STM JOURNALS

Journal of
Energy, Environment &
Carbon Credits

ISSN: 2249-8621
Volume 14, Issue 3, 2024
September–December
DOI (Journal): 10.37591/JoEECC

https://journals.stmjournals.com/joeecc

Research JoEECC

Improving Plastic Bottle Waste Management System of India Using RVMs

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Abstract

India is ranked first as the most populous country in the world, and plastic waste management has been a major ongoing concern for India. With the growing economy and population, the growth of plastic waste generation has been exponential but plastic waste management has been underachieved. The excess utilization and mishandling of single-use plastic have depreciated the performance of the plastic waste management system of India. This study emphasizes on increasing the collection of plastic bottle waste using three real-time variants of reverse vending machines – RVM BC-200, RVM PRO, and RVM PRIME – that will create a beneficial impact on the recycling of the plastic bottles that are collected and hence ameliorate the plastic management system of India. This research uses data analysis and data visualization tools to propose an in-depth comparison between the three real-time variants of RVMs and a proposed hybrid model to achieve the optimal goal.

Keywords: Mismanaged Waste Index, single-use plastic, reverse vending machines, collection capacity, plastic waste, plastic bottle waste, ecosystem, plastic waste management system

INTRODUCTION

In a developing country like India where development is booming, the usage of plastic will be amplified in coming years. Plastic is an artificial polymer that is known for its versatility and durability, due to its availability and inexpensive nature it has quickly spread throughout our lives and is being used in a wide range of consumer goods, healthcare, packaging, electrical and electronics, and constructions. The most conspicuous application of plastic can be the production and usage of personal protective equipment (PPE) during the worldwide COVID-19 outbreak [1]. Plastic production is not seen as a problem anymore, but the recycling of plastic waste (PW) is a global issue that needs to be resolved. India ranks fourth position in the Mismanaged Waste Index (MWI) [2], with 98.55% of generated waste being mismanaged [2]. India is the second-largest consumer of plastic globally [3], with 43% of all plastics produced in India being used for packaging in which the majority is of single-use plastic (i.e., plastic bottles) that contributes significantly to PW generated [3]. Globally, 42% of overall plastics produced are consumed by the packaging sector and 17% by the construction sector [4]. The extensive use of plastic and mismanagement of PW harms the ecosystem, wildlife, and human health [5].

When waste is converted to useful materials it is known as recycling [6]. With the support of the government, Western countries have fully implemented recycling but in our country, recycling is carried out without any interest [6]. As per the Central Pollution Control Board (CPCB), India

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Received Date: August 22, 2024
Accepted Date: August 28, 2024
Published Date: September 10, 2024

Citation: Dhaval Powle, Krish Patel, Gaurav Keshari, Javic Kothari, Aditya Kasar. Improving Plastic Bottle Waste Management System of India Using RVMs. Journal of Energy, Environment & Carbon Credits. 2024; 14(3): 31–40p.

generates 9.46 million tonnes of PW annually out of which 40% of PW goes uncollected [7]. Uncollected PW becomes a threat to the ecosystem as it may end up in landfills, pollution on the streets, or be littered at a place where it can easily cause blockages in the water bodies [8]. The majority of PW ends up in landfills and requires a long time to break down. PW would require specific environmental conditions to lose some of its properties such as molecular weight, crystallinity, functional groups, mobility, structure substituents, and added additives all affect how plastics degrade, but still, it is unpredictable when the PW in a landfill will decompose [9]. One of the biggest problems with PW in India is inadequate waste collection infrastructure and a lack of efficient sorting and recycling systems [10].

Single-use plastics are plastic products that are intended for single use and thrown away or recycled. In our country, most of the plastic production is for single-use plastic such as plastic containers, straws, coffee stirrers, soft drink and water bottles, and food packaging. Between 1950 and 2015 only 9% of PW produced was processed for recycling [11]. It is estimated that globally the production of plastic and its related products will double by the year 2035 and will be four times in 2050 because of economic and population growth [11]. About 6300 million tons of plastic total produced out of which 4900 million tons of plastic ended up in either landfills or elsewhere in the environment (about 78% of total PW is dumped) [11].

Management of uncollected PW such as polyethylene terephthalate (PET) bottles is a major concern for India. If the collection of uncollected PW increases, it will lead to an increase in the recycling of PW. To increase the collection of PET bottles, reverse vending machines (RVMs) can be a solution. It is a type of vending machine that accepts empty plastic bottles and returns reward vouchers or cash-back coupons to users [12]. RVMs can accept materials such as beverage cans, bottles, glasses, and plastics depending on the type of machine [6]. An RVM can also be used as a solution to the problem of sorting waste to enhance the recycling process, the machine compresses the bottle to reduce its size and allow more of it to be stored within it before they are collected and returned to the bottling company for recycling [13]. India has already employed the method of RVMs, but its implementation lacks accessibility due to RVMs being situated in specific locations (i.e., airports, and corporate offices) that are not reachable to most of the population, therefore lacks in the collection of plastic bottles which leads to littering on the streets. As per research in India, the lack of awareness and involvement prevented the adoption of RVMs from being as effective as it may have been [14]. Still, convenience and incentive factors drove citizens' desire to adopt recycling methods using RVMs [14]. RVMs contribute to improving the PW management system by reducing the amount of waste going to landfills [15]. RVMs are capable of sorting recyclables efficiently and can save up to 90% of the energy needed to recycle materials [15].

The motivation for our study is to increase the accessibility of RVMs in all states of India depending on the plastic bottle waste (PBW) they produce, which will increase the collection of uncollected PBW. This intention will increase the recycling of plastic bottles and enhance the PW management system. This study has forecasted the estimated year at which 100% of PBW will be collected using three real-time RVM variants that are RVM BC- 200, RVM PRO, and RVM PRIME. This research involves data visualization tools and data analysis to provide a detailed comparison between the performance of the three RVM variants with the proposed hybrid model to achieve an optimal goal.

PROPOSED METHODOLOGY

This study aimed to understand the feasibility of the integration of RVMs into the PW management system of India. This would require undertaking the factors that contribute to the generation of PW such as the increasing population of India, extensive manufacturing of plastic, amount of collection of recyclable PW for recycling and recovery, and types of PW generated. However, it was decided to limit the scope of the study by concentrating only on increasing the collection of recyclable PBW for recycling and recovery. The amount of recyclable PBW that is collected will rise in response to increased PBW recycling, which will have a positive impact on the PW management system of India [16].

Dataset Description

The CPCB data is used in our research [17]. This contains the latest data on total PW generated for 34 states and union territories of India from 2011 to 2020 as shown in Table 1.

As there was no specific dataset available regarding total PBW, we have considered CPCB dataset of total PW as total recyclable PBW that can be collected by RVMs. Preprocessing was done on the data to populate some missing values by using the mean of the year before and the year after. Our study comprises data for the total population of India state-wise for the year 2020 that is used to separate states of India into large and small categories. As the collected data for total PW is available till 2020 hence data for the population of India is considered only for 2020.

Proposed Method

In this study, we propose that the collection of PBW can be increased using RVMs, by implementing RVMs in all the states of India depending on their total PBW generation. We propose a comparison between the three real-time RVM variants and a hybrid model designed by a combination of these RVM variants for generating the optimal amount of collection of PBW. Table 2 states the specifications of the three real-time RVM variants.

Forecasting Total Plastic Bottle Wastage

Using the Microsoft Excel forecasting data feature, by average method, the data of total PBW in metric tonnes (mt) has been forecast from 2021 to 2060 using the previously collected data from 2011 to 2020.

Estimation of RVMs Required per State Initially in 2021

Firstly, using the pre-processed data we calculated the mean of PBW state-wise, utilizing the value of the mean, the total number of RVMs required initially in 2021 (India) was calculated by applying Equation (3) given below. In a year there are 52 weeks, if all three RVM variants would be able to collect a maximum number of PBs every 2 weeks (refer Table 2 for maximum PBs capacity of RVM variants), the number of PBs collected by RVM variants per year (p.y.) is deduced by Equation (1). The average weight of an empty 1L PB is 19.7 g; using this the total capacity of 1 RVM p.y. mt is calculated by Equation (2). Here a 2-week cycle is introduced to collect the old, scrapped bottles from the RVMs so that they can be transported for recycling. Table 3 shows the intermediate results for forecasting the break-even point.

$$\text{Number of PBs collected by 1 RVM p.y.} = \frac{\text{maximum PBs capacity of RVM variant} \times 52}{2} \quad (1)$$

$$Total\ capacity\ of\ 1\ RVM\ p.\ y.\ mt = number\ of\ PBs\ collected\ by\ 1\ RVM\ p.\ y. \times 19.7 \quad (2)$$

$$\text{Total number of RVM required initially in 2021 (India)} = \frac{\text{mean of PBW per state mt}}{\text{total capacity of 1 RVM p.y.mt}} \quad (3)$$

Table 1. Central Pollution Control Board (CPCB) dataset of total plastic waste (PW) per year in metric tonnes.

Year	Odisha	Haryana	Madhya Pradesh
2011	897	55480	16887
2015	27859	36851	30885
2020	51270	185168	138484

Table 2. Specifications of reverse vending machines (RVMs).

Specifications	RVM BC-200	RVM PRO	RVM PRIME
Height	1400 mm	1800 mm	1800 mm
Width	700 mm	900 mm	1050 mm
Depth	700 mm	900 mm	950 mm
Maximum plastic bottles capacity	1000 bottles of 1 L	1500 bottles of 1 L	2500 bottles of 1 L
Power supply	230 V/440 V	230 V/440 V	230 V/440 V
Body structure	MS powder coated	MS powder coated	MS powder coated
Crushing mechanism	Flaking	Compression /Flaking	Compression /Flaking

Table 3. Results of the total number of reverse vending machines (RVMs) required initially.

	RVM BC-200	RVM Pro	RVM Prime
Number of plastic bottles (PBs) collected by 1 RVM per year (p.y.)	26000	39000	65000
Total capacity of 1 RVM p.y. mt	0.5122	0.7683	1.2805
Total number of RVMs required initially in 2021 (India)	4882195	4882195	2441097

Table 4. Number of reverse vending machines (RVMs) per state.

State	Mean of Plastic Bottle Waste (PBW) per State mt	Total No. of Machines Initially per State in 2021
Maharashtra	360442	703713
Gujarat	269295	525761
West Bengal	250493	489053
Delhi	242291	473040
Telangana	208335	406745
Tamil Nadu	205725	401650

Regardless of the different capacities of RVM BC-200 and RVM PRO, we are still considering the same number of RVMs initially in 2021 in India to make the comparison between the machines based on their collection performance and hence to eliminate bias due to differences in the initial number of machines in 2021. As RVM PRIME capacity is 1.5 times more than RVM BC-200, using the same number of machines required initially in 2021 as used for RVM BC-200 and RVM PRO would be very uneconomical and impractical as it would achieve its objective in the following year. To keep RVM PRIME within the same standards as RVM BC-200 and RVM PRO, we have reduced the number of initial machines required initially in 2021 by 50%, hence reducing the biases. Table 4 shows the intermediate calculation for the initial number of RVMs required per state in 2021.

Forecasting Collected PBW, Uncollected PBW, and the Break-even Point

The collection is defined as the amount of PBW mt an RVM has collected over the year and is calculated using Equation (4) and uncollected is defined as the amount of PBW mt that is inaccessible for collection and is calculated using Equation (5). The break-even point depicts the estimated year at which 100% of PBW will be collected and the recycling rate of collected PBW is projected to reach 100%. Using the forecast data of total PBW, we have concluded the performance of the RVMs. To enhance the performance of RVMs, the number of RVMs is incremented by 5% p.y. for constant progress towards the goal. Increasing the number of RVMs by 5% is an introductory case that is logically and economically suitable. This 5% p.y. increment for the machine is constant for all three RVM variants. Incrementing the number of RVMs by 5% p.y. allows for gradual growth over time, this incremental approach can be more manageable and sustainable compared to large, sudden changes. The total number of RVM p.y. is the sum of RVM after incrementing the machines by 5% every year.

$$Collection\ mt = total\ capacity\ of\ 1\ RVM\ p.y.\ mt \times total\ number\ of\ RVM\ p.y. \quad (4)$$

$$Uncollected\ mt = total\ PBW\ p.y.\ mt - collection\ mt \quad (5)$$

Proposed Hybrid Model

For this study, a hybrid model is proposed for achieving an optimal break-even point by implementing a combination of the three RVM variants. For this model total population of India (per state) factor is taken into consideration because PBW is directly proportional to the population [18], states with a greater population would require more RVMs so that these machines can collect PBW effectively and should be easily accessible to the population in the state.

Partitioning States of India into Two Categories

Large states and small states – Using the median method on the data of India's total population (per state) in 2020, the states have been partitioned into large and small states. States with a population greater than the median value are considered under the large states category and those less than the median value are under the small states category. Partitioning of the states has been done using the population factor rather than the geographical area of states reason being states with denser populations would require a greater number of RVMs to be conveniently accessible by the population.

Estimation of the initial number of RVMs required by the category of states in 2021. Considering the efficiency of plastic bottles collection and the accessibility of RVMs to most of the population in the states, we have segregated the three RVM variants into 2 categories of the states. For large states with denser populations, RVM BC-200 and RVM PRO variants are to be implemented using Equations (6) and (7), and for small states with sparse populations, RVM PRO and RVM PRIME variants are to be implemented using Equations (8) and (9). A 60:40 ratio is implemented for the usage of RVM in the 2 categories of the state, where in large state 60 represents RVM BC-200 and 40 represents RVM PRO, and for small state 60 represents RVM PRO and 40 represents RVM PRIME. The 60:40 ratio provides a balanced distribution between two components – the total collection capacity of PBs p.y. and the substantial accessibility of RVMs to the entire population – ensuring that neither overwhelms the other. From Table 2, the same dataset of total PBW from 2011 to 2020 is considered for the calculation of the number of RVMs, since the RVM implementation ratio is 60:40 the dataset is also partitioned in a 60:40 ratio. Table 5 represents the top five large states category and the sum of the RVMs, and Table 6 represents the top five small states category and the sum of the RVMs.

Large state initial RVM equations for 2021.

$$\text{Number of RVM BC} - 200(60\%) = \frac{\text{60\% of the mean of PBW per state mt}}{\text{total capacity of 1 RVM BC} - \text{200 p.y.mt}} \tag{6}$$

$$\text{Number of RVM PRO}(40\%) = \frac{\text{40\% of mean of PBW per state mt}}{\text{total capacity of 1 RVM PRO p.y.mt}} \tag{7}$$

Small State initial RVM equations for 2021.

$$\text{Number of RVM PRO}(60\%) = \frac{\text{60\% of mean of PBW per state mt}}{\text{total capacity of 1 RVM PRO p.y.mt}} \tag{8}$$

$$\text{Number of RVM PRIME}(40\%) = \frac{\text{40\% of the mean of PBW per state mt}}{\text{total capacity of 1 RVM PRIME p.y.mt}} \tag{9}$$

Table 5. Number of reverse vending machines (RVMs) in large states.

State	Number of RVM BC-200 (60%)	Number of RVM PRO (40%)
Maharashtra	351205	156091
Gujarat	343474	152655
West Bengal	307218	136541
Tamil Nadu	294443	130863
Karnataka	253939	112862
Total number of RVMs	2667265	1185452

Table 6. Number of reverse vending machines (RVMs) in small states.

State	Number of RVM PRO (60%)	Number of RVM PRIME (40%)
Delhi	194644	77857
Punjab	43357	17343
Jammu & Kashmir	19343	7737
Mizoram	10226	4090
Uttarakhand	9694	3878
Total number of RVMs	327025	130809

Forecasting the collected PBW, uncollected PBW, and break-even point. Increasing the rate at which the number of RVMs is incremented from 5% to 6% p.y. will help to accelerate the progress towards the goal. Incrementing the number of RVMs by 6% is an introductory case which is logically and economically suitable. This adjustment will reflect a desire for faster improvement, therefore for our proposed model, the rate of increasing the number of RVMs is 6% p.y. Equation (10) calculates the total collection of PBW, and Equation (11) calculates the total uncollected PBW, where Equations (12) and (13) are used for intermediate calculations, hence using this computation the break-even point is estimated for the hybrid model.

$$Total\ collection\ of\ PBW\ by\ RVMs\ in\ India\ p.y.mt = collection\ of\ PBW\ in\ large\ states\ p.y.mt + collection\ of\ PBW\ in\ small\ states\ p.y.mt \quad (10)$$

$$Total\ uncollected\ PBW\ in\ India\ p.y.mt = total\ PBW\ p.y.mt - total\ collection\ of\ PBW\ by\ RVMs\ in\ India\ p.y.mt \quad (11)$$

$$Collection\ of\ PBW\ in\ large\ states\ p.y.mt = total\ capacity\ of\ 1\ RVM\ BC-200\ p.y.mt \times total\ number\ of\ RVM\ BC-200\ (60\%) + total\ capacity\ of\ 1\ RVM\ PRO\ p.y.mt \times total\ number\ of\ RVM\ PRO\ (40\%) \quad (12)$$

$$Collection\ of\ PBW\ in\ small\ states\ p.y.mt = total\ capacity\ of\ 1\ RVM\ PRO\ p.y.mt \times total\ number\ of\ RVM\ PRO\ (60\%) + total\ capacity\ of\ 1\ RVM\ PRIME\ p.y.mt \times total\ number\ of\ RVM\ PRIME\ (40\%) \quad (13)$$

RESULTS AND CONCLUSION

For this study, Microsoft Excel forecasting data technicalities are used for data analysis and data visualization. Figure 1 portrays the future regression trend of total PBW till 2060 of India with upper and lower bounds defined. Based on this forecast, the performance of the three RVM variants is evaluated and set against the execution of the hybrid model. Figures 2 to 4 describe the performance of RVM BC-200, RMV PRO, and RVM PRIME, respectively.

The goal of this study is to achieve the break-even point that outlines 100% collection of PBW and projects 100% recycling of the plastic bottles that are collected by RVMs. The performance graph characterizes three curve lines that are forecasted PBW curve, the total collected PBW by the RVM curve, and the total uncollected PBW by the RVM curve, based on these curves the performance of the RVM variants and hybrid model is analyzed. Figure 2 curve indicates the period of collection of RVM BC-200 from 2021 to 2052 and the year at which break- even is achieved is 2052. Though RVM BC-200 has reached a break-even point, this is still not an optimal solution as for this variant the overall number of machines is significant, but the individual RVM collection capacity is very less – 1000 PBs every 2 weeks – resulting in a delay in break-even point and taking more than 3 decades to reach our desired goal. Figure 3 concludes that, using RVM PRO the break-even point is reached early in the year between 2045 and 2046 compared to RVM BC-200. Although the initial number of machines is the same for RVM BC-200 and RVM PRO the early arrival of the break-even point is due to the RVM PRO's better per-machine collection capacity which is 1500 PBs every 2 weeks.

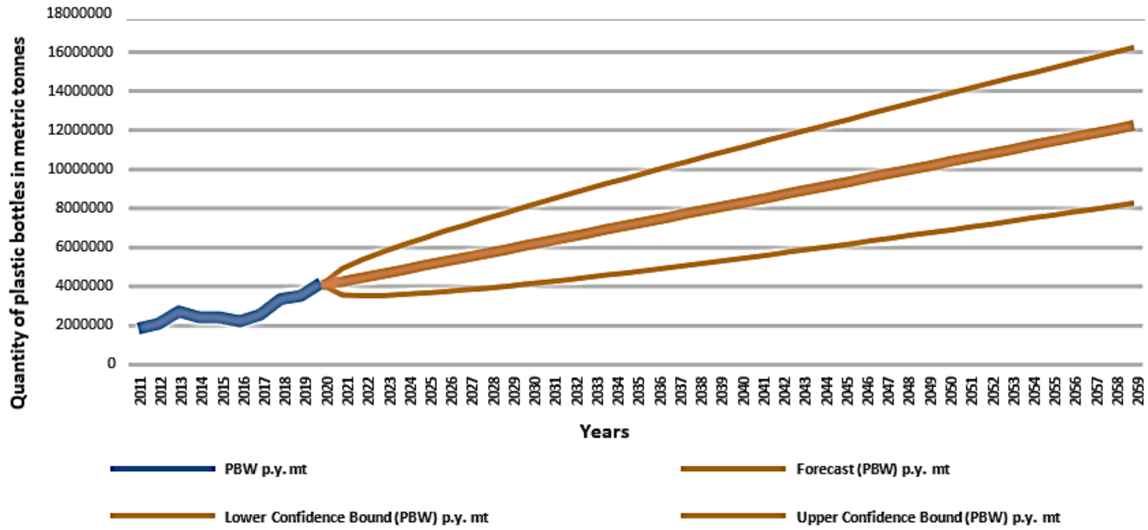

Figure 1. Forecasted regression of total plastic bottle waste (PBW).

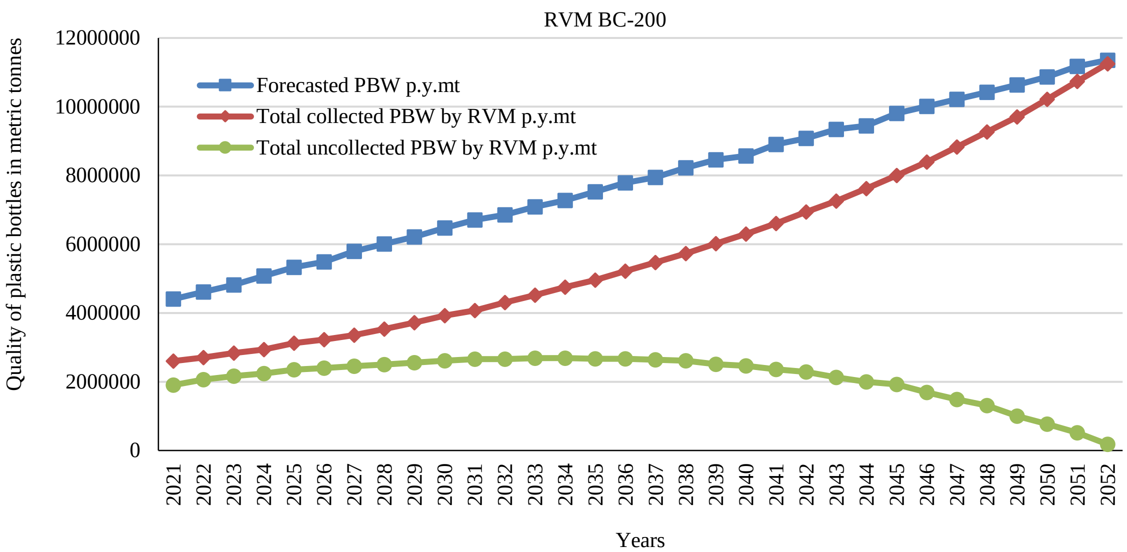

Figure 2. Performance of RVM BC-200.

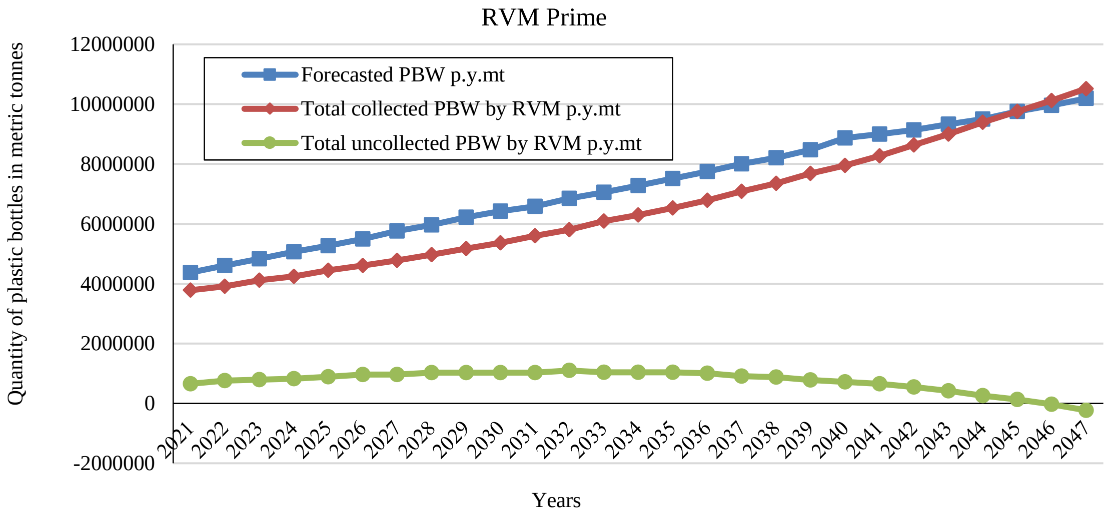

Figure 3. Performance of RVM PRO.

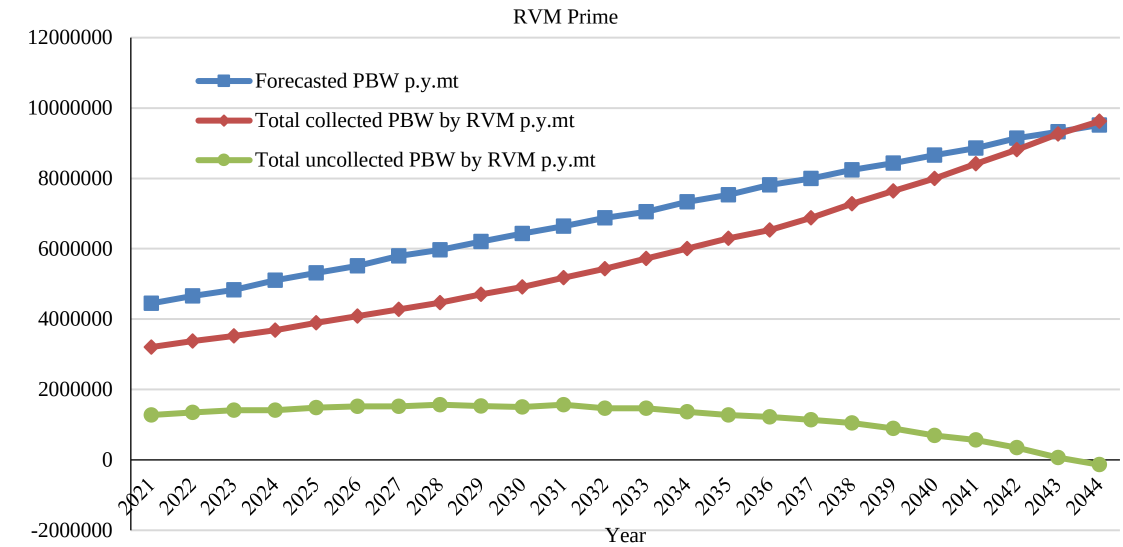

Figure 4. Performance of RVM PRIME.

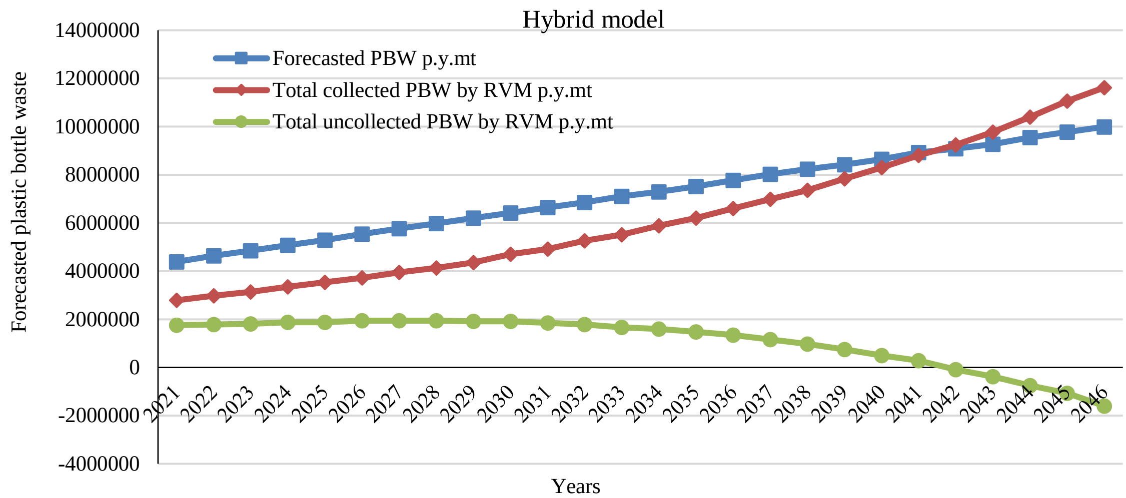

Figure 5. Performance of hybrid model.

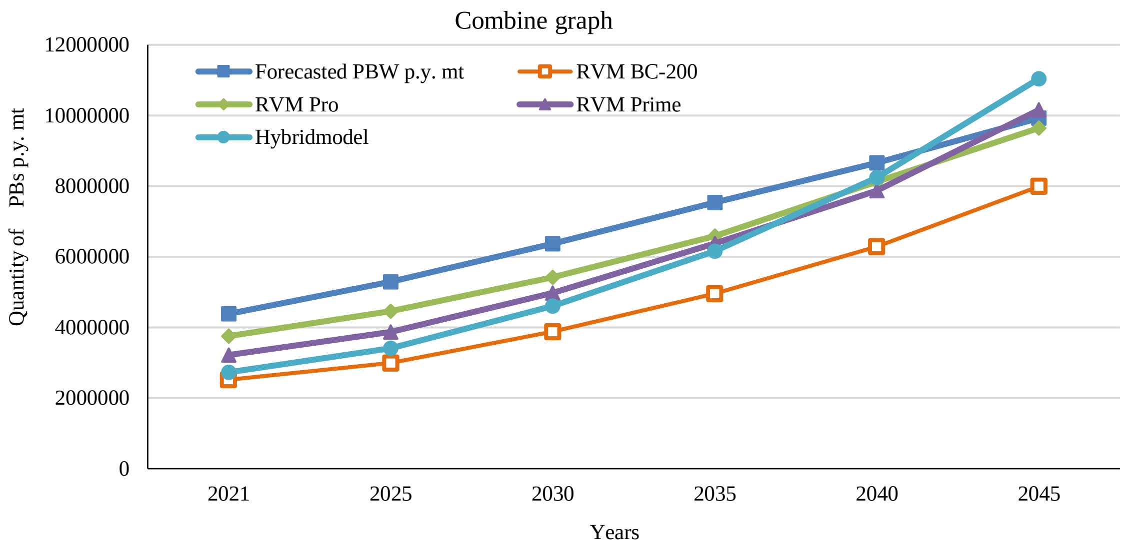

Figure 6. Comparison of performances.

RVM PRIME has a per-machine PBs collection capacity of 2500 PBs every 2 weeks, Figure 4 concludes that the break-even point is achieved in the year between 2043 and 2044, which is a much better solution with half the initial number of RVMs (PRIME) when compared to the other two RVM variants (BC-200 and PRO). In comparison, the hybrid model exhibits a phenomenal output as the break-even point is achieved in the year between 2041 and 2042, which is the best and most optimal result. Figure 5 outlines the performance of the hybrid model.

Implementation of RVM BC-200 and RVM PRO delivers a significant number of machines but poor machine collection capacity. These machines are easily accessible by the population but are not efficient enough to achieve optimal solutions. RVM PRIME has half the number of machines but a finer per-machine collection capacity making it efficient but inaccessible to the population. We have combined these three RVM variants to create a much optimal model – a hybrid model – with RVM BC-200 and RVM PRO will be operational in a large state in a ratio of 60:40 where RVM BC-200 will improve the accessibility of machines to the population and RVM PRO will improve the PBs collection rate. In small states, RVM PRO and RVM PRIME will be functional in a ratio of 60:40 where RVM PRO improves accessibility of machines to the population and RVM PRIME improves the plastic bottles collection rate. In the proposed hybrid model the break-even point is achieved in the year between 2041 and 2042, which is earlier than any of the individual RVMs, with more accessibility of RVMs to the population that boosts the awareness of using RVMs in India while being cost-effective to the government and with greater collection of PBW will increase the recycling of PBW. Figure 6 summarizes the performance of all RVM variants against the hybrid model. For adoption of the proposed hybrid model, major challenges the government could face will be the dysfunctionality in the maintenance of RVMs, time and cost to attain the vast manufacturing of the RVMs, lack of infrastructure in different states of India as RVMs require electricity and water supply that may not be available in many cities, and insignificant monetary rewards that will discourage people to use RVMs [19]. The conclusion of our study is to illustrate the capabilities of RVMs to refine the collection, reduce, and increase the recycling of PBW which will amplify the overall plastic management system of India.

Future Work

Implementation of real-time RVM-based bins for collecting different types of single-use PW like polyethylene, and plastic containers. More accurate results can be generated if specific data for total recyclable PBW in India is applied in the study. The performance of the hybrid model can be improved by using machine learning techniques.

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