Review article

Feasibility of Reverse Vending Machine for PET Bottle Recycling in Case of ABC Hypermarket

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Curr. Appl. Sci. Technol. 2024, Vol. 24 (No. 2), e0258442; https://doi.org/10.55003/cast.2023.258442

Received: 30 March 2023, Revised: 23 May 2023, Accepted: 1 September 2023 Published: 9 November 2023

Abstract

The prevalence of polyethylene terephthalate (PET) in beverage packaging has increased microplastic (MP) accumulation in the environment. MP can become a component of air pollution, especifically of particulate matter with a diameter of less than 2.5 microns (PM2.5). Unfortunately, Thailand has a low recycling rate for plastic bottles, with only 4.5% being recycled. Reverse Vending Machines (RVMs) were introduced in the early 2010s as a potential solution to this problem. RVMs incentivize recycling by providing rewards or refunds for each bottle deposited, thereby reducing the amount of PET waste and MP in the environment. This study analyzed usage and waste collection data from RVMs located at 15 locations of a hypermarket chain in Thailand from June 2020 to December 2022. The results showed that the average PET bottles collected from each machine was approximately 670 kg per year, which was lower than the break-even point of 3,200 kg per year. Economic feasibility indicators also suggested that the use of RVMs might not be economically sound. This study proposed suggestions to improve the business model of RVMs and offered policy recommendations to the government on how to enhance the effectiveness of RVMs.

Keywords

circular economy;

polyethylene terephthalate (PET);

reverse vending machine (RVM);

supply chain management (SCM);

sustainability;

sustainable development goals (SDGs)

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1. Introduction

In the US, polyethylene terephthalate (PET) packaging accounted for 44.7% of single-serve beverage packaging and 12% of international solid waste. Only 4.5% of plastic bottles in the US were recycled. PET bottle has been one of the most favorable food and beverage packaging materials worldwide [1]. This is due to its properties that are light, safe, strong, and transparent.

Plastic particles are hazardous and dangerous. They impact the food chain and living environment. Plastic waste undergoes degradation processes in the environment, leading to a modification of its size. Polyethylene and polyester are the most common microplastics (MPs) detected. MPs have been linked to oxidative stress, cytotoxicity, transfer to other tissues, and MPs even find their way into human body through food [2-6]. MPs may contribute to cancer [6]. In addition, MPs possess the ability to disseminate into the ambient air as a constituent of particulate matter (PM) of 2.5 micrometers or less in size. Studies indicated that MPs could amalgamate and end up as air pollution in diverse settings across the globe, including regions such as China, France, Germany and Thailand [7-13]. Furthermore, evidence demonstrates the presence of MPs in both outdoor and indoor air, and fibers have been detected in marine ecosystems and aquatic organisms. Consequently, the inhalation of MPs poses a potential risk to human health, particularly in young children who frequently engage in hand-to-mouth behaviors [8, 14].

Numerous studies have demonstrated the existence of a variety of MPs, including those generated from operational loss, synthetic fabrics, road dust, vehicular tires, and plastic packaging. Th particles can become airborne [7, 9, 11]. In Thailand, some research was conducted to identify the types of polymers present in microplastics, including PET, high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS). These polymers were found to be mixed into PM2.5 particles in various regions of Thailand, including but not limited to Bangkok, Samutprakan, Samutsakhon, Nakhonpathom, Nonthaburi, and Pathumthani [11].

The issue of plastic waste is a significant environmental concern in Thailand. As presented in Table 1, there was an average of 26.54 million tons of plastic wastes generated per year during 2018-2022, out of which only about 9.47 million tons (35.68%) were recycled per year. This ratio indicates an ineffective waste sorting system for recycling. In addition, the average plastic waste per person has increased by approximately 14.20% every year over the past 5 years [15].

Table 1. Annual quantities of waste in Thailand 2018-2022

Year	Municipal Solid Waste (Mt/year)	Recycling Waste (Mt/year)	Plastics Waste (Mt/year)	Ratio Plastics Waste per Person (g/person/day)
2018	27.93	9.76	3.57	95
2019	28.71	12.52	3.45	96
2020	25.37	8.36	3.23	127
2021	24.98	7.89	3.79	139
2022	25.70	8.80	4.80	191
Average	26.54	9.47	3.77	129.60

Source: Pollution Control Department [15]

A total of 25.70 megatons (Mt) of municipal solid waste was generated in 2022. Of this total, 1.7 Mt, accounting for 7% of the waste, was managed directly at the source, as shown in Figure 1. Approximately 78% of the waste, translating to 20 Mt, was collected by garbage trucks. At sorting service centers, 4.8 Mt of waste (representing 19% of the total waste) underwent sorting and was

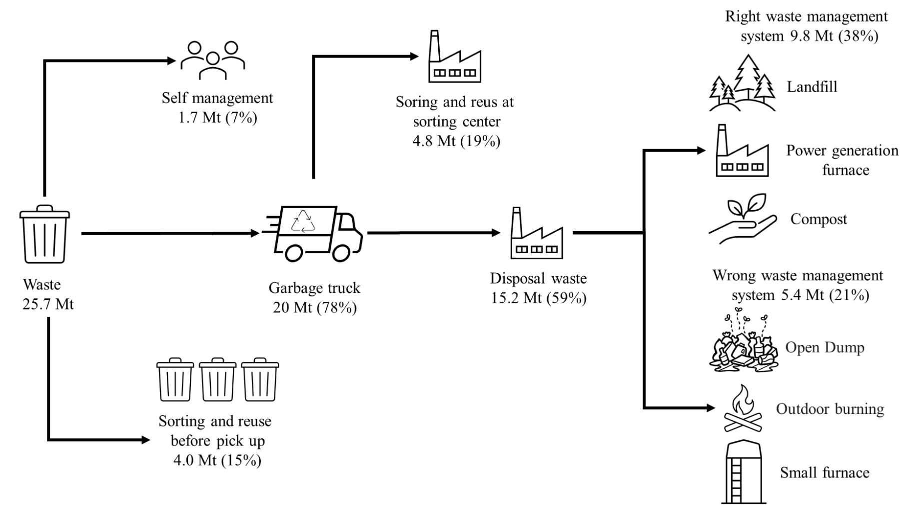

Figure 1. Waste management system in Thailand [15]

subsequently reused, whereas 15.2 Mt, or 59% of the overall waste, was designated for immediate disposal. Of the overall quantity, 9.8 Mt (38%) were disposed of by means of burial, energy-generating incineration such as refuse derived fuel (RDF), and composting. On the other hand, 5.4 Mt (21%) were incorrectly disposed of via open dumping, open-field burning, or small-scale incineration, leading to environmental contamination.

Sorting and reuse of approximately 4 million tons (15%) of waste occurred even before the collection stage, a task predominantly carried out by small waste pickers. These individuals, often overlooked, play an essential role within the waste management hierarchy. They meticulously sift through accumulated waste, extracting PET bottles in an effort to prepare them for the recycling process. Following the extraction, these PET bottles are gathered and subsequently sold to sorting centers. Their activities underscore the significance of their contribution to the recycling process, particularly as it pertains to the comprehensive supply chain. They function as the initial checkpoint in the process, ensuring valuable materials like PET bottles do not end up in landfill, but are rather put on the path to recycling and reuse. Their work demonstrates the integral role of waste pickers in enhancing environmental sustainability and waste management efficacy.

The progression of plastic waste management is being driven by the plastic waste management roadmap 2018-2030 [15], which comprises of two principal targets. The primary target emphasizes the reduction and eventual eradication of plastic use, replacing it with more environmentally sustainable materials. Actions towards this goal involved the prohibition of three specific plastic types by 2018, namely cap seals, oxo-degradable plastics, and microbeads. Subsequent steps also aimed to completely remove four other types of plastics by 2021, including lightweight plastic bags, styrofoam containers for food, single-use plastic cups, and plastic straws. The secondary target of the roadmap, set for 2027, is to attain a complete recycling rate for plastic waste, recycling 100% of plastic waste generated.

As the roadmap is implemented, it significantly impacts the lifecycle of PET bottles. With the targeted reduction and eventual elimination of certain types of plastic, manufacturers may have to rethink the production process of PET bottles, focusing on environmentally friendly alternatives. Moreover, with the ambitious goal of 100% plastic recycling by 2027, the PET bottle supply chain will need to incorporate comprehensive recycling strategies. This should involve every step from the design and production stages to ensure PET bottles must be easily recyclable, to the post-consumer stage where effective collection, sorting, and recycling systems need to be in place. As such, the roadmap directly informs and influences the management strategies in the PET bottle supply chain to promote a more sustainable and circular economy.

Figure 2 presents the supply chain of PET bottles. PET plastic is a petroleum-based polymer. The PET supply chain begins with crude oil. PET raw material is sourced from refined oil and then used to make PET bottles. Beverage producers fill the bottles with their products. The finished goods are kept in warehouses. When warehouse managers get sale orders, they distribute the products to wholesalers and retailers. End users buy the beverages from various distribution channels. Typically, they consume beverages and throw the PET bottles into bins [16]. This consumption pattern causes a lot of plastic waste worldwide. Some of the bottles are transformed into Refuse Derived Fuel (RDF), while others, if not managed properly, go to landfill, or are even dumped into the ocean. When plastic waste is improperly burned, especially in an open space, PM2.5 may be created. Therefore, there is a need for a new approach to help bring PET bottles back into proper recycling processes.

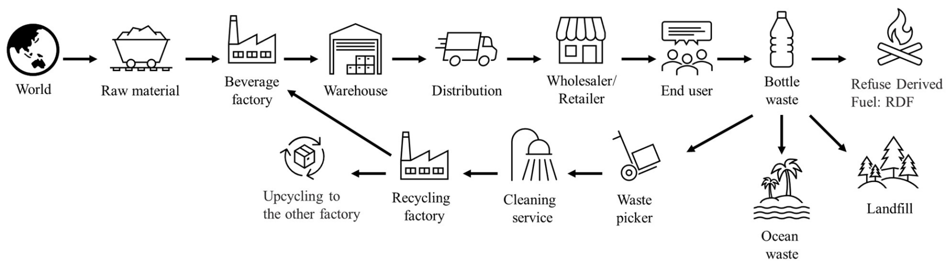

Figure 2. A typical PET bottle supply chain

PET bottle waste should be recycled into raw materials as much as possible [16]. In order to recycle PET waste, the PET bottles are collected, sorted, and cleaned by cleaning services. Eventually, the PET waste is sent to recycling factory and turned into PET pellets. Recycling plants can produce new products such as Dacron material, strapping bands, and geotextiles [17].

The above conventional loop sounds promising, but perhaps it is not good enough. The more contemporary concept of the circular economy can make plastic waste management more environmentally sound. By focusing on design-based implementation, the circular economy concept involves minimizing losses of waste and energy used for recycling and increase of the value of waste products via upcycling, which is seen for some Adidas' products [18-20]. Thus, Reverse Vending Machines (RVMs) can assist in the accomplishment of the UN Sustainable Development Goals (SDGs), especially for SDG 9 – Industry, innovation, and infrastructure, SDG 1 2 – Responsible consumption and production, SDG 13 – Climate Action, and SDG 14 Life below water [21].

RVMs were designed to allow consumers to recycle PET bottles more conveniently. It is expected that when RVMs are more widely used, more plastic waste will be collected more effectively. These machines facilitate the initial segregation of bottles, preventing them from being contaminated, a benefit that gives them an edge over the conventional small waste pickers. In addition to this, the RVM technology assists waste pickers by providing them a platform to sell recyclable PET bottles directly via the RVM, eliminating the need to transport them to sorting centers. This not only streamlines the process but also enhances the value and potential profitability of recycling initiatives. In the US and in some European countries, RVMs have been used as a common method of PET waste collection. This is in part due to the assistance of some regulatory devices such as the Bottle Bill or Deposit-Refund System (DRS), Carbon Neutral 2030, and Extended Producer Responsibility (EPR) [22-24].

In Thailand, RVMs were first introduced in 2012 [25]. The use of RVMs has gradually grown and become more popular lately [26]. Innovative Thai companies have implemented several RVMs including Circular One (Sustaintech and Tencent Cloud), P'Pet (Thana Steel Work Co., Ltd.), and Refun Machine (Refun Co., Ltd.). RVMs can be found in some office buildings and commercial stores nowadays [26].

While RVMs are primarily designed to increase recycling rates, they can also indirectly contribute to reducing PM2.5 pollution by reducing the amount of plastic waste that ends up in landfills or in the environment. When plastic waste is not properly disposed of, it can break down into smaller pieces, including microplastics, that can become airborne and contribute to PM2.5 pollution. However, to convince businesses and companies to use more RVM, there is a need for a study that shows the impacts and economic feasibility of the use of RVMs. This study collected data on the use of RVMs by one of the largest hypermarket chains in Thailand as a case study. The aim of the study was to analyze the appropriate use and location of RVMs, and their economic feasibility. It is expected that the results of the study can be used by other businesses and organizations, and prompt them to consider introducing RVMs into their facilities.

The RVM process is opposite of a typical vending machine. The purpose of a vending machine is to distribute products, while the purpose of an RVM is to collect the products back once consumed. RVM is usually designed to identify plastic waste via some technology like a barcode that can verify its properties such as weight, type, and size [27]. RVM can receive used materials such as bulbs, cans, papers, and plastic bottles such as soft drink bottles and water bottles [28]. RVM can operate 24 h a day [29]. When users insert the bottles, RVM verifies the plastic bottle types by barcode, brand, raw material, size, shape, and weight [27]. After that, the plastic bottles are kept in RVM. More advanced versions of RVMs are equipped with more advanced technologies. For example, consumers can redeem the values of their returned waste as digital money, e-coupons, or in some other forms, as opposed to cash [30-33].

Nowadays RVMs have become very popular, they have been designed and installed in many countries like Australia, China, Denmark, Germany, Greece, Japan, European countries, Norway, South Korea, the US, and Thailand. RVMs have been installed at bus stops, hospitals, offices, railway stations, shopping malls, schools, subways, supermarkets, universities, etc. [26, 27, 30, 34, 35]. RVMs reduce the needs of staff and save time and energy.

The first RVM design was patented in the US by Elmer M. Jones and Sue Walker Vance in 1920. The machines were popular in places that had mandatory recycling laws or container deposit legislation. In some places such as in the US, the bottle factories paid funds into a centralized pool to be disbursed to people who recycled the containers. At the time, the machines were known as "Bottle Return Machines" (BRMs). The first BRM took approximately three decades to create and manufacture after declaration of intellectual property [36, 37].

In Sweden, Wicanders supervised the full procedure. The device was in use throughout the 1950s. In 1962, an advanced automatic bottle return machine was designed and manufactured by Arthur Tveitan ASA in Norway. A Norwegian recycling company called Tomra Systems ASA claimed to have invented the first fully automated recycling vending machine in 1972 [38].

In the US, with the existence of "the Bottle Bill" or "the Container Deposit Regulations", RVMs have become particularly common. Around ten US states and eight Canadian provinces have rules mandating a refundable deposit on containers to encourage recycling. Similar regulations exist in some developed countries such as Sweden, Canada, and Norway [38-40]. The machines are placed in convenient places for consumers, such as supermarkets, to motivate people to recycle.

In Europe, RVMs have been used to deposit beverage packaging for more than five decades. These machines provide a coin back for each returned bottle. In Finland, an excise tax is levied on beverage containers that do not belong to a container recycling system. To encourage people to utilize an RVM in the first place, the business model relies substantially on government support in the form of a deposit return policy [23, 25, 37].

RVMs are also used in some other countries such as Bangladesh, China, Dubai, India, Indonesia, Greece, Kazakhstan, Malaysia, Philippines, Russia, Sri Lanka, Thailand, and Turkey [26, 30, 35, 38-40]. Nowadays, there are over 100,000 RVMs that have been installed throughout the world. The global RVM market size was valued at $372.0 million in 2020, and is expected to reach $736.9 million by 2030, with a CAGR of 6.6% from 2021 to 2030 [38, 40, 41].

In Thailand, RVMs were first introduced in the early 2010s [25]. An RVM was installed at King Mongkut's Institute of Technology Ladkrabang (KMITL) in 2014 for a pilot study. The study found that approximately 21% more PET bottles were collected when the RVM was installed in the study area compared to Business as Usual (BAU) waste collection in the area [41]. Watanyulertsakul *et al*. [26] designed an automatic RVM for deposition of PET bottles and aluminum cans in 2019. RVMs now can be found in some office buildings and commercial stores such as Central, Emquartier, Lotus, Siam and The Mall.

In the conventional linear economy, natural resources became waste once produced into some kinds of products that are then consumed. The circular economy, on the other hand, is based on three principles, driven by design [42-44]:

1) Eliminate waste and pollution: Eradication of waste and pollution begins with the design. The fundamental concept is that all designs necessitate materials to be reintegrated into the economic cycle upon completing their utilization. The circular economy takes the linear source-make-deliver system and makes it circular.

2) Products and materials circular (at their highest value): The goal of the circular economy is to recycle resources and products at their best value. This means maintaining materials in use as a product, and if that is no longer possible, as raw materials, components, or ingredients. Nothing goes to waste, and the natural quality of products and resources is preserved as much as possible, as presented in Figure 3.

3) Regenerate nature again and again: Instead of endlessly harming nature, the circular economy promotes biodiversity and encourages regenerative approach that allows the renewal of nature.

In Thailand, PET recycling has been driven largely by informal waste pickers. This system has been proven ineffective as reflected by the number that only approximately 35% of PET waste get recycled [45, 46]. Of course, this is in part due to ineffective waste sorting in the first place.

An RVM can play an important role in the circular economy for various reasons. First, since RVM is intended to ease waste collection, consumers may feel that it is quite convenient to return the waste and, as a result, more waste likely to get back in the loop. Second, since an RVM can be designed to accept only specific forms and design of wastes, manufacturers need to think about the design of their product a from the start to make it returnable to an RVM. This allows the products and their waste forms to be designed in a way to preserve their properties and value as much as possible. The consumers would be incentivized to return their waste to an RVM and thus gain a reward.

2. Materials and Methods

2.1 Study area

This study selected a large hypermarket chain in Thailand as a case study. The studied company is hereafter referred to as "ABC" because the company wants to remain anonymous. In 2022, ABC had a total of 2,293 stores in different sub-brands in Thailand. The brands were divided by size and location as described in Table 2. ABC installed the first RVM in June 2020. As of 2022, they have installed RVMs in a total of 15 locations as listed in Table 3.

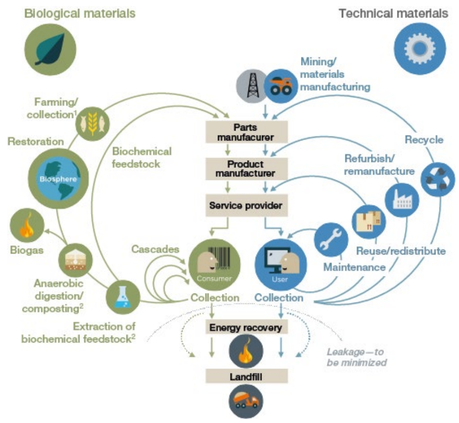

Figure 3. Diagram of the Circular Economy [43]

Table 2. ABC store type

Store Type	Area (sq.m.)	Product (SKU)	Open Hours (Hours per Day)	Branch
Head Office	10,000	-	Office Hours	1
Premium Hypermarket	2,400-2,900	27,000	13	1
Hypermarket	2,000-10,000	17,000-36,500	13	526
Supermarket	500-1,200	8,000-21,000	13	1,574
Mini Supermarket	80-300	300-8,000	13	191

Table 3. RVM locations at ABC stores

Machine No.	Store Location	Store Type	City
1	Head Office ABC	Head office	Bangkok
2	Hypermarket A	Hypermarket	Bangkok
3	Hypermarket B	Hypermarket	Bangkok
4	Hypermarket C	Hypermarket	Nakhonratchasima
5	Mini Supermarket A	Mini Supermarket	Bangkok
6	Mini Supermarket B	Mini Supermarket	Bangkok
7	Mini Supermarket C	Mini Supermarket	Bangkok
8	Mini Supermarket D	Mini Supermarket	Bangkok
9	Hypermarket D	Hypermarket	Chonburi
10	Mini Supermarket E	Mini Supermarket	Bangkok
11	Mini Supermarket F	Mini Supermarket	Nonthaburi
12	Extra A	Extra	Bangkok
13	Hypermarket E	Hypermarket	Bangkok
14	Hypermarket F	Hypermarket	Nonthaburi
15	Hypermarket G	Hypermarket	Udonthani

2.2 Data collection

Monthly usage data during June 2020 to December 2022 were collected from the main server that was connected to RVMs in each store. The server uses Metabase v0.43.3 as a platform for data collection and sharing. A snapshot of Metabase dashboard is shown in Figure 4. The attributes exported from the database include account, branch, deposit transaction, container type, time, weight, quantity, etc. These attributes were needed for the economic feasibility study, which is detailed in Section 2.3.

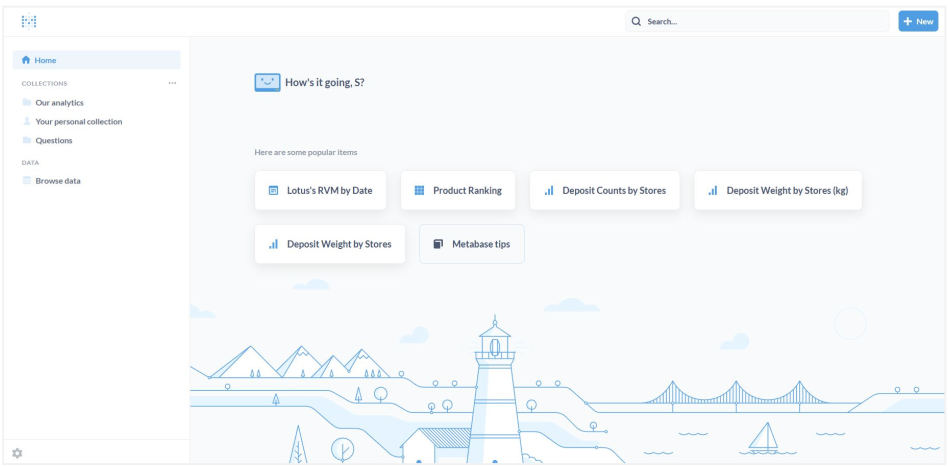

Figure 4. Metabase dashboard that links to data of RVM in each store

2.3 Economic feasibility analysis

An economic feasibility analysis was conducted in this study to explore the profitability of the machines. The net profit is the result of the difference between revenue and cost (equation 1).

$$\text{Net profit} = \text{Revenue} - \text{Operating cost} \tag{1}$$

The revenue is obtained from the multiplication of the weight and price of the deposited bottles (equation 2). Per equation 2, the revenue used in this study only considers the values of recycled bottles. It excludes other additional revenues such as advertisement fees on the machine, which were not generated from the machines during the study period yet.

$$\text{Revenue} = \text{Weight (kg)} \times \text{Price (THB/kg)} \tag{2}$$

The operating cost consists of two components: fixed cost and variable cost, as can be seen in equation 3. Fixed cost includes expenses such as preventive maintenance (PM) cost, and server hosting fee. PM costs are those that relate to the regular upkeep and servicing of the RVM, including routine check-ups, cleaning, minor rectifications, replacement of aged parts, and software upgrades. Server hosting fees encompass the costs associated with hosting and maintaining the server infrastructure required for the operation of the machines. These costs typically form part of a contractual agreement between the machine owner and the service provider and are usually disbursed on a monthly or yearly basis.

$$\text{Operating cost} = \text{Fix cost} + \text{Variable cost} \tag{3}$$

Variable costs for the RVM operation, in this scenario, include the expenses related to the handling of collected bottles, such as transportation, storage, and processing costs. However, these are borne by the LSP. Additionally, the redemption cost for ABC's coins signifies the monetary reward offered to users for each bottle they recycle using the RVM and served as a motivational tool to boost recycling habits. These costs will fluctuate in relation to the volume of bottles collected by the RVM. More specifically, as the RVM bottle collection increases, these costs will correspondingly rise, and conversely, if fewer bottles are collected, these expenses will decrease. This correlation makes these costs variable in nature.

The operating costs of the RVM also includes additional expenses such as store rental fee, RVM depreciation, maintenance cost, server hosting fee, electricity fee, internet fee, the ABC coin redemption cost and transportation cost of the deposited bottles to the recycling facility, which are shown in equation 4. These costs are summed up to calculate the total operating cost, which comprises both fixed and variable costs. By analyzing and managing these operating costs effectively, the profitability and viability of the RVM can be optimized.

$$\text{Operating cost} = (\text{Store rental fee}+\text{RVM depreciation}+\text{Maintenance cost}+\text{Server hosting fee})+(\text{Electricity fee}+\text{Internet fee}+\text{ABC's coin redemption cost}+\text{Transportation cost}) \tag{4}$$

Three economic factors indicating economic feasibility used in this study are: 1) Break-Even Point (BEP); 2) Payback Period (PP); and 3) Return on Investment (ROI) [38, 47]. BEP is the level of production at which the costs of production equal the revenues for a product. It is applied here to assess whether revenue generated by the RVM can cover all associated costs or not. BEP is determined by dividing the total fixed costs per year by the sale price per kilogram of bottles received minus the variable costs per kilogram of the bottles (equation 5).

$$\text{Break-Even Point} = \text{Fixed cost} / (\text{Sale price per kg} - \text{Variable cost per kg}) \tag{5}$$

Payback Period (PP) is the amount of time required to reach BEP for the RVM and is shown in equation 6. The PP is typically calculated by dividing the initial investment cost by the average annual return generated by the RVM. It represents the length of time it takes for the RVM to generate enough revenue to cover the investment. The investment cost for an RVM involves not only the purchase price of the machine but also the costs associated with its initial installation. These could potentially include site preparation, transportation, assembly, and initial training of personnel to operate and maintain the machine.

The average annual return indicates the average amount of revenue earned from the collected bottles and other sources (if applicable) per year. This includes the revenue generated from the sale of recycled materials, such as PET bottles. To calculate the average annual return, the sum of the total revenue earned by the RVM over a certain period (e.g., several years) is divided by the number of years in that period.

$$\text{Payback Period} = \text{Investment cost}/\text{Average annual return} \tag{6}$$

Return on Investment (ROI) is a performance metric used to assess the profitability of an investment or to compare several investment alternatives. ROI is expressed as the ratio of net profit per investment cost. For this study, ROI can be calculated by comparing the net profit generated by the RVM with the initial investment cost presented as equation 7.

$$\text{Return on Investment} = (\text{Net profit/Investment cost}) \times 100 \quad (7)$$

It is important to note that BEP is a significant measure in investment analysis as it indicates the number of PET bottles required for the investment to become profitable. The PP offers a timeline specifying when the initial investment is projected to be recovered. Additionally, the ROI grants a broader perspective on the profitability of the investment throughout its entire lifespan. When assessing potential investments, these metrics are typically used in unison as they provide complementary insights into the financial feasibility of the project.

In addition to these quantitative measures, it is equally crucial to weigh other potential impacts and benefits of the investment. These could include environmental benefits through the reduction of plastic waste, the potential for job creation in waste management and recycling sectors, as well as community development through heightened environmental awareness. While these benefits might not be directly quantifiable in financial metrics like BEP, PP, and ROI, they significantly contribute to the overall value and impact of the investment.

3. Results and Discussion

3.1 Functions and specifications of the RVMs

The RVMs were designed to accept PET bottles from users. When the users insert a PET bottle into the machine, they get an e-coin returned. The rate was 5 bottles per ABC coin (1 ABC coin = 1 THB). The machine was designed to accept bottles with no residual contents only. Figure 5 shows an example of an RVM installed at an ABC location.

Figure 5. An ABC RVM at a hypermarket in Bangkok

The machine uses a barcode scanner to scan the bottle's barcode and measure the bottle's characteristics. It only accepts the kind of bottles already registered in the database. The machine then opens the cover, and the user inserts the PET bottles into it. It should be noted that users are supposed to remove the bottle cap before depositing the bottles. The cap can be placed into the designated cap hole. During deposition, the weight of the bottle is compared with the bottle profile database. If the weight matches with the database, the machine accepts the PET bottle. If not, the machine rejects it. RVM specifications are summarized in Table 4.

Table 4. RVM specifications

Items	Designation
Input	PET bottles, clear and contaminants free
Material processing technology	Shredding
Bin	1 bin for one material
Output/Reward	Fidelity points collection
Service lifetime	5 years
Price	350,000 THB (VAT included)
Average power consumption	300 THB/month or ≈ 1,500 watts
Maintenance fee	25,000 THB/year
ABC coin (e-coin redemption)	8,000 THB/year
Capacity	10 kg of PET bottles.

Once the bottles are accepted, the RVM shreds the PET bottles into small pieces and puts them into a storage area. The machine uses a 5G cellular system and Wi-Fi network adaptor that allows the RVM to update its database in real-time.

3.2 PET bottle supply chain with the RVM installation

With the existence of RVM, the bottle supply chain is changed from the typical bottle supply chain presented in Figure 1. ABC signed an agreement with a Logistics Service Provider (LSP) to handle PET waste once they were accepted by the RVMs. The PET waste return route was designed and managed by the LSP. ABC coordinated with the LSP to collect the waste once the storage bin's capacity was reached. After that, PET bottles were recycled by the recycling factory to be processed as raw materials again. These raw materials were used to produce PET bottles or other related products. This supply chain, therefore, changed from a linear one to a circular loop, as shown in Figure 6.

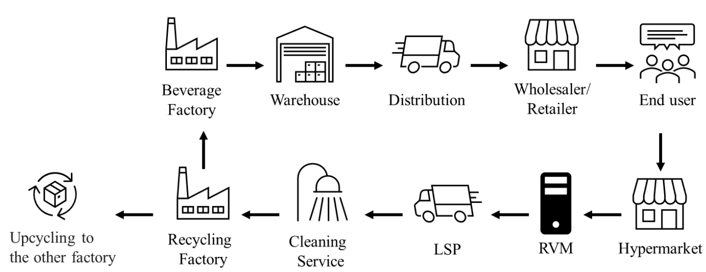

Figure 6. Circular PET bottle supply chain management in this case study

When the RVM is filled, the store supervisor alerts the LSP. The LSP then collects the PET bottles from the machine. However, this method can cause delays, rendering the machine temporarily unavailable for accepting further PET bottles. We recommend implementing a real-time data linkage system that would provide updates on the quantity of PET bottles within the machine, facilitating more efficient operations.

3.3 RVM bottle collection

The RVMs were installed at 15 locations in June 2020. Table 5 summarizes the number of deposited bottles in different locations by year from June 2020 to December 2022. It is noticeable that the ‘Hypermarket’ and ‘Extra’ store types generally received more bottles than the ‘Mini Supermarket’ store type, which is a small store. Figure 7 presents the amount of PET bottles received from all 15 locations combined from June 2020 to December 2022. The average monthly bottles received were 308 kg, 911 kg, and 510 kg in 2020, 2021, and 2022, respectively. The fluctuations in the number of bottles received were the result of changes in reward promotions offered.

Table 5. Total annual PET bottle weight in June 2020-December 2022

Store Location	City	Jun-Dec 2020	Jan-Dec 2021	Jan-Dec 2022	Total
Hypermarket A	Bangkok	2,874.49	3,297.51	946.59	7,118.59
Extra A	Bangkok	1,694.20	3,026.68	,867.83	6,588.71
Hypermarket B	Bangkok	1,291.02	1,725.54	1,186.68	4,203.24
Hypermarket E	Bangkok	1,696.76	1,242.54	419.39	3,358.69
Head office ABC	Bangkok	730.05	261.54	217.15	1,208.74
Hypermarket F	Nonthaburi	479.93	431.10	63.46	974.49
Hypermarket G	Udonthani	254.32	259.02	302.20	815.54
Mini Supermarket C	Bangkok	341.37	248.66	204.00	794.03
Mini Supermarket D	Bangkok	160.95	142.07	30.78	333.80
Mini Supermarket A	Bangkok	176.71	98.24	57.07	332.02
Mini Supermarket F	Nonthaburi	n/a	67.80	28.76	96.56
Mini Supermarket E	Bangkok	n/a	24.78	0.02	24.80
Hypermarket D	Chonburi	n/a	n/a	16.56	16.56
Mini Supermarket B	Bangkok	n/a	6.73	7.85	14.58
Hypermarket C	Nakhon Ratchasima	n/a	n/a	9.15	9.15
	Total	9699.80	10,832.22	5,357.49	25,889.50

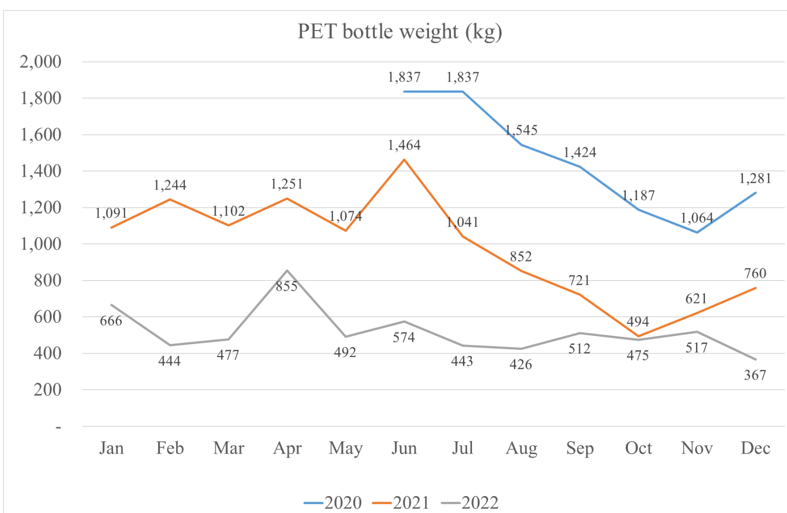

Figure 7. Total monthly RVM transactions during 2020-2022

With all data from 15 locations combined throughout the study period, the average amount of PET bottles received per machine per year was approximately 670 kg. The average price of PET waste throughout the period was 13.55 THB/kg. Therefore, the average annual revenue of an RVM was calculated to be approximately 9,078.50 THB/year/machine. These numbers were used for economic feasibility analysis in Section 3.5.

3.4 RVM revenues and costs

Per the data and assumptions explained in Section 3.3, the approximate revenue per machine per year was 9,079 THB (ABC Hypermarket had established a goal to achieve a 20% annual growth in the collection of PET bottles from RVM). In terms of operating cost, included were depreciation of the machine, maintenance cost, reward redemption (ABC coin), and electricity cost. These costs are listed in Table 6. It should be noted that rental fees, internet fees, and transportation costs were excluded. The internet for the machine, during the period of the study, was free of charge because the stores already had wi-fi internet in place. The transportation cost was absorbed by the LSP per the agreement with ABC.

3.5 Economic feasibility analysis

Based on the cost and revenue breakdown presented in Section 3.4, an economic feasibility analysis is presented in Table 7. The Break-Even Point (BEP) was calculated to be 3,200 kg/year. Therefore, compared to the average amount of PET bottles collected per machine per year (670 kg/machine/year), the BEP was not reached.

Derived from the BEP of 3,200 kg and given that a single PET bottle weighs approximately 25 g (40 PET bottles equating to 1 kg), the BEP translates to a requirement of 128,000 PET bottles per machine annually. This breaks down to 10,667 PET bottles per month or around 356 PET bottles per day, which is equivalent to 8.9 kg of PET bottles daily.

However, due to the average losses experienced per machine, the calculation of the PP results in a negative value (-3.20 years). This negative value indicates that the investment has not generated enough returns to cover the initial investment cost within the calculated period. In other words, it suggests that the investment is not yet profitable and has not reached the point where it can cover its costs.

Out of the 15 studied locations, only 2 locations, Hypermarket A (3,559 kg/year) and Extra A (3,294 kg/year) were able to reach the BEP. These stores are of the hypermarket and Extra store type, which are large, occupying areas of over 5,000 sq.m. Moreover, these 2 locations were able to meet the BEP due to 3 contributing factors:

1) User behavior: The user behavior plays a pivotal role in the efficiency of bottle collection and recycling. Understanding the tendencies of users regarding the accumulation and disposal of bottles is crucial. Various strategies can be designed to stimulate the collection and deposit of bottles at specified sites. For instance, in locations where bringing water bottles on public transportation is not allowed, provisions could be made for people to deposit their bottles before boarding. These behavioral evaluations could aid in the creation of more effective strategies for PET bottle collection and recycling.

Table 6. Summary of revenues and costs of an RVM (5 years projection)

List	Unit	Year 1	Year 2	Year 3	Year 4	Year 5
Revenue						
Recycled PET bottle	kg/year	670	804	965	1,158	1,389
PET waste price	THB/kg	13.55	13.55	13.55	13.55	13.55
Total revenue	THB/year	9,079	10,894	13,073	15,688	18,825
Expense						
Investment cost						
ABC RVM (350,000 THB/machine)	THB/year	70,000	70,000	70,000	70,000	70,000
Total depreciation cost	THB/year	70,000	70,000	70,000	70,000	70,000
Fixed cost						
Preventive maintenance cost	THB/year	25,000	25,000	25,000	25,000	25,000
Server hosting fee	THB/year	12,000	12,000	12,000	12,000	12,000
Total fixed cost	THB/year	45,000	45,000	45,000	45,000	45,000
Variable cost						
Electricity cost	THB/year	3,600	3,600	3,600	3,600	3,600
ABC coin (redemption)	THB/year	8,000	9,600	11,520	13,824	16,589
Total variable cost	THB/year	3,600	3,600	3,600	3,600	3,600
Total operating cost	THB/year	118,600	120,200	122,120	124,424	127,189
Net profit (Loss)	THB/year	-109,522	-109,306	-109,047	-108,736	-108,364

Table 7. Economic feasibility analysis of ABC RVM

Economic Feasibility Analysis	Unit	Value
Break-Even Point (BEP)	kg	3,200
Payback Period (PP)	year	-3.20
Return on Investment (ROI)	%	-155.71%

2) Store type: The type of store is another influential factor. Stores such as hypermarkets tend to have larger commercial spaces, attracting a higher number of customers and leading to greater customer engagement. These establishments have a higher likelihood of bottle collection due to the substantial volume of customers they serve daily, thereby generating more waste, including PET bottles.
3) Traffic density: High footfall areas, such as those experiencing daily visitor counts of between 7,000 to 8,000 individuals, tend to have a higher yield in terms of PET bottle collection. The more people frequenting a location, the more likely it is for waste, including PET bottles, to be generated. High traffic density can therefore enhance the effectiveness of bottle collection and recycling initiatives.

3.6 RVM business model and policy recommendations

3.6.1 Suggestions on RVM business model

The inability of the RVM to generate profit can be attributed to the high operating costs. These costs typically involve three main elements: the initial investment cost, maintenance cost, and electricity cost. To mitigate these costs, certain strategies can be employed. One strategy is to simplify the maintenance process. If the technology integrated into the RVM is not excessively intricate, the cost for maintenance services can be significantly reduced. Furthermore, efforts to decrease electricity consumption can also prove beneficial in terms of cost reduction. Therefore, in the design and implementation of RVMs, it is important to build appropriate technology that is not only simple and cost-effective to maintain but is also energy efficient in order to minimize electricity costs.

3.6.1.1 Cost of RVM

The RVM used by ABC was a domestic innovation. The approximate cost per machine was 350,000 THB, which was way higher than some low-cost machines developed in bigger and more mature markets in China and India, which cost only about 60,000 THB and 90,000 THB per machine, respectively [37]. This signifies that an optimal approach for implementing RVM technology in Thailand could involve utilizing fundamental, yet effective technology that aligns with business needs. Therefore, a design for an appropriative RVM that only accepts and compresses bottles are proposed [48]. Such a design could potentially reduce the machine costs by approximately 30-35% (the price range for the RVM should be between 120,000 and 150,000 THB).

Also, to convince more businesses to consider using the machines at their locations, the machine developers might want to consider machine rental model, to ease the initial cost burden on their prospective customers. Nevertheless, it should be noted that revenue for the RVM should also be generated from other sources to ensure economic sustainability.

3.6.1.2 RVM revenue model

1) Additional revenues:
The stores should seek additional revenue from other channels besides the direct revenue from waste collection and recycling. One of the possibilities is the revenue from advertisements. Usually, RVMs should be placed where customers can easily access them. These locations ensure visibility for many other customers. Therefore, the machines should probably be open for advertisements with some fees, which can create some additional revenue for the machine owners. This approach could generate additional income for the machine operators. The suggested fee for advertising is between 2,000 and 2,500 THB, translating to annual revenue of 24,000 to 30,000 THB per machine.

2) Inclusion of other associated values:
Sometimes, the value of the machine may not come directly as generated revenues only. Climate change is one of the most important environmental issues these days. This is especially important for big companies that are supposed to contribute to tackle the problems and present an image of sustainability. Recycling PET bottles can earn some carbon credits. In Thailand, the carbon credits can be recognized by Thailand Voluntary Emission Reduction Program (T-VER), which is managed by Thailand Greenhouse Gas Management Organization (TGO). In 2022, 1 kg of recycled PET bottles led to a reduction of approximately 1.03 kg of CO_2e. Therefore, the average PET bottles collected per machine per year (670 kg) is equivalent to 690.1 kg of CO_2e or 53.12 THB. This number is still fractional compared to the total cost of machine operation. However, companies can acquire intangible assets from sustainability image. This particular subject could be utilized in the Environmental, Social, and Governance (ESG) report as evidence of sustainable practices [19, 20].

3) Upcycling of PET bottles:
The concept of upcycling is to add value to an object rather than simply recycling it [17, 43, 48, 49]. For PET bottles, this might involve creative processes that transform the bottles into new products of higher quality or value than the original. This can be achieved through artistic endeavors, such as turning bottles into decorative items, or through industrial processes that turn the bottles into new products like clothing, furniture, or even building materials [18-20]. Not only does upcycling create new economic opportunities, but it also promotes environmental sustainability by reducing waste and the demand for new raw materials [42]. In terms of RVMs, promoting and facilitating upcycling could attract more users to the machines, thus enhancing their profitability and impact.

3.6.1.3 Application of the 3E concept to the RVM

To increase public awareness and usage of RVMs, the 3E principles - Education, Enforcement, and Engineering - should be applied. In this case, the RVM has already been adjusted according to engineering bases. To further increase engagement, it is crucial to enhance the aspect of education. This can be done by providing information through the machine interface itself. Examples include displaying videos on the benefits of using RVMs, or instructions on how to deposit bottles into the machine correctly.

Moreover, the role of enforcement is equally essential, which is where the government steps in. For example, it could impose regulations requiring the return of plastic bottles, much like the 2021 law mandating stores to stop providing plastic shopping bags. This combination of Education, Enforcement, and Engineering could potentially increase the use of RVMs in our society.

3.6.2 Policy recommendations

In this section, the crucial role that laws and regulations should play in promoting the wider use of RVMs were considered. Key legislation and principles such as the Bottle Bill, Extended Producer Responsibility (EPR), and the Bio-Circular-Green Economic Model (BCG model) can significantly shape the landscape for RVM implementation. These regulatory measures and models have the potential to boost recycling rates, encourage sustainable practices, and promote the economic viability of RVMs, thereby supporting their broader deployment.

3.6.2.1 Regulatory approach

Associated regulations and laws have proven to be a success factor in other countries where the use of RVMs is more common and successful. For example, the "Bottle Bill" or similar laws were used in many countries [1, 17, 22, 23, 37, 50, 51]. The law requires a refundable deposit included in the beverage price upfront. Consumers are supposed to return the bottles via designated machines to get a refund of the deposit [41]. In Europe, the Bottle Bills accounted for approximately 60% of bottle recycling [52]. Table 8 shows the application of the Bottle Bill around the globe.

Table 8. Application of the Bottle Bill in international countries [53, 54]

Country	Implementation	Approximate Deposit	PET Return Rate (%)	Application of the Bottle Bill
Australia	South Australia, New South Wales	AUD 0.10 (2.26 THB)	56-79%	South Australia was the first state to introduce such laws, followed by other states.
Canada	Most provinces	CAD 0.15 - 0.25 (2.61 – 6.52THB)	60–84%	Each province has its own specific regulations regarding the deposit value and types of containers.
Denmark	Nationwide	DKK 1.5 - 3 (7.51 – 15.02 THB)	94%	Each country has its own specific deposit system.
Estonia	Nationwide	€0.10 (3.71 THB)	89%	
Lithuania	Nationwide		90%	
Netherlands	Nationwide	€0.10 - €0.25 (3.71 - 9.32 THB)	70%	
Sweden	Nationwide	SEK 1 - 2 (3.21 - 6.43 THB)	90%	
Germany	Nationwide	€0.25 (9.32 THB)	98%	Applies to both reusable and one-way containers.
Norway	Nationwide	NOK 2 - 3 (6.31 - 9.46 THB)	92%	Known for having one of the world's most efficient recycling systems.
United States	10 states and Guam	\$0.05 - \$0.15 (1.74 - 5.21 THB)	38–81%	The refund values and types of containers covered vary by state.

The goal of a bottle bill is to reduce litter and increase recycling. Consumers can return empty containers to an RVM to reclaim the deposit. In turn, these RVMs are reimbursed by beverage distributors for each container they take back. To encourage more users to use the RVMs in Thailand, similar laws should be passed and enforced in Thailand.

3.6.2.2 Extended producer responsibilty approach

Extended Producer Responsibility (EPR) is an environmental policy approach where producers are given significant responsibility—financial and/or physical—for the treatment or disposal of post-consumer products. The concept of EPR was introduced in Sweden by Thomas Lindhqvist in a 1990 report to the Swedish Ministry of the Environment [38].

The principle behind EPR is to shift the responsibility for waste management from governments (and thus taxpayers and society at large) to the entities producing and profiting from the products that become waste. This shift is intended to provide incentives for producers to make more sustainable decisions about product design and materials selection. EPR programs can be developed for various types of products, including packaging, electronics, tires, batteries, and PET bottles [24].

EPR can certainly be integrated with RVM as a comprehensive strategy to manage post-consumer waste. Here are a few ways how [53, 54]:

1) Incentivizing recycling: Under EPR, producers can be obligated to collect and recycle a certain percentage of the products they sell. RVMs can facilitate this by providing an easy and convenient way for consumers to return their used products, such as PET bottles. Consumers can be incentivized to use RVMs through rewards or deposit-refund systems.

2) Data collection: RVMs can provide valuable data on the types and quantities of products being returned for recycling. This information can help producers track their progress toward meeting their EPR obligations and can also inform the design of more sustainable products.

3) Cost allocation: The costs of operating RVMs can be covered as part of the producers' EPR obligations. This could include the costs of collecting, transporting, and recycling the returned products, as well as administrative costs. By internalizing these costs, EPR can incentivize producers to reduce waste and improve the recyclability of their products.

4) Promoting sustainable product design: By linking the costs of waste management to specific products (via RVMs), EPR can incentivize producers to design products that are easier to recycle or that have a lower environmental impact.

Also, EPR can play a significant role in promoting a Bio-Circular-Green Economic (BCG) Model. The BCG model is a sustainable development framework that promotes the utilization of biological resources, circular economy principles, and green technologies for economic growth.

3.6.2.3 The BCG model

RVMs alone are unable to attract continuous recycling activities, they need to be paired with some promotional events, law enforcement, and perhaps more interesting incentives to encourage the public to use the machine. Furthermore, recent developments in the EU demonstrate that there is the political will to improve current plastic waste management practices [37, 38]. Therefore, more implementation of RVMs in Thailand could be a solution to help PET recycling rates as part of the circular economy concept in Thailand. This is especially important and promising since the circular economy is part of the Bio-Circular-Green Economic Model (BCG Model), the key policy theme proposed by Thai government during the APEC 2022 conference [55, 56]. Thai governments have consistently promoted the BCG Model over the past few years. If the government can raise awareness of sustainability for Thai people, especially the younger generations, more PET bottles can be recycled in a proper loop, in which the RVM can play an important role.

By implementing the BCG Model, RVMs can be aligned with the principles of the circular economy and contribute to the reduction of plastic waste and the conservation of resources. The BCG Model encourages the adoption of innovative technologies and practices that enhance the efficiency and effectiveness of waste management systems. RVMs, with their automated collection and sorting capabilities, align well with the BCG Model's objectives of minimizing waste generation, maximizing resource recovery, and reducing environmental impact.

Furthermore, the BCG Model promotes collaboration and partnerships among stakeholders, including government agencies, businesses, and communities. By fostering collaboration, RVMs can benefit from supportive policies, incentives, and investment opportunities, which can contribute to their expansion and increased engagement.

3.6.2.4 The case study on the success of RVM implementation and its application in Thailand

Successful case studies of RVM implementation were seen in countries like Germany and Sweden [37, 38]. These countries implemented both Bottle Bill systems and Extended Producer Responsibility (EPR) regulations, which significantly contributed to the success of RVMs in promoting PET bottle recycling.

In Germany, the implementation of a comprehensive bottle bill system, known as the "Einwegpfand" (one-way deposit), was instrumental in driving PET bottle recycling rates [37]. Consumers pay a deposit when purchasing beverages in single-use PET bottles, and they receive a refund when they return the bottles to RVMs (9.32 THB/bottle). This incentive has led to high participation rates (98%) and increased collection of PET bottles through RVMs. Additionally, the implementation of EPR regulations ensures that producers bear the responsibility for the recycling and proper disposal of their PET bottles, further supporting the effectiveness of RVMs.

Similarly, Sweden has achieved remarkable success in PET bottle recycling (90%) through the combination of a bottle bill system and EPR regulations [37, 38]. The Swedish deposit-refund system, known as "Pant", encourages consumers to return their PET bottles to RVMs by offering a financial incentive (3.21-6.43 THB/bottle). The collaboration between stakeholders, including producers, retailers, and waste management entities, ensures the proper collection, sorting, and recycling of PET bottles. EPR regulations complement the bottle bill system by holding producers responsible for the entire lifecycle of their products.

To apply these success factors to the case of RVM implementation in Thailand, a similar approach should be adopted [15, 55, 57-59]. By incorporating the successful strategies from bottle bill systems and EPR regulations, Thailand can create a supportive environment for RVMs and foster a culture of responsible recycling, leading to significant improvements in PET bottle recycling rates and environmental sustainability [38].

In order to promote recycling and the effective operation of RVMs in Thailand, a proposed policy is to establish a deposit return system with a deposit of 2 THB per bottle. The system would operate in such a way that customers are required to pay the 2 THB deposit when purchasing beverages packaged in eligible bottles. Upon returning the bottles to designated return points, customers would then receive the full deposit amount back. The responsibility for managing the deposit system, including the collection and refund process, would need to be clearly defined and coordinated among relevant stakeholders, such as retailers, manufacturers, and recycling entities. It would be essential to establish effective communication channels and infrastructure to facilitate the smooth operation of the deposit return system.

Moreover, public awareness campaigns, educational initiatives, and convenient placement of RVMs across Thailand can enhance public engagement and participation in PET bottle recycling. Collaboration between the government, industry associations, retailers, and waste management entities will be crucial factors driving the success of RVM implementation and PET bottle recycling efforts in Thailand.

4. Conclusions

In this study, the data obtained from the use of a domestically designed RVM at 15 locations of ABC, which is one of the largest hypermarket chains in Thailand, from June 2020 to December 2022, was presented. The average weight of PET bottles collected from each machine per year was found to be approximately 670 kg per year, which was much lower than 3,200 kg per year per machine required for BEP to be reached. In this study, the use of RVMs was not economically sound. This was basically due to the high cost of operations, and the fact that the amount of waste collected and thus the revenue generated were not sufficient.

In summary, the future success of RVMs in Thailand will rely on the implementation of the Bottle Bill system and EPR regulations. A Thai bottle bill system would involve refundable deposits on PET beverage containers and would encourage consumers to return them through RVMs for recycling. EPR regulations would hold producers accountable for the lifecycle of their products, including PET bottles. These measures would create a supportive environment for RVMs, promoting proper collection, sorting, and recycling of PET bottles.

Close collaboration between the government, industry associations, retailers, and waste management entities are essential. Public awareness campaigns, educational initiatives, and convenient RVM placement would further encourage public engagement. This comprehensive approach, incorporating the business model, bottle bill, EPR, and BCG model, could well lead to significant progress in reducing pollution and fostering responsible recycling practices in Thailand.

It is suggested, however, that some studies with a wider scope should be conducted to learn more about the situation of RVMs in Thailand. This study is still limited to only one model of RVM machine implemented at 15 locations of a hypermarket brand. Most of the locations are in Bangkok and metro areas. There are several issues that need to be addressed for the RVM system to be effectively implemented. Firstly, some studies should be extended to, perhaps, cover other models of RVMs, domestic and import. It would also be interesting to understand the behavior of customers in different regions of Thailand. The act of depositing bottles and the process of gathering them for submission need to be made more user-friendly and convenient. The unfamiliarity of many individuals with RVM technology could be a burden rather than a benefit. The sustainable advantages that these machines offer may not be readily apparent to everyone.

Secondly, there is a significant distinction between RVMs and typical vending machines. Traditional vending machines are profit-generating entities, whereas RVMs entail costs for the owner. This aspect might act as a barrier to widespread adoption. As such, measures to educate the public about the long-term environmental and societal benefits of using RVMs should be considered. Conducting research with a wider scope will not only allow us to understand the current limitations of the RVM system in Thailand but also provide actionable insights that are needed to improve the adoption and effectiveness of RVMs.

5. Acknowledgements

This research was funded by the School of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), 1 Chalongkrung Rd., Ladkrabang, Bangkok 10520, Thailand. We thank the hypermarket for the data in this study. Special thanks are also given to Thana Steel Design Co., Ltd. which produced ABC RVMs. We also appreciated the help of our colleagues in the Ph.D. program in Logistics and Supply Chain Management, Department of Civil Engineering, School of Engineering, KMITL, who made helpful contributions and shared valuable information with us.

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