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Environmentally Sustainable Municipal Solid Waste Management - A Case Study of Kolhapur, India

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ABSTRACT

Municipal Solid Waste Management plays an important role in sustainable development. The concept of waste to resource is a latest one for confounding waste problems of our society. The expansion of urban areas, industrialization and changing patterns of consumption results in increased Municipal Solid Waste generation which deteriorate the quality of environment, posing risk to the sustainable development. The authors of the present paper address the issue of Municipal Solid Waste by taking the case of Kolhapur, India. It discusses the present municipal waste management system, technologies, projected population, projected solid waste generation and transforming the waste into value added product. In an evolutionary approach, it points out the challenges that the sector is facing and makes an attempt to suggest a way forward through technologies and estimation of value-added products that can be produced from the solid waste. Such an approach attempts to achieve environmentally sustainable municipal solid waste management with economic model put in place.

1. Introduction

Around the world, waste generation rates are rising day by day. In 2016, World's generation rate of solid waste was 2.01 billion metric tons, giving a footprint of 0,74 kg per capita per day. In 2051, The solid waste generation is expected to increase up-to 3.42 billion metric tons. The people living in developing countries like India, especially the poorer people, are more critically disturbed due to unsustainable management of solid waste. On the other hand, 90% of the generated waste is not dumped on dumpsites and is openly burnt in low-income countries. These practices are creating serious health issues to the human kind and leading several environmental consequences. Unsustainably managed solid waste is a major source for creating various diseases, methane generation from dumping heaps contributing to climate change conditions, and polluting the ground water due to leachate generation. Managing the solid waste properly is vital for sustainable and liveable cities (Bhargava et al., 2020a; Bhargava et al., 2020b), but it is very difficult to carry out and is a challenge for many cities. Effective waste management is not economical, often comprising 20%–50% of municipal budgets. Hence, municipal service requires an integrated system that should be socially supported, efficient and sustainable for managing the waste (Url-1, 2019).

In India, most of the dumpsites of mega cities have been exceeded above their capacity. The permissible height limit is 20 meters which in ground is not the case, almost all the metropolitan cities have been exceeded way beyond the expectations. More than 10,000 hectares of land of India is occupied by solid waste dumpsites in urban land. Per person waste generation is about 200 grams to 620 grams and it will be going to increase in next decades. Out of total waste generation, about 70-80% of municipal waste collected and only 20-30% of this waste is treated. The escalation of airless open dumping site of waste releases methane and other gases, which absorbs the sun's radiation, warms the atmosphere, depletes ozone layer, leading to global warming which will harm the entire world in subsequent years. Leachate, which is a blackish liquid seeping out from the waste is slowly degrading over a period of 20 to 30 years, which pollutes soil, groundwater and nearby surface water. Foul odour coming out from dumping sites and smoke from the burning wastes are other consequences of dumping waste in the open. As the open dumpsites are easily accessible by the people, it has become a site for further dumping by the public which further leading to unsustainable management of the waste (Url-2, 2018).

In Kolhapur city, 165 metric tons of solid waste is generated every day. The segregated dry waste and wet waste is collected from individual houses and public bins and transported to the Kolhapur dumping site situated at Kasaba Bawada. Kolhapur Municipal Corporation (KMC) is trying to aware people to segregate wastes through various public awareness campaigns. Wastes collected by KMC is given to Zoom fertilizer project company. The dumped waste is processed to convert it into compost. The recyclable material such as Plastic and scrap materials are separated from dumped waste and sent to recycling and reusing unit.

The solid waste collection and transportation is done as per scheduled timetable and route fixed by KMC, done every day from 6 AM to 2 PM. Vehicles used for transportation includes damper, tempo, RC trucks etc. which are 22 in number. These vehicles are closed type. Transport system collects solid wastes daily from all the parts of city. Suitable arrangement has been made in the vehicles to shut out the falling of waste. The solid waste treatment plant treats 165 metric tons of Municipal Solid Waste (MSW) per day in the Kolhapur. The dumpsite is established in an area of 38,800 m^2 on 30-year lease contract (Url-3, 2020). The biodegradable waste is converted to compost and sold in the market.

In Kolhapur, tremendous amount of waste generated and dumped into the dumpsites. Since last year, KMC is actively participating and educating people about segregation of Solid waste management. Kolhapur has Refused Derived Fuel (RDF) and Bio-methanation plant (BMP) for segregated waste. By taking account of future waste generation, these two treatment plants are not sufficient. There is a need to forecast the population and waste generation per capita per year. Estimation of waste to energy should be studied to have sustainability in Municipal Solid Waste Management (MSWM) for upcoming years. Hence in this paper, a detailed study of sustainable MSWM and waste to energy options along with revenue generation in Kolhapur city is included.

2. Literature Review

Sustainable Solid Waste Management requires rich understanding of population trends, management practices, waste generation data, proper knowledge and active willingness of stakeholder. Life cycle assessment, characterization of waste stream, capacity building and bridging gap between problem areas are some concepts that needs incorporation (Jha et al., 2011). India is the 2nd most populous country with lack of proper knowledge and awareness in public about solid waste management. It is a big problem. Still, we use some technologies which are not as effective as other treatment technologies. According to waste composition and population generation trend we have to use suitable technologies (Soni, 2019).

Government legislation and policy rules have been made, but there is lack of proper implementation. Lack of finance, Institutional deficiency, and lack of public support are the main barriers of Indian solid waste management. The local bodies should be encouraged and give legislative powers to decentralise the management practices to ensure business environment among the private sector (Nandan et al., 2017). Quality of MSW generated is different for different cities.

According to survey conducted by TATA Energy research Institute, Composition of MSW in medium and small-scale cities and towns contains biodegradable waste (50-80%) and non-biodegradable waste (15-50%) (Pamnani et al., 2014). Therefore, we cannot implement developed countries management practices as they have more non- biodegradable waste. Processing operation such as incineration and pyrolysis are least suitable in Indian cities. More attention should be given for treatment of waste having moisture and high percentages of non-combustibles (Kumar et al., 2013).

It is forecasted that population of India would be around 1,823 million by 2051 and around 300 million tons per annum will be the solid waste generation (Joshi and Ahmed, 2016). Sustainable planning can help in utilizing these wastes into resource. Generally, Government bodies and municipality give attention toward present problems arising due to solid waste by neglecting Future problems. There should be positive focus on long term planning and implementation (Agarwal et al., 2015). Sustainable solid waste management can provide long term planning and assistance leading to have more positive approach for current and future environment problems. Various technologies are available to treat the solid waste in a sustainable way. Dry waste can be treated by Anaerobic Digestion, Incineration, Pyrolysis and Gasification (Rafey et al., 2020). Though they have some disadvantages in Indian condition but can be efficiently run in other developed countries.

Vermicomposting, conventional windrow composting and bio methanation are common technologies for wet or biodegradable waste. Plastic waste to fuel technology is also an emerging technology for plastic waste (Verma and Bisen, 2020). There is enormous potential of solid waste to energy in India. Various component of solid waste has economic value. Therefore, focus on waste segregation much be given so that different type of waste can be treated with respect to their type and nature (Bag et al., 2015).

3. Technological Options for Transforming Waste into Usable Products

Various technologies for solid waste transformation into resource are given in Table 1.

4. A Case Study

4.1. Study area

The Kolhapur city is located in Maharashtra, India. Kolhapur has area around 66.82 km^2.The latitude and longitude are 16°42' and 74°16' respectively. The population of Kolhapur is 5,49,236 according to 2011 census. 165 metric ton of solid waste is generated every day (Biraje et al., 2010) organic manure. Plastic bags, bottles, and scrap materials are separated from dry waste for recycling and reusing. KMC is trying to get people participation to segregate wastes through publicity and public awareness campaigns with the help of social organizations. The segregated dry waste and wet waste is collected from each house and public bin and transported to the Kolhapur dumping site situated at Kasaba Bawada. The waste dumped at this project is processed to convert it into compost or Wastes collected by corporation is given to Zoom Fertilizer project company. The solid waste collection and transport is done as per time-table and collection route fixed by the corporation, done every day from morning 6 to 2 in the afternoon. The solid waste treatment plant treats 165 tons of solid waste per day. The dumping site is established in an area of 38,800 square meters (4 hector) on 30-year lease contract and Zoom Fertilizer company treats the waste to produce compost. The wet solid waste is converted to compost and sold in the nearby market (Url-3, 2020).

In Kolhapur, tremendous amount of waste generated and dumped into the dumpsites. Since last year, Kolhapur Municipal corporation is actively participating and educating people about segregation of Solid waste management. Kolhapur has RDF and BMP for segregated waste.

However, in upcoming decades these plants are not sufficient to treat the solid waste due to higher solid waste generation. Generation of solid waste can be calculated by considering the population forecast and per person solid waste generation rate. This will lead to have proper forecasting of solid waste generation in upcoming years and thereby proper operational plant can be arranged for future. Its economical revenue generation will lead to sustainable management of solid waste in Kolhapur city.

Table 1. Various technologies for solid waste transformation

No	Technology (Url-4, 2016)	Information about the technology
1	Windrow composting	Windrow composting is preferred in an area where higher ambient temperature is available. Organic matter (Wet waste) is converted into compost by aerobic decomposition. The aerobic microorganism oxidizes the wet waste into carbon dioxide and oxides of nitrogen. Carbon is used as an energy source and nitrogen is been recycled. Temperature of mass rises due to exothermic reaction. In this method, refused wet waste is delivered on the open land in about 20 windrows. The time required for windrow composting is approximately 4-8 weeks (Url-5, 2000).
2	Vermicomposting	Vermicomposting is a process of converting organic matter into Bio-fertilizer using earth worms (Url-6, 2016). These worms give out an excreta material in the form of 'vermicasts' when feed on the organic waste. this excreta material is rich in Nitrates, phosphorous, magnesium, calcium and potassium. This is used as fertilizer and can be used to enhance the soil quality (Url-7, 2020).
3	Bio methanation	Bio methanation is a process in which microorganism converts organic matter into biogas (Url-8, 2009). It is a complex process leading to generation of methane and carbon dioxide. Bio methanation involves the process of Hydrolysis, acidogenesis, acetogenesis and methanogenesis (Url-9, 2016).
4	RDF	RDF is a fuel derived from dry or non-biodegradable waste. It can be used to produce electricity or steam. Waste which has higher calorific value can be used to produce RDF. Dry solid waste with Caloric value 1500 Kcal/kg or more can be accepted in RDF plant (Url-10, 2016). Process of conversion of dry waste into RDF include Screening, Coarse Shredding, bag splitting, shredding, Magnetic Separation and Refining Separation (Url-11, 2020).
5	Incineration	Incineration involves burning of dry waste with energy recovery. But it will only disappear the solid waste problem and can leads air pollution. This is the most common method of waste to energy (WTE) around the world. It can reduce the volume of waste by 95-96%. Incineration process depends on composition and degree of recovery of material such as metals from ash for recycling (Url-12, 2020).
6	Integrated system (Composting + RDF)	The aim of Integrated System is to achieve zero discharge. It could include composting of wet waste. Dry waste can be processed as RDF. Sanitary landfill can be included for refused waste coming out from Composting and RDF.
7	Sanitary landfill	Sanitary landfill includes disposal of solid waste on land scientifically. The solid waste is either buried in underground or in large piles. The ground or base can be guarded with a thick plastic and a layer of clay which should be impervious. A collection system is there in the sanitary landfill to collect the leachate and gases coming out from the filled waste of sanitary landfill.

4.2. Population forecasting

The design population forecasting is estimated with due to all factors governing the future growth rate and development of the project area in the industrial, commercial, educational, social and administrative spheres. The development of a particular region depends upon natural, physical and socio-economic factors. Among these factors the population plays significant role in determining the future pattern of progress and development. Factors affecting changes in population are: increase due to births, decrease due to deaths, increase/ decrease due to migration and increase due to invasion. The present and past population record is obtained from the Indian census population records. After collecting these population figures, the population at the end of design period can be predicted using various methods which includes arithmetic, Geometric and incremental increase method.

The study of population from 1951 to 2051 is considered for sustainable solid waste management of Kolhapur. After India got the independence, in 1951, Population growth of the city was increased continuously. The growth rate was 47.08% which was the highest peak in the growth rate. since 1951 to 2011, the growth rate was decreased and it was 13.21% in 2011. If we consider the area of Kolhapur, in 1971, it was 66.82 sq.km. and there is no extension in the area of Kolhapur till today but the population has increased to 5,49,236.

It indicates that the population is increased without increase in the area of Kolhapur city (Url-13, 2020). Therefore, limited area and higher population is the major reason behind the pollution of the city. The records of population were found in the census of India, 1961, 1971, 1981, 1991, 2001 and 2011 (Ramotra and Swami, 2016) and is given in Table 2 as population data.

Table 2. Population data 1951-2011 (Ramotra and Swami, 2016)

Year	Population
1951	1,36,835
1961	1,87,442
1971	2,59,050
1981	3,40,625
1991	4,06,370
2001	4,93,167
2011	5,49,236

The population is forecasted using the Arithmetic progression, geometric progression and incremental increase from 2021 to 2051 based on census of India, 2001.The average value calculated and used for further study. The calculated population data is given in Table 3 and Graphical Representation of Population Data is given in Fig. 1.

Table 3. Population Forecast (Year 2011-2051)

Year	Arithmetic population	Geometric population	Incremental increase population	Average population
2021	6,05,305	6,11,600	6,13,281	6,10,062
2031	6,61,374	6,81,300	6,68,823	6,70,499
2041	7,17,443	7,58,800	7,15,864	7,30,703
2051	7,73,512	8,45,085	7,54,402	7,91,000

4.3. Solid waste generation and forecasting

The solid waste generation of year 2021 is considered as 800 grams per person per day. 100 grams per person per day of waste generation is added to each decade's (2021-2051) waste generation due to the increased solid waste generation per person in next decades. Therefore, for year 2011, 2021, 2031, 2041, 2051 the waste generation would be 700, 800, 900, 1000, 1100 per person per day respectively. The Solid Waste Generation data is given in Table 4 and its graphical representation is given in Fig 2.

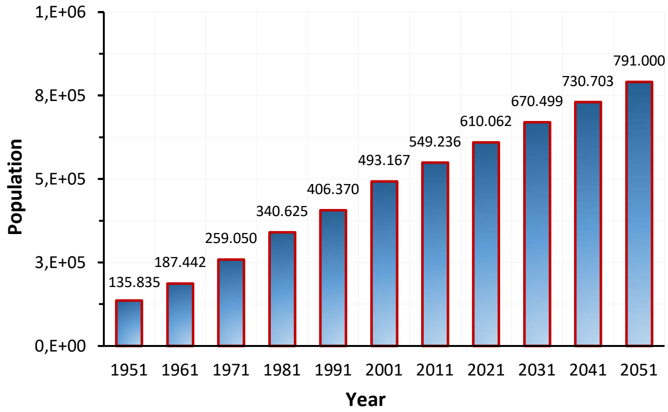

Fig. 1. Population projection (Year 1951-2051)

Table 4. Solid waste generation

Year	Solid waste generation (gm/person/day)	Solid waste generation (kg/day)	Solid waste generation (Tones/year)
2011	700	3,84,465.2	1,40,329.798
2021	800	4,88,049.6	1,78,138.104
2031	900	6,03,449.1	2,20,258.922
2041	1000	7,30,703	2,66,706.595
2051	1100	8,70,100	3,17,586.5

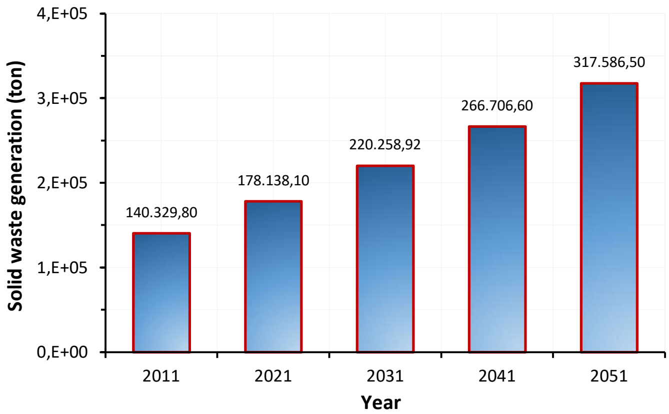

Fig. 2. Solid waste generation (2011-2051)

4.4. Transformation of waste to value added products

The generation of large amount of solid waste could be managed by converting it into "resource" in the form of revenue generating products. Some of this might be Composting, Biofuel and Power generation. 85% of Indian solid waste is biodegradable and remaining 15% being non-biodegradable accounts for the power production. Table 5 gives the data about the generation of biodegradable and non-biodegradable waste in tons per year in upcoming years of the Kolhapur City.

4.4.1. Compost production

Table 6 gives details about the quantity of compost that could be generated from the projected solid waste generation for the city. This is calculated by assuming, 83 kg compost could be produced from one ton of waste generated. It is clear that there is an increased amount of compost generation for the projected population. This throws light upon the need for decentralized SWM at the district level itself. The calculated compost generation data is given in Table 6 and its graphical representation is depicted in Fig. 3.

Table 5. Generation amount of biodegradable and non-biodegradable waste

Year	Total solid waste generation (tons/year)	85% of total solid waste for compost and biofuel using biodegradable waste (tons/year)	15% of total solid waste for power generation using non-biodegradable waste (tons/year)
2011	1,40,329.80	119280.33	21049.47
2021	1,78,138.10	151417.39	26720.72
2031	2,20,258.92	187220.08	33038.84
2041	2,66,706.60	226700.61	40005.99
2051	3,17,586.50	269948.53	47637.98

Table 6. Compost generation

Year	Solid waste used for compost and biofuel in tons/year	Kg of compost produced per year
2011	119280.33	10138827.91
2021	151417.39	12870478.01
2031	187220.08	15913707.08
2041	226700.61	19269551.49
2051	269948.53	22945624.63

From the above data it can be concluded that the compost waste generation is almost tripled in just 4 decades. This is because of the increase in waste generation rate. The treatment system used today cannot be used after 4 decades. Care must be taken to have sustainable compost management.

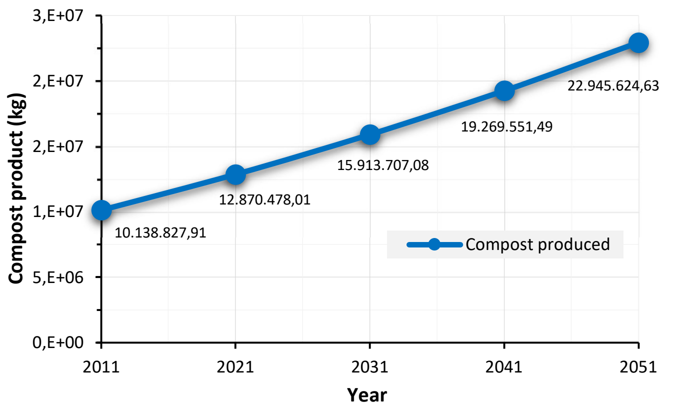

Fig. 3. Compost generation

4.4.2. Biofuel production

Biofuel is becoming quite popular in developing countries due to its easy production and reduced implementation cost. For the urban area customized biogas units are available which consumes less space and no odour production. The production for the region is estimated by taking into account that per 1000 tons of waste leads to 21.43 m^3 of biogas production. Figure provides details on the volume that can be obtained from the projected population. The calculated Biogas Generation data is given in Table 7 and graphically represented in Fig. 4.

Table 7. Biogas generation

Year	85% of solid waste generation for compost and biofuel using biodegradable waste in tons/year	Volume of biogas produced, m^3 per year
2011	119280.33	2556.18
2021	151417.38	3244.87
2031	187220.08	4012.13
2041	226700.61	4858.19
2051	269948.53	5785.00

Biogas generation is increasing as increase in the decade year. Only in 4 decades the volume of biogas produced is almost tripled. As the biogas can be used for various purposes as fuel, there is an extortionate scope in the biogas making business. The increase in biogas production is due to increase in waste generation rate.

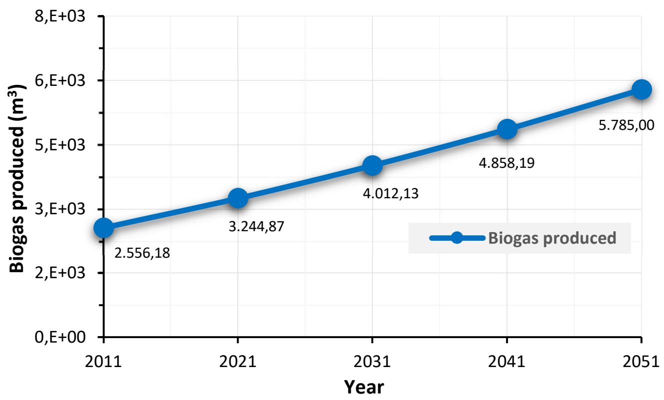

Fig. 4. Biogas generation

4.4.3. Power generation

Power generation is accounted by the 15% of total solid waste generated by the district population which comes under non-biodegradable. From 100 tons per day of waste it is assumed that 1 MW electricity could be generated. Table 8 gives details of the power generation for the City. It is clear that for the year 2051 it is possible to generate around 476.38 MW of power which is quite appreciable. Fig. 5 shows the graphical representation of Electricity Generation.

The data explains that the electricity generation rates are rising for next decades. There for sustainable waste management of non-biodegradable waste will lead to a resourceful power from rejected waste. The electricity generation rate is almost tripled and this generated power can be used in maintaining the waste management plant and other plants. Hence, electricity can be saved to much extent.

Table 8. Electricity generation

Year	Solid waste for power generation (Tons/year)	Waste generation (Tons/day)	MW per day of electricity produced	MW per year of electricity produced
2011	21049.47	57.67	0.58	210.49
2021	26720.72	73.21	0.73	267.21
2031	33038.84	90.52	0.91	330.39
2041	40005.99	109.61	1.10	400.06
2051	47637.98	130.52	1.31	476.38

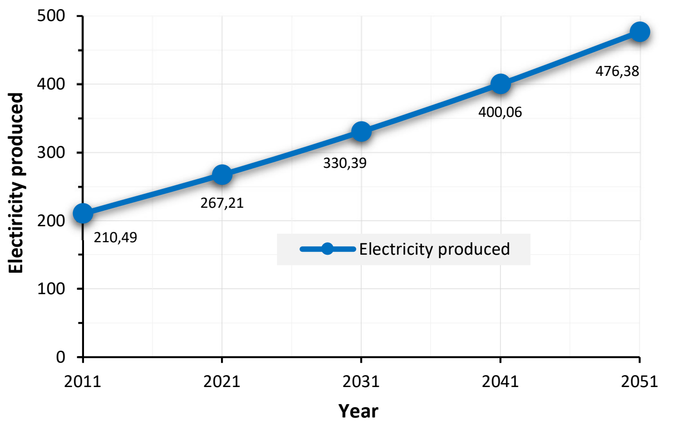

Fig. 5. Electricity generation

4.4.4. Revenue generation

The revenue generated from compost, biofuel and power generated can be found out for upcoming years (Table 9). The compost rate for 2011 is considered as Rs.10 per kg. For subsequent decade years, extra Rs. 5 per kg is added to compensate the time value of money. Therefore, compost rate for 2011, 2021, 2031, 2041, 2051 would be Rs. 10, Rs. 15, Rs. 20, Rs. 25, Rs. 30, respectively.

Table 9. Revenue generation

Year	Compost Revenue Generated in Rs. per year	Biofuel Revenue Generated in Rs. per year	Power Revenue generated in Rs. per year	Total Revenue Generated in Rs. per year
2011	10,13,88,279.10	1,02,247	1,02,24,720	11,17,15,246
2021	19,30,57,170.15	1,94,692	1,81,71,272	21,14,23,134
2031	31,82,74,141.60	3,00,910	2,88,87,336	34,74,62,387
2041	48,17,38,787.25	4,37,237	4,27,52,072	52,49,28,096
2051	68,83,68,738.90	6,07,425	6,01,64,000	74,91,40,164

The biofuel rate for 2011 is considered as Rs. 45/liter that is Rs. 45000/m^3. Adding Rs. 15 for every subsequent decade year to compensate the time value of money. Biofuel rate for Year 2011, 2021, 2031, 2041, 2051 would be Rs. 45, Rs. 60, Rs. 75., Rs. 90, Rs. 105 per m^3, respectively.

Similarly, the power generation rate for year 2011 is taken as Rs. 4000/MW. Adding Rs.1600 for every next decade year to compensate the time value of money. Power Generation Rate for year 2011, 2021, 2031, 2041, 2051 would be Rs. 4000, Rs. 5600, Rs. 7200, Rs. 8800, Rs. 10400 respectively (Table 9 and Fig 6). Represents the Revenue generated from compost, biogas and power production.

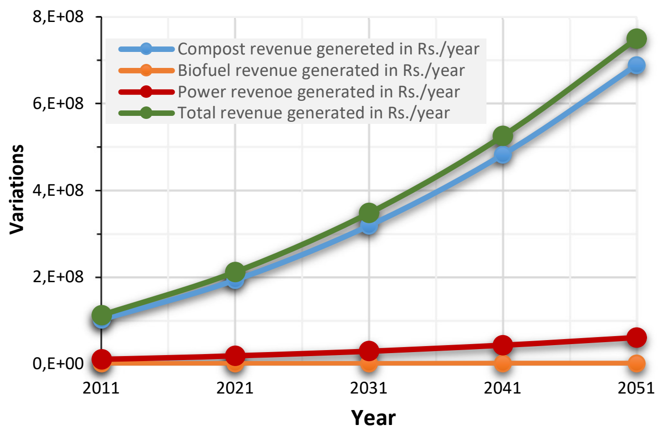

Fig. 6. Revenue generation

5. Conclusion

With the rapid pace of urbanisation in India and migration of village workers to urban areas, the solid waste generation is increasing thereby posing serious threat to environment and human beings. MSWM in India started from 1960, but has still not achieved any great success. Enforcement of effective legislations on take-back obligations should be in place. Therefore, appropriate planning and implementation of MSWM is crucial for maintaining sustainable development. The present case study highlights the significance of decentralized MSWM for Kolhapur district which provides different scenarios that already exists and new technologies that could be adopted. The solid waste generation for the projected population is calculated along with the quantity of value-added products that could be derived from this waste. These methods are not only minimizing environmental risks but have enough potential to maximize the economic and technical aspects of waste. It is acclaimed that segregation of waste, combining with electricity and biogas recovery would be the best option for MSWM. Moreover, these practices avoid the potential materials loss from MSW that increases the environmental and economic impacts. However, incentives and training to formal and informal sectors are highly needed to do segregation at source that minimizes the losses of energy and material. It can help in minimizing adverse impacts associated with MSW and fulfil the goals of sustainable development introduced by United Nations. The district of Kolhapur needs to innovate and evolve an efficient MSWM system with enough incentives, economic inputs and provisions which should be viable as well as socially acceptable. Since the major concern is the nature of mixed waste in MSW and its segregation, reduction of such organic waste generation by effective separate collection should be seen as an alternative route for effective MSWM. It helps in accelerating the recycling rate and seen as a resource for social, economic and environmental benefit. This can be achieved only through effective policy intervention which focuses more on alternate innovative pathways like separation at source; therefore, not following "control and command" route of policy formulation. Sustainable and economically viable waste management must ensure maximum resource extraction from waste, combined with safe disposal of residual waste through the development of engineered landfill and waste-to-energy facilities.

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