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Life Cycle Economic Impacts of Reusable Plastic Crate

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Abstract: Given the importance of packaging in fruit and vegetable transportation, life cycle assessment was applied to study the environmental impacts. However, economic evaluation was rarely combined with environmental performance. In this paper, life cycle costs (LCC) models are built, while reusable plastic packaging (two business models: purchased reusable plastic packaging-PRPC, and rent/leasing-RRPC) and disposable packaging (cardboard box-CB) are selected for the life cycle economic studies, and then results are studied combining life cycle assessment results. The findings are: 1) At selected reference scenario, purchased reusable plastic crate (PRPC) mode has the lowest costs while cardboard box highest; 2) All packaging types transportation costs have positive linear correlation with transportation distance, so is the reciprocal of circulation times; 3) Optimizing reverse logistics, storage ratio, folded percentage, reduced crate price and extended lifetime could lead to positive financial performance for RPC, while the crate rotation factor increase and circulation crate number increase has negative influence.

1. Introduction

At the moment, the world produces about 4 billion metric tons of food per year, and food processing, packaging and logistics takes up nearly half of the energy consumed in the food system. According to FAO data, agricultural food systems emit more than one-third of the world's anthropogenic greenhouse gas emissions, cause about 90% of the world's deforestation, and consume 70% of the world's total freshwater use [1]. Global food loss and waste rate is 1/3, resulting in economic losses of up to 1 trillion U.S. dollars. Food processing, packaging and logistics takes up nearly half of the energy consumed in the food system [2]. Various forms of packaging and containers are developed along the fruit and vegetables logistics [3]. Corrugated box, plastic crates that are reusable or disposable, wood box, foam box are different types of secondary packaging.

Life cycle perspective is typically applied to have a thorough opinions for environmental, economic and social influence [4]. Life cycle cost is a good tool, and is modelled according to the LCA pattern and sums all costs, which occur in the life cycle of a product (the economic benefits or costs attributable to the network infrastructure, manufacturing, transportation, storage, disposal, and general operating drivers) for one of the actors (e.g. supplier, producer, user, consumer, recycler) [5]. In 2011 Menesatti et al. investigated the economic benefits of using reusable plastic packaging in the floral supply chain, and the results showed that reusable plastic packaging exhibited high economic benefits compared to traditional paper packaging under long-term (>1 year) use conditions, and logistics management has an important impact on the cost of the full life cycle of packaging [6]. In 2017 Nophanut Katephap and Sunpasit Limnararat compared the economic and environmental benefits of disposable versus recyclable packaging for automotive parts under different reverse logistics management modes (one-way, round-trip, and multiple times), and proposed a mathematical model for calculating the total packaging cost[7]. The results of the study showed that, compared to disposable packaging, the total recyclable packaging under a multiple reverse logistics scenario, the total cost of recyclable packaging can be reduced by 61% and the amount of packaging waste can be reduced by 68%. For RPC shipping fruit and vegetables, in 2014 Accorsi et al. focuses on the purchase of crates as the main scenario, and limited research has been conducted on rent/leasing scenarios[8]. In the case of the multiple reverse logistics scenario of reusable plastic crates for fruits and vegetables, the transportation routes are much more complex, and therefore more elements need to be considered in order to assess the cost of reusable plastic crates and disposable packaging from a practical point of view. In 2022, Accorsi et al proposed a model for calculating the cost of recyclable packaging operators in the food industry, which included packaging material costs, cleaning costs, storage costs, transportation costs, and a sensitivity analysis taking into account the proportion of packaging cleaned, distribution rates, etc. The model was applied to the Italian food supply chain[8]. It can be seen that there are less studies on the RPC LCC with fruit and vegetables, and different elements exploration is insufficient. The LCC application on RPC has not been thoroughly investigated together, and the key setting of LCC is not well summarized nor clearly presented. This study presents the findings of using LCC models for evaluating RPC performance, and combine environmental impacts from the same life cycle, thus giving a clearer picture of scenarios applying RPC with economic considerations.

2. Methods

LCC for packaging normally includes packaging price, transportation cost, HR costs, management costs, logistics tracing costs, damage and lost cost, income etc. [9]. In this study, two types of transportation packaging are RPCs and disposable Cardboard boxes (CBs). RPCs can be categorized into rental mode RPCs (RRPCs) and purchase mode RPCs (PRPCs). The dimensions and capacities of the transportation packages involved in this study are set to be the same: 600*400*240 (mm), and weight of loaded goods to be 15kg while RPC life span 3 years. Other basic parameters are set in the following table 1:

Table 1: Basic parameters of transportation packaging.

Basic info	Unit	CB	PRPC	RRPC	Data source
weight/piece	kg	0.807	1.709	1.709	Questionnaire & site survey
material		Paper	PP	PP	Questionnaire & site survey
Broken and lost percentage (/3 years)	%	NA	8	8	Questionnaire & site survey
Unit price	¥/piece	5	30	0.027 (¥/piece/day)	Questionnaire & site survey

The scope of the study includes the economic costs of transport packaging throughout its life cycle, focusing on six components: packaging acquisition (production) costs, transportation costs, labour costs, cleaning costs, storage costs and waste disposal costs. Production costs are replaced by the purchase or rental price of the transport packaging, covering the cost of the packaging itself and the labels on it; transportation costs include the cost of all transportation of the packaging from the manufacturer to the waste disposal site, and are related to the total distance of all vehicle transportation; labor costs refer to the cost of loading, unloading, and sorting of the packaging at all the nodes involved; cleaning costs are only related to the RPC, and refer to the water produced by the packaging due to cleaning in the use phase. Cleaning cost is only related to RPC, which is the cost of water, detergent, labor, etc. generated by the cleaning of the packaging during the use phase;

Warehousing cost is also only related to RPC, which refers to the management cost of the packaging due to warehousing at all the nodes involved; For the waste disposal cost, according to our actual visit and research, we found that the disposal cost of both CB and RPC is actually the recycling revenue.

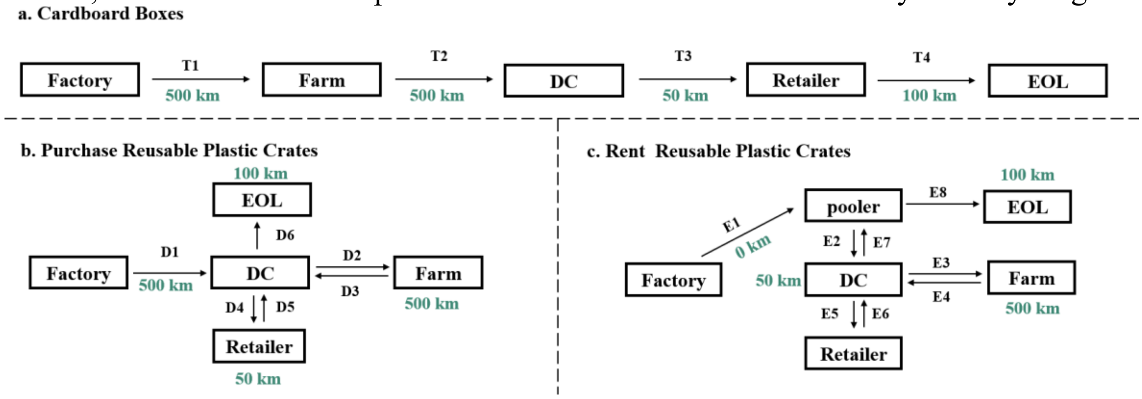

Figure 1: LCC system boundary of CB and RPC.

The system boundary in this study is from cradle to grave. The system boundary begins with the production of transportation packaging and includes transportation, use, and cleaning (if any) until its end-of-life. In the case of disposable cardboard boxes (Figure 1a), they are produced in factories and transported to farms (T1), where they are filled with goods such as vegetables and fruits. The filled cardboard boxes are transported to distribution centers (DC, T2), then distributed to retailers for sale of goods (T3), and finally transported to waste treatment centers for disposal.

For RPC, it is characterized as reusable. According to the RPC business operation model, it can be categorized into purchase mode and rent mode. The system boundary of RPC in both modes has the same starting point and the same end point, and the difference lies in the cycle path during its use. As shown in Figure 1b, PRPCs are first transported from the production plant to the DC, then sent from the DC to the farmland, filled with fruits and vegetables, and sent back to the DC, which in turn is distributed to the stores. The emptied PRPC is returned to DC and completes the first cycle. During the lifetime of the PRPC, it will be recycled again and again until it is scrapped. For PRPC it is assumed that its cleaning has the responsibility of the distribution center itself, so there is no transportation involved in that segment.

In the rent/leasing mode, RPCs are first transported from the production plant to the rent/leasing center (pooler), and then transported by the pooler to the DC. subsequent transportation of RRPCs between DCs, farms, and stores is the same as in the self-purchase mode. When the RRPC is scrapped, it is transported back from the DC to the pooler and then sent for recycling. For RRPC, regular transportation between DC and wash center is also covered in this study.

Based on the research objectives and scope of the study, the cost of transportation packaging is divided into six parts in this study: acquisition/production cost (TCpack), transportation cost (TCTRP), labor cost (TCLC), cleaning cost (TCCC), storage cost (TCSC), and waste disposal cost (TCEOL) (see Equation (1) for details). Disposable cardboard boxes include only production costs, transportation costs, labor costs, and waste disposal costs (see Equation (2) for details) because they serve only one fruit and vegetable shipment and do not need to be recycled.

$$TC = TC_{pack} + TC_{TRP} + TC_{LC} + TC_{SC} + TC_{CC} + TC_{EOL} \quad (1)$$

$$TC = TC_{pack} + TC_{TRP} + TC_{LC} + TC_{EOL} \quad (2)$$

Production cost is the cost incurred in the production process of transportation packaging and is expressed in this study as the purchase or rental price of packaging. This cost is related to the number of packages required (TN), and the unit price (CU). The basic formula is as follows:

$$TC_{pack} = TN \times CU \quad (3)$$

For CBs, its (TC_{CB}) is calculated as:

$$TC_{CB} = TN \times CU = \frac{TQ}{LW} \times CU \quad (4)$$

TQ is the total quantity of product within defined time, unit is kg; LW is product weight per packaging, unit is kg.

For RPC, its TC_{PRPC} is calculated as:

$$TC_{PRPC} = TN \times CU = (RN + BP \times RN) \times CU = (CRF \times BN + BP \times CRF \times BN) \times CU \quad (5)$$

RN is actually needed crate number, unit is piece; BP is crate broken and lost percentage at defined time, in percentage; BN is no of crate needed for transportation, which is calculated as:

$$BN = \left\lceil \frac{TQ}{LW \times CT} \right\rceil \quad (6)$$

CT is circulation time within defined time, unit is time.

Transportation costs are related to the transportation unit cost (TUC, \$/ (km*vehicle)) and the total distance travelled by all vehicles involved (TDis). The transportation roadmap is shown in Figure 1. The calculation formula is as follows:

$$TC_{TRP} = TUC \times TDis_{is} \quad (7)$$

For CB, the total transportation distance ($TDis_{CB}$) is calculated as follows:

$$TDis_{CB} = \lceil NV \rceil \times T = \left\lceil \frac{TN}{NQ} \right\rceil \times [T1 + T2 + T3 + T4] \quad (8)$$

NV is the number of fruit and vegetable transportation vehicles, in units of vehicles; *NQ* is the number of transportation packages that can be loaded per vehicle, in units; *T* is the total distance of DCB transportation per car, Ti is the distance between each node, i is the node number.

For PRPC, its total transportation distance ($TDis_{RRPC}$) is calculated as follows:

$$TDis_{PRPC} = \lceil NV1 \rceil \times FP \times (D1 + D6) + \lceil NV2 \rceil \times (FP \times D2 + D3 + D4 + FP \times D5) \times CT \quad (9)$$

$$NV1 = \left\lceil \frac{RN}{NQ} \right\rceil, NV2 = \left\lceil \frac{BN}{NQ} \right\rceil$$

D is the total distance transported per vehicle for PRPC, Di is the distance between each node, and i is the node number; *FP* is the folding factor of RPC.

For RRPC, its total transportation distance ($TDis_{PRPC}$) is calculated as follows:

$$TDis_{RRPC} = \lceil NV1 \rceil \times FP \times [(E1 + E2 + E7 + E8)] + \lceil NV2 \rceil \times \left[FP \times CP \times (E9 + E10) \times \frac{LT \times 12}{CF} + (FP \times E3 + E4 + E5 + FP \times E6) \times CT\right] \quad (10)$$

CP is the RRPC cleaning ratio, expressed as a percentage; *LT* is the RRPC lifetime in years; *CF* is the RRPC cleaning frequency in months (intervals)/times; *E* is the total distance of RRPC transportation per vehicle, Ei is the distance between each node.

Labor cost (TCLC) is mainly generated by activities such as unloading and loading packagings of fruits and vegetables, loading and unloading trucks from packagings, and sorting of packagings and fruits and vegetables. In this study, it is related to the unit labor cost (LUC) and the total handling time (HT) for all segments, which is calculated by the following formula:

$$TC_{LC} = LUC \times HT \quad (11)$$

The storage cost (TCSC) is mainly generated by the overhead required by RPC when it is stranded at each node, and is related to the unit storage cost (SUC), packaging quantity (BN), storage time (ST), and storage percentage (SP). CB does not involve storage cost. The formula for calculating the

RPC storage cost is as follows:

$$TC_{SC} = SUC \times ST \times SP \tag{12}$$

Since RPCs will be recycled over the course of their lifespan, they need to be cleaned at a certain frequency, incurring a certain cleaning cost. The cost is related to the number of packagings (BN), the frequency of cleaning (CF), the cleaning ratio (CP) and the cost per unit of cleaning (CUC). CB, on the other hand, provides only one fruit and vegetable transportation and packaging services, and therefore does not need to be cleaned. the RPC cleaning cost (TCCC) formula is as follows:

$$TC_{CC} = BN \times CUC \times CP \times \frac{LT \times 12}{CF} \tag{13}$$

After CB and RPC have completed their transportation mission, they will be transported to end-of-life points or recycling centers for disposal. According to the actual research, both kinds of transportation packaging can be recycled after end-of-life, so the waste disposal cost is actually the packaging recycling revenue. This cost is related to the actual number of packagings (RN, RN=BN=TN for CB) and the unit disposal cost (DUC), which is calculated as follows:

$$TC_{CC} = RN \times DUC \tag{14}$$

In order to conduct LCC analysis of RPC, and to compare the cost differences between different transportation packaging and operation modes, this study firstly set up a reference scenario of RPC usage based on literature research and actual research. Meanwhile, the data entries and data values to be used in costing were determined from literature, questionnaire surveys and interviews with enterprises & project partners. In case of missing or unreliable data, hypothetical data based on expert feedback and data from the database were used to supplement the data.

In the reference scenario, the purpose of using the transport packaging can be described as completing the distribution of 1,800 tons of fruits and vegetables per year (5,400 tons over 3 years). Also in the reference scenario the reverse logistics of the RPCs and possible collapses are not considered. In addition to some basic parameters of the transport packaging, including: the amount of fruit and vegetables that could be loaded per packaging was set to 15 kg with standard size crate [10], the weight of one packaging was set at 0.807 kg for CB, the other parameter settings involved in the reference scenario are detailed in Table 2.

In the reference scenario, to complete the transportation of 5400 tons of fruits and vegetables, 360000 (5400000kg / 15kg) CBs or 5000 (BN) RPCs are theoretically required, but considering that RPCs are actually used with a certain amount of retention at each transportation node, the actual rotation number of RPCs (RN) to be produced is 10000 with the setting of the twofold flow factor. In addition, since there is an 8% broken and lost percentage of RPCs in 3 years of use, the total number of RPCs to be produced (TN) is 10800. It should be noted that for RPCs, TN is only used to calculate production costs and RN is only used to calculate part of the transportation (e.g., manufacturer-distribution center and distribution center-end-of-life point) and end-of-life costs. In the transportation, cleaning, loading and unloading scenarios of RPC recycling, basic number (BN) is used as its input quantity.

In the transportation phase, CB is one-way transportation, i.e., fruits and vegetables are transported from farms to distribution centers and then to stores. RPC, on the other hand, needs to be transported in multiple cycles under the path of "distribution center-farm-distribution center-store-distribution center", and there will also be transportation to the washing center once a month. At the same time, it should be noted that, in practice, after the RPC is put into use, in the DC - farmers and from the store - distribution center of the two sections of the empty packaging distribution journey, the vehicle will not be empty RPC, but will be loaded with other fruits and vegetables. Therefore, since the vehicles and RPCs serve other purposes at the same time, the transportation costs for that part of the journey are apportioned, which is referred to as reverse logistics in this study, and the apportionment result is calculated by considering the crediting percentage to calculate the apportionment result. In the reference scenario, 100% of the reverse logistics is accounted for (without considering apportionment). In order to simplify the calculation, it is assumed that the model used in the packaging and distribution phase and the use phase of transportation is the same model, which is a 13 m van with a design capacity of 35 tons and no refrigeration function.

Table 2: LCC reference scenario parameters.

1. Basic setting	Unit	CB	PRPC	RRPC	Data source
F&V total weight (/3years)	kg	5400000	5400000	5400000	Questionnaire & site survey
Crate rotation factor (CRF)	NA	NA	2	2	Assumption
Circulation time (/3years)	time	NA	72	72	Assumption
2. Transport cost	Unit	CB	PRPC	RRPC	Data source
Unit transport price	¥/(km*vehicle)	6	6	6	Questionnaire & site survey
Crate number/verhicle	piece	2,000	2,000	2,000	Questionnaire & site survey
Packaging manufacture - DC/farmland	km	500	500	500	assumption
DC -farmland	km	NA	500	500	assumption
DC -retailer/store	km	50	50	50	assumption
DC -pooler	km	50	50	50	assumption
DC-WTC	km	100	100	100	assumption
DC-Cleaning center	km	NA	10	10	assumption
Reverse logistics with other goods	km	NA	0%	0%	assumption
3. Labor cost	Unit	CB	PRPC	RRPC	Data source
Unit labor cost	¥/(hour)	11	11	11	assumption
Empty packaging load/unload efficiency	piece/(hour)	500	500	500	assumption
Loaded packaging load/unload efficiency	piece/(hour)	250	250	250	assumption
4. Storage cost	Unit	CB	PRPC	RRPC	Data source
Unit Storage cost	¥/(hour*500 packaging)	NA	10	10	assumption
Farmland storage total time	hour	NA	20	20	assumption
DC storage total time	hour	NA	20	20	assumption
Store/retailer storage total time	hour	NA	20	20	assumption
Storage percentage	%	NA	30	30	assumption
5. Cleaning cost	Unit	CB	PRPC	RRPC	Data source
Unit cleaning cost	¥/piece	NA	0.5	0.5	assumption
RPC cleaning frequency	time/month	NA	1	1	assumption
RPC cleaning percentage	%	NA	100%	100%	assumption
6.EoL cost	Unit	CB	PRPC	RRPC	Data source
Distance to WTC	km	100	100	100	assumption
Unit treatment cost	¥/(each)	1	5	5	Questionnaire & site survey

From the above reference scenario, it can be seen that the size, capacity and material of the transportation package are fixed parameters. Variables mainly include transportation distance, the number of times the RPC is circulated, the model and whether there is reverse logistics. Therefore, the total amount of fruit and vegetable transportation, transportation distance, the circulation times, the broken and lost percentage, the proportion of hoarding, the folding coefficient, the proportion of reverse logistics are selected to carry out a one-way analysis of these variables, to explore the effect of the combination of parameters on the cost of transportation packaging.

3. Results and discussion

The objectives of this study were 1) to quantify and assess the costs of reusable plastic crate (RPC) for fruits and vegetables throughout its life cycle of production, transportation, use and disposal; 2) to evaluate and identify the key factors affecting the economic costs of RPC through different scenarios of key factors (e.g., single factors: transportation distance, number of times of circulate, crate folding coefficients, packaging readiness rate, and reverse logistics, or a combination of these); 3) to compare the economic costs of RPC with other transport packaging made of different food contact grade materials (disposable cardboard boxes (CB)); 4) to combine LCC with LCA, and map the most preferential zones for RPC to be advantageous in both economic and environmental performance.

3.1 Reference scenario results

The results of the full life cycle analysis of the three packages under the reference scenario are shown in Figure 2. It can be seen that under the reference scenario, PRPC has the lowest TC and CB has the highest TC. Purchase cost and transportation cost contribute more than 90% to the cost of the three transportation packaging modes. For CB total cost composition, its purchase cost has the largest share, followed by transportation cost. For RPC, transportation costs contributed the most to the TC for both purchase and rental modes.

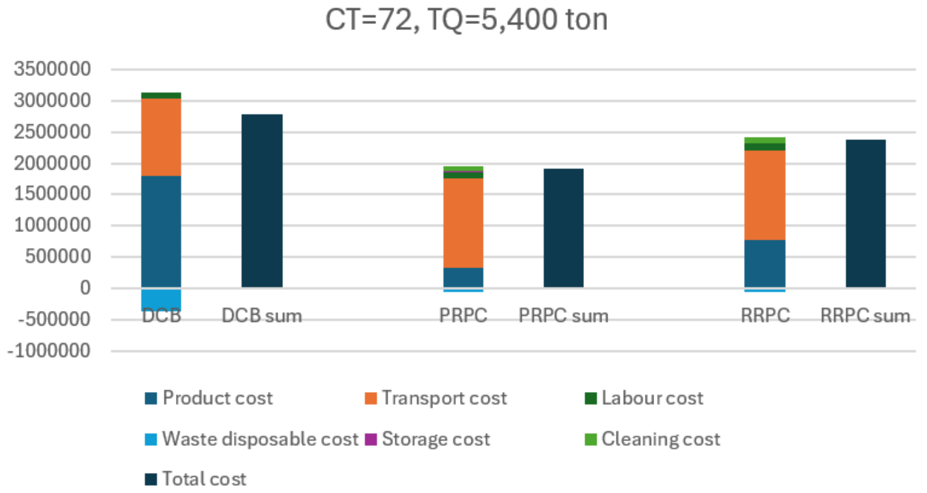

Figure 2: The full life cycle analysis of the three packages under the reference scenario.

3.2 Influence of transportation on LCC of RPC

Since the transportation cost contributes the most to the TC cost of RPC and there is a linear positive correlation between the transportation cost and the transportation distance according to Eq. 7, this subsection explores the effect of the transportation distance on the TC of transported packages. Meanwhile, since the total transportation distance TDis of RPC consists of multiple inter-node distances, it is positively correlated with the circulation times. Therefore, this section sets the distance between distribution centers-farms as a variable, by which to explore the effect of transportation distance on the TC of three transportation packages.

The results are shown in Figure 3, and it can be found that the transportation distance is linearly and positively correlated with the TC of the three packaging and transportation modes. Meanwhile, it can be calculated that the TC of CB is the highest when the distance between the distribution center and the farm is less than 771.33 km, and the TC of CB is the lowest when the distance is more than 1076.53 km, while the TC of PRPC is always the lowest when the distance between the distribution center and the farm is more than 1076.53 km, while the TC of PRPC is always the same. And the TC of PRPC is always lower than that of RRPC.

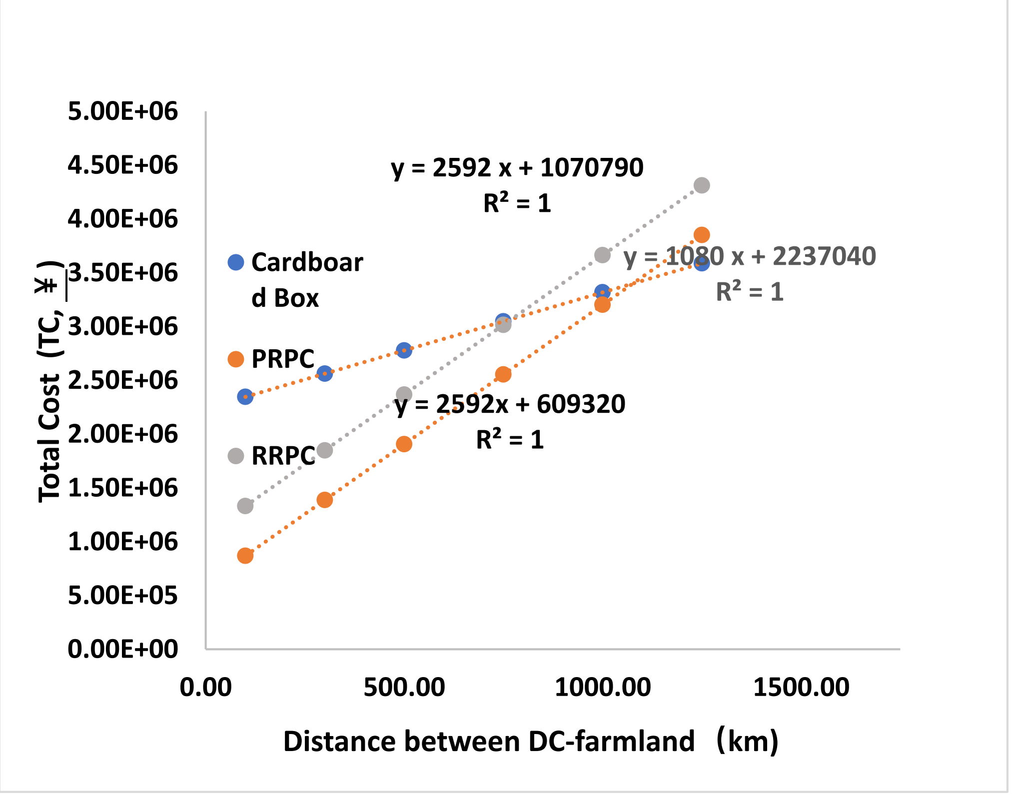

Figure 3: Results of transportation influence on LCC.

3.3 Influence of circulation time on LCC of RPC

The circulation times (CT0) has a direct correlation with both the transportation distance and the number of packaging required, with implications for both purchase and transportation costs. Therefore, the impact of the circulation times on the full life cycle cost of the RPC is discussed next. In addition, upward rounding is set for both the number of required RPCs and the number of vehicles calculation during the model setup for TC calculation, and this setting affects the model fit between TC and CT. Therefore, in this subsection, the upward rounding setting in the TC calculation model is eliminated.

The results are shown in Figure 4, where the circulation times is an inverse propotional shift function of the RPC life cycle cost. With other parameters of the reference scenario unchanged, the cost of CB is always the highest when the circulation times (3 years) is greater than 40 times, and the lowest when the circulation times is less than 18 times. And the cost of RRPC is always higher than that of PRPC, which is due to the reason that its acquisition (rent/leasing) cost is greater than that of PRPC and there are some more nodes for transportation, cleaning and warehousing costs than PRPC. And when CT has been increasing, the total cost of RRPC will gradually converge to that of PRPC due to 1) the proportion of transportation cost to the total cost increases, 2) the proportion of circulating stage (Farm-DC-Retailer) to the transportation cost increases, and 3) the cost of both transportation modes of the circulating stage (Farm-DC-Retailer) is the same, and therefore the total cost of RRPC will gradually converge to that of PRPC. This conclusion provides suggestions for the selection of RPC by the DC mode provide suggestions.

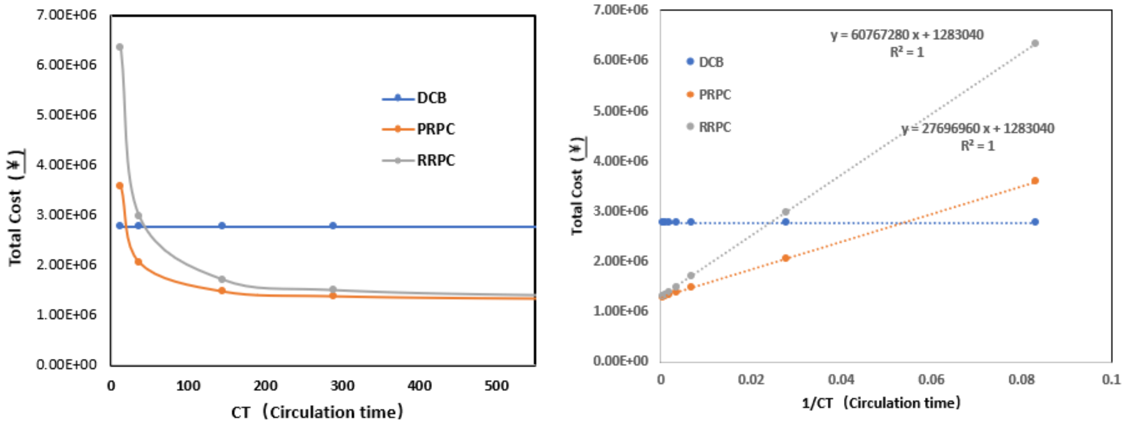

Figure 4: Results of transportation influence on LCC.

3.4 Influence of TQ on LCC of RPC

In order to investigate the impact of the total amount of fruit and vegetables transported on the life cycle cost of transport packaging, two additional settings of 10,000 tons per year (30,000 tons over 3 years) and 50,000 tons per year (150,000 tons over 3 years) were added to the reference scenario. The results are shown in Figure 5. It can be found that all three packaging costs are the highest for CB and the lowest for PRPC under the three total fruit and vegetable volume settings. At the same time, this study apportioned the three packaging costs to each ton of fruits and vegetables to be transported, and found that as the total amount of fruits and vegetables transported increased, the packaging costs borne by each ton of fruits and vegetables decreased.

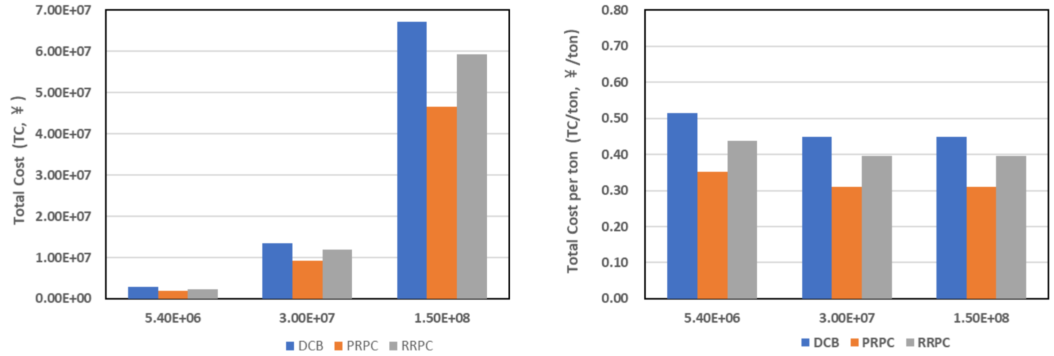

Figure 5: Results of TQ influence on total LCC and per ton LCC.

3.5 Influence of reverse logistics on LCC of RPC

Based on the research, it was found that in practice, RRPCs are used for other transportation purposes on the return trip in empty packaging, which can share the cost of that transportation. Therefore, it is assumed that 100%, 75%, 50% and 25% of RRPCs are used for transportation of other fruits and vegetables on the return trip, respectively. Then the reverse logistics counted within the system boundary are 0%, 25%, 50% and 75% respectively. The results are shown in the Figure 6 below, and it can be seen that the TC of RRPC is lower than that of PRPC in the base case when the percentage of reverse logistics accounted for is 25%.

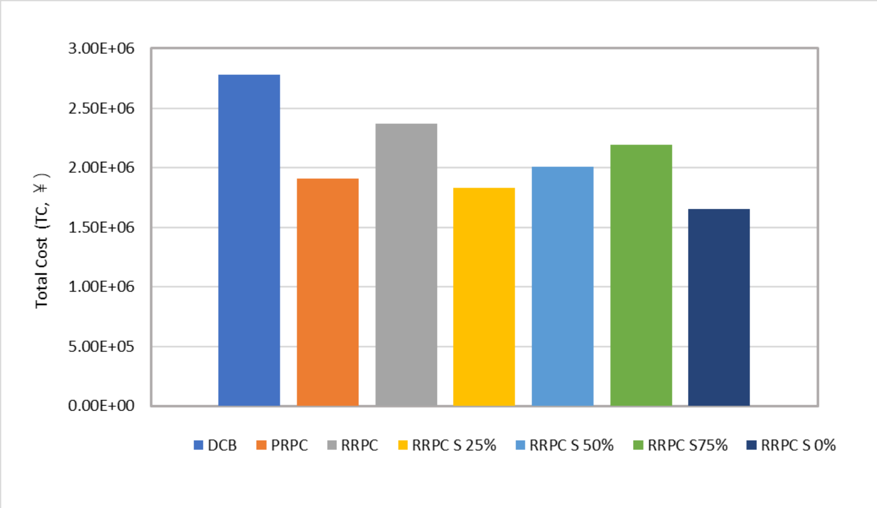

Figure 6: Reverse logistics influence on LCC.

3.6 Results of other parameters impacts

In addition to the above factors, the following 8 scenarios (as shown in Table 3) were set up to discuss the impact of other relevant factors on RPC life cycle costs. For statistical convenience, the three packaging costs were allocated to each ton of fruits and vegetables to be transported. The distance inflection point from the distribution center to the farm was also further analysed for different scenarios where the two RPCs have lower cost than the CB.

Table 3: More scenario settings with other parameters.

Scenario No.	Scenario description
scenario 0	Reference scenario
scenario 1	Storage percentage reduced to 15% (from 30%)
scenario 2	RPC is foldable, and folding coefficient is 0.25
scenario 3	RPC price is 1/6 of original price
scenario 4	Crate Rotation Factor is adjusted from 2 to 3
scenario 5	CRF is still 2, but crate no. in circulation is 1.5
scenario 6	Broken and lost percentage is reduced from 8%/3 years to 1.5%/ 3 years
scenario 7	Life span of RPC extended from 3 years to 8 years (annual F&V volume shipped is still 1,800 ton)

The results are shown in Figure 7. It can be found that reducing the percentage of RRPC hoarding (scenario 1) does not affect its cost much, which is still higher than that of PRPC, while the distance inflection point changes very little from the reference scenario. The use of folding packaging (scenario 2), on the other hand, significantly reduces the cost of RPCs, due to the fact that folding can significantly save transportation space and reduce the number of vehicles needed for transportation, thus reducing transportation costs. Similarly the optimization of the price of RPCs (scenario 3) can lead to a reduction in their total cost by reducing their purchase/rental cost. When the flow coefficient is increased (scenario 4), although the cost of RPC increases, it is still lower than that of CB due to the fact that the flow coefficient is related to the RN, and increasing the flow coefficient only increases the cost of purchasing RPCs and the cost of transporting, cleaning, and stocking them at the out-of-cycle stage of the RPC cycle, but does not affect the cost of transporting and maintaining them in the cycle. Therefore, after increasing the amount of RPC used in the cycle (scenario 5), it can be found that although the cost of PRPC is still lower than that of CB, the cost of RRPC is higher than that of CB, and optimizing the rate of broken and lost percentage (scenario 6) and increasing the service life of RPC (scenario 7) can also lead to a reduction in its total cost.

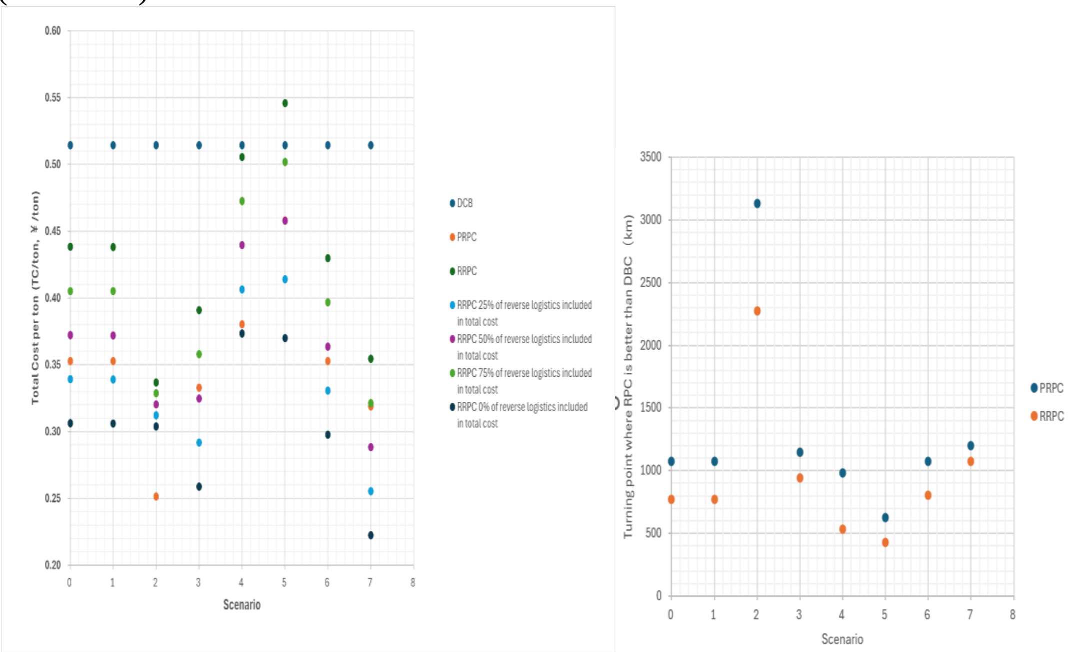

Figure 7: (a) Analysis of life cycle cost of three packaging under different scenarios; (b) The distance turning point (where DB becomes more favourable) under different scenarios.

4. Conclusion

At selected reference scenario, purchased reusable plastic crate (PRPC) mode has the lowest costs while cardboard box highest; Packaging cost and transportation cost takes up more than 90% of the total costs; All packaging types transportation costs have positive linear correlation with transportation distance, while based on reference scenario then changing transportation distance, cardboard box has highest life cycle costs below 771.33 km from Distribution Center to Farmer, plus 50KM from Distribution Center to Retailer, while after 1076.53KM+50KM, it becomes the lowest; and other parameters related to transportation management during packaging operation such as flow coefficient (packaging preparation rate), broken and lost percentage, etc. also affect packaging cost, so rational operation management is crucial for RPC cost. The reciprocal of circulation times also has a positive linear correlation with total RPC cost. Other factors like reduced breakage rate or storage rate has minor influence.

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