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Packaging Plastic Waste Management for a Circular Economy and Identifying a better Waste Collection System using Analytical Hierarchy Process (AHP)

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Abstract

One of the biggest challenges for solid waste management systems is the ever-growing use and disposal of plastic materials which have severe repercussions on the environment and ocean. Linear economy (take, make, throw) recycles as little as 2 % of plastics globally, wasting the humongous amount of resources. This is high time for the implementation of the circular economy, especially among plastics. A circular economy would both maximize the merits of plastics and minimize their ill effects, through such actions as producing them from plants rather than fossil fuels; redesigning products to cut waste and make them last; boosting recycling and reuse, and utilizing plastic wastes as a resource; to name a few. Categorizing the post-industrial plastic waste can lead to differentiating recyclables, reusable from dead-end plastics. This will help us to reduce what we don't need and reuse what we need. In this study, we are focusing on the plastic waste generated by packaging industry because they contribute the highest (almost 40%) of total plastic waste generated. A model for recycling the waste generated from packaging industry has been proposed which provides recycling of the waste in multiple levels i.e. we can extract the same product from the waste by high grade recycling of can use them in secondary operations like as charcoal, construction material. After that an AHP analysis has been prepared for identifying best plastic waste collection methods because for successful operation of recycling to happen, collection and proper segregation is a very important prerequisite. Results showed that Deposit and Refund method collection is best suited for waste collection method as it is supporting the concept of circular economy. At the end, a case study of successful implementation of Circular Economy is presented.

Keywords: Circular Economy (CE), Analytical Hierarchy Process (AHP)

1. Introduction

Plastic waste management is a technique of segregating, properly utilizing the resources in terms of waste disposal, and avoiding ways to deal with them that cause harm to the environment. It is very important to understand and implement waste management solutions to plastics because there is only a limited amount of resources available and the population is using the plastics in every possible way. Be it FMCG (fast-moving consumer goods), construction and materials, packaging industry, electronics, industrial goods, etc. every market sector uses plastics and only a few of them treat the plastic after its life cycle for recycling or reuse. Even in the past, the plastic waste recovery rate was very unsatisfactory.

Nomenclature

VC	Vehicular Collection
KC	Kerbside Collection
DOR	Drop Off Recycling
BBC	Buy Back Centre
D/R	Deposit/Refund Centre

Only 9% of plastic waste produced between 1950 and 2015 was processed for recycling and it is estimated that if the production of plastic and its related products will double in 2035 and will be four times in 2050 because of economic and population growth **(Mroweic et al 2017).** Out of 6300 million tons of plastics total produced about 4900 million tons of plastic ended up in either landfill or elsewhere in the environment (about 78 percent of total plastic waste is dumped).

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And if things do not get changed in future the plastic waste quantity is expected to be nearly 12000 million tons **(Barra and Leonard, 2018)**, which is alarming. It is high time that we must make some changes in the way plastic products are being used.

The Circular Economy brought a revolutionary change for plastic waste management. Circular Economy emphasizes on zero waste methodology by innovation and rethinking design to increase product life cycle for better use and less frequent waste, reusability, and recyclability in all ways possible so that the waste would not end up in landfills or marine litter. The World Economic Forum also introduced The New Plastic economy which pointed out how plastic rethinking and redesigning will make major implications **(World Economic Forum, 2016).** Europe has also signed the Plastic Pack which aims to make plastic life circular for better tomorrow (**Plastic The Facts, 2017**).

The remainder of this paper is organized as follows: Section 2 is devoted to the literature review and plastic and their types are discussed in Section 3. Section 4 focuses on the generation and wastage of plastic industry wise. Section 5 proposes our model for Circular Economy in plastics used in Packaging Industries. Section 6 supports the model by creating an AHP model to identify the best plastic waste collection method we should employ for achieving Circular Economy. Section 7 presents a case study of Circular Economy used to convert waste plastic in high grade fuel.

2. Literature Review

A literature review has been done on the circular economy, plastic waste management and circular economy of plastics on search engines like Springer, Taylor and Francis online, Emerald Insight and from Google scholars. Several general articles and videos illustrating the concepts of plastic waste and how circular economy can help reduce them are being studied. **(Bozena Mrowiec,2018)** pointed out the assumptions and action plans for making the Circular Economy plan work for Plastics based on the European Commission's plan introduced in 2015.

Performance indicators have been developed for assessing the Circular Economy of bioplastics and how they can be more beneficial than conventional plastics **(Spierling S., Venkatachalam V., Behnsen H., Herrmann C., Endres HJ. 2019).** Effects of Black Plastic (single-use packaging and trays) on the environment and on marine life are very severe as they contain hazardous chemicals. Waste Electronic and Electrical Equipment (WEEE) also produces black plastics **(Andrew Turner, 2018).** Recycled plastic products must pass certain tests and criteria chemically to be declared as fit for use for foods and drinks

(Birgit Geueke, Ksenia Groh, Jane Muncke 2018). (Burlakovs, J.; Kriipsalu, M.; Porshnov, D.; Jani, Y.; Ozols, V.; Pehme, K.-M.; Rudovica, V.; Grinfelde, I.; Pilecka, J.; Vincevica-Gaile, Z.; Turkadze, T.; Hogland, W.; Klavins,2019) Shared the challenges, concerns, and solutions for plastic waste treatment. They introduced Thermogravimetry for plastic waste decomposition as a method. The circular economy has to go hand in hand with the safety of the users in case of recycling and reusability especially in plastics where the renewed product has to be hazard-free for use in grocery products **(Tom Keijer, Vincent Bakker and J. Chris Slootweg, 2019).**

3. Industry Wise Distribution of Consumption and Waste Generation of Plastics

Because of multiplecharacteristics and properties possessed by plastics they are used in almost every market sector. Some of the sectors which have a large share of plastic usage are building and construction, consumer products, electronics and electrical appliances, packaging, automobiles sector, etc. Talking about the global plastic production and generation by market sector packaging is alone responsible for 36 percent of plastic production and 46 percent of plastic waste generation **(Geyer, 2020). (IHS Markit, 2018**) Report data tells us that the packaging sector is responsible for around 35-40 percent of usage as shown in Figure 1 and 59 percent of waste generation. Since the packaging industry is responsible for almost half of the waste generation while rest industries combined is possible rest half, we have chosen to take the packaging industry as our prime focus to study the recycling and reusability for creating a circular economy of plastic. In the packaging industry, four types of plastics are used almost 90 percent of the time which are PP, LDPE, HDPE, PET **Geyer et al. (2017).**

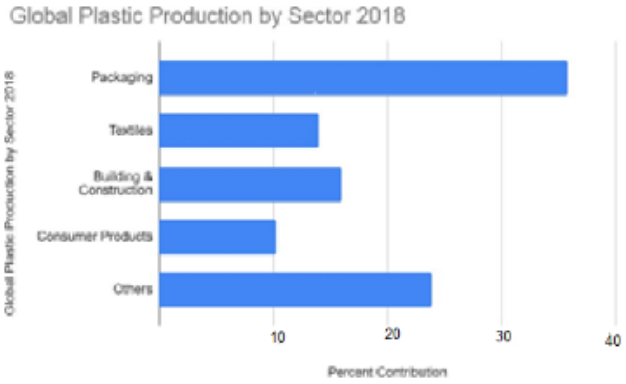

Figure 1. Industry Wise Distribution of Plastic Production Globally 2018

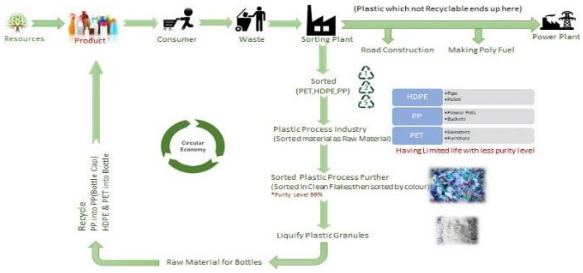

Figure 2. A Circular Economy Model for Recycling Packaging Industry Plastic waste to produce the original product

4. Circular Economy in Packaging Industry Plastics

As we have concluded in section 4 that most packaging materials are made of HDPE, PP, and PET type plastics. So we will create a flow map (Figure 2) for these plastics and will form a sustainable circular model. The journey of plastic will start with someone buying the product from stores and using it until the product life cycle ends. After that post consumed plastic waste will be dumped into the garbage bags which will be collected by concerned authorities and will be transported to sorting plants where sorting on the broader level happens (segregating hard plastic, soft plastic, very large bags, small bags, etc).

Most of the plastic will fall in HDPE, PP, or PET category but if some other type of plastics also gets along which cannot be recycled then this type of plastic is segregated from the rest and sent to serve other purposes. These plastics on further heating and processing can be converted into poly fuel (for burning purposes), char or sludge as construction materials, or if not those it can always be used as energy fuel for generating power (electricity) in power plants.

Now the HPDE, PP, and PET are being sorted and sent to plastic processing plants where they are used as raw materials. Sorted plastic is further being sorted on the bases of colors and types where they can achieve purity level up to 99 percent. After sorting is done individual sorted granules are being liquified which will act as raw material for making bottles (or products for which they are used). Then PP is being sent to produce the bottle caps (figure 2) and HDPE and PET into the bottle manufacturing line. These products are not as good as new to use, and they are being sent to serve their purposes. In this way, we can achieve circularity in these plastic types and apparently in the whole process of packaging.

5. AHP for best Waste Collection Method

For the implementation of the model proposed above to work it is very important to have a proper plastic waste collection method which will act as raw material for the recycling facility. There are 5 major waste collection methods employed by municipalities across the globe namely Curbside Collection, Vehicular Collection, Drop Off Recycling, Buy Back Centers and Deposit/Refund program **(Salman Zafar, 2020).** Now for choosing one of these methods several important factors have been identified like the operational cost of the method, its social impact, environmental impact, ease of sorting at facility end and ease of collection by workers.

Now, our aim is to find best method for packaging plastic waste collection method. For which our next step is to have some expert opinion regarding the economy and level of operations for all types of garbage collection methods. We conducted a questionnaire in which 200 experts from Civil Engineering background (govt. officials, academicians, Ph.D. scholars) participated.

We asked them to give rating to different methods of waste collection based on their operations cost, social impact, environmental cost, ease of sorting. Following those results we came up with an AHP model to formulate the best packaging plastic waste collection method.

Analytic hierarchy process (AHP) is a structured multi-attribute decision method (**Saaty, 1990**). The main benefit of AHP is its competence to check and reduce the inconsistency of professional judgment's. AHP is applied based on the information collected to choose the best method for plastic waste collection.

Our goal is to have a plastic waste collection method which will support the Circular Economy as shown in hierarchical manner in Figure 3. We have chosen four criteria to determine the importance of collection method which are Environmental Impact of the Method, Social Impact of the Method, and Ease of Sorting at the plant after collection and Operational Cost for the Methods.

Our alternatives are

- **Vehicular Collection Method (VC)** – Waste is supposed to be collected from houses daily, once a day. Use for management of solid waste to replace drop off or curbside waste collection method which causes odor and smell due to waste collection at one place and not feasible for large population areas(**Aung May Tin, Donald L. Wise , Wei-Han Su, Lars Reutergardh, Seong-Key Lee,1995)**
- **Curbside Collection Method (CC)-** Bins are places for a locality which are emptied once a day. For Increasing waste collection and reducing waste collection cost. Household waste is brought at one point of the communal waste collection point.**(Cristina Mora, Riccardo Manzini , Mauro Gamberi & Alessandro Cascini,2013)**
- **Drop Off Recycling (DOC)-** They are dedicated, large bins(often machines) where plastics are disposed by their type. These boxes are examined in a systematic approach. Collection boxes place near to society which can be easy to access**.(Ni-Bin Chang, Y.L. Wei,2000)**
- **Buy Back Centre (BBC) –** They are stations or vending machines or shops where we can replace our waste with some useful items. Fixed or mobile buy back center are two options for recycling the waste**(Irina Safitri Zen,Chamhuri Siwar2015**).
- **Deposit/ Refund Method(D/R)-** These are bank type stations where we can deposit our waste and gain some sort of credit or even cash from them. Deposit refund system gives tax return when its packaging returns for recycling**(Margaret Walls,2011)**

Process Tree for Choosing best Waste Collection Method

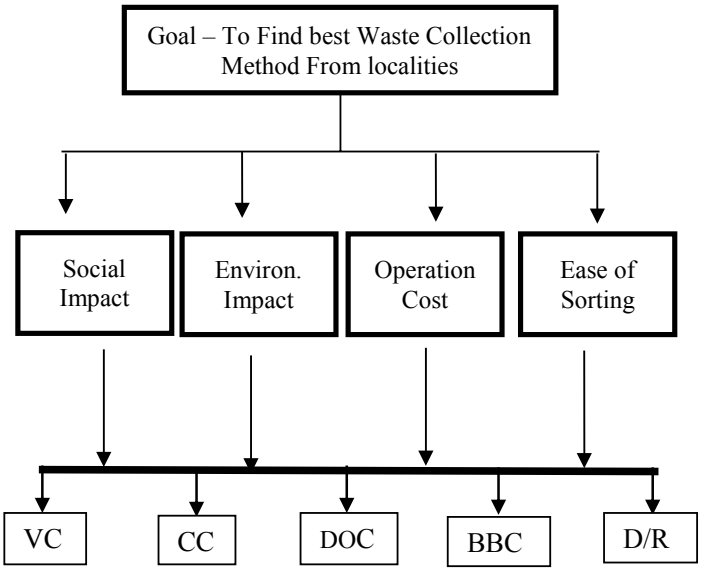

Figure 3. Hierarchy of choosing the best Waste Collection Method

Table 1 shows the pairwise comparison of all criteria to calculate the weightage of each of these criteria's for making decision of choosing best plastic waste collection method.

Table 1. Pairwise Comparison of Criteria's.

	Social Impact	Environmental Impact	Operation Cost	Ease of Sorting
Social Impact	1	1/3	5	7
Environmental Impact	3	1	7	9
Operation Cost	1/5	1/7	1	3
Ease of Sorting	1/7	1/9	1/3	1

In order to ensure the consistencies of all the judgements made above in all the matrix reciprocals, Consistency Ratios were found out for each of the matrix calculated using the largest eigen value of the eigen vectors

$$\lambda_{max}=5.4032$$

$$\text{CI(Consistency Index)}= (\lambda_{max}-\lambda)/(n-1)$$

Where n=number of alternatives, λmax is calculated from table 1

$$\text{CR(Consistency Ratio)}= \text{CI/RI}$$

RI is calculated from Random Consistency Index Table for n=5

RI(n=5)=1.12

CI=0.1008

CR=0.09 (<0.1)

Hence the calculation is consistent.

Similar calculations are being done for table 2-6 and their values for CR being calculated in similar way

Table 2. Weightage of Criteria's (CR=0.06)

	Weightage
Social Impact	0.2912
Environmental Impact	0.5739
Operation Cost	0.09
Ease of Sorting	0.04

In order to ensure the consistency of the judgment in all the comparison matrices, consistency ratios (CRs) were calculated and all the CRs were less than 0.01.

From Table 2 we can see that highest importance has been given to Environmental Impact which also makes sense because the aim of Circular Economy is to create an economy for better and sustainable environment.

Similar calculations were performed for each of the building the comparison matrices for each of the criteria's

Table 3. Social Impact (CR=0.09)

	Weightage
VC	0.1499
CC	0.03164
DOC	0.0533
BBC	0.338
D/R	0.426

Table 4. Environmental Impact (CR=0.081)

	Weightage
VC	0.3716
CC	0.0368
DOC	0.0764
BBC	0.1580
D/R	0.3554

Table 5. Operations Cost (CR=0.095)

	Weightage
VC	0.2433
CC	0.4998
DOC	0.1578
BBC	0.0385
D/R	0.0605

Table 6. Ease of Sorting (CR=0.091)

	Weightage
VC	0.0308
CC	0.0881
DOC	0.4402
BBC	0.2475
D/R	0.1932

Table 7. Result

	Weightage
VC	0.2797
CC	0.0788
DOC	0.0911
BBC	0.2024
D/R	0.3411

Table 3 to 6 have the final weightages for each of the criteria's where importance of the alternatives is being

consulted by Post Graduate students, Professors and Professionals in Civil Engineering. Table 7 is the final result obtained which shows us Deposit and Refund plastic waste collection method should be chosen over others for given alternatives and in the sense it is was we were pretty much expecting because the idea of choosing the waste collection method is not only to create a clean environment but to also create some sort of economy from the waste which will work both ways i.e. helping the society in terms of monetary help or goods exchange and helping governing bodies to collect the plastic waste for their better use. Although this solution is the best one for current situation, our aim to form a perfect Circular Economy is adapt refusing the Plastic based products in the first place. But because of numerous physical and economical properties of Plastic that's not going to happen spontaneously, it will be incremental change which we all have to take for making earth a better place to live.

6. Case Study-Rudra Environmental Solutions (Jejuri- Pune (M.H) (INDIA)))

Rudra Environment Solutions is a company that is transforming plastic waste into a poly fuel using thermo catalytic depolymerization which can be used for burning without any further processing in households and companies.

India alone generates 26000 tons of plastic every year which makes it the 15th largest plastic waste producer. In the broader category plastic is segregated into thick plastic and thin plastic. Thick plastic can be recycled very easily but thin plastic (also known as multi-layer plastic (MLP)) ends up in landfills most of the time.

Rudra President Medha Tadpatrikar took the matter in her own hands and started finding the solutions to make something valuable from the plastic waste. They talked to many chemicals, mechanical, and polymer engineers who are working with plastics. Then they came to a thought that if the plastic is made of crude oil why can't we reverse it. After many failed experiments they adapted a technology that generates high-grade fuel from plastic waste which has high calorific value and is more environments friendly at a mere cost of 23-34 Rupees per liter. The poly fuel generated has a Sulphur output of 0.17ppm in comparison to diesel's 80ppm output.

They created a 50kg plant in Jejuri(outskirts of Pune (M.H, India) which later converted into a 500kg capacity plant. The next challenge for them after creating this technology was to collect plastic from across the area. For that Rudra Founders decided to collect the plastic waste on their own which will be multilayer beneficial which is the plastic collection for the environment safety and their plants use.

They have adopted an important concept of segregation at source means separating different types of plastic waste at its source so that they don't end up in landfills. They created a cycle of the collection in which residents put their plastic waste at a predefined location and once a day the waste gets collected. Proper education has been provided to residents about the harm and cause of plastics waste and how to segregate plastics at home.

After reaching plant plastic is segregated by hard and soft plastics. Their shredding process is done separately and then they get fed to the reactor where an anaerobic reaction happens which yields almost 70% of poly fuel with 10-15 % of synthesis gas(which can be reused in the process) and a bit of char or sludge (which is used in the construction of roads). 100 % of plastic waste is recycled by this process.

Current Plant of **500kg** Capacity in their Jejuri (Pune) Factory. The plant is able to process plastic waste that is not easily recyclable including wrappers, other thin plastic and residual plastic waste material from businesses and households. Each ton of plastics produces approximately **600 to 650 liters of fuel** – Around **20% fuel** used in the process. Only **20 to 25% synthetic gas** – used in the process which is very good in comparison to other processes. Merely 5 to 10% moisture is used in the process, **5 to 10% Residual char** – can be used as road filler with bitumen. One more fascinating work of Keshav Sita trust is creating awareness of waste plastic & segregation at source.

Collects waste plastic from more than **15000 households** in and around Pune. Other Collection areas include Thane, Dombavali, Baramati, Bhimashankar and nearby forts. Till date they have collected more than **275 MT of waste** plastic that is **Saving of 16.50 lakh KG of emission.**

Rudra has helped 10 companies so far to install their technology in their respective campuses and is aiming for more. Their model is sustainable, circular, and ecofriendly

7. Conclusion

In growing world use of plastic is exponentially increasing with this the major problem is plastic waste which increase drastically with use of plastic. Environmental concern associated with plastic waste has incited the research in sustainable energy in which circular economy playing major role for recycling the plastic waste and make it use again without extracting natural resources. In this paper different types of plastic are covered along with their uses and recycle stages.

To find the best waste collection method using multiple criteria's we have used Analytical Hierarchy process (AHP) for decision making. AHP is an effective method to deal with complex MCDM problem. Best waste collection method is found out in accordance with less social and environmental impact, low operation cost and ease of sorting. Here AHP is used mainly to weigh criteria and purposed most preferable among the studied waste collection methods. Sub criterias such as VC, CC, DOC, BBC and D\R. Best among these is found out using AHP which supports main criterias. Results stated that deposit or refund method is best option among all. D/R method effectively collects the waste and some monitory gains are also possible. Overall, this paper helps to achieve circular economy for plastic waste management.

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