Overview of Municipal Solid Waste Generation, Composition, and Management in India

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Abstract: India has drawn the world's attention due to the high-paced growth of industrialization, urbanization, and population. However, another aspect of higher economic development has resulted in increased waste generation and consumption of natural resources, and hence ecological degradation and pollution. As awareness increases of the detrimental effects of currently used waste disposal methods on the environment, accountability is needed for an effective waste management system. This paper presents the existing situation of municipal solid waste (MSW) generation, composition, management, and problems associated with it in Indian cities. Statistically, urban India produced around 62 Mt of solid waste (450 g/capita/day) in 2015. Approximately 82% of MSW was collected and the remaining 18% was litter. The waste treated was only 28% of the collected waste, and the remaining 72% was openly dumped. Waste collection efficiency ranges between 70% and 95% in major metropolitan cities, whereas in several smaller cities it is below 50%. Most urban local bodies (ULBs) are unable to manage such a large amount of solid waste due to financial debilities and inadequate infrastructure. Source segregation of waste, doorstep collection, options for recycling and reuse, technologies for treatment, land availability, and disposal competence are a few of the prime challenges. Addressing these challenges, this paper discusses the current government's policies, financial supports, and incentives for solid waste management (SWM), as well as gaps and suggestions of current SWM rules. This paper also addresses a comparative view of MSW management in different countries and adoption of waste processing technologies for a particular place in India. This study can assist decision makers, planners, municipal authorities and researchers to create a more efficient plan for the current status of, challenges of, and barriers to SWM in India. **DOI: 10.1061/(ASCE)EE.1943-7870.0001490.**

Author keywords: Municipal solid waste (MSW); Solid waste management (SWM); Generation rate; Municipal solid waste management (MSWM); Waste management; Waste to energy; India.

Introduction

India is one of the fastest developing countries in the world. India's economy has overtaken the UK for the first time in more than 100 years. India is the sixth-largest economy in terms of gross domestic product (GDP) and the third-largest economy in terms of purchasing power parity (PPP) (Gramer 2016). At 7.6% of growth rate in fiscal year 2016, India is now the fastest-developing economy and second most populous nation in the world. It is expected that the population of India will increase from 1,029 million to 1,400 million during the period 2001–2026, an increase of 36% in 26 years, resulting in an annual population growth rate of 3.35% (Gupta and Arora 2016; Sahu et al. 2014).

The level of urbanization in India increased from 27.8% to 31.6% during the period 2001–2011, and it is expected that up to 50% of the Indian population will live in cities in the next 10 years (Devi et al. 2016; Gupta and Arora 2016). The high rate of population growth, fewer opportunities in rural areas, and a shift from the low-paying agriculture sector to higher-paying urban occupations are mostly responsible for urbanization (Vij 2012). According to the census of 2011, the Indian population was 1,027 million, of which 377 million were urban people (around 31% of the total population) living in 7,936 towns/cities. This is an effect of India rapidly shifting from an agricultural-based nation to an industrial and service-oriented country (Joshi and Ahmed 2016). The total number of towns in the nation increased from 5,161 to 7,936 from 2001 to 2011, an increase of 2,775 within a decade (CPCB 2016). In the future, it is anticipated that India's municipal solid waste (MSW) amount will increase significantly, because the country is striving to attain an industrialized-nation status by the year 2020 (Gidde et al. 2008; Gupta and Arora 2016; Sahu et al. 2014; Sharholy et al. 2008).

Rapid industrialization, population explosion, and economic growth in India led to the migration of people from villages to cities, generating thousands of metric tons of MSW daily in terms of kg/capita/day, as a consequence of improved lifestyle and social status (Devi et al. 2016; Kumar et al. 2009). Municipal solid waste management (MSWM) through suitable waste management technologies greatly depends upon the composition of the MSW. A sustainable waste management scenario is a very complicated task in India because of the changing waste composition and varying waste generation rates. The Impact of ineffective waste management could be local, regional, or global, as can be seen in climate change and environmental degradation (Agamuthu et al. 2007).

Landfilling is an integral part of any planned MSWM system, and a final place of MSW disposal after considering all available MSWM techniques (Aljaradin and Persson 2012; Annepu 2012; Devi et al. 2016; Wilson et al. 2012). Landfilling is the most usual MSW disposal practice in the world, probably because it is the most economical and does not require skilled workers (Chen et al. 2016).

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Unsanitary landfilling poses a huge threat to the environment in the form of CO_2, CH_4, and leachate production or greenhouse gas (GHG) leakage (Kalyani and Pandey 2014). Methane is the second most abundant greenhouse gas, and is responsible for 14% of global GHG emissions and, in turn, climate change (GMI 2011, 2013; ITA 2016; Wanichpongpan and Gheewala 2007). Methane generates 21 times more global warming than does CO_2; 1 t methane is equivalent to 21 t CO_2 over a long duration, whereas during the first year of release, CH_4 is 71 times more powerful than CO_2 (Annepu 2012; Chien Bong et al. 2017; ERC 2015; Fei et al. 2016; GMI 2011, 2013; MEF 2010; Pariatamby et al. 2015; World Bank 2005; Unnikrishnan and Singh 2010; Zhu et al. 2008). In 2012, the United States disposed of 135 Mt in landfills, or 53.8% of the total generated MSW (USEPA 2014), and several landfills have either reached or nearly reached their capacity (Khan et al. 2016).

As of 2015, 18 nations in the EU banned the landfilling of all recyclable waste by 2025, and many countries (e.g., the United Kingdom, Poland, and France) inflicted taxes on landfilling to make it a less attractive option for waste disposal (WEC 2016). Nevertheless, more than 80 Mt of municipal waste was landfilled in Europe in 2013 (Ecoprog CEWEP 2014). Methane emissions from landfilling decreased from 179.6 Mt CO_2 equivalents (eq) in 1990 to 148.0 Mt CO_2 eq in 2014, and the amount of landfill gas collected and combusted increased. In addition, the number of active MSW landfills in the United States decreased over 20 years, from about 6,326 in 1990 to about 2,000 in 2010 (USEPA 2016). Thus, it is necessary to discover and implement more ecofriendly MSWM techniques to divert the MSW from landfills.

This paper provides a comprehensive review of the current situation of MSW generation, composition, and management in Indian cities to deal with a huge amount of MSW and associated problems. Some important highlights of SWM policies, programs, rules, gaps, and suggestions are addressed. Some technological options are identified for waste treatment based on city population size, waste generation rate, and amount of biodegradable fraction of waste. This paper is partitioned into four portions. Section "MSW Generation and Composition" provides a brief overview of solid waste quantification and composition in India. Section "MSW Management in India: Status, Challenges, and Suggestions" discusses the existing situation of MSW management, policies, rules, incentives and financial supports in India. A comparative view of MSWM among developed and developing countries are also presented in this section. Section "Solid Waste Management Revised Rules 2016, Gaps, and Suggestions" gives an in-depth view of SWM revised rules 2016, as well as limitations of these rules and some suggestions for improvement. Section "Technological Options for Treatment of MSW and Selection" discusses integrated technological options to manage MSW in India cities. This section also focuses on some major challenges in the implementation of MSWM in India and gives some recommendations to improve it.

MSW Generation and Composition

According to the Central Pollution Control Board (CPCB 2016), urban India generated 62 Mt of MSW in 2015, or 169,864 t/day or 450 g/capita/day. Approximately 82% (50 Mt) of MSW was collected, and the remaining 18% (12 Mt) consisted of litter. Waste treated was only 28% (14 Mt) of the collected waste, and the remaining 72% (36 Mt) was openly dumped (CPCB 2016; MNRE 2016). In 1947, 2001, and 2011, the total urban solid waste was 6, 31, and 48 Mt, respectively (Rawat et al. 2013; Singh et al. 2011). At this rate, the total urban MSW will be 165 Mt by 2030, 230 Mt by 2041, and 436 Mt by 2050 (Annepu 2012; WtR 2014). The CPCB report indicated that the solid waste production rate lies between 200 and 300 g/capita/day in small towns/cities with populations less than 0.2 million. It is usually 300–350, 350–400, and 400–600 g/capita/day in cities with population ranges of 200,000–500,000, 500,000–1 million, and above 1 million, respectively (CPCB 2016; CPHEEO 2016a; MNRE 2016). Table 1 lists the impact of population growth on solid waste generation until 2041. The total waste generated in 366 Indian cities was 31.6 Mt in 2001 and 47.3 Mt in 2011. It has been estimated that these 366 cities will produce 161 Mt of MSW in 2041, or roughly 5 times more in 4 decades. At this rate, the total urban MSW will be 165 Mt by 2030, 230 Mt by 2041, and 436 Mt by 2050 (Annepu 2012; WtR 2014).

Based on the business-as-usual (BAU) scenario, the waste generated in India in 2001 needed 240 km^2, or 50% of the area of Mumbai city, for unsanitary disposal, and the area required by the end of 2011 was 380 km^2, or 90% of the area of Chennai city (the fourth-largest city in India areawise). It is estimated that waste generated by 2021 will need 590 km^2, which is nearly equal to the area of Hyderabad (the largest city in India areawise). According to the Ministry of Finance, if MSW is not properly handled, the requirement of land for solid waste disposal will be more than 1,400 km^2, by the end of the year, equivalent to the area of Hyderabad, Mumbai, and Chennai jointly (Table 2) (Annepu 2012; Kalyani and Pandey 2014).

MSW composition in India is approximately 40%–60% compostable, 30%–50% inert, and 10%–30% recyclable. According to the National Environmental Engineering Research Institute (NEERI), Indian waste consists of 0.64% ± 0.8% nitrogen, 0.67% ± 0.15% phosphorus, and 0.68% ± 0.15% potassium, and has a 26 ± 5C:N ratio (Gupta et al. 2015; Joshi and Ahmed 2016). Changes in the physical structure of Indian MSW over time are listed in Table 3. The data show that during 1996–2011 the waste composition changed rapidly and there was more than a 280% and 1,200% increase in paper and plastic waste, respectively. The best efforts to use compostable and combustible waste were through the

Table 1. Calculated and expected population growth and national waste generation rate

Year	Urban population (million)	Per capita waste generation rate (kg/day)	National waste generation rate (million tons/year)
2001	197.3	0.439	31.63
2011	260.1	0.498	47.3
2021	342.8	0.569	71.15
2031	451.8	0.649	107.01
2036	518.6	0.693	131.24
2041	595.4	0.741	160.96

Sources: Data from Annepu (2012); WtR (2014).

Table 2. Area of land required for unsanitary disposal of municipal solid waste generated in India

Years	Area of land occupied/required for MSW disposal (km^2)	City equivalents (areawise)
1947–2001	240	50% of Mumbai
1947–2011	380	90% of Chennai
1947–2021	590	Hyderabad
2009–2047	1,400	Hyderabad + Mumbai + Chennai

Sources: Data from Annepu (2012); Kalyani and Pandey (2014).

Table 3. Change in MSW composition over time

Year	MSW composition (%)							
	Biodegradable	Paper	Plastics/rubber	Metal	Glass	Rags	Others	Inerts
1996	42.21	3.63	0.6	0.49	0.6	Nil	Nil	45.13
2005	47.43	8.13	9.22	0.5	1.01	4.49	4.016	25.16
2011	52.32	13.8	7.89	1.49	0.93	1	—	22.57

Sources: Data from Joshi and Ahmed (2016); PC (2014); Zhu et al. (2008).

adoption of compostable and waste-to-energy (WtE) technologies, respectively.

Based on the Earth Engineering Center (EEC 2012), regional variations of MSW composition are presented in Table 4. Metropolitan cities of India are the main source of urban waste (around 40%), followed by North India, South India, West India, and East India. On average, the major component of urban MSW is organic matter (51%); recyclables are 17.5%, and the remaining 31% is inactive waste. Urban MSW average moisture content is 47% and the calorific value is 1,751 kcal/kg. This composition was recorded at the dumping sites of MSW, so the real percentage of recycled waste in India is not known, because unofficial picking of waste is not considered in the composition. If informally collected waste is taken into account, it will definitely change the composition of MSW significantly, and help in estimating the actual waste generated (Annepu 2012).

MSW Management in India: Status, Challenges, and Suggestions

The primary motive of MSWM strategies is to address the health, environmental, aesthetic, land-use, resource, and economic concerns related to the improper disposal of waste (Ferronato et al. 2018; Marshall and Farahbakhsh 2013). Nevertheless, in Indian cities, MSW is disposed of unscientifically in low-lying areas or open dumps without taking proper precautions or operational controls, which has adverse impacts on all components of the environment and human health (Agarwal et al. 2016; Alam and Kulkarni 2016; Bundela et al. 2010; Devi et al. 2016; Gidde et al. 2008; Gupta and Arora 2016; Kalyani and Pandey 2014; Kaushal et al. 2012; Kumar and Samadder 2017; Kumar 2005; Mani and Singh 2016; MEF 2010; Narayana 2009; P.U. Asnan 2006; Rajput et al. 2009; Sahu et al. 2014; Sharholy et al. 2008; Unnikrishnan and Singh 2010; Vij 2012; Zhu et al. 2008). MSWM in India is regulated by the Solid Waste Management Rules, 2016. These rules state that all municipal authorities or ULBs are answerable for generation, on-site storage, collection, transportation, processing, and treatment of MSW in an ecologically congruous way with due thought to the standards of economy, energy, aesthetics, and preservation (Mani and Singh 2016; Sastry 2010). However, in most Indian cities, the MSWM system consists of only four activities, i.e., waste generation, collection, transportation, and disposal (Bundela et al. 2010; Gidde et al. 2008; Gupta and Arora 2016; Kaushal et al. 2012; Sahu et al. 2014; Sharholy et al. 2008). ULBs spend INR 500–INR 1,500/Mt (1 US$ = 67 INR) on SWM, 60–70% of which is spent on collection, 20%–30% of which is spent on transport, and less than 5% of which is spent on the final treatment of waste, which shows that barely any attention is given to waste disposal (Annepu 2012; CPHEEO 2016b; MNRE 2016; Tushar et al. 2016). Poor collection and inadequate transportation are responsible for the accumulation of MSW in every nook and cranny of the cities (Alam and Kulkarni 2016; Bundela et al. 2010; Gidde et al. 2008; Gupta and Arora 2016; Gupta et al. 2015; Kaushal et al. 2012; Sahu et al. 2014; Sharholy et al. 2008).

MSW collection efficiency for selected Indian states is shown in Fig. 1, which is based on the data provided by Ministry of New and Renewable Energy (MNRE) for 2015 and by CPCB for 2010. Most Indian states are unable to collect the total quantity of generated waste. The waste collection efficiency in India ranges between 70% and 100% in major metropolitan cities, whereas in several smaller cities it is below 50%. The treated quantity of generated waste was only 28% in 2015, and in point of fact, nothing is scientifically managed in sanitary landfills. The comparative quantity of MSW generated by different Indian states in 2000, 2010, and 2015 is listed in Table 5. In 2015, Maharashtra generated the largest quantity of MSW (14,900 Mt/day) among all states. The waste collection efficiency was 85% and energy recovery potential 62 MW. Table 5 also indicates the amount of waste collected and treated in 2010 and 2015 by Indian states.

Indian ULBs are confronting challenges in giving a successful and energetic MSWM framework to society. Most ULBs are unable to collect and treat such colossal quantities of solid waste due to the lack of a suitable collection system, transportation system, options for recycling and reuse, treatment availability, disposal capacity, technical expertise, financial resources, and labor availability (Bundela et al. 2010; Gupta and Arora 2016; Gupta et al. 2015; Kaushal et al. 2012; Periathamby et al. 2012; Sahu et al. 2014; Sharholy et al. 2008; Upadhyay et al. 2012). The difficulties in providing the desired level of public service are often attributed to municipalities using a major portion of their financial resources for MSW collection, with very little left thereafter for its management. In addition, political, sociocultural, and institutional factors significantly affect MSWM plans (Devi et al. 2016). Solid waste segregation, collection, transportation, treatment, and scientific disposal are largely inadequate, leading to environmental degradation and poor quality of life (Annepu 2012; Zhu et al. 2008). Therefore, MSW management is one of the most challenging environmental issues in India (Archana et al. 2014; Bundela et al. 2010; Devi et al. 2016; Gupta and Arora 2016; Kaushal et al. 2012; Kolekar et al. 2016; Korai et al. 2017; Kumar et al. 2009; Sahu et al. 2014).

Table 4. Regional variation of MSW composition in India

Region/City	MSW (Mt/day)	Compostable (%)	Recyclables (%)	Inerts (%)	Moisture (%)	Calorific value (kcal/kg)
Metros	51,402	50.89	16.28	32.82	46	1,523
Other cities	2,723	51.91	19.23	28.86	49	2,084
East India	380	50.41	21.44	28.15	46	2,341
North India	6,835	52.38	16.78	30.85	49	1,623
South India	2,343	53.41	17.02	29.57	51	1,827
West India	380	50.41	21.44	28.15	46	2,341
Overall urban India	130,000	51.3	17.48	31.21	47	1,751

Sources: Data from Annepu (2012); Rana et al. (2015).

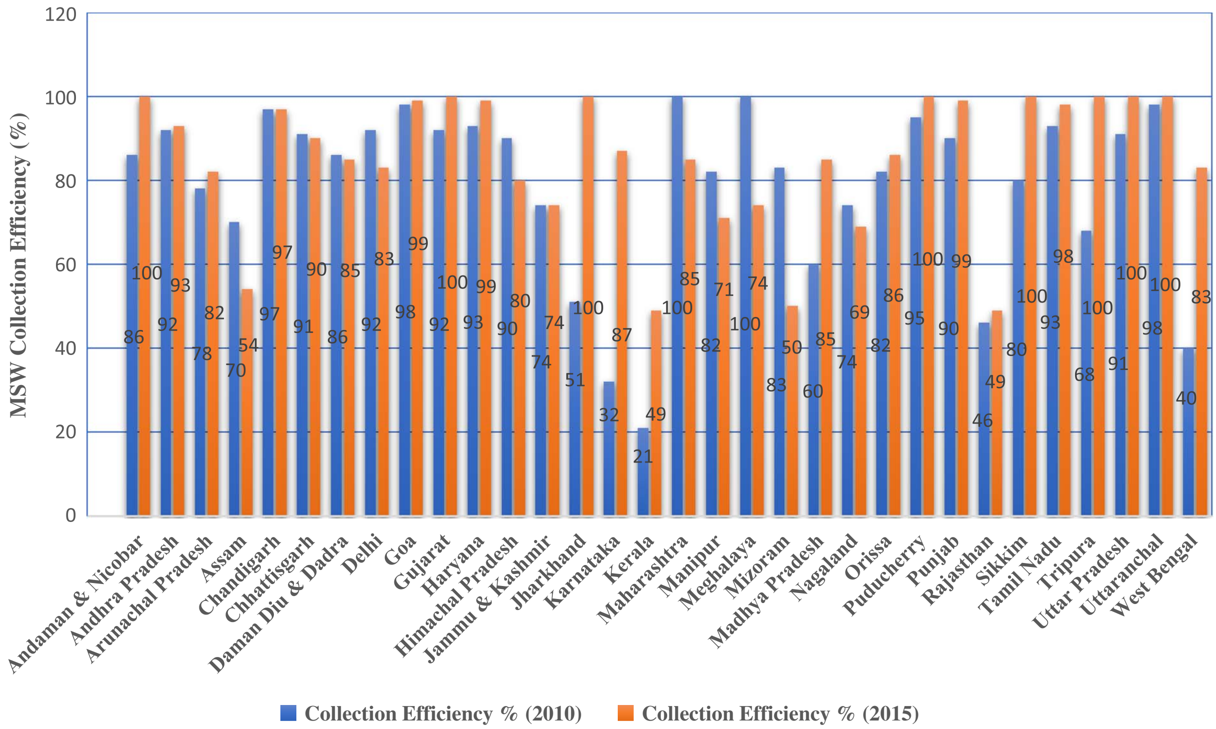

Fig. 1. MSW collection efficiency of selected Indian states. (Data from CPCB 2013; MNRE 2016.)

The current status of MSWM in India is presented in Table 6. A door-to-door waste collection system has been introduced in 18 states only, whereas 11 others are still waiting for this facility. Only five states are working on source segregation of waste, and others are still dumping mixed waste at the dump sites. There are 95 sanitary landfill sites in the country, and a total of 1,285 sites have been identified for construction of new landfill sites by 242 ULBs. Around 553 ULBs operate composting/vermicomposting facilities, and 173 ULBs are working on it. In addition, 645 small-capacity biogas plants are operated, of which 600 are in Kerala state. So far, only six WtE plants are under operation, and the remaining five have been shut down due to lack of technical expertise and high moisture content of the waste (or getting poor quality of waste to make fuel) (CPCB 2016).

According to the report of the Task Force Planning Commission, the unused combustible solid waste including residual derived fuel (RDF) has a capacity of 439 MW, 1.3 million m^3 production of biogas per day or 72 MW of electricity through biogas, and 5.4 Mt compost per year to boost agriculture sector (PC 2014). Due to the Swachh Bharat Mission (SBM), the WtE sector has attracted new interest in the last few years, although the government's heavy focus on solar power has influenced the development of biomass energy sectors alongside WtE (Zafar 2016).

According to MNRE, the present status of waste generated in India is capable of generating about 500 MW of electricity, which can be increased to 1,075 MW by 2031 and further to 2,780 MW by 2050 by removing barriers in the Indian WtE sector. Statewise energy recovery potential from generated MSW is presented in Fig. 2 (MNRE 2016). As reported by the Ministry of Urban Development (MoUD), there are 7 functional plants (92.4 MW), 4 nonfunctional plants (40.6 MW), 31 plants under construction (241.8 MW), and 21 plants under tendering (163.5 MW) in the country. Total power generation capacity of all existing and planned WtE plants in India is 538.3 MW. The functional and nonfunctional plants are listed in Table 7 (MoUD 2016). At the direction of the Supreme Court, MNRE has taken up five WtE plant projects with an aggregate capacity of 57 MW for the Programme on Energy from Urban, Industrial, and Agricultural Waste, of which two plants are operating and the remaining three projects could not be completed due to the paucity of funds and some technical reasons (MNRE 2016).

There are 45 small operational plants in India for compost generation, with an aggregate capacity of 0.7 Mt/year. Currently, these plants are producing only 0.15 Mt per year due to market limitations. A further 37 cities have entered into agreements with private partners with the potential to produce 0.725 Mt of compost per year (MoUD 2016). According to MNRE, 4.3 million family-type biogas plants have been constructed in India at the household, community, and organization levels. More than 150 small plants with a capacity of 0.5–50 Mt/day are running in Maharashtra state and some other states. So far, large-scale biogas plants have not been successful in India, although these plants have been fruitful in some other nations. The failure of such plants is not related to the basic technology; it is more due to insufficient knowledge of the process and planning capability and due to the imbalance between the expectations of the concessioner and the consignee with respect to quantity and quality of MSW supply (CPHEEO 2016b; MNRE 2016).

Comparative View of MSWM in Developed and Developing Countries

A broad review of MSW generation and management for different countries in 2016 is given in Table 8, including both developing and developed countries. Countries are grouped based on their gross national income, including high-income countries (HICs), e.g., France, Germany, Spain, the United Kingdom, the United States, and Italy; upper-middle-income countries (UMICs), e.g., Brazil, Mexico, Poland, Lithuania, and Latvia; lower-middle-income countries (LMICs), e.g., Algeria, China, India, Jordan, Turkey, Bulgaria, and Thailand; and lower-income countries (LICs),

Table 5. Statewise MSW statistics in India and energy recovery potential

		2000	2010			2015			
Number	State/Union territories	MSW generated (Mt/day)	MSW generated (Mt/day)	MSW collected (Mt/day)	MSW treated (Mt/day)	MSW generated (Mt/day)	MSW collected (Mt/day)	MSW treated (Mt/day)	Energy recovery potential (MW)
1	Andaman & Nicobar	—	50	43	0	70	70	5	1
2	Andhra Pradesh	4,376	11,500	10,655	3,656	11,500	10,656	9,418	43
3	Arunachal Pradesh	—	94	N/A	0	180	82	74	1
4	Assam	285	1,146	807	73	650	350	100	2
5	Bihar	1,819	1,670	1,670	0	1,670	N/A	N/A	6
6	Chandigarh	200	380	370	300	340	330	250	1
7	Chhattisgarh	—	1,167	1,069	250	1,896	1,704	168	7
8	Daman Diu & Dadra	—	41	N/A	0	85	85	0	1
9	Delhi	4,000	7,384	6,796	1,927	8,390	7,000	4,150	28
10	Goa	—	193	N/A	N/A	183	182	182	1
11	Gujarat	—	7,379	6,744	873	9,227	9,227	1,354	31
12	Haryana	4,232	537	N/A	0	3,490	3,440	570	13
13	Himachal Pradesh	725	304	275	153	300	240	150	6
14	Jammu & Kashmir	35	1,792	1,322	320	1,792	1,322	320	7
15	Jharkhand	—	1,710	869	50	3,570	3,570	65	17
16	Karnataka	3,278	6,500	2,100	2,100	8,784	7,602	2,000	35
17	Kerala	1,298	8,338	1,739	4	1,576	776	470	6
18	Lakshadweep	—	21	21	4.2	21	—	—	0
19	Maharashtra	9,099	19,204	19,204	2,080	26,820	14,900	4,700	62
20	Manipur	40	113	93	3	176	125	—	1
21	Meghalaya	35	285	238	100	268	199	98	1
22	Mizoram	46	4,742	3,122	0	552	276	0	2
23	Madhya Pradesh	2,684	4,500	2,700	975	5,079	4,298	802	19
24	Nagaland	—	188	140		270	186	18	1
25	Orissa	655	2,239	1,837	33	2,460	2,107	30	9
26	Puducherry	69	380	N/A	0	495	495	0	2
27	Punjab	1,266	2,794	N/A	0	3,900	3,853	32	15
28	Rajasthan	1,966	5,037	N/A	0	5,037	2,491	490	19
29	Sikkim	—	40	32	32	49	49	0.3	0
30	Tamil Nadu	5,403	12,504	11,626	603	14,532	14,234	1,607	53
31	Tripura	33	360	246	40	407	407	0	1
32	Uttar Pradesh	5,960	11,585	10,563	0	19,180	19,180	5,197	72
33	Uttaranchal	—	752	N/A	0	1,013	1,011	0	5
34	West Bengal	4,621	12,557	5,054	607	8,674	7,196	1,415	32
Total		104,250	127,485	89,335	14,183	142,566	117,643	33,665	500

Sources: Data from CPCB (2013, 2015); MNRE (2016).

e.g., Bangladesh, Ghana, Nepal, Pakistan, Nigeria, Uganda, and Zimbabwe. Table 8 shows that there is a positive correlation between the quantity of waste treated and income levels of a country. In HICs, most of the waste is collected and treated in a scientific way, whereas LICs are still working on open dumping. The concept of the Five Rs approach is effectively adopted in HICs, whereas LICs and LMICs are still fighting for 100% collection efficiency of MSW. Now, HICs are focusing more on reducing and recycling, instead of landfilling and incineration of MSW, whereas open dumping and sanitary landfilling are the most preferable options in LICs and LMICs. The total percentage of recycling and composting is highest in Germany (66.2%), followed by Nepal (55%), Lithuania (48%), Italy (45.1%), the United Kingdom (44.5%), Poland (44%), France (41.7%), the United States (34.6%), Bulgaria (31.8%), and Spain (29.7%).

Table 6. Current status of MSW management in India

Parameter	Status
House-to-house collection of waste	18 states (of 29)
Segregation of waste at the source	5 states (of 29)
Number of unsanitary landfill sites identified	1,285
Number of sanitary landfill sites constructed	95
Number of ULBs operating compost/ vermicompost facilities	553
Number of ULBs under construction compost/ vermicompost facilities	173
Number of operating pipe composting facilities	7,000
Number of operating RDF facilities	12
Number of operating biogas plants	645
Number of energy generation plants	11 (6 operational)
Waste generation	143,449 Mt/day
Waste collection	117,644 Mt/day (82%)
Waste treated	32,871 Mt/day (28%)

Source: Data from CPCB (2016).

After investing millions of dollars on MSWM, Indian performance is still very poor among LMIC, UMIC, and HIC countries. The waste collection efficiency of India (82%) is the lowest in the LMIC group, behind that of China (90%), Turkey (84%), Thailand (100%), Bulgaria (94%), Jordan (90%), and Algeria (92%). The quantity of waste treated in India is only 28%, whereas it is 92% in China, 100% in Turkey and Bulgaria, 55% in Jordan, and 46% in Thailand. Algeria, Pakistan, India, and Thailand have higher percentages of open and illegal waste dumping: 96%, 90%, 72%, and 54%, respectively. As a large waste-generating country, India needs to focus its MSWM heavily on high waste recycling, composting,

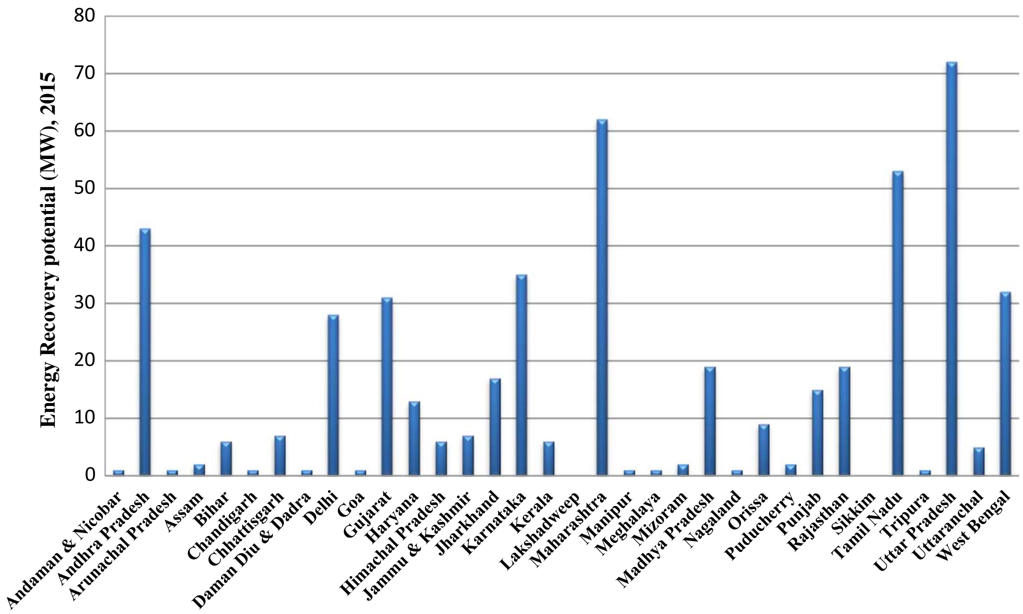

Fig. 2. Statewise energy recovery potential of generated MSW. (Data from MNRE 2016.)

Table 7. List of functional and nonfunctional waste treatment plants in India

Number	City/town	Waste intake (Mt/day)	Technology	Power generation capacity (Mw)	Current status
1	Okhla, Delhi	2,000	Incineration	16	Operational
2	Pune, Maharashtra	700	Gasification/pyrolysis	10	Operational
3	Solapur, Maharashtra	400	Anaerobic digestion	3	Operational
4	Karimnagar, Telangana	1,100	RDF-based	12	Operational
5	Ghazipur, Delhi	1,300	Incineration	16	Operational
6	Jabalpur, Madhya Pradesh	600	Incineration	11.4	Operational
7	Narela-Bawana, Delhi	1,300	Incineration	24	Operational
8	Kanpur, Utter Pradesh	1,500	RDF-based	15	Nonoperational
9	Elikkta, Aandhra Pradesh	200	RDF-based	6.6	Nonoperational
10	Vijayawada, Andhra Pradesh	225	Incineration	6	Nonoperational
11	Rajahmundry, Andhra Pradesh	1,074	Incineration	13	Nonoperational

Source: Data from MNRE (2016).

and anabolic digestion to reduce the load on waste disposal through incineration and sanitary landfilling.

Government Incentives and Financial Support for SWM

The WtE sector of India began in 1987, and it is looking for a successful role model even after investing millions of dollars. Many ambitious WtE projects have been set up in different parts of the country or are under construction, and hopefully, things will turn bright in coming years. The overall initiatives and financial support related to SWM in India are summarized in Table 9. In order to advance SWM in India, the central government started many programs, missions, schemes, and policies. The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was a massive city-modernization mission launched in December 2005 for 7 years (2005–2012) which aimed to create economically productive, efficient, equitable, and responsive cities. Urban Infrastructure and Governance (UIG) and Basic Services to Urban Poor (BSUP) were 2 submissions of this program for 65 mission cities. Nonmission cities had two subschemes, the Urban Infrastructure Development Scheme for Small and Medium Towns (UIDSSMT) and the Integrated Housing and Slum Development Programme (IHSDP). The Government of India (GOI) allocated of INR 660,000 million for this program over the 7-year period, of which INR 315,000 million was for 367 projects in UIG, INR 163,000 million was for 213 projects in BSUP, INR 114,000 million was for 29 projects in UIDSSMT, and INR 68,000 million was for 33 projects in IHSDP. An award of INR 25,000 million was also provided by the 12th Finance Commission (FC) to all ULBs with Class I cities for SWM in this period (Rathore et al. 2010). A significant motivating force of INR 50,000 was prescribed by the 13th FC for grid-connected renewable power based on MSWM unforeseen circumstances for the accomplishments of the states in renewable energy competence from 2010 to 2014 (Mani and Singh 2016).

One of the important declarations of the Indian government in the development agenda is the Swachh Bharat Mission. This is a national campaign, which includes 4,941 statutory cities and towns of the country, to clean the streets, roads, and infrastructure, and to implement 100% SWM in 1,000 cities by 2019. It was officially launched on October 2, 2014, with the aim to accomplish the vision of Clean India by October 2, 2019, the 150th anniversary of Mahatma Gandhi's birth. The estimated cost of this mission is over INR 620,000 million for urban regions (SBM-Us) and INR 1,004,470 million for rural regions (SBM-Gs). A grant of INR 146,230 million was allocated for a 5-year period, i.e., 2014–2019, by the Indian Government for SBM-Us, of which INR 73,660 million

Table 8. Comparison of MSW quantification and management in different countries

Country	Income level	Waste generated (1,000 t/year)	Waste generated (kg/capita/day)	Collection efficiency (%)	Disposal methods of collected MSW (%)							Reference
					Open dumping	Sanitary landfilling	Composting	Recycling	Incineration	Others	Total treated waste	
Brazil (2015)	UMIC	79,900	1.07	91	41.3	58.7	—	—	—	0	58.7	Alfaia et al. (2017)
Mexico (2016)	UMIC	39,326	N/A	N/A	—	97	—	3	—	—	100	Antonio et al. (2017)
Poland (2016)	UMIC	11,654	0.84	84	—	36.5	16.2	27.8	19.4	—	100	Eurostat (2018)
Lithuania (2016)	UMIC	1,272	1.21	94	—	29.8	23.5	24.5	17.4	4.78	100	Eurostat (2018)
Latvia (2016)	UMIC	802	1.12	90	—	64.3	10	15	0	10.5	100	Eurostat (2018)
China (2014)	LMIC	178,100	0.65	90	8.12	60.2	—	—	29.8	1.79	91.8	Mian et al. (2016)
India (2015)	LMIC	62,000	0.45	82	72	—	—	—	—	28	28	MNRE (2016)
Turkey (2010)	LMIC	33,763	1.11	84	—	84.4	0.43	8.72	0	—	100	Bakas (2013)
Thailand (2015)	LMIC	26,850	1.13	100	54	—	—	14.5	—	31.5	46	Yukalang et al. (2017)
Bulgaria (2012)	LMIC	2,881	1.12	94	—	64.2	9.12	22.7	3.78	0.13	100	Eurostat (2018)
Jordan (2014)	LMIC	2,007	0.9	90	45	48	—	7	—	—	55	Saidan et al. (2017)
Algeria (2015)	LMIC	164	0.93	92	96	1	1	2	N/A	N/A	4	Kouloughli and Kanfoud (2017)
Pakistan (2014)	LIC	25,915	0.84	60	90	N/A	N/A	N/A	N/A	N/A	N/A	Korai et al. (2017)
Nigeria (2009)	LIC	25,000	0.55	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Ogunjuyigbe et al. (2017)
Bangladesh (2012)	LIC	22,980	0.41	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nasrin (2016)
Ghana (2010)	LIC	4,640	0.47	85	26	2	—	—	19	53	100	World Bank (2012)
Zimbabwe (2015)	LIC	1,399	0.53	76	91	—	2	5	2	—	9	Dzinotizei (2016)
Nepal (2012)	LIC	524	0.31	62	8	37	30	25	—	—	92	ADB (2013)
Uganda (2012)	LIC	430	0.34	39	—	100	—	—	—	—	100	Scarlat et al. (2015)
France (2016)	HIC	34,143	1.4	100	—	22.4	18.3	23.4	35.9	—	100	Eurostat (2018)
Germany (2016)	HIC	51,633	1.7	100	—	1.43	18.02	48.2	31.2	—	98.81	Eurostat (2018)
Italy (2016)	HIC	30,117	1.36	100	—	24.7	19	26.1	19.5	10.7	100	Eurostat (2018)
UK (2016)	HIC	31,663	1.32	100	—	18.8	16.97	27.5	34.6	—	97.91	Eurostat (2018)
US (2014)	HIC	250,400	2.01	100	—	52.6	—	34.6	12.8	—	100	USEPA (2014)
Spain (2016)	HIC	20,585	1.21	100	—	56.7	11.5	18.2	13.6	—	100	Eurostat (2018)

Table 9. India's SWM acts, policies, rules, programs, and financial supports

Category	Year	Acts/policies/rules/programs/financial supports
Acts and laws	1860	Indian Penal Code, 1860: Solid waste management comes under Chapter XIV of The Indian Penal Code, 1860, because it is considered an offence affecting the public health, safety, convenience, decency, and morals.
	1974	The Water Act (Prevention and Control of Pollution), 1974: This Act deals with protection and control of water pollution in the country and provides power to central and state boards to prevent water pollution and impose penalty of defaulters.
	1977	The Water (Prevention and Control of Pollution) Cess Act, 1977: This act related to levying and collection of cess on water consumed for sanitary land filling, composting, and anaerobic digesters in MSWM.
	1981	Air (Prevention & Control of Pollution) Act, 1981: An Act that provides for the prevention, control, and abatement of air pollution.
	1986	Environment (Protection) Act, 1986: This act deals with the protection and improvement of the environment and matters connected there with.
	1995	National Environment Tribunal Act, 1995: An act that provides relief and compensation for damages to person, property, and the environment due to any accident.
	1997	National Environment Appellate Authority Act, 1997: To hear appeals with respect to restriction of areas in which industries may or may not be established.
Policies	1991	Eco-mark Scheme, 1991: To encourage consumers to purchase environmentally friendly products.
	1992	National Conservation Strategy and Policy Statement on Environment and Development, 1991: For dealing with various problems of environment and development in a comprehensive manner.
	1992	Policy Statement for Abatement of Pollution, 1992: The objective of this policy is to integrate environmental considerations into decision-making at all levels.
	2006	National Environment Policy, 2006: This policy emphasizes conservation, prevention of degradation, and equity of natural resources.
	2008	National Urban Sanitation Policy, 2008: The goal of this policy is to transform urban India into community-driven, totally sanitized, healthy, and livable cities and towns.
	2008	Service Level Benchmarks (SLBs): To introduce greater accountability among ULBs and improve urban services, the MoUD has prepared SLBs at the national level for performance monitoring and evaluation against agreed targets in four key sectors: water supply, MSWM, sewerage, and storm water management.
	2010	National Mission on Sustainable Habitat (NMSH): NMSH is one of the eight missions under the National Action Plan on Climate Change; it aims to make cities sustainable through improvements in energy efficiency in buildings, management of solid waste, and a shift to public transport.
	2012	PPP Toolkit for SWM: PPP Toolkit is an attempt by MoUD to provide a comprehensive knowledge of SWM for implementers. It has been prepared to provide a step-by-step approach for identifying, evaluating and implementing PPP projects in the SWM sector.
Rules	1989	Hazardous Wastes (Management and Handling) Rules (1989, amended January 2003, August 2010, April 2016): Hazardous Waste Rules deals with resource recovery and disposal of hazardous waste in an environmentally sound manner.
	1998	Biomedical Waste (Management and Handling) Rules (1998, amended September 2003, March 2016): These rules applied to all who generate, collect, receive, store, transport, treat, dispose, or handle biomedical waste in any form.
	2000	Municipal Solid Wastes (Management and Handling) Rules (2000, amended April 2016): All the ULBs in the country are directed to manage MSW in a scientific way. These rules cover all the aspects of MSWM such as collection, segregation, recycling, treatment and disposal in an environmentally sound manner.
	2001	The Batteries (Management and Handling) Rules (2001, amended May 2010): These rules are applicable to every stakeholder associated with the manufacturing, assembling, handling, and utilization and reuse of batteries or components thereof.
	2011	Plastic waste (management and handling) rules (2011, amended March 2016, March 2018): These rules advance plastic waste minimization, source segregation, recycling, role of waste pickers, and waste processors in collection of plastic waste for sustainability of waste management system. According to these rules, carrying of plastic bags by consumers and coretailers is not allowed, and the use of recycled plastic for sorting, carrying, or packing foodstuffs is prohibited.
	2011	E-waste (management and handling) rules (2011, amended March 2016, March 2018): These rules are associated with the generation, collection, storage, transport, import, export, environmentally sound recycling, treatment, and disposal of e-waste items.
	2016	Construction and Demolition Waste Management Rules, 2016: These rules addressed the indiscriminate disposal of C&D Waste and enable these wastes to be reused and recycled in a gainful manner.
Programs for promoting SWM	2005	Jawaharlal Nehru National Urban Renewal Mission: Urban Infrastructure and Governance, Basic Services to Urban Poor, Urban Infrastructure Development Scheme for Small and Medium Towns (UIDSSMT), and Integrated Housing and Slum Development Programme (IHSDP)
	2012	Programme on Energy Recovery from Solid Waste
	2014	Swachh Bharat Mission
	2014	National Mission for Clean Ganga (NMCG)
	2015	Smart Cities Mission
	2015	Atal Mission for Rejuvenation and Urban Transformation (AMRUT)

Table 9. (*Continued*.)

Category	Year	Acts/policies/rules/programs/financial supports
Grants allocated by Finance Commission	1992	10th FC: The aggregate grant of INR 53,800 million was recommended by the 10th FC, of which INR 43,800 million was for rural local bodies (RLBs) and INR 10,000 million was for ULBs during 1995–2000.
	1998	11th FC: During 2000–2005, the 11th FC recommended a grant of INR 100,000 million to local bodies, of which INR 22,100 was for MSWM and the remaining grant was for the maintenance of other civil services.
	2002	12th FC: The 12th FC allocated grants of total INR 250,000 million to RLBs (INR 200,000 million) and ULBs (INR 50,000 million) to supplement resources during 2005–2010.
	2007	13th FC: The 13th FC sanctioned a grant of INR 875,190 million to local bodies (INR 630,510 million for RLBs and INR 244,680 million for ULBs) during 2010–2015.
	2013	14th FC: During 2015–2020, the 14th FC allocated a grant of INR 2,874,360 million to RLBs (INR 2,002,922 million) and ULBs (INR 871,438 million) for SWM, water supply, sanitation, street lighting, and so on. It was more than 3 times the grant allocated by the 13th FC. The allotted grant was recommended in two parts: a basic grant and a performance grant. In the case of RLBs, the basic and the performance grant ratio was 90:10, whereas in case of ULBs it was 80:20.

will be spent on SWM. A total fund of INR 521,660 million was released for SBM-Gs in March 2018. SBM is as of now providing viability gap funding (VGF) up to 20% to distinct ULBs and states (MoDWS 2018; Deshpande and Kapur 2018). Still, ULBs are unable to raise the remaining 80% disbursement necessary for SWM reformation in their towns and cities. More practical plans and economic models should be discovered. When tending to the components of SBM for urban areas, state governments and ULBs are expected to focus on a set of social needs and results that characterize the scope and complexity of the task.

The GOI approved a program for energy recovery from MSW and industrial and agricultural waste in 2012. Under this program, the government provides financial assistance of INR 20 million/MW and a maximum of INR 100 million/project for power generation from MSW. The minimum financial support of INR 20 million/MW (maximum INR 50 million/project) is providing power generation from biogas (minimum 12,000 m^3/day) at sewage treatment plants through anaerobic digestion (AD) of urban and agricultural waste. Financial assistance of INR 300,000 is provided for organizing any event such as training courses, seminars, workshops, publicity/awareness, and so on. In addition, for the supply of waste at the site of the project, ULBs are given a financial incentive of INR 1.5 million/MW and provided land for WtE facilities at nominal rent for long-term leases (30 years and above) (Aswani 2012). State nodal agencies also are given a stimulus of INR 500,000/MW power production for promotion, coordination, and monitoring of projects. MNRE took up five plants projects with an aggregate capacity of 57 MW in 2014, as part of their Programme on Energy from Urban, Industrial, and Agricultural Waste, of which two plants are operational and the remaining three projects could not be completed due to the paucity of funds and some technical reasons (MNRE 2016).

According to SWM Tool Kit (2012), SWM must be treated as a particular and elite project, which needs huge capital venture along with operation and maintenance cost. The master committee of MoUD (2011) estimates that the per person investment cost and per person operations and maintenance cost for SWM both are maximum in Grade 1A cities (INR 900/year and INR 269/year, respectively) compared with other grades (1B, 1C, 2, and 3). It is supposed that big cities will endorse highly mechanized frameworks, smaller cities will choose comparatively more labor-intensive processes, and Grades 3 and 4 cities will adopt the least expensive technologies (Mani and Singh 2016; MoUD 2016).

The central government's incentive is available for SWM projects in the form of a maximum 35% grant/viability gap funding for each project, and the contribution of the state government is 25% for SWM projects, to match a 75% central share. Tipping fees are announced by the ULBs or by any state agency to pay the concession of the waste processing facility of the state government or the disposal of residual concrete waste on landfill; fees are in the range of INR 927–2450/t (CII 2017; SMA 2016). The complete capital grant is credited to the loan account of the beneficiary. A few state governments, such as Andhra Pradesh, Maharashtra, Gujrat, Karnataka, Haryana, Rajasthan, Tamil Nadu, Madhya Pradesh, and Uttar Pradesh, have declared policy measures. These relate to the allocation of land, facilities for evacuation, the supply of garbage, and selling and purchasing of power to promote setting up more WtE projects (Mani and Singh 2016; MoEFCC 2016). More incentives and operational support is expected to encourage anaerobic digestion, composting, and incineration based WtE plants.

Solid Waste Management Revised Rules 2016, Gaps, and Suggestions

The Ministry of Environment, Forest, and Climate Change (MoEFCC) revised SWM Rules in 2016, in supersession of MSW Rules 2000, to improve the collection, segregation, recycling, treatment, and disposal of solid waste in an environmentally sound manner. The modern rules not only focus on source segregation of wet, dry, and hazardous waste and their distinct treatment, but also emphasize the segregation and treatment of construction and demolition (C&D) waste in a separate chapter. Similarly, the plastic waste, e-waste, fly-ash, and biomedical waste management rules were also revised. These rules reflect modern frameworks, technology advancements, and ideas for integrated solid waste management (ISWM). Table 10 summarizes the SWM revised rules 2016 and reasonable changes in MSW rules 2000.

Limitations of SWM Rules 2016 include

1. The informal sector is significantly ignored in the new rules;
2. Revised rules do not push waste management to a decentralized level, whereas central treatment such as WtE has been encouraged;
3. Although distinct categories are included for wet, dry, C&D, and hazardous waste, a distinct category for sanitary waste is absent;
4. The new rules are not clear about the penalty to be imposed on plastic manufacturing companies or how the supervision system would be carried out;
5. A GPS/GIS framework is absent for tracking trucks carrying segregated solid waste;
6. The use of user's fee should be spelled out, particularly for first-mile waste management, such as payouts to waste collectors'

Table 10. Major highlights of SWM revised rules 2016 and changes

Characteristics	Municipal solid waste (management and handling) rules, 2000	Solid waste management rules, 2016	Reasons and likely implications
Title	Municipal Solid Waste (Management and Handling) Rules, 2000	Solid Waste Management Rules, 2016.	These rules have now been extended beyond municipal area, and hence the word municipal has been removed.
Application	Apply to every municipal authority	Rules are now implemented outside of municipal areas, such as in urban agglomerations; census towns; notified industrial townships; Indian Railways; airports; airbases; ports and harbors; defense establishments; special economic zones; government organizations; and places of pilgrimage and religious and historical importance.	To ensure the effective implementation of the Rules and achieve objectives of the Swachh Bharat Mission.
Duties of waste generator	N/A	Waste generators will use three color-coded waste containers for segregation of solid waste into three waste streams, namely biodegradable, nonbiodegradable, and domestic hazardous, and will hand it over to authorized ragpickers or waste collectors or local bodies. If a programmer organizes a program of more than 100 people, he will notify the local authority at least three working days in advance. It is the responsibility of the organizer to segregate waste and hand it over to the local authority. All resident welfare associations, market associations, gated communities, institutions (area >5,000 m^2), hotels, and restaurants will segregate waste at the source, and all recyclable material will be handed over to authorized waste pickers.	Now rules emphasize source segregation of waste, recovery, reuse and recycling. This will improve the waste segregation and utilization, and produce less waste or only inert to landfill.
Collection and disposal of sanitary waste such as diapers, sanitary pads, and other items	N/A	Manufacturers or marketing companies of sanitary napkins and diapers will provide a wrapper for the disposal of each napkin or diaper with packets and will be responsible for awareness of proper disposal. Consumers will securely wrap these used items in pouches provided by the manufacturers and shall place the same in the bin meant for dry waste. Manufacturers of disposable products such as glass, tin, plastic packaging, and so on will provide required financial aid to local authorities to establish an SWM system.	Collection and disposal issues of sanitary waste have been addressed. This will improve the waste utilization and management.
Responsibilities of the Ministry of Urban Development (MoUD)	N/A	The MoUD will formulate national policies and strategies for SWM in which policies on WtE, promoting research and development, project finance, training of local bodies, providing technical guidelines, and measures taken by the states from time to time will be reviewed.	The national policies will be a guiding tool for local authorities in SWM.
Promotion of marketing and utilization of compost	N/A	The Ministry of Chemicals and Fertilizers will provide market development assistance to make fertilizers through solid waste. In addition, the Ministry of Agriculture will provide flexibility in fertilizer control orders for the manufacture and sale of compost, and laboratories will be set up to test the quality of manure produced by the local authorities.	Compost plants will be economically viable and gainful utilization of waste will improve.
Promotion of WtE plants	N/A	The Power Ministry will fix tariffs for electricity produced by WtE plants and ensure the mandatory purchase of electricity generated from such WtE plants. MNRE will help to create basic infrastructure for WtE plants and provide suitable subsidies or incentives to these WtE plants. All industrial units using fuel located within 100 km of a solid waste RDF plant will use RDF fuel for at least 5% of their fuel requirement. Nonrecyclable waste with a calorific value of 1,500 kg/kg or more will not be disposed of on landfills and will only be used for generating energy in cement or thermal power plants or as feedstock for preparing RDF.	This will make WtE plants economically viable and improve the gainful utilization of waste. A provision to utilize 5% of RDF will support the WtE plants and reduce fossil fuel consumption.

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Table 10. (*Continued*.)

Characteristics	Municipal solid waste (management and handling) rules, 2000	Solid waste management rules, 2016	Reasons and likely implications
Duties of the secretary, state urban development department, commissioner, municipal administration, local body director, local authority, and village panchayat	In metropolitan cities, the urban development secretary of the state shall be responsibilities for enforcement of the provisions of these rules, and the district magistrates of the districts within their jurisdiction.	They are responsible for preparation state policies and SWM strategies in consultation with stakeholders including representatives of waste pickers. Waste generators will have to pay a user fee to the waste collector and a spot fine for littering and nonsegregation of waste.	Integration of waste pickers in SWM will improve the collection, segregation, and recovery of reusable waste. The fee or penalty will improve waste collection and strengthen the financial status of the local authority.
Criteria and standards for waste treatment facility and pollution control	—	The SWM rules provide criteria for site selection, development of facilities at the sanitary landfills, pollution prevention, and closure and rehabilitation of old dumps, and specify criteria for mountainous areas. Landfill sites shall be least 500 m from residential areas,100 m from rivers, 200 m from ponds, 300 m from highways or railway lines, 500 m from earthquake zones, and 20 km from airports. Buffer zones will be identified for SWM and disposal facilities for more than 5 t/day. The emission standards have been completely revised and include parameters for dioxins, furans, and reduced limits for particulate matter from 150 to 100 and now to 50. In addition, compost standards have been modified to align with fertilizer control orders.	The selection criteria of buffer zones of waste treatment and landfill facilities will facilitate smooth running of the facilities without any pollution issues.

Sources: Data from CPHEEO (2016a); MoEFCC (2016).

collectives for doorstep collection, segregation, recycling, composting, and so on;

7. Horticultural/agricultural waste should be handled separately, and burning of garden waste and leaves should be prohibited;
8. The State Pollution Control Board is responsible for the processing of domestic hazardous waste, but it should be compulsory to transported this to regional secured landfills center or to treat it in treatment, storage, and disposal facilities; and
9. ULBs do not have the technological knowledge for biomining and bioremediation actions. This needs to be done through a special purpose vehicle after an appropriate environmental impact assessment, and so on.

Proposals to improve the SWM rules include

1. More focus on the recycling system is required. Smaller ULBs can easily create cooperative societies to deal with the initiative of garbage collectors and recycling of collective materials to establish an incineration plant with large companies.
2. More attention is needed on ULBs operating with scavengers and nongovernmental organizations (NGOs) to set up an effective waste collection system and material recovery facilities.
3. WtE incineration plants are still under testing. The setup cost of incineration plants, as well as pollution control tools, should be restrictive for small ULBs.
4. A separate section is required for management of household biomedical and sanitary waste. Sanitary waste should be collected in red sacks door-to-door two days each week, and transportation of sanitary and biomedical waste to common biomedical waste treatment facilities should be compulsory.
5. Separate collection of gel-based napkins needs to be emphasized, and their flushing needs to be restricted.
6. Recycling technologies for making structural from plastics or converting waste plastics and non-recyclables to Light Diesel Oil as mentioned in the Planning Commission report 2014 should be delineated and their standards prescribed. This is feasible in smaller ULBs also.
7. There is a need to change the behavior of the authorities related to domestic waste, because when it comes to implementing the rules framed they are not adequately focused.

In summary, the Revised Rules (2016) are an enormous step to improve solid waste management, but they do not deal with all the issues. These rules should be upgraded if they are expected to play a crucial role in advancing waste management systems and sanitation in India.

Technological Options for Treatment of MSW and Selection

Preferably, MSWM should incorporate the principles of waste minimization, recycling, resource recovery, and an integrated waste disposal facility, leading to effective service delivery in a feasible manner (Bernstad Saraiva et al. 2017; MEF 2010; Muriana 2017; Singh et al. 2011). An ISWM is based on the five-level MSWM hierarchy: source reduction and reuse, recycling, composting, WtE, and landfilling for the purpose of reducing the quantity of waste while maximizing resource recovery and efficiency (Fig. 3) (Guerrero et al. 2013; Dasanayaka and Wedawatta 2014; Kumar and Goel 2009; Lawrence 2012; MoUD 2016; Ramasami and Velumani 2016; Senzige et al. 2014). Nowadays, waste minimization and reuse/recycling are more important. Landfilling is no longer the first choice for waste disposal among the other methods such as composting and incineration; now it is the last step after all possible material and energy recovery in SWM practices (Bosmans et al. 2013; Ecoprog CEWEP 2013; Francis et al. 2013; Dasanayaka and Wedawatta 2014; Zhao et al. 2015). In ISWM facilities, waste is

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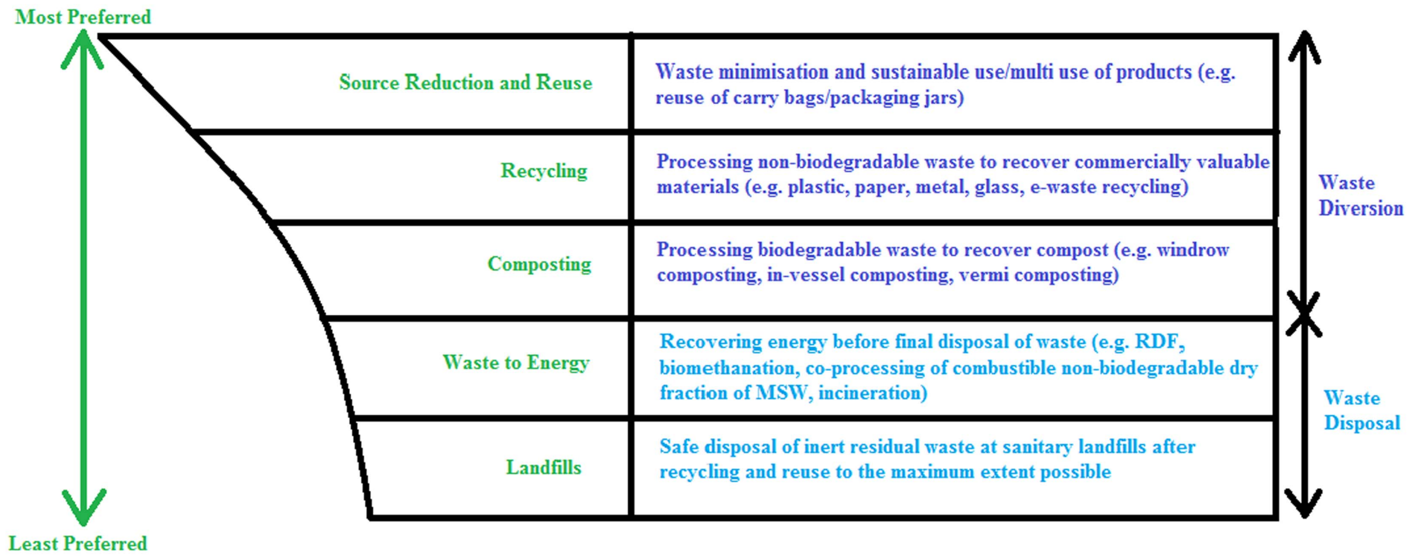

Fig. 3. Integrated solid waste management hierarchy. (Data from Agarwal et al. 2016; Chien Bong et al. 2017; CPHEEO 2016b; ERC 2015; McAllister 2015; Rathore et al. 2010.)

sorted at transfer stations and distributed within the facility. Waste suited for thermal treatment goes to an incineration, gasification, or pyrolysis facility; appropriate waste for biological treatment goes to either a composting facility or anaerobic digestion; and rest goes to the landfill (Khan et al. 2016; Sukholthaman and Sharp 2016). Several nations, including Germany, Japan, Austria, Denmark, Netherlands, and Singapore, have practically eliminated landfilling by a combination of recycling, composting, and WtE in ISWM systems. Therefore, adopting a technology with an integrated arrangement gives the best performance at the least cost over the life of a facility (PPP Canada 2014). There is an urgent need in India for planning and implementing effective, economical, and integrated strategies for management and treatment of solid waste.

At present, there are many waste treatment techniques available, such as composting (aerobic composting and vermicomposting), anaerobic digestion, recycling, RDF, incineration, pyrolysis, gasification, engineered landfills, and so on. However, each technique can have positive and negative effects. Research shows that MSW from Indian cities contains about 40–60% organic matter, which can be easily recycled as compost or used for generating biogas (Bag et al. 2015; Devi et al. 2016; Kalyani and Pandey 2014; Kaushal et al. 2012; Kumar et al. 2017; Mani and Singh 2016; Narayana 2009). Where material recuperation from waste is impossible, energy recovery from waste is given priority through the generation of heat, power, or fuel. Anaerobic digestion, composting, pyrolysis, gasification, incineration, and RDF production are commonly adopted WtE technologies (At et al. 2016; Fernández-González et al. 2017; Schreck and Wagner 2017). At the end of the hierarchy, residual waste, which ideally includes inactive waste, is disposed of in sanitary landfills, which should be made according to the terms of the SWM rules 2016 (CPHEEO 2016a).

The selection and adoption of MSW processing technologies should be based on defined criteria, including population size, quantity of waste generation, characteristics of the waste, cost of waste processing technology, environmental conditions, the feasibility of the technology, policies of the country, and so on. The biggest constraints in SWM are the collection, separation, and transportation of the solid waste to a region where centralized or decentralized composting or anaerobic digestion along with composting can be implemented at a large scale (Mani and Singh 2016). The efficiency of recycling and composting are greatly reduced due to the absence of source separation. Table 11 illustrates the selection of waste treatment technology based on population size, waste generation rate, and amount of biodegradable fraction of waste. Cities with a population 0.1–2 million or above and waste quantity ranging from 500 to 1,100 Mt/day can adopt the most common technologies to treat the waste in an integrated way, comprising waste treatment plants using anaerobic digestion, chemical conversion, and RDF. The range of biodegradable waste should vary from 30 to 60%, depending upon the generation of waste and the technologies that are in practice. AD plants and vermicomposting are capable of handling effectively up to 30 Mt/day and are acceptable for small towns. Aerobic composting plants are operational up to 500 Mt/day, and WtE plants are cost-effective for processing waste of 500 Mt/day and above. Cities in mountainous areas facing land crisis can use technologies such as anaerobic digestion, vessel composting, static pile composting, and RDF.

Chemical characteristics of MSW such as moisture content, C:N ratio, calorific value, pH value, and temperature are very useful to determine which treatment technology should be adopted. Both technologies anaerobic digestion and composting require moisture content 50%–60% and C:N ratio 20–30. Waste is considered for incineration if its calorific value is greater than 1,500 kcal/kg. The desired calorific value of waste can be achieved through effective segregation of wastes. WtE technologies such as incineration, gasification, pyrolysis, and so on require a high working temperature between 850°C and 1,400°C, whereas biological conversion techniques such as anaerobic digestion, composting, and vermicomposting need 20°C to 55°C (CPCB 2015).

Depending on the type of incoming waste, appropriate technological options can be identified and suggested for processing of MSW: for anaerobic digestion, wet biodegradable waste is required; for RDF, high-calorific valued combustible wastes is required for combustion in the form of briquettes or pellets; for conventional microbial windrow/vermicomposting, wet biodegradable waste is required; for fuel oil, plastic waste is required; for pyrolysis, organic waste is required; and for gasification, organic or fossil-based carbonaceous material is required. Mass Burning is the only method

Table 11. Waste treatment technological options based on population size, quantity of waste generation, and biodegradable fraction of waste

Number	Population range	Waste generation range (Mt/day)	Percentage of biodegradable waste	ISWM technological options: Wet waste	ISWM technological options: Dry waste	Minimum requirement	Value added product
1	Above 2 million	Above 1,100	35–50	Composting	RDF	Segregate wet organic waste at source for biomethanation.	Compost/biogas/RDF/electricity
				Anaerobic digestion	WtE	Dry waste to be recycled or converted in to RDF	Recyclables: paper/plastics/metals
				WtE		Inert to landfill	
2	1–2 million	550–1,100	40–55	Composting	RDF	Segregate wet organic waste at source for biomethanation.	Compost/biogas/RDF/electricity
				Anaerobic digestion	WtE	Dry waste to be recycled or converted in to RDF	Recyclables: paper/plastics/metals
				WtE		Inert to landfill	
3	0.1–1 million	30–550	40–55	Composting	RDF	Segregate wet organic waste at source for biomethanation.	Compost/biogas/RDF/electricity
				Anaerobic digestion		Dry waste to be recycled or converted in to RDF	Recyclables: paper/plastics/metals
						Inert to landfill	
4	50,000–100,000	10–30	45–60	Composting	—	Segregate wet organic waste for biomethanation/vermicomposting	Compost/biogas
				Vermicomposting		Dry waste for recycling and material recovery	Recyclables: paper/plastics/metals
				Anaerobic digestion		Inert to landfill	
5	Less than 50,000	Less than 10	45–65	Composting	—	Segregate wet organic waste for biomethanation/vermicomposting	Compost/biogas
				Vermicomposting		Dry waste for recycling and material recovery	Recyclables: paper/plastics/metals
				Anaerobic digestion		Inert to landfill	
6	Hill towns	State capitals	30–50	Anaerobic digestion	RDF	Segregate wet organic waste at source for biomethanation.	Biogas/RDF
						Dry waste to be recycled or converted in to RDF	Recyclables: paper/plastics/metals

Sources: CPCB (2015); MNRE (2016); SMA (2016).

which does not require a high level of waste segregation and can use mixed waste, but it should be free from inert materials and high moisture content. Hence, ISWM coupled with waste reduction and energy recovery potential is suitable for Indian cities.

During this study and conversation with the ULBs, the following constraints were observed:

1. Public participation in SWM is very poor. Awareness and sensitization programs should be conducted in the field of SWM to create behavioral changes in the public. People should be encouraged to keep segregated bins for wet, dry, and hazardous waste at the household level and to stop littering on the streets. Segregation of waste must be made compulsory in all government offices, commercial establishments, households, and so on, and a penalty should be charged for noncompliance.
2. All ULBs should adopt a time-bound action plan for the collection, segregation, storage, transportation, processing, and disposal of MSW effectively under programs such as SBM, NMCG, and Smart City Mission. Waste management technologies should be adopted according to local needs in their respective areas. ULBs should estimate the quantity of waste generated every day in order to ensure its supply in required quantities and quality to WtE plants in a definite manner; if they fail to do so, a penalty should be imposed on them. Waste generated in rural areas/villages should be considered, and proper mechanisms should be started for its collection and disposal.
3. There should be an agency to technically assist the local bodies, either at state or national level, to prepare the plans. Furthermore, a detailed assessment is required for how ULBs can meet targets of MSW rules, including financial requirements. There should be also some professional staff in ULBs for handling specific responsibilities for MSWM. Proper training should be given to ULB workers regarding segregation of waste and efficient use of resources. Technical reasons are the common excuse for nonoperation of a plant. This should be resolved in a time-bound manner without hampering the operations of the project.
4. In order to maximize the collection efficiency, the role of scavengers should be taken into consideration within the formal system by ULBs and state governments. ULBs should make efforts to involve civil society, NGOs, and resident welfare associations in the management of waste. Participation of the private sector should be in a wholehearted manner; various incentives, such as tax exemptions or rebates for equipment and machinery, can be offered. All anticipated obstacles must be removed.
5. Based on success stories in WtE field, states should be encouraged to adopt innovative methods for scientific disposal and treatment of MSW which suit their local conditions the best. These techniques should be efficient, financially affordable, and environmentally compatible, should not compromise the viability of WtE plants, and should ensure better public health.

6. The concept of the Five Rs should be adopted effectively based on its implementation in European nations. The government should provide similar policies and guidelines to different states for the adaptation of technology according to the amount of waste generated in the WtE sector. A regulating mechanism should be developed to ensure that all the WtE plants in the country follow the environmental norms, and defaulters must be penalized.
7. There should be a monitoring committee, consisting of representatives from all the central ministries, state governments, and ULBs, to coordinate the efforts at each level. The committee may also have technical experts, financial analysts, representatives from the private sector, and so on.
8. Tariffs on electricity generated by all WtE plants should be decided through a process of competitive bidding. Tipping fees and electricity generation prices should be introduced.
9. To maintain regular communication with ULBs, the State Pollution Control Board and the Pollution Control Committee should have sufficient infrastructure.

Conclusion

It can be safely concluded that due to rapid urbanization, industrialization, population growth, and economic development, the amount of waste production in India has increased significantly. The waste composition also changed in last 2 decades of economic growth since 1996. The MSWM system in India is not appropriate due to its dependence on insufficient waste infrastructure, the informal sector, and open waste dumping. There are some major challenges related to effective waste policies, appropriate technology selection, and sufficiency of trained people in the waste management field. Moreover, poor public involvement in SWM and lack of responsibility for waste within society are also major issues. There is a need to raise community awareness and change people's outlooks, because this is a basic requirement for developing an appropriate and sustainable SWM system. Until these primary necessities are achieved, India will continue to suffer from poor SWM and the related impacts on human health and the environment.

In the Indian context, MSW has various technical alternatives for energy recovery. An ISWM system combined with waste reduction and energy recovery potential is essential to achieve sustainable SWM in India. WtE facilities are not only possible but essential to satisfy the needs of growing cities, improve environmental health, and to be an example for cities in India as well as in other developing nations. Many things should be implemented for the improvement and development of MSWM status in India, such as

1. Solid waste should be sorted at the source to reduce the waste quantity for disposal and increase the recycling rate. Waste with high calorific value needs to be separated from organic waste with a high moisture content; it is necessary to provide combustible waste in WtE plants.
2. Waste recycling and making products from waste through suitable treatment options will provide new employment opportunities.
3. Minimizing waste generation and maximizing recycling and reuse are major challenges. Recycling industries in India should be improved. Color-coded containers for named waste varieties should be provided and publicized to encourage segregation and recycling behaviors.
4. Because the informal system of MSWM still makes a vital contribution in India, state governments need to consider organizing and managing this informal system so that it can be better controlled by municipal authorities.
5. At present, there is no restriction on the quantity of MSW generation, and the waste disposal techniques are responsible for the production of more waste. Improvement of the garbage-fee levying system and increasing waste collection and disposal charges

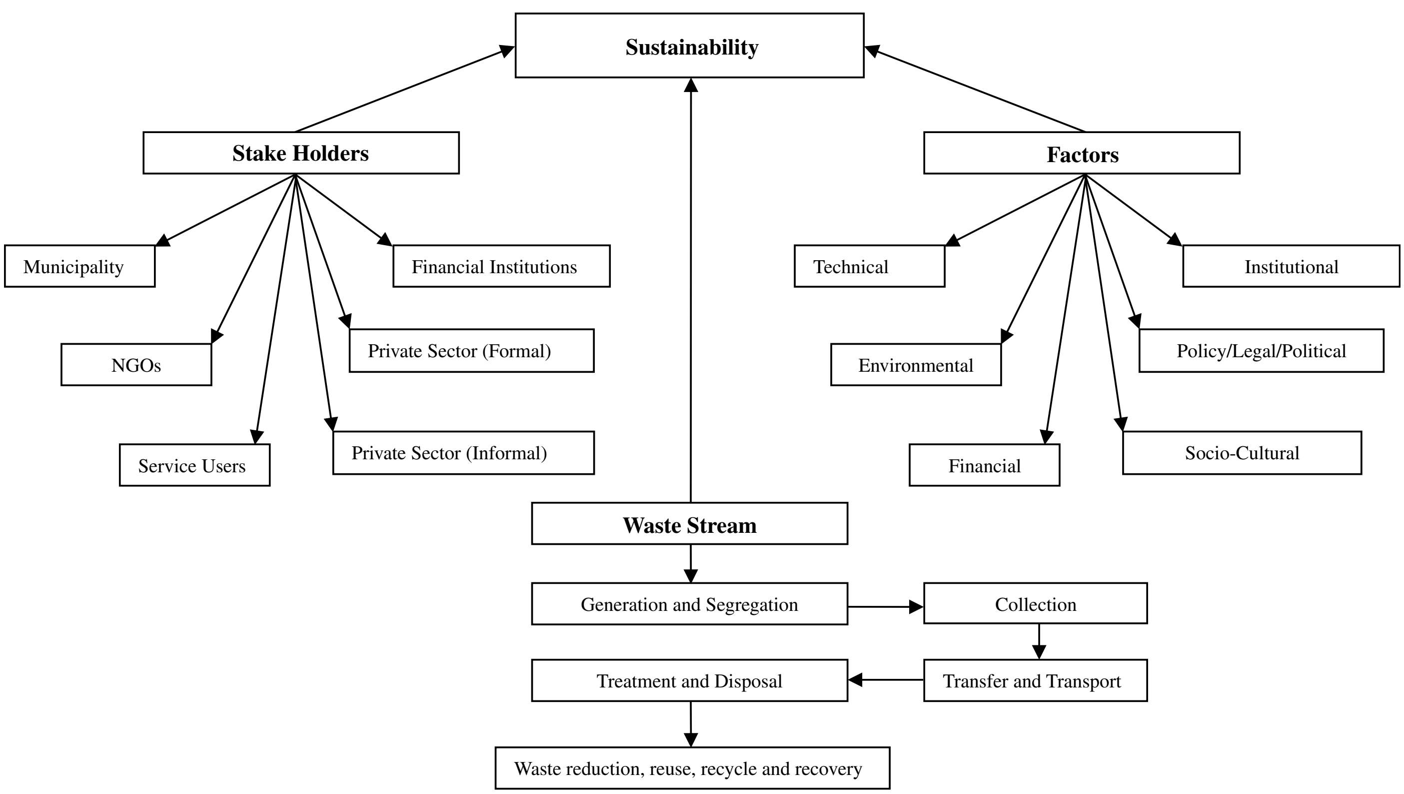

Fig. 4. MSWM sustainability model for Indian cities.

can recover the costs and raise capital for investment in new facilities.

6. The present SWM crisis in India needs to be addressed as a whole; when preparing long-term solutions, focus on fixing existing problems should be maintained.
7. In most regions of India, scavengers and sweepers are still considered to be the lowest category of citizens. To alter the views and attitudes of the people, the community should raise awareness about this important service, the people engaged in such activities should be designated as a green brigade or crew, and so on. A sustainability model provided by the National Solid Waste Association of India (NSWAI) to solve the problems of SWM in India is presented in Fig. 4.

Data Availability Statement

In this work, no data was generated. All supporting data was obtained from previously published articles in journals, the outcomes of the international conferences, and published reports by Government organizations. All references are cited in the text and are listed below.

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