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Original Research

Circular Economy Designing of Municipal Waste Cooking Oil: A Case Study of Semarang City, Indonesia

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Abstract

Waste cooking oil (WCO) that is not managed optimally will harm the environment and human health. However, WCO can be recycled into valuable products. In this paper, appropriate WCO management is designed to minimise the cost of collection to a recycling centre as raw material for other products. The post-use products were analysed for circularity based on economic, environmental, and social aspects. A questionnaire-based survey was used to map community behaviour towards post-use products. Furthermore, the design of the waste collection point is carried out using the Maximal Covering Location Problem (MCLP) and the creation of the retrieval route using the Sequential Insertion (SI) algorithm. This study found a circularity framework for waste originating from households whose presence is scattered in small quantities. This study found phenomena related to community behaviour towards WCO and succeeded in developing the collection points and routes design in two scenarios. The municipal government can utilise the strategy of WCO collection points, and optimal WCO collection routes based on community behaviour to manage WCO waste better. Estimates of the WCO's potential, the costs required to handle, and the financial benefits and opportunities for running a circular economy were also analysed. The results of this study could be a good case study of WCO management, especially to develop economic circularity in developing countries.

Keywords: circular economy, collection centre, community behaviour, optimal route, waste cooking oil

Introduction

Population growth exerts pressure on natural resource consumption, and this unfettered growth makes it imperative to shift from the traditional linear model (take-make-dispose) to a circular economy (CE) [1]. Companies must maintain materials in a proper status towards the CE by avoiding dissipation of materials into the environment. Key strategies to prevent dissipation are increasing material efficiency and maintaining the material in the in-use state [2]. The CE framework is robust because it is based on reducing resources

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through efforts to increase resource efficiency through the 6Rs (reuse, reduce, recycle, recovery, redesign, and remanufacturing). Studies on the CE framework have been growing since the sustainable development goals (SDGs) were endorsed. Previous researchers have studied CE in the furniture industry [3-6]. Many studies on plastic products and its relation to CE have also been carried out [7-10] as well as studies related to CE on electronic products [8, 11, 12]. However, the application of CE on domestic waste management are still limited to the waste sorting process [13] and the economic potential of household waste [11]. Post-use products of household waste have great potential to be utilised but are limited to the collection and selling process. For this reason, developing a framework to achieve a CE in household waste management is necessary.

Waste cooking oil (WCO), as part of household waste, is important to be considered since its generation is increasing. Post-use management that is not optimal causes a high amount of WCO and is dangerous for the environment [14]. Therefore, WCO management has become a public concern [15]. China and Mediterranean countries produce large amounts of WCO, around 3-5 kg of WCO per capita yearly [16-18]. Like other countries, Indonesia has great potential for WCO. Based on the questionnaire survey, for instance in Semarang City, 90% of households and 67.6% of small culinary enterprises dispose of the WCO in drains, soil, temporary waste collection, and landfill [19, 20].

Several previous studies have examined that WCO can be recycled into more valuable products, including biodiesel [4, 21, 22]. Although the recycling of WCO into biodiesel still has technical problems [23], such processing also has environmental benefits in the categories of climate change, photochemical oxidant formation, fine dust, oil and gas depletion, and water pressure indicators [24]. WCO can also be processed into soap products to increase its economic value and reduce environmental impact. Utilising waste into a valuable product will minimise environmental impact [9, 25, 26].

Therefore, improper handling of WCO can cause environmental pollution, especially in water and soil [27]. Furthermore, WCO can also damage the aquatic environment because the oil layer in the water will cover the surface and prevent oxygen from diffusing into the water molecules [28]. However, using WCO can provide economic, social, and environmental benefits. From an economic perspective, WCO can be used as raw material for biodiesel production and replace palm oil as a natural resource [21]. From an environmental perspective, recycling WCO can reduce waste discharged into the environment [29] and from a social perspective, the WCO induces recycling business and creates jobs [19]. Therefore, it is imperative to implement efficient measures to dispose of and reuse WCO. One of the critical problems in WCO recycling is the WCO transportation model from the household. Several studies have reviewed the design of the WCO collection. However, it is limited to the party who will manage it, namely in terms of management efficiency between manufacturers or third parties, and aspects of environmental impact, such as comparing door-to-door management (DTD), schools (SCH) and urban collection channels (UCC) [18, 30]. Several previous studies on collection centres and route optimisation in waste transportation systems have been carried out, but they are still limited to municipal solid waste [31-34].

This study aims to determine the community's behaviour towards WCO, their willingness to collect WCO and design the optimal collection channel and route, especially in Semarang City. These efforts aim to reduce the amount of WCO disposed directly to the environment. By reducing the amount of directly disposed WCO, the environmental impact can be reduced by reducing the dependencies on palm oil resources as a raw material for biodiesel.

This paper establishes a framework for general household waste management. The proposed framework is compatible for household waste types, and in this study is used for WCO management. This research takes a case study of WCO management in Semarang. This framework can be replicated for other household waste, for example paper waste or other organic waste. This framework takes a case study in Semarang, but it is hoped that this framework can be applied to other cities, or a wider scope, for example, for one province or a country by making adjustments to the data used, for example the amount and supply points, the distance, capacity, and so on.

This research collaborates several methods such as The Maximal Covering Location Problem (MCLP) and Vehicle Routing Problem (VRP). MCLP is used to determine the location of the collection centre, while VRP is used to determine the transportation route. The VRP method chosen for determining the waste route is Sequential Insertion (SI).

Material and Methods

Circular Economy (CE) Framework in Household Waste

In designing a circular economy framework, it is essential to consider community behaviour towards waste. The amount and distribution of household waste will affect waste collection location. Furthermore, the collection point location will affect the design of the waste collection route to the recycling centre. After the circular economy design is carried out, it is necessary to evaluate its economic, environmental, and social benefits. The design of the circular economy framework for household waste can be seen in Fig. 1.

Consumer Behaviour

Four key factors play a role in the collection of cooking oil waste, namely; projected economic benefits

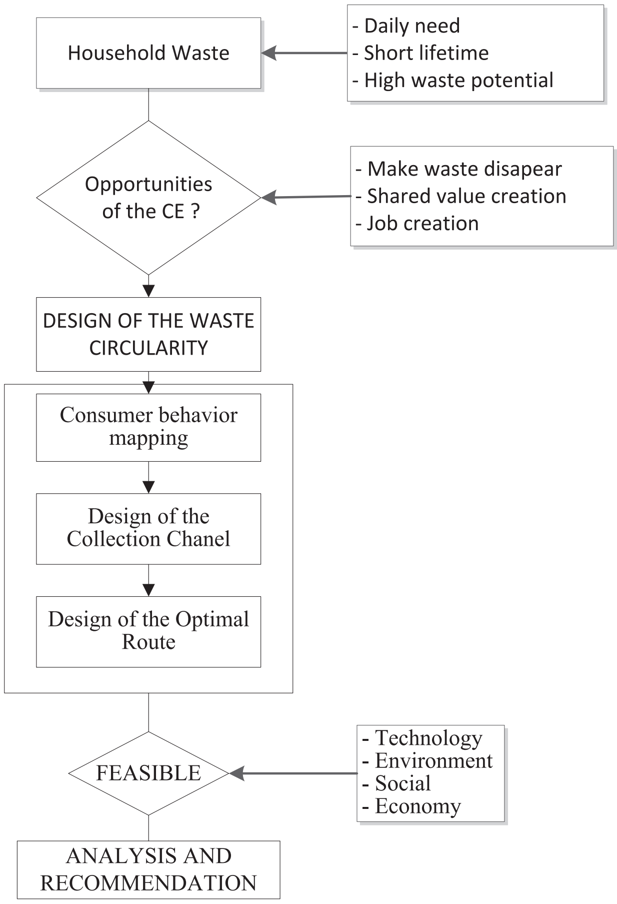

Fig. 1. Circular economy (CE) framework of household waste.

to cover waste management system costs, awareness of environmental issues from local authorities, interest in promoting environmental issues, and social benefits such as job creation (Vinyes et al., 2013). It is essential to carry out a behavioural survey to determine the potential for cooking oil waste generated by households. For example, information regarding the level of demand for cooking oil, the potential for waste generated, and how WCO has been treated so far. A survey regarding the distance that allows them to want to collect waste is also essential for the success of the collection stage. The distance from the household to the collection centre that is tolerable for consumers will be the basis for determining the collection centre. It is also essential for the designer to know the preferred collection centre manager, whether government, school, or non-governmental organisation. This information can be obtained by surveying cooking oil consumers.

Questionnaires were distributed to 347 households in Semarang City randomly to get the amount of WCO produced by each family in a month, data about the distance to the collection centre from the community, and the behaviour of cooking oil waste management that is currently occurring in the community in the Semarang City. Meanwhile, a literature survey was conducted by accessing data from the Central Statistics Agency of Semarang City in 2018 to determine the number of households in each sub-district. The Google Maps program was used to find the distance between 177 urban villages in Semarang City. Standard operational procedures (SOP) of municipal waste management were also collected from Environmental Agency Semarang City.

Design of Collection Points

The Maximal Covering Location Problem (MCLP) model is used to minimise the number of facilities that must be established but still provide comprehensive coverage of the WCO supply points and sequential insertion (SI) for route formation [35, 36]. This study determines the minimum number of collection channels that must be established to cover all supply points so that the objective function is written in Eq. (1)

$$\text{Min } Z = \sum_{j=1}^{m} X_j \tag{1}$$

The number of collection centres is the accumulation of the selected alternative collection centre placement points. The number of alternative points for the placement of collection centres is the same as the number of sub-districts in the district. The limiting function requires that all of the WCO supply points be covered so that the limiting function is written in Eq. (2).

$$\sum_{i=1}^{m} a_{ij} x_i \geq 1\,, i = 1, 2, \ldots m \tag{2}$$

Eq. (2) states the entire supply of cooking oil waste that the collection channel must cover. The WCO supply point and the collection channel location must be located in the same range or less.

$$X_j \in [0,1] \forall j \in V \tag{3}$$

$$a_{ij} \in [0,1] \forall i, j \in V \tag{4}$$

$$Y_i \in [0,1] \forall i \in V \tag{5}$$

Eqs (3), (4), and (5) state that Xj, aij, and Yi are binary delimiters. Another equation used is the equation for calculating the capacity of a collection channel, which is written in Eq. (6)

$$C_j = \sum_{j=1}^{m} Y_i S_i \tag{6}$$

Eq. (6) states that the collection channel capacity at point j is the accumulation of the multiplication of the cooking oil waste supply at point i by 1 or 0. 1 means that the supply of cooking oil waste at point i is covered, and 0 means the supply of cooking oil waste at the point i was not covered. From Eq. (1)-(6), Z refers to the number of the collection channel; m refers to the number of sub-district (Abdullah, 2013), X_j refers to the selected or not selected j becomes collection channel; X_j is $\begin{cases} 1\text{: j become collection centre } \forall\, j \in V \\ 0\text{: other} \end{cases}$; a_{ij} refers to the distance requirements are met or not; $a_{ij} = \begin{cases} 1\text{: distance i to j} \leq D\ \forall\, i, j \in V \\ 0\text{: other} \end{cases}$; D is range (km); C_j is the capacity of the collection channel at point j; Y_i represents whether or not the supply of cooking oil waste is included at point I; Y_i represents $\begin{cases} 1\text{: the point i is included in the collection channel j } \forall\, i \in V \\ 0\text{: other} \end{cases}$; and S_i is the supply of WCO at point i.

Design of Collection Route

The problem of transportation or distribution by considering the transportation route, the type of transportation used, and the vehicle scheduling problem is known as the vehicle routing problem (VRP). The VRP can be used to find an optimal route to minimise costs based on the total distance or travel time with the capacity limitation of the vehicle [33, 37]. Determination of WCO transportation routes begins with the vehicle leaving the depot empty (not yet loaded) to several collection channels to transport WCO. When the load on the vehicle has reached the maximum limit, the vehicle will go to the depot for unloading. Then the vehicle will start to carry out the transport again, and so on until the set time limit ends. Vecchi et al. (2016) stated that VRP can reduce the distance travelled by trucks and cost savings, thus, reducing carbon dioxide emissions. The basic form of VRP assumes that an unlimited number of vehicles, served by one route, several trips, and the total goods to be transported from all waste bank units in one route do not exceed the vehicle capacity, including capacitated vehicle routing problems with multiple trips, time window, pickup, and delivery (CVRP-MTTWPD).

The sequential insertion (SI) method is popularly used in VRP because it is fast in providing solutions, easy to implement, and easy to develop to deal with vehicle scheduling route problems. There are two routes in forming a route solution: combining existing routes with savings criteria and identifying which customers must be served with the cost of insertion criteria. SI algorithms to obtain optimal solutions and computer simulation techniques to determine the ability of solutions to address probabilistic demands have already been used [38]. A VRP model with a heterogeneous vehicle fleet size and mixed vehicle routing (HFSMVR) using a SI approach was developed [39]. Meanwhile, modelled heterogeneous fleet vehicles routing with overload and time window (HFVROTW) can be solved through SI heuristics using a penalty function allowing capacity violations [40]. SI algorithms for the initial solution search were used to integrate three specific variants of VRP, namely VRP with multiple time windows, VRP with heterogeneous fleets, and VRP with numerous scheduling [35].

The objective function of adopting the SI model is to minimise the total distance travelled from the route. Each route starts from the depot. Each collection channel is served exactly once on one route (See Eqs (7)-(10)).

$$\text{Min } J = \sum_{i \in V} \sum_{j \in V} \sum_{t \in T} \sum_{k \in K} C_{ij} X_{i,j,k}^{t} \tag{7}$$

$$\sum_{j \in C} X_{0,j,k}^{1} = 1\ \forall k \in K \tag{8}$$

$$\sum_{j \in C} \sum_{t \in T} \sum_{k \in K} X_{i,j,k}^{t}\ \forall j \in C, j \neq i \tag{9}$$

$$\sum_{j \in C} \sum_{t \in T} \sum_{k \in K} X_{i,j,k}^{t}\ \forall j \in C, i \neq j \tag{10}$$

The load capacity in the truck on a trip is the capacity accumulation of the collection channel. The load capacity on a trip does not exceed the vehicle's maximum capacity (See Eqs (11)-(12)).

$$Q = \sum_{i \in C} d_i Y_{i,k}^{t}\ \forall t \in T, \forall k \in K \tag{11}$$

$$Q \leq 15 \tag{12}$$

The trucks go to the depot for unloading. The route completion time is calculated from the total time the truck travels plus the service time (loading-unloading). The route completion time does not exceed the maximum working time provided. The route can be started from the intermediate facility on the next trip if sufficient time is needed. Each route ends at the depot.

The design of the WCO taking route is assumed to be symmetrical, where the distance from location i to location j is equal to the distance from location j to location i. Congestion is neglected, and truck speed is assumed, i.e., 40 km/h. The loading time at the collection channel is about 4 minutes for every 1 m^3 or 0.353 tonnes. In comparison, the unloading time at the depot is assumed to be 2 minutes per 1 m^3. Some of the limitations that are considered in designing the route include WCO transportation time according to the operator's working hours (7 hours), the vehicle used is a dump truck with a capacity of 15 tons, and the vehicle departs from the depot (Tambak Aji landfill) and returns to the depot as well (The model is defined in the Eqs (13)-(17)).

$$\sum\nolimits_{i\in C} X^t_{i,0,k} = 1\ \forall t \in T, \forall k \in K \tag{13}$$

$$CT = \sum\nolimits_{i\in V}\sum\nolimits_{j\in V}\sum\nolimits_{t\in T} T_{i,j}X^t_{i,j,k} + \sum\nolimits_{t\in T}^{t=t} S^t_k, \forall k \in K \tag{14}$$

$$CT \le 420 \tag{15}$$

$$\sum\nolimits_{j\in C} X^t_{X,j,k} = 1\ \forall t \in T(1), \forall k \in K \tag{16}$$

$$\sum\nolimits_{j\in C} X^t_{X,0,k} = 1\ \forall k \in K \tag{17}$$

V refers to the set of all vertices with 0 as a depot [39]; C is the set of the collection channel [17]; E is the set of directed ribs [35]; T is the set of the trip [17]; K is the number of vehicles [35]; J refers to the total mileage; C_{ij} is the distance from i to point j; $X^t_{i,j,k}$ defined as whether or not there is a trip from point i to point j on trip t; $X^t_{i,j,k}$ is $\begin{cases}1, \text{truck k travels from point i to j on the trip t} \\ 0, \text{other}\end{cases}$; d_i refers to the capacity at the facility; Q is the payload capacity on one route; $T_{i,j}$ is the travel time from point i to point j; S^t_k is the service time (loading-unloading); and $Y^t_{i,k}$ defined as $\begin{cases}1, \text{there is a load on i carried by vehicle k on trip t} \\ 0, \text{other}\end{cases}$.

Result and Discussion

Consumer Behaviour Towards Post-Use Cooking Oil

Of the 357 respondents spread across Semarang City, most of them reused cooking oil two times (47%), many also used only one frying pan (41.2%), but some still used cooking oil more than two times (11.8%). The average WCO production per household is around 0.97 litres per month. Most of the WCO ends up in waterways (66%), soil (8.6%), and landfill (15.8%). Only a tiny proportion of them reuse WCO (0.9%) as a lubricant and collect it in the waste bank. This situation happens due to a lack of understanding of the dangers of WCO if disposed of (54.9%). They throw away WCO because it is considered easy and practical. If there is a cooking oil waste collection point, 68% are willing, 18.44% are neutral, and 13.56% are unwilling to collect the WCO. The fairest distance to the collection point for cooking oil waste is about 2 km. The WCO containers that most customers favour before being sent to the collection point are plastic bottles (58.50%), small cans (23.05%), glass (9.22%), and others (9.23%). The parties deemed appropriate as the organiser of WCO collection are sub-district (59.08%) or non-governmental organisations (33.43%). The most chosen WCO collection period is once a month (40.06%), while others can choose any time (31.41%), can be every week (14.99%), and others (13.54%).

Design of Collection Centre

The distance between supply points and the range influences the location and number of collection channels. The distance between supply points is the distance between subdistricts in each district. Meanwhile, the range is the farthest distance from the collection channel that is still tolerated by households, which is 2 km. Based on MCLP calculated using Solver in Microsoft Excel 2013, the number of collection channels that must be established is 95. The largest capacity is in the Tlogosari Kulon collection channel, 16,024 litres or 5,659 tons. If the container facility is in the form of a drum with a total of 200 litres, it takes about 81 drums and an area of approximately 5.25 x 5.25 m. On the other hand, the collection channel with the least capacity is the Terboyo Kulon collection channel, only 146 litres (0.05 tonnes), so one storage drum is sufficient. The significant difference in supply point collections is influenced by distance to other subdistricts and the number of households. It is hoped that customers are more motivated to collect WCO, this study develops scenario 2 with a shorter range of 1 km. Scenario 2 requires 146 collection channels. The largest collection channel capacity is in Sendang Mulyo village, with a shorter range of 8,860 litres (45 drums). The total area required for the drum is approximately 5.65 m x 2.90 m. The smallest collection channel capacity is still in Terboyo Kulon, with a capacity of 146 litres (1 drum).

Design of Collection Route

The factor that determines the order of the route is the service time. The point with the fastest service time will be visited first. Service time includes travel time and loading-unloading time. The loading time is around 1 m^3 per 4 minutes and the unloading time is approximately 1 m^3 per 2 minutes. When converted into tonnage, the loading-unloading time is around 0.06 tonnes per minute. The transport route uses the Sequential Insertion algorithm VRPMTIFTW model. The principle of route formation is by inserting a collection channel with the fastest turnaround time. Insertion will continue and stop when the service time has expired, the truckload has reached maximum capacity, or all collection channels have been serviced. The resulting collection routes in scenario 1 are shown in Fig. 2, while the route in scenario 2 is shown in Fig. 3. Details regarding cycle time, quantity and distance (km) are explained in Table 1.

The longest travel time in scenario 1 is 366 minutes, with a total load of 14 tons (route 2). Meanwhile, the collection route with the most cargo is 15 tons, with a travel time of 304 minutes (route 1). The longest travel route is not necessarily the route with the most loads, and vice versa. The route with the longest travel time does not always carry the most WCO. Travel time is related to the distance between points on a route. Meanwhile, many WCOs have been collected related to the potential of WCO supply along the route. The total mileage is 800 km, with the farthest distance of 107 km (route 7). By shortening the range in scenario 2, the required trips are 12 trips for 12 days. The route requires the longest collection time of 380 minutes (route 2). The route with the most cargo (15 tons) in route 1. The total mileage also increased to 889 km. This situation is because scenario 2 has more points to visit. The farthest distance is 102 km (route 6).

Scenario Comparison

The costs involved are different for each scenario. Table 2 shows that the total cost per year for scenario 1 is IDR 1,081,109,400 and for scenario 2 is IDR 1,094,658,500. Both have a difference between IDR 13,549,000. The price difference occurs due to the need for storage drums and fuel costs. Scenario 2 requires more drums than scenario 1 because scenario 2 has more collection channel than scenario 1. In addition, scenario 2 has more trips, namely 12 days with additional total mileage, so the fuel operating costs will also be more significant.

Other costs such as the depreciation of the hauling fleet, maintenance, and operating wages of labour for both scenarios remain the same. The purchase of a truck is only made once every eight years because that is assumed to be the economic life of the truck, so the asset depreciation cost for the truck is IDR 39,000,000 per year. Maintenance of trucks is carried out once a year with IDR 10,000,000. Operational costs in the form of monthly labour salaries are adjusted to the minimum wage for Semarang City in 2019. If it is assumed that collectors will purchase the collected cooking oil waste for IDR 4,000, the total profit from the 373,734 litres of cooking oil waste will be 1,494,946,000. This potential profit has covered the investment budgets of both scenarios. With shorter coverage, the need for a collection channel and mileage increases. However, this makes it easier for the community to collect cooking oil waste at the collection channel. Another advantage of scenario 2 lies in saving land. The capacity of the scenario 1 collection channel requires 81 storage drums, while, in scenario 2, only 45 storage drums are required. The distance of 1 km means the supply of cooking oil waste is not concentrated too much at one point but spread over several points so that the amount is not too large.

Even though scenario 2 requires an additional trip, it does not require other workers and vehicles because the difference is insignificant. The comparison between scenarios 1 and 2 can be seen in Table 3. This study recommends scenario 2 with the advantage of a shorter range and fewer land requirements. The need for narrow land is essential because, if the land required is too

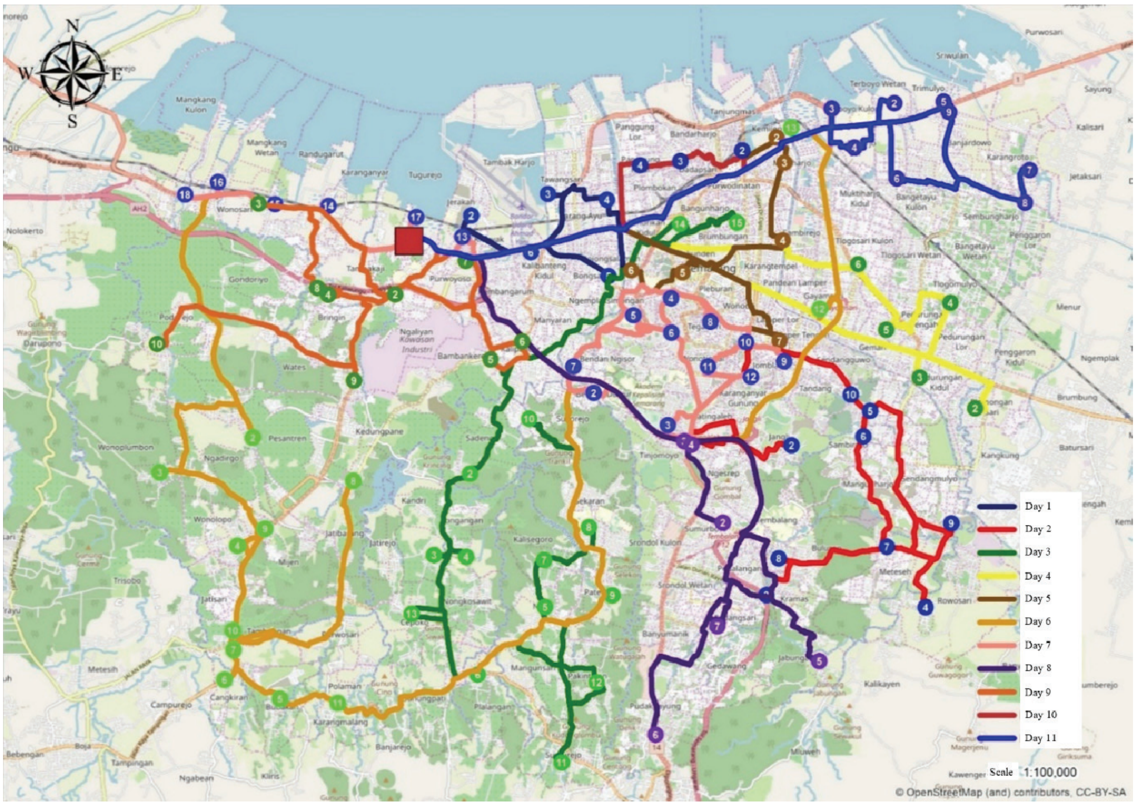

Fig. 2. Collection route in scenario 1.

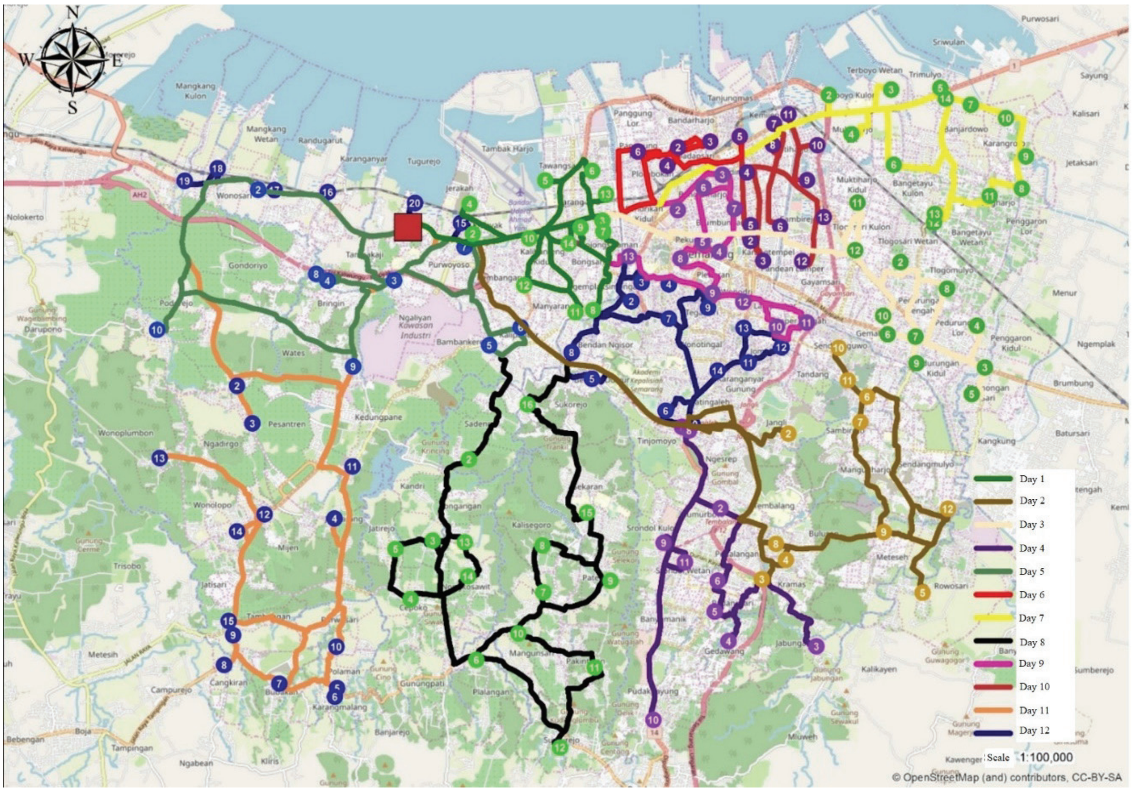

Fig. 3. Collection route in scenario 2.

Table 1. Details regarding cycle time, quantity and distance (km) in scenario 1 and 2.

	Scenario 1			Scenario 2		
Day	Cycle time (minute)	Quantity (ton)	Distance (km)	Cycle time (minute)	Quantity (ton)	Distance (km)
1	304	15	37	339	15	61
2	366	14	84	380	14	94
3	384	14	97	348	14	78
4	324	14	58	317	13	62
5	301	13	66	308	12	65
6	346	12	105	350	12	102
7	357	12	107	321	11	88
8	256	11	79	210	9	52
9	210	9	52	223	9	44
10	215	9	38	283	9	86
11	269	9	76	254	7	86
12	-	-	-	205	6	71

large, it will be difficult for the manager. Meanwhile, a shorter distance will make it easier for people to collect. The success of WCO management is very much influenced by the willingness of the community to participate. Although the cost requirements in scenario 2 are remarkable, the difference is insignificant.

Discussion

Design of the WCO Collection Procedure

The design of the WCO collection procedure is adjusted to the customer behaviour obtained from

Table 2. Transportation cost of collection based on the scenario.

Cost element	Unit	Cost. per unit (IDR)	Scenario 1 (2 km)		Scenario 2 (1 km)	
			Amount	Total Cost (IDR)	Amount	Total Cost (IDR)
Storage Drum	Unit	492,500	1,912	941,839,300	1,938	954,646,700
Vehicles depreciation	IDR	39,000,000	1	39,000,000	1	39,000,000
Vehicles maintanance		10,000,000	1	10,000,000	1	10,000,000
Operator (3 operator)	Man-month	2,310,000	36	83,163,150	36	83,163,150
Fuel	Liter-month	5,150	1,380	7,107,000	1,524	7,848,600
				1,081,109,400		1,094,658,500

Table 3. Comparison between scenario 1 and scenario 2: cost and performance.

No.	Indicator	Unit	Scenario 1	Scenario 2
1	Range	km	2	1
2	Number of the collection channel	unit	95	146
3	Number of trips	day	11	12
4	Maximum capacity	litre	16,024	8,860
5	Maximum drum requirements	unit	81	45
6	Maximum land requirement	m^2	32	17
7	Number of fleets	unit	1	1
8	Fuel requirements	litre	115	127
9	Maximum turnaround time	hours	366	380
10	Maximum trip distance	km	107	102
11	Cost requirement	IDR	1,081,109,400	1,094,658,500

the questionnaire results in Semarang City. First, the community collects WCO to a collection channel determined according to the village where they live. Then, the period of collecting WCO is once a month on a predetermined working day. WCO is brought from the house using plastic bottles. WCO in the bottle is put into the storage drum that has been provided and poured. Then, the drum should be closed when left. The design for collecting WCO is different from existing mechanisms, for example, in Thessaloniki, Greece. Although the collection uses plastic bottles delivered to the nearest collection channel, management in Thessaloniki involves 50 companies. One company called „Revive", which was founded in 2006, in 2010 already had 1900 collection points in Greece, covering an area of only 131,957 km^2. Collection channels are like trash bins where people can deposit WCO at any time and in the nearest place [15]. Every day, a fleet travels around to transport WCO from each collection channel. Applying the WCO collection model in Thessaloniki still needs several considerations in Indonesia, especially in Semarang City. Not many companies are willing to invest in this project, so it is best to start by government initiatives.

The Role of WCO Management in the Circular Economy

The circular economy concept aims to keep raw materials in a closed circle. Several studies related to the collection of WCO to be used as raw material for other products have been conducted, for example: WCO as a raw material for biodiesel [24, 41], soap [42, 43], and others. However, research on WCO collection activities and costs associated with the WCO value chain is still extremely limited. One of them is a study that verifies whether companies that collect, process, and sell WCO to mills show a loss or a profit [41]. Another study is the domestic WCO collection system that compares school lines, door-to-door (DTD), and Urban Collection Channels (UCC) to be promoted as a WCO collection technique in cities in Mediterranean countries [18, 30].

WCO is a product that has a short life, so it has the potential to become waste. WCO is routinely used by households and damages the environment when improperly disposed of, so it is especially important to be recycled. Waste that can become a product that is more valuable and has the potential to create jobs is interesting to design in a circular economy framework. In this study, the majority of Semarang people still adhered to linear economics in using cooking oil, from the process of cutting down palm trees, producing cooking oil, using cooking oil, and eventually disposing of the cooking oil at the end. Meanwhile, WCO has materials that can be used to make biodiesel or soap [44]. If the collected WCO is processed into biodiesel, it will save the need for palm oil.

This study is limited to the area of Semarang City. However, the WCO collection framework can be developed in a wider area, into one province and even a country. WCO collection will shift the linear economy towards a circular economy. The next research challenge in a wider area is certainly not only in determining the WCO collection centre and the route to the depot. The study can go as far as to determine the number and location of the depots, as well as determine the optimal location of the biodiesel plant, which will be interesting to study.

Conclusion

This research has found that limited knowledge and public awareness of the environment influence people's behaviour in Semarang City, so they prefer to throw away rather than recycle. With the high willingness of the community to collect WCO at the collection point with a maximum range of 2 km, this is a challenge for the government to manage WCO optimally. By designing a collection point with MCLP and a collection route with an SI approach, this study recommends the design of a WCO collection point and route with a range of 1 km. It is hoped that shorter distances will make it easier for the community to deposit WCO at the collection point. Another advantage is that the maximum drums required at the collection point is less, so the area needed to site the drums is less. Although costs and routes are more, the difference is not significant. This study also recommends the WCO collection procedure that considers the behaviour of the people in Semarang City. The community will collect WCO put into plastic bottles to the nearest collection channel once a month on a predetermined working day. The collection will involve the subdistrict staff. Further research needs to conduct experiments to determine whether the potential supply of WCO in the community can be maximally collected. Thus, the barriers and drivers for the community to be willing to collect WCO at the collection point can be identified. The triple helix cooperation between academia, government, and industry in maximising existing WCO recycling management needs to be studied more to achieve a circular economy.

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Competing Interest

The authors declare that there is no conflict of interest exists.

Author Contributions

The conceptualization was performed by Sri Hartini. Writing-review & editing was performed by Bimastyaji Surya Ramadan and Diana Puspita Sari. Anisa Amalia Utami and Yusuf Widharto validated the data presented. All authors read and approved the final version of the manuscript.

Availability of Data and Materials

The datasets generated are available from the corresponding author on request.

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