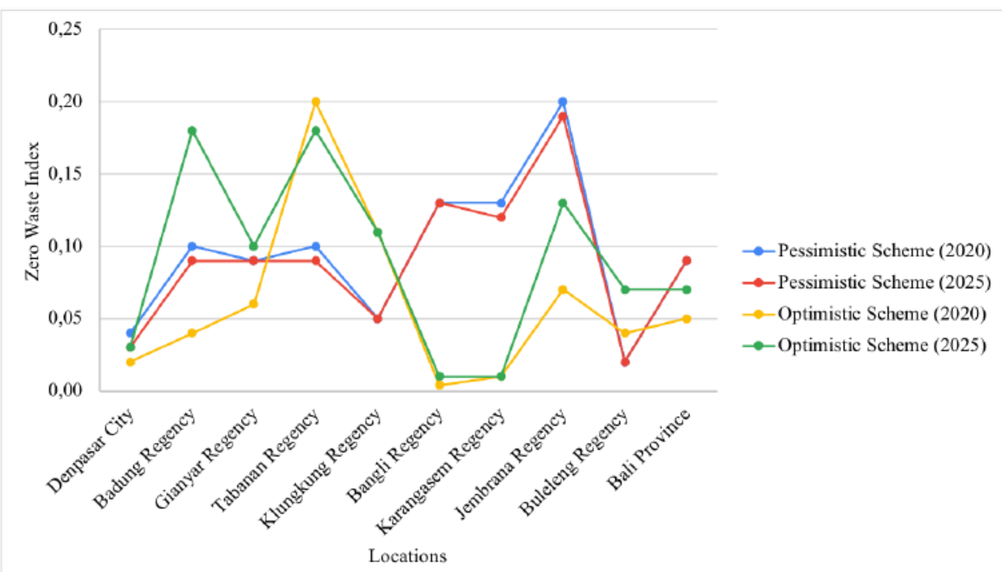

Figure 9

ZWI Comparison between two schemes

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GraphicalAbstract.docx