Evaluation of Solid & Liquid Waste Management (SLWM) technologies and examination of their impact on environment and employment

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Abstract

Inappropriate disposal of Solid and Liquid Waste (SLW) is a severe threat and leads to significant damage to the environment and public health. With the imminent and fast approaching water crisis, it is extremely essential to effectively treat the SLW before it enters the water bodies. In this paper India's current ecosystem of waste management has been represented and major challenges in the rural and urban context have been highlighted. Also, studies conducted in the space indicate that in order to reduce the ill-effects of SLW, focus should be on the management of waste at the point of generation by adoption of approaches such as reuse, recycle and recover (R3). This paper attempts to evaluate technologies designed for Waste management based on major parameters such as affordability, scalability, sustainability, universal, rapid, excellence and distinctive. Based on the current scenario in India there is a large scope for improvements in collection, segregation, treatment and disposal of waste. Most of the waste management systems are driven by the informal sector which is unregulated and unregistered. Thus, in future, as the SLW value chain formalizes a large number of employment opportunities are expected to emerge.

Keywords: Solid and liquid waste, technology, evaluation, employment.

I. Introduction

The Government of India had launched the Swachh Bharat Mission on 2nd October 2014 as an effort to achieve universal sanitation coverage. The household toilet coverage across India, rose to 89% in August 2018 from 39% in October 2014, which is around 23% year on year growth (Ministry of Drinking Water and Sanitation (MDWS), India 2018) [1]. However, on account of the large number of toilets that have been installed, the ground water is at a risk of being contaminated due to inadequate disposal of faecal waste. Improper solid waste disposal leads to leachate formation, which subsequently percolates and contaminates the groundwater. The quality of water in the tube wells and boreholes majorly depends on the soil percolation capacity and the quality of aquifers where it gets stored. Thus, with the increased quantity of waste being dumped in landfills the quality of water has become a major concern. In rural areas, the absence of formal collection of waste and sewage system leads to additional challenges with respect to waste disposal. This is the major challenge that has to be solved in order to prevent the water crisis. Managing the waste in an appropriate manner is the solution, however, as easy as it sounds the network of multiple stakeholders, unstructured processes and informal ecosystem in India makes the space extremely complex.

In India, Urban and rural households rely on different sources of drinking water. According to the latest National Family Health Survey, 91% of urban households and 89% of rural households have access to improved source of drinking water.

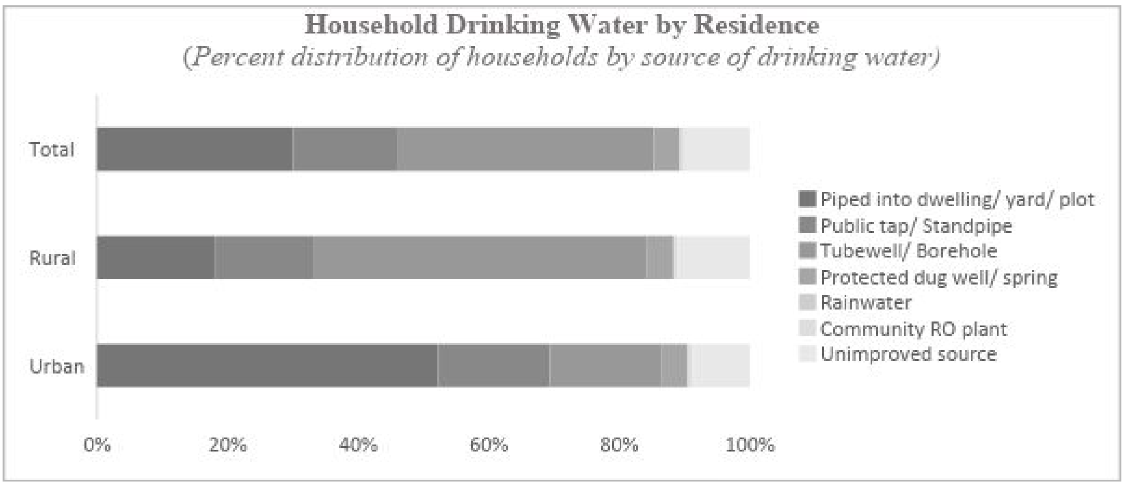

Figure 1: Percentage distribution of households by source of drinking water (Ministry of Health and Family Welfare 2016) [2]

The survey stated that improved sources of drinking water include piped water, public taps, standpipes, tube wells, boreholes, protected dug wells and springs, rainwater, and community reverse osmosis (RO) plants. As shown in the data above, results indicate that the main sources of drinking water for urban households are water piped into their dwelling, yard, or plot (52%). In contrast, rural households rely most on tube wells or boreholes (51%).

On account of the approaching drinking water crisis and with the objective of bringing improvement in cleanliness and hygiene in rural areas, the guidelines provided by the Ministry of Drinking Water and Sanitation clearly mentions solid and liquid waste management (SLWM) as one of the key components of Swachh Bharat Mission - Gramin (SBM-G). SLWM can be defined as the end to end process of collection, transportation, processing, recycling, treatment, and disposal of waste material in a scientific manner. The major challenges in developing countries such as India is the lack of awareness at the ground level where waste is generated. Nature of waste generated in rural areas of India is very different as compared to the Urban areas. Solid waste generated in rural areas is predominantly organic and biodegradable (MDWS, India 2018) [1]. This leads to unhealthy environment, therefore, domestic solid waste should be managed properly.

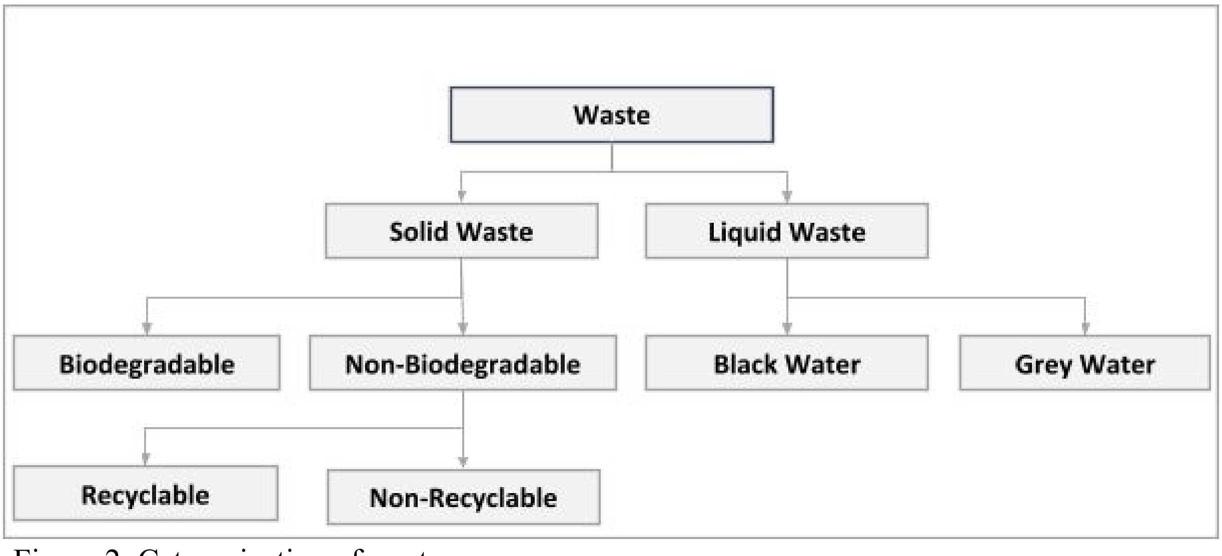

Figure 2: Categorization of waste

Solid waste can be categorized as biodegradable and non-biodegradable. Biodegradable waste can be decomposed by biological processes. Food waste, animal waste and farm waste are some examples of biodegradable waste that are generated in rural India. This type of waste can be recovered through various processes in the form of manure/compost, biofuel or biogas. Waste that cannot be broken down by biological processes are categorized as non-biodegradable, which can further be classified as recyclable and non-recyclable waste. Paper, metal, plastic bottle and other such waste that can be processed to recover economic value are called recyclable waste. Remaining waste that cannot be recovered to generate economic value such as thermocol, thin plastic bags and rappers, tetra packs etc. fall under the non-recyclable category.

Liquid waste includes all forms of water that has been used once and is not fit for other uses. There are two main types of waste water- Black water and Grey water. Black water is the waste water from toilets which contains faecal matter. Waste water that has not come into contact with faecal matter such as water from the bathroom and kitchen is called grey water. This waste water generally contains lower quantity of pathogens as compared to black water (Water and Sanitation Program (WSP) of World Bank, 2012) [3].

II. Solid waste management ecosystem

India generates solid waste of about 1.2 lakh tonnes per day. Waste generation depends on multiple factors such as population density, economic status, commercial activity, culture and region. As you will see in Figure 3, states with high population have large waste generation. The top states contributing to the waste generation are Maharashtra, Uttar Pradesh, Tamil Nadu and West Bengal.

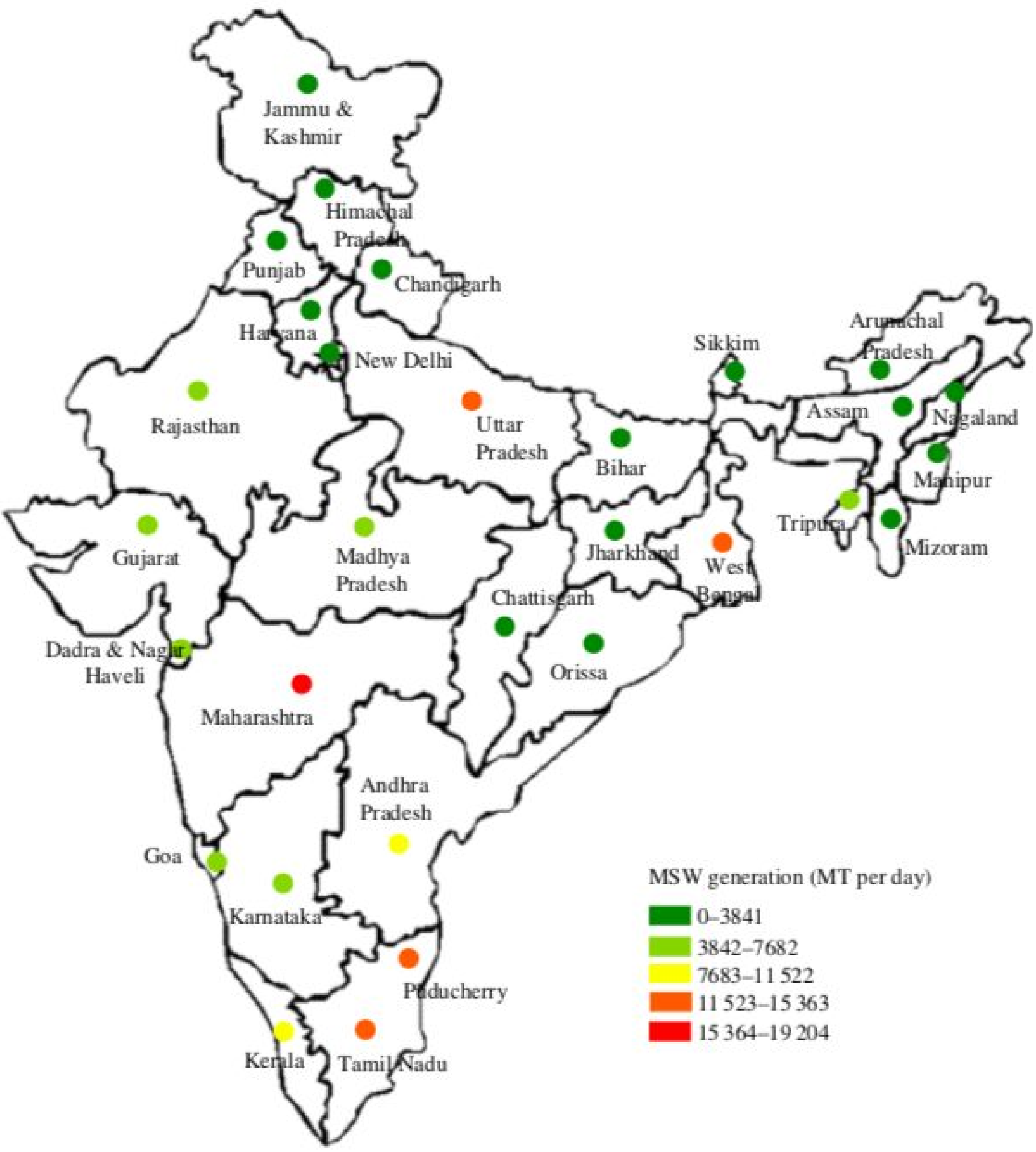

Figure 3: Statistics of MSW generation in India (Kumar et al. 2017) [4]

Interesting aspect to observe is that almost all the waste generated in collected as shown in Figure 4. Even though the percentage of waste collected is high, developing countries face challenges due to inadequate institutional facilities, expertise, financial resources and administrative enforcement of environmental regulations. Financial constraints are due to insufficient fee structure. Also, the guidelines are based on technically advance nations and their regulation, which may not be directly applicable for the rural areas in developing nations. Additionally, the most important aspect is the waste minimization at the source of generation and maximum utilization of recovered and recycled products which is mainly driven by the informal sector. (C. Visvanathan et al, 2003) [5]

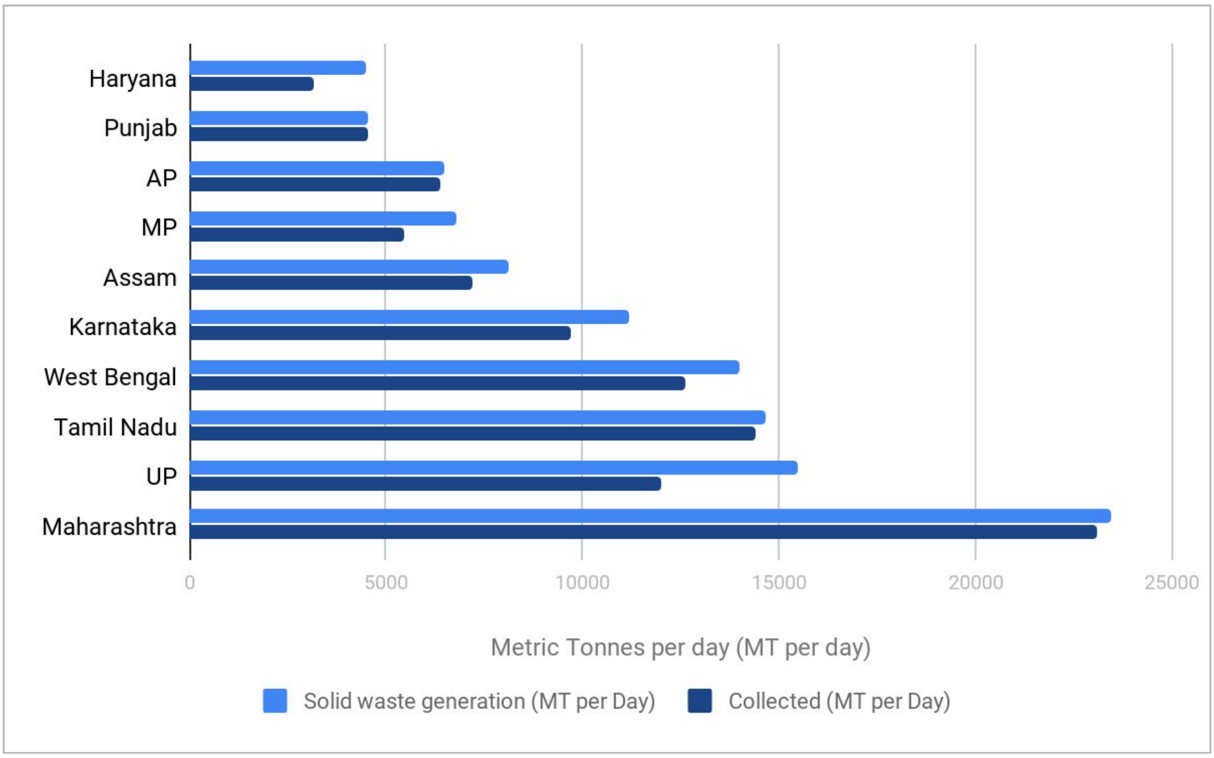

Figure 4: Solid waste generation and collection for top 10 states in India (CPCB 2018) [6]

The composition of the solid waste generated in India shows that around 40% is compostable and could be treated to generate manure which could be reused in farming and plantation. Another 20% that includes paper, plastic, textile, glass and metal is majorly recyclable. Remaining 40% inert solid waste is currently dumped in landfills which could lead to numerous issues such as groundwater pollution is not disposed correctly.

Table 1: Average composition of MSW in Indian metro cities. (Kumar et al. 2017) [4]

Percentage (%) by weight							
Compostable	Inert	Paper	Plastic	Textile	Glass	Metal	Leather
41	40	6	4	4	2	2	1

Average composition of solid waste suggests that majority of the waste could be treated. Efficient recovery of waste would reduce the waste dumped in landfills. The current waste management data of the top 10 generating states indicates that there is tremendous scope for treatment and recycling. (CPCB 2018) [6]

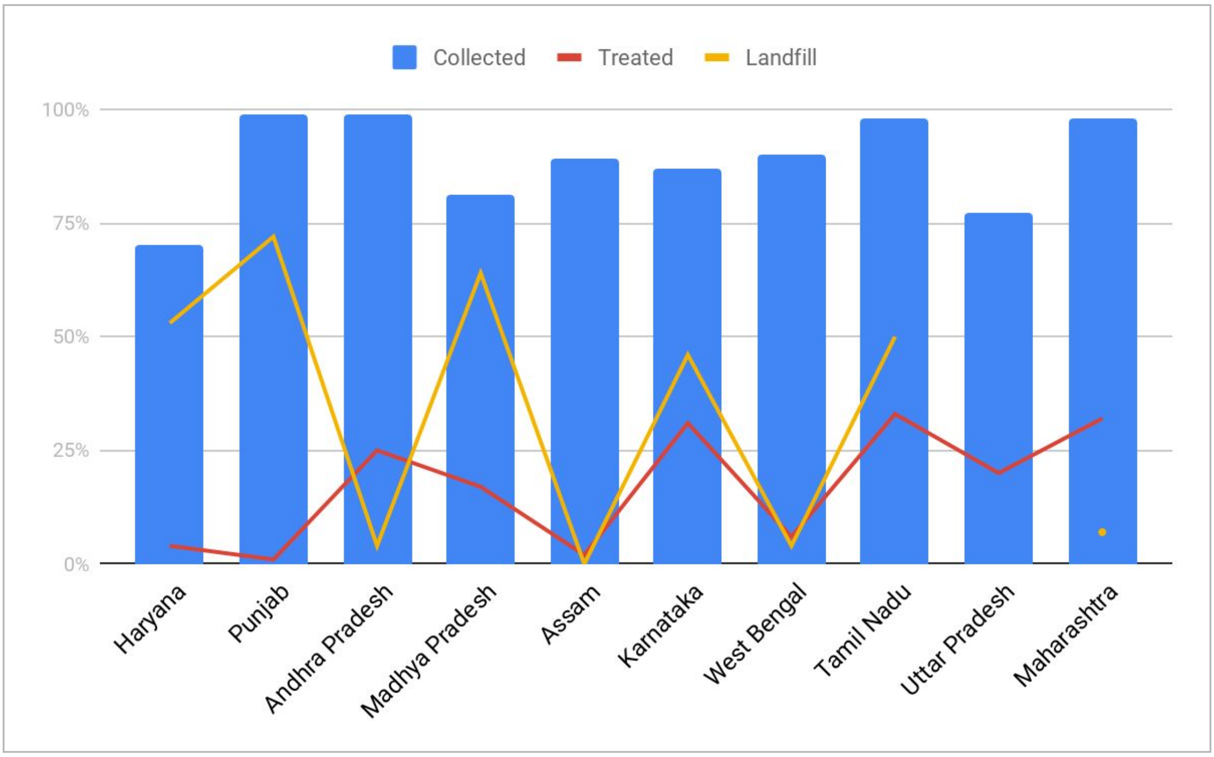

Figure 5: Waste treated and dumped in landfill as a percentage of total solid waste generated

The percentage of treated waste is less than 30% for most of the states indicating a minimum gap of 10% based on the composition of waste generated mentioned in Table 1. Treatment of solid waste can be done through technologies such as composting, vermi-composting, biogas plant, pelletization and waste to energy. A more detailed view of the actual gap in the treatment infrastructure can be seen in the Table 2. Most of the states require investment in terms of waste treatment infrastructure.

Table 2: Solid waste processing facilities set up in India (CPCB 2018) [6]

States	Compositing	Vermi-composting	Biogas	Pelletization	Waste to Energy
Andhra Pradesh	20	19	7	0	10
Arunachal Pradesh	0	0	0	0	0
Assam	1	0	0	0	0
Bihar	0	0	0	0	0
Chhattisgarh	4	1	0	0	0
Goa	14	0	0	0	1
Gujarat	0	93	1	3	0
Haryana	3	1	0	0	0
Himachal Pradesh	10	0	0	0	1
Karnataka	131	88	13	12	0
Madhya Pradesh	19	1	1	1	1
Maharashtra	52	34	38	5	2
Mizoram	0	0	0	0	0
Meghalaya	1	1	0	0	0
Orissa	1	0	0	0	1
Punjab	0	1	0	2	8
Sikkim	2	0	0	0	0
Tamil Nadu	757	141	39	12	4
Uttar Pradesh	28	-	-	4	4
West Bengal	21	0	0	0	1

III. Methodology:

Technological innovation has become an integral part of the development sector in India over the last decade. In order to create large scale impact organizations are adopting advanced technologies customized to the user's requirements. India is a diverse country; therefore, technological interventions vary based on the geographical location, socio-economic parameters, cultural factors etc. As a result, there is a need for evaluating technologies through a framework that reduces the subjectivity involved.

The evaluation model presented in this paper is designed to reduce the subjectivity of evaluating technologies so as to take an informed decision while solving issues on the field. Major parameters that are applicable for the bottom of the pyramid have been considered and modified to suit the ground scenarios. The framework includes parameters such as **A**ffordability, **S**calability, **S**ustainability, **U**niversal, **R**apid, **E**xcellence and **D**istinctive. This section tries to explain each parameter of the evaluation framework in detail along with quantitative methods for computing a ratio that could guide the rating process. All the parameters are rated based on certain quantitative ratios wherein 10 indicates a high score and 1 indicates a low score. The scales have been defined based on field level insights and understanding of the development sector.

Affordability is essential to create access for everyone across the economic pyramid. The target customer at the bottom of the pyramid require the product to be very low cost. In remote rural areas the funds required to purchase any product are generally collected on a monthly basis to avoid the burden of large money involved with one time payment. Therefore, to compare the affordability of different products the upfront capital is split over a suitable payback period and compared with the monthly income of the household.

C_m = Cost per month based on certain defined payback period for the product/service

D_m = Disposable monthly income of the household

$$Affordability\ ratio = C_m / D_m$$

Tata Trusts work in the development sector reveals that around 70% of the household income in remote rural areas is utilized for basic necessities such as food and fuel. The rest of the income is split across education, healthcare transport, communication etc. The scale is based on the assumption that 10% of the total monthly income is the disposable income of the household for purchasing additional products or services, which is considered as the average score that is 7.

Scale	1	2	3	4	5	6	7	8	9	10
Affordability ratio	100%	75%	50%	25%	20%	15%	10%	7%	5%	3%

Scalability in terms of implementation of product or service is a critical parameter. It is required to create an impact by reaching out to large number of individuals across the society. Depending on the product or service the target audience may only be a few hundred thousand, or few million and in some cases, it could reach hundreds of millions. Therefore, for the context of technologies that are to be installed in rural areas in India, scalability ratio can be defined as the ratio of the time required to set-up 1 product to that required to scale to 1 lakh products or installations.

T_1 = Time to install 1 products

T_{lakh} = Time to install 1 lakh products

$$Scalability\ ratio = (T_1/T_{lakh})$$

Ratio value of 1 implies that time to install 1 lakh products is same as installing 1 product and is benchmarked at a scale of 7 which is considered as the average score.

Scale	1	2	3	4	5	6	7	8	9	10
Scalability ratio	0.01	0.015	0.03	0.06	0.12	0.25	0.5	0.75	1	1.2

Sustainability is required in the societal, environmental and financial context. The stakeholder involved with the technology implementation and utilization are the human capital or societal equity. *Societal sustainability* ensures that the stakeholders are benefitted and not exploited or endangered by the technology. The scaling will be done based on the percentage of stakeholders benefitting by the technology. *Environmental sustainability* involves reduction in ecological footprint by managing the consumption of energy and reducing waste as well as treating toxic waste before releasing it in the environment. This could be measured through two different factors- one computing the energy sustainability, which is a ratio of the renewable energy used to the total energy consumed, second the waste sustainability will give a sense of the volume and toxicity of waste generated. *Financial sustainability* of a product is the measure of the operational and maintenance expenditure of using the product or service and comparing it to the revenue or savings generated. In the development sector business model should be financially sustainable in 3-5 years depending on the technology installed.

S_T = Total number of stakeholder involved

S_N = Number of stakeholders who are neutral

S_B = Number of stakeholder that are benefitting by the technology

E_R = Amount of renewable energy consumed in a year

E_T = Total amount of energy consumed

W_T = Total waste generated in one cycle

R_T = Total amount of raw material input into the system

T_f = Toxicity factor

R = Revenue for the duration of 1 year

S = Savings for the duration of 1 year

Opex = Operational costs

$$\textit{Societal Sustainability ratio (SS)} = [S_B/(S_T - S_N)] \times 10$$

$$\textit{Environmental Sustainability ratio (ES)} = [(E_R / E_T) \times 10 + \{1-(W_T/R_T)\} \times 10 + (T_f)]/3$$

$$\textit{Financial Sustainability ratio (FS)} = R / Opex \text{ or } S/Opex$$

$$\textbf{Sustainability ratio} = [SS + ES + FS] /30$$

In case no energy is consumed by the technology the ratio E_R / E_T will be considered as 1, since this would imply maximum environmental sustainability.

Scale	**1**	**3**	**5**	**7**	**10**

Toxicity factor	>80% toxic output	50% toxic waste	30% toxic waste	Within specified standards	Better than standards

Scale	1	2	3	4	5	6	7	8	9	10
Financial Sustainability ratio	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3
Sustainability ratio	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

Universal implies that the product or service is user friendly irrespective of the skill levels of the consumer. Products that can be used by beneficiaries irrespective of their education level or age will have the highest rating. Technologies that could be used by children or senior citizens in rural areas will be scored the highest. As the difficulty of using the product increases the score reduces.

Scale	1	3	5	7	10
People who can use the technology	Expert technicians	Advanced training required for local personnel	Trained local personnel	Basic education till 10^{th} grade	Children/ senior citizens

Rapid in terms of implementation speed is an important criterion for evaluating a technology. In order to achieve accelerated impact creation, speed of action is essential. Based on the technology, geographical specifications and end-user the timelines for product implementation benchmark should be defined. Products time to implement may be compared to the existing solutions implementation timelines.

T_{new} = Time to implement new products after Purchase order (PO) is placed

$T_{existing}$ = Time to implement the existing conventional products after PO is placed

$$Rapid\ ratio = T_{existing} / T_{new}$$

Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rapid ratio	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3

Excellence in technological as well as non-technological innovations such as business model is required for any innovation to succeed. To create large scale impact in the development sector we need technologies that are durable and reliable. Therefore, while evaluating technologies we must make sure that the products perform satisfactorily based on the use-case. One such way of computing the performance capabilities is to compare the technological efficiency of the product with that of the current conventional product. Products that have a higher efficiency would be graded a higher score.

E_{new} = Efficiency of the product being evaluated

$E_{conventional}$ = Efficiency of the conventional product

$$Excellence\ ratio = (E_{new} - E_{conventional}) / E_{conventional}$$

Scale	1	2	3	4	5	6	7	8	9	10
Excellence ratio	-60%	-50%	-40%	-30%	-20%	-10%	0%	20%	40%	60%

Distinctive products or services are the ones that are unique as compared to the existing products. The extent of uniqueness is used to quantify the distinctive factor, which is in turn used to rate the technology. The score is the highest for the completely unique technology and low for already existing technologies.

Scale	**1**	**3**	**5**	**7**	**10**
Distinctive factor	No uniqueness	Functionalities as a combination of existing products	Minor unique aspects with major commonalities	Majorly unique with some common functionality	Completely unique

All the parameters contribute to the final score which will be used to consider the technology as relevant for the consumers. Weightage is assigned to each parameter based on the users and the impact of each parameter on the target consumers.

Parameter	**Weightage (%)**
Affordability	20
Scalability	15
Sustainability	20
Universal	10
Rapid	10
Excellence	20
Distinctive	5

The evaluation framework will be useful when multiple stakeholders rate the products and the normalized score is used to compare the technologies. This will reduce the subjectivity involved in the evaluation process even further.

IV. Analysis:

1. Technology evaluation

The main purpose of a technology is to solve gaps or needs that have been observed in the current system. Remotely located rural areas in India are usually neglected in terms of waste management services. Due to challenges such as geographical constraints, local authorities and waste operators are unable to provide appropriate public services. Thus, proper waste management facilities are observed to be the major challenge in remote rural areas. Wide variety of technologies have been developed in the solid and liquid waste management space. Some of these technologies have been evaluated based on the specific requirements of the target users and locations. The technologies are 1) biogas plants 2) waste plastic to energy plants 2) faecal waste bio-digesters.

	Unit	**Biogas plant**	**Waste plastic to energy**	**Bio-digesters**
1. Affordability				
C_m	₹/household	250-300	100-200	350-400
O_m	₹/household	500-650	50-100	0
D_m	₹/household	5000-7500 [6]		
Affordability factor	%	12-15%	3-5%	5-7%
Rating		6.5	10	9
2. Scalability				
T_1	Months	3-6	3-6	3-6
T_{lakh}	Months	12-18	6-12	12-18
Scalability ration		0.25	0.5	0.25
Rating		6	7	6
3. Sustainability				
S_T	Number	250-300	10,000-11,000	900-1,000
S_B	Number	200-300	9,500-10,000	900-1,000
S_N	Number	50-100	500-1,000	900-1,000
SS		10	10	10
E_R	MWh/Year	0	0	0
E_T	MWh/Year	0	15-20	0
W_T	kg	0	0	0
R_T	kg	2000	200	2500
T_f		7	7	7
ES		9	6	9
RS	₹ lakh/ Year	8-10	8-10	0

Opex	₹ lakh/ Year	3-4	7-8	0
FS		10	9	10
Sustainability ratio		9.5	8	9.5
4. Universal				
P		Basic education	Trained local personnel	Children/ senior citizens
Rating		7	5	10
5. Rapid				
T_{new}	Months	3-6	3-6	3-6
$T_{existing}$	Months	3-6	3-6	3-6
Rapid ratio		1	1	1
Rating		7	7	7
6. Excellence				
E_{new}	%	80-85%	60-70%	85-90%
$E_{conventional}$	%	80%	50%	80%
Excellence ratio		5-10%	20-25%	5-10%
Rating		7.5	8	7.5
7. Distinctive				
Distinctive factor		Minor unique aspects with major commonalities	Minor unique aspects with major commonalities	Majorly unique with some common functionality
Rating		5	5	7
Total Rating		**7.25**	**7.7**	**8.15**

Source: Tata Trusts work in the sector

The final score of the technologies indicates that all the three products have an above average rating and therefore may be considered for implementation. The promising scope of these technologies portrays a huge potential in the solid and liquid waste management space. Additionally, to offset the major challenge of high costs the Government of India has subsidized most of the products to boost the penetration of these technologies in the market.

2. Regulatory enablers

Under SBM (G), assistance for SLWM projects is based on the total number of households within a Gram Panchayat (GP) [1].

Maximum Permissible Funds for SLWM (SBM)	Number of households in the GP
₹ 7 lakh	<150 households
₹ 12 lakh	<300 households
₹ 15 lakh	<500 households
₹ 20 lakh	>500 households

The Ministry has put together certain criteria for selection of technology, which include:

- Availability of space near houses and housing pattern.
- Geophysical condition of the village including topography, soil structure and ground water conditions.
- Sources and pattern of water supply (individual / public).
- Availability of common space in and around the village.
- Economic status and human resources available with the GP.

The Ministry of Drinking Water and Sanitation in association with Tata Trusts held a workshop on Solid and liquid resource management in February 2018, to promote awareness across stakeholders in the space. All these measures imply a promising future for the technologies in the SLWM space and this would lead to increased employment across the sector.

3. Employability evaluation

Technology innovations across the globe are changing the fundamental nature of work. Increased automation through technologies such as robotic process automation, machine learning and artificial intelligence has resulted in higher productivity, increased efficiency and convenience. This shift in the industry has also raised questions about the impact of automation on employment, wages and type of work. These questions lead to formation of views against implementation of technology. However, technologies are extremely diverse and are completely dependent on the problem that is being solved, which can be seen by the example that solid and liquid waste management technologies are completely different from robotic arms installed in manufacturing facilities. Technologies such as biogas plants, waste plastic to oil etc. are expected to generate employment opportunities across the different stages of the product implementation value chain. As the Government of India is majorly focusing on sanitation infrastructure to reduce open defecation across the country, solid and liquid waste management system in rural India appears to be neglected to some extent. A large amount of waste that is being collected requires proper waste disposal mechanism. This gap is expected to develop into a completely new industry with emerging opportunities for wide range of skill sets. The development of SLWM system is expected to involve mobilization of manpower across the value chain of technology adoption, which includes the development, implementation and operation stages.

a. Product development stage

Increased demand of products implies increased employment opportunities in the companies that develop the products. The Government of India has set a target of installing 10GW of Biogas power plants by 2022. Grid connected renewable power target for 2017-18 includes 340 MW bio-power and 10 MW waste to power. Under off-grid renewable system, targets of 15 MW waste to energy, 60 MW biomass non-bagasse cogeneration, 7.50 MW biomass gasifiers, and 1.1 lakh family size biogas plants have been set for 2017-18. Against this target, 0.15 lakh biogas plants installations have been achieved, which implies a huge gap in the existing supply (Ministry of New and Renewable Energy (MNRE), India 2014) [7]. Technologies such as biogas plants, waste plastic to oil have not penetrated the rural India market based on the difference between the target and the achieved numbers. As the installation of these technologies increases, the demand of the products will increase and thus the manpower required to develop the products is expected to increase tremendously.

a. Implementation stage

Fabricating a product does not necessarily imply that it will benefit the end user. Unless the implementation is done properly the work in not complete. This stage may include various steps such as transportation of the product, civil work to install the product, training the concerned people etc. Each step requires manpower, which could be employed from the local areas to reduce costs. Irrespective of the origin of manpower, large employment opportunity is generated during the implementation stage.

b. Operational phase

Once the implementation of the technology is complete it is extremely essential to operate and maintain the product throughout its lifespan. Monitoring the working of the product is important to ensure good performance and maximum output. Each biogas plant or waste plastic to oil plant will require at least 2 operators. Also, the raw material needed for working of the plant should be collected and segregated based on the technology. The role of the informal sector is very important in India and ideally must be integrated with the formal system. Huge number of people in India earn their livelihood by collecting and selling recyclable waste and a large network of these informal workers exists. They are mostly involved in labour-intensive, small scale, majorly unregulated and unregistered low-technology manufacturing or services. (Kumar S et al, 2017) [4] Numerous people in India are dependent on waste picking for their source of income. A study of six cities in India found that waste pickers recovered approximately 20% of waste, with 80,000 people involved in recycling approximately three million tonnes. (Annepu RK. 2012) [8] Currently, mostly the recyclable waste is collected due to the value attached with it, however, once these technologies such as biogas plants and waste plastic to oil are implemented the increased demand for biodegradable waste and non-recyclable plastic waste will lead to increased opportunities for the informal workers. Upgradation of the current work has also been observed in places such as Bangalore where companies are trying to formalize the waste management sector. The transition of focus from waste collection and dumping it in landfills to waste reduction, segregation, recycling and recovery is expected to create significant job opportunities.

V. Conclusion

The current solid waste management ecosystem requires focused efforts to the use waste as a resource with increased reuse, recovery and recycling. The waste management sector needs profitable businesses with the regulators defining clear performance requirements. Technologies are rapidly being development in the solid and liquid waste management space and therefore finding the suitable technology for a gap that exists in the waste management system at the bottom of the pyramid is possible. However, the most important part is to study the gaps and stakeholder's situation and then design a solution based on multiple parameters. The combined efforts of the Government of India and informed stakeholder is expected to lead to immense improvements in the solid and liquid waste management space in India in the coming decade. Increased awareness of the potential in the solid management sector is expected to indirectly increase employment across the value chain of the sector.

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