Renewable and Sustainable Energy Reviews

An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations

--Manuscript Draft--

Manuscript Number:	RSER-D-20-04221R2
Article Type:	Review Article
Section/Category:	Waste to Energy
Keywords:	Municipal Solid Waste; waste to energy; Landfill; Anaerobic Digestion; life cycle assessment
Corresponding Author:	Vivekanand Vivekanand, Ph.D. Malaviya National Institute of Technology (MNIT) Jaipur, INDIA
First Author:	Kishan Kumar Prajapati
Order of Authors:	Kishan Kumar Prajapati
	Monika Yadav
	Rao Martand Singh
	Priti Parikh
	Nidhi Pareek
	Vivekanand Vivekanand, Ph.D.
Abstract:	In developing countries, urbanization and rapid population growth has resulted in a substantial increase in generation of Municipal Solid Waste (MSW). Safe collection, transportation and treatment of MSW are among the major issues facing medium to large Indian cities. Poor MSW management practices have negative impact on public health, environment and climate change. India currently only treats 21% of MSW while the remainder disposed in unsanitary landfill sites with no recycling and treatment technologies . This paper reviews the existing MSW management practices, challenges and provides recommendations for improving MSW management for the city of Jaipur in Rajasthan state. Major challenges faced by Indian cities include uncontrolled landfilling, failings in the implementation of MSW (management and handling) legislation and inadequate public participation in management. Recommendations for improvement include public awareness campaigns, Public-Private Partnership (PPP), investment in lined landfills, recycling, waste to energy techniques (incineration, gasification, pyrolysis, anaerobic digestion), landfill gas recovery from MSW, improved optimization models to minimize cost as well as resources utilized in the MSW management and the use of life cycle assessment tools to minimize environmental impact. This study will provide policy makers and private sector stakeholders to develop strategies for future planning, investment and execution of improved MSW management in Indian cities.
Response to Reviewers:	Dear Editor, 20th Aug, 2021 RSER Thank you very much for the detailed review of our manuscript (Ms. Ref. No.: RSER-D-20-04221R1). Please find attached the revised version of our manuscript entitled “An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations” for kind consideration. Authors are grateful for the suggestions and comments given by reviewers which has helped to improve the quality of the paper. Kindly consider our detailed response to the reviewer’s comments given below. The changes made in the manuscript are obvious being in ‘Track change mode’. Page

and Line numbers mentioned below are as per in Track Change mode of revised manuscript.

We hope that the revised manuscript is suitable for publication in Renewable and Sustainable Energy Reviews journal.

Thank you very much in anticipation.

Yours sincerely
Vivekanand (on behalf of all the authors)

Reviewers and/or Editors' comments:

Reviewer #2:

The authors tried to improve the manuscript. However, still, there are many questionable issues.

1.In the response of 1st comment, why Jaipur city was selected for the proposed study. I am not satisfied with the authors' answer. To be honestly, this study has not a meaningful contribution considering the answer of this comment. Because, if other cities of India are experiencing good SWM then, its simple just take those policies and apply in this city. The authors should establish a technical and logical grounds to emphasize on the selection of Jaipur city for this study.
Response:
In Northern India, the major cities with high MSW generation are Delhi, Jaipur, Lucknow and Kanpur. Apart from the Jaipur city which is capital of desert state of India i.e. Rajasthan, all other city's MSW management system has been reviewed in the already existing reports in Literature. Though, there is no review that highlights the status of MSW management in Jaipur and underlying challenges. Hence, the selection of Jaipur city is based on information in R1 version as per details below:
(1) the importance of city (Page No. 18; Line No. 248 - 250)
(2) high MSW generation (Page No. 18; Line No. 250 - 251) and
(3) no literature availability (Page No. 2; Line No. 35-37).

The idea is also to make scientific community and people aware of the current status of Jaipur's MSW management and relevant work going on.

The second concern of the reviewer is that if other cities of India are experiencing good SWM then, why not take those policies and apply in this city.

As mentioned in the study, there is no single city of India, whose MSW management system can be termed as ideal due to the vast Indian subcontinent, climate, food habits as well as composition of MSW. Only Pune city is doing comparatively good in terms of MSW management. Though, the MSW management model of one city cannot be applied as it is to another city due to the difference in the MSW composition which in turn is affected by the lifestyle of population, eating habits as well as climate (Page No. 18; Line No. 241 - 247).

This is particularly significant for a country as diverse as India. Pune is located in southern India and is different from Jaipur in all aspects mentioned earlier. This is why geographical based studies usually come into play for specific location. Though some parts of management model of different cities regarding waste collection, segregation, awareness campaigns, PPP can absolutely be followed and authors has taken note of that in the corresponding sections of recommendation about which part of MSWM system of other cities can be adopted for Jaipur.

2.I am not satisfied with the section of 5.6. Application of life cycle assessment, how this section is related to the MSWM of Jaipur?
Response:
Life cycle Assessment (LCA) is very strong tool to evaluate, compare and analyse diverse environmental impacts by the different combinations of MSW management techniques so as to select a sustainable combination for a city. LCA tool can be used for analysing the possible impacts of waste management techniques before implementing them on ground level. Therefore, it is a part of recommendation as a future research area which needs to be explored by the waste management researchers for Jaipur city. These types of studies have been done so far for comparing the combinations of MSW management practices for Bangalore, Delhi and Mumbai [Reference No. 32, 63, 96, 97]. Though, for Jaipur, it has not been performed yet and hance recommended by the authors as future area for research which will certainly aid value to the study.

3.Quality of all Figures, especially Figure 2 is really poor. I cannot read the values in Figure 2.
Response:
Authors sincerely apologise for the same and have improved the quality and visibility of all figures including Figure 2.

4.In the response of comment 4, I am still unable to understand the impact of this too old data. How the authors think that this old data will help the policymakers to make a nice MSWM plans for Jaipur city?
Response:
There is some misunderstanding regarding this comment. Comment 4 in earlier reviewer's comments was: "In Table 1, the physical composition of MSW in Indian cities is given, but which cities". In response to this comment authors had modified table 1 by adding the column of cities as well as some more data. The data given in the table 1 has been taken from the graphs of reference [17] – Kumar et al., 2020 which is a recent study (Page No. 9-10).

5.In the response of comment 12, totally unacceptable answer, the authors failed to establish a marginal contribution in terms of new and different recommendation to handle MSW for Jaipur city. The answer of this comment is in totally contradiction with the answer of the comment 1. If these generic suggestions can be applicable for Jaipur based on their proven performance for other cities, then, why not the MSWM models of other cities can be applied in Jaipur?
Response:
Authors would kindly like to state that by generic recommendations, the authors meant the most basic starting points on which any MSW model is based, which are – collection and segregation of waste. There is no contradiction in authors stand regarding this. Authors have stated this in the response of comment 1 also, that no city of India has a perfect MSW model yet. Though some sections of MSW models from other cities can definitely be adopted for Jaipur regarding collection and segregation of MSW. However, the technical aspects of MSW management can be designed only by

doing proper feasibility analysis of different techniques and choosing the suitable option on the basis of MSW composition of Jaipur city which is different from other cities, as India itself is diverse country and Jaipur is capital of desert state of India i.e. Rajasthan. That is why the use of mathematical models, techno-economic analysis and tools like LCA are required to be taken as future studies to predict the suitable management technique or combinations of techniques which would be feasible to be implemented in Jaipur. Authors group has already started exploring some of these future research areas for providing solutions to Jaipur's MSW situation. Though, those studies will come into the scope of full research papers. The present study by the authors is a review that summarizes the scattered online and offline data regarding the current state of MSW management in Jaipur.

Editorial Requirements:
1.Submit the original manuscript showing clearly all textual changes using track changes. Just highlighting textual changes in yellow (or other colour) is not acceptable. This includes all edits related to reviewer(s) comments and the Editorial points.
Response:
The original manuscript has been revised in the "track change mode" with clearly indicating all changes done in the manuscript.

2.Submit the clean revised version of the manuscript.
Response:
The clean version of the revised manuscript has also been submitted.

3.Provide a 'Response to reviewers and Editor document' with a point by point response to each comment from the reviewer(s) and the Editor (i.e. points 1 to 7). Carefully and fully address the issues raised and refer to each comment from the reviewer(s) and the Editor clearly in the revised/edited/changed text in the marked-up copy of the original manuscript (e.g. line number X to Y on page X in the marked-up manuscript) in this response.
Response:
A "Response to reviewer and editor" document has been submitted providing point by point response to all comments of reviewers as well as editor along with mentioning the line numbers and page numbers (as appearing in Track Change mode).

4.Read the 'Guide for Authors' at https://www.elsevier.com/journals/renewable-and-sustainable-energy-reviews/1364-0321/guide-for-authors very carefully. It is the sole responsibility of the author(s) to ensure that their article is correct and meets RSER style and format fully in terms of contents and layout (e.g. authorship, order of authorship, addresses, article structure, keywords, abbreviations, nomenclature, captions on figures and tables, acknowledgement of those that helped and or funded the research including datasets, references).
Response:
Authors have gone through the "Guide for authors" carefully. The submitted manuscript is as per the journal format in terms of referencing style, citations, article structure etc.

5.Ensure that permission is attained for all copyrighted graphics, images, tables and/or figures. Note that for any figures, graphics or images published elsewhere by the author or others, the author(s) must arrange permission and this must be clearly stated in the 'Acknowledgements' section at the end of the article. If the author(s) cannot arrange permission, then the graphics, images, tables and or figure must be removed from the manuscript.
Response:
All the graphs, figures and tables provided in the manuscript are originally drawn and prepared by the authors. Hence, no permission is required.

6.Check the English carefully for grammar, spelling and syntax.
Response:
Authors have gone through the manuscript carefully to find the grammatical, spellings and syntax errors. The corrections have been made wherever required.

	7.Check your manuscript for intentional or unintentional plagiarism of your own work or work by others elsewhere. All author(s) must read 'Ethics in publishing' in the 'Guide for Authors' and 'Publishing Ethics' at https://www.elsevier.com/about/our-business/policies/publishing-ethics and 'Ethical guidelines for journal publication' at https://www.elsevier.com/authors/journal-authors/policies-and-ethics Response: Authors have read 'Ethics in publishing' in the 'Guide for Authors' and have checked the manuscript for intentional or unintentional plagiarism.

Dear Editor, 20th Aug, 2021
RSER

Thank you so much for the detailed review of our manuscript (**Ms. Ref. No.: RSER-D-20-04221R1**) and kind consideration.

Please find attached the revised version of our manuscript entitled "*An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations*" for kind consideration.

Authors are grateful for the suggestions and comments given by reviewers which has helped to improve the quality of the paper. Kindly consider our detailed response to the reviewer's comments given below.

The changes made in the manuscript are obvious being in **'Track change mode'** in the revised manuscript.

We hope that the revised manuscript is suitable for publication in *Renewable and Sustainable Energy Reviews* journal.

Thank you very much in anticipation.

Yours sincerely
Vivekanand (on behalf of all the authors)

Dear Editor, 20th Aug, 2021
RSER

Thank you very much for the detailed review of our manuscript (**Ms. Ref. No.: RSER-D-20-04221R1**).

Please find attached the revised version of our manuscript entitled “An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations” for kind consideration.

Authors are grateful for the suggestions and comments given by reviewers which has helped to improve the quality of the paper. Kindly consider our detailed response to the reviewer’s comments given below.

The changes made in the manuscript are obvious being in **‘Track change mode’. Page and Line numbers mentioned** below are as per **in Track Change** mode of revised manuscript.

We hope that the revised manuscript is suitable for publication in *Renewable and Sustainable Energy Reviews* journal.

Thank you very much in anticipation.

Yours sincerely
Vivekanand (on behalf of all the authors)

Reviewers and/or Editors' comments:

Reviewer #2:

The authors tried to improve the manuscript. However, still, there are many questionable issues.

1. In the response of 1st comment, why Jaipur city was selected for the proposed study. I am not satisfied with the authors' answer. To be honestly, this study has not a meaningful contribution considering the answer of this comment. Because, if other cities of India are experiencing good SWM then, its simple just take those policies and apply in this city. The authors should establish a technical and logical grounds to emphasize on the selection of Jaipur city for this study.

Response:
In Northern India, the major cities with high MSW generation are Delhi, Jaipur, Lucknow and Kanpur. Apart from the Jaipur city which is capital of desert state of India i.e. Rajasthan, all other city's MSW management system has been reviewed in the already existing reports in Literature. Though, there is no review that highlights the status of MSW management in Jaipur and underlying challenges. Hence, the selection of Jaipur city is based on information in R1 version as per details below:
(1) the importance of city (Page No. 18; Line No. 248 - 250)
(2) high MSW generation (Page No. 18; Line No. 250 - 251) and
(3) no literature availability (Page No. 2; Line No. 35-37).

The idea is also to make scientific community and people aware of the current status of Jaipur's MSW management and relevant work going on.

The second concern of the reviewer is that if other cities of India are experiencing good SWM then, why not take those policies and apply in this city.

As mentioned in the study, there is no single city of India, whose MSW management system can be termed as ideal due to the vast Indian subcontinent, climate, food habits as well as composition of MSW. Only Pune city is doing comparatively good in terms of MSW management. Though, the MSW management model of one city cannot be applied as it is to another city due to the difference in the MSW composition which in turn is affected by the lifestyle of population, eating habits as well as climate (Page No. 18; Line No. 241 - 247).

This is particularly significant for a country as diverse as India. Pune is located in southern India and is different from Jaipur in all aspects mentioned earlier. This is why geographical based studies usually come into play for specific location. Though some parts of management model of different cities regarding waste collection, segregation, awareness campaigns, PPP can absolutely be followed and authors has taken note of that in the corresponding sections of recommendation about which part of MSWM system of other cities can be adopted for Jaipur.

2. I am not satisfied with the section of 5.6. Application of life cycle assessment, how this section is related to the MSWM of Jaipur?

Response:

Life cycle Assessment (LCA) is very strong tool to evaluate, compare and analyse diverse environmental impacts by the different combinations of MSW management techniques so as to select a sustainable combination for a city. LCA tool can be used for analysing the possible impacts of waste management techniques before implementing them on ground level. Therefore, it is a part of recommendation as a future research area which needs to be explored by the waste management researchers for Jaipur city. These types of studies have been done so far for comparing the combinations of MSW management practices for Bangalore, Delhi and Mumbai [Reference No. 32, 63, 96, 97]. Though, for Jaipur, it has not been performed yet and hance recommended by the authors as future area for research which will certainly aid value to the study.

3. Quality of all Figures, especially Figure 2 is really poor. I cannot read the values in Figure 2.

Response:

Authors sincerely apologise for the same and have improved the quality and visibility of all figures including Figure 2.

4. In the response of comment 4, I am still unable to understand the impact of this too old data. How the authors think that this old data will help the policymakers to make a nice MSWM plans for Jaipur city?

Response:

There is some misunderstanding regarding this comment. Comment 4 in earlier reviewer's comments was: "**In Table 1, the physical composition of MSW in Indian cities is given, but which cities**". In response to this comment authors had modified table 1 by adding the column of cities as well as some more data. The data given in the table 1 has been taken from the graphs of reference [17] – Kumar et al., 2020 which is a recent study (Page No. 9-10).

5. In the response of comment 12, totally unacceptable answer, the authors failed to establish a marginal contribution in terms of new and different recommendation to handle MSW for Jaipur city. The answer of this comment is in totally contradiction with the answer of the comment 1. If these generic suggestions can be applicable for Jaipur based on their proven performance for other cities, then, why not the MSWM models of other cities can be applied in Jaipur?

Response:

Authors would kindly like to state that by generic recommendations, the authors meant the most basic starting points on which any MSW model is based, which are – collection and segregation of waste. There is no contradiction in authors stand regarding this. Authors have stated this in the response of comment 1 also, that no city of India has a perfect MSW model yet. Though some sections of MSW models from other cities can definitely be adopted for Jaipur regarding collection and segregation of MSW. However, the technical aspects of MSW management can be designed only by doing proper feasibility analysis of different techniques and choosing the suitable option on the basis of MSW composition of Jaipur city which is different from other cities, as India itself is diverse country and Jaipur is capital of desert state of India i.e. Rajasthan. That is why the use of mathematical models, techno-economic analysis and tools like LCA are required to be taken as future studies to predict the suitable management technique or combinations of techniques which would be feasible to be implemented in Jaipur. Authors group has already started exploring some of these future research areas for providing solutions to Jaipur's MSW situation. Though, those studies will come into the scope of full research papers. The present study by the authors is a review that summarizes the scattered online and offline data regarding the current state of MSW management in Jaipur.

Editorial Requirements:

1.Submit the original manuscript showing clearly all textual changes using track changes. Just highlighting textual changes in yellow (or other colour) is not acceptable. This includes all edits related to reviewer(s) comments and the Editorial points.

Response:

The original manuscript has been revised in the "track change mode" with clearly indicating all changes done in the manuscript.

2.Submit the clean revised version of the manuscript.

Response:

The clean version of the revised manuscript has also been submitted.

3.Provide a 'Response to reviewers and Editor document' with a point by point response to each comment from the reviewer(s) and the Editor (i.e. points 1 to 7). Carefully and fully address the issues raised and refer to each comment from the reviewer(s) and the Editor clearly in the revised/edited/changed text in the marked-up copy of the original manuscript (e.g. line number X to Y on page X in the marked-up manuscript) in this response.

Response:

A "Response to reviewer and editor" document has been submitted providing point by point response to all comments of reviewers as well as editor along with mentioning the line numbers and page numbers (as appearing in Track Change mode).

4.Read the 'Guide for Authors' at https://www.elsevier.com/journals/renewable-and-sustainable-energy-reviews/1364-0321/guide-for-authors very carefully. It is the sole responsibility of the author(s) to ensure that their article is correct and meets RSER style and format fully in terms of contents and layout (e.g. authorship, order of authorship, addresses, article structure, keywords, abbreviations, nomenclature, captions on figures and tables, acknowledgement of those that helped and or funded the research including datasets, references).

Response:

Authors have gone through the "Guide for authors" carefully. The submitted manuscript is as per the journal format in terms of referencing style, citations, article structure etc.

5.Ensure that permission is attained for all copyrighted graphics, images, tables and/or figures. Note that for any figures, graphics or images published elsewhere by the author or others, the author(s) must arrange permission and this must be clearly stated in the 'Acknowledgements' section at the end of the article. If the author(s) cannot arrange permission, then the graphics, images, tables and or figure must be removed from the manuscript.

Response:

All the graphs, figures and tables provided in the manuscript are originally drawn and prepared by the authors. Hence, no permission is required.

6.Check the English carefully for grammar, spelling and syntax.

Response:

Authors have gone through the manuscript carefully to find the grammatical, spellings and syntax errors. The corrections have been made wherever required.

7.Check your manuscript for intentional or unintentional plagiarism of your own work or work by others elsewhere. All author(s) must read 'Ethics in publishing' in the 'Guide for Authors' and 'Publishing Ethics' at https://www.elsevier.com/about/our-business/policies/publishing-ethics and 'Ethical guidelines for journal publication' at https://www.elsevier.com/authors/journal-authors/policies-and-ethics

Response:

Authors have read 'Ethics in publishing' in the 'Guide for Authors' and have checked the manuscript for intentional or unintentional plagiarism.

An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations

Kishan Kumar Prajapati[1], Monika Yadav[1], Rao Martand Singh[2], Priti Parikh[3], Nidhi Pareek[4], Vivekanand Vivekanand[1]

[1]Centre for Energy and Environment, Malaviya National Institute of Technology, Jaipur 302017, Rajasthan, India.

[2]Department of Civil and Environmental Engineering, Norwegian University of Science & Technology (NTNU), Trondheim 7034, Norway

[3]Engineering for International Development Centre, Department of Civil, Environmental and Geomatic Engineering, University College London, Chadwick Building, Gower Street, London, WC1E6BT, United Kingdom.

[4]Department of Microbiology, School of Life Sciences, Central University of Rajasthan, Bandarsindri, Kishangarh, Ajmer, Rajasthan 305801, India

*Corresponding author. Tel.: + 91 141 2713573 E-mail: vivekanand.cee@mnit.ac.in

ABSTRACT

In developing countries, urbanization and rapid population growth has resulted in a substantial increase in generation of Municipal Solid Waste (MSW). Safe collection, transportation and treatment of MSW are among the major issues for Indian cities. Poor MSW management practices have negative impact on public health, environment and climate change. India currently only treats 21% of MSW while the remainder disposed in unsanitary landfill sites with no recycling and treatment technologies. This paper reviews the existing MSW management practices, challenges and provides recommendations for improving MSW management for the city of Jaipur in Rajasthan, India.

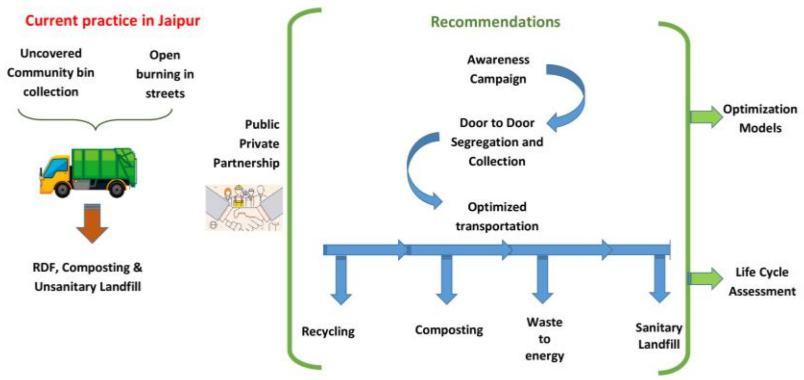
Despite being the state capital as well as the top tourist destination in northern part of India, there is no detailed study which reviews the waste management strategies of this city along with identifying the key challenges. The study reveals that the major challenges for MSW management in Jaipur include uncontrolled landfilling, inadequate public participation as well as failings of implementation of MSW legislation and waste conversion.

Recommendations for improvement include public awareness campaigns, public-private partnership, investment in lined landfills, recycling and waste to energy techniques.

Optimization models and life cycle assessment tools should be employed to minimize cost and the environmental impact of MSW management. This study will provide policy makers and private sector stakeholders to develop strategies for future planning, investment and execution of improved MSW management in Indian cities.

Keywords: Municipal solid waste; Waste to energy; Landfill; Anaerobic digestion; Optimization models; Life cycle assessment

Graphical Abstract



List of abbreviations

AD	Anaerobic digestion
BLF	Bioreactor landfilling
CPCB	Central Pollution Control Board
CDC	Centre for Communication Development
GIS	Geographic information systems
GHG	Greenhouse gas
JMC	Jaipur Municipal Corporation
LFGR	Landfill gas recovery
LCA	Life cycle assessment
MoEF	Ministry of Environment and Forests
MSW	Municipal solid waste
MSWM	Municipal solid waste management
NGO	Non-governmental organizations
PPP	Private-public partnership
RDF	Refused derived fuel
SEG	Socio-economic group
SPCB	State Pollution Control Board
TPD	Tonne per day
ULB	Urban local bodies
VS	Volatile solid

1. Introduction

Rapid urbanization, industrialization, and population growth have resulted in substantial increase in rates of solid waste generation in urban centers. As per United Nations, the 52% population of world was urban in 2011 and it is estimated to reach to 67.2% till 2050 [1]. This increase will transform the social structure, living standards, resource utilization as well as waste generation by people. The generation rate of municipal solid waste (MSW) can be directly correlated to the economic growth of a country i.e., gross domestic product and population density [2, 3]. Annual worldwide total solid waste generation is approximately 17 billion tonne per year, and this sector contributes to 16% greenhouse gas (GHG) emissions responsible for global warming [2, 4].

In developing countries such as India, typical per capita, MSW generation rate is about 0.49 kg/day which is lower than the 1-2.5 kg/day waste generation rates in developed countries. In future, waste consumption and generation patterns in developing countries will replicate those in developed nations. Currently, India handles 62 million tonne MSW per year [5]. However, the collection and treatment efficiency of the country is around 90% and 27% respectively. Remaining untreated MSW at present itself is a major problem which would sustain in a disastrous way [6]. Jaipur city having 3.04 million population, is the capital of Rajasthan state where a rise in infrastructure development and living standards has led to waste generation amounting to 1000 tonne per day (TPD) [7, 8]. This quantity of waste is one-third of the total waste generated by entire Rajasthan state.

Most of the Indian cities failed to have the desired level of municipal solid waste management (MSWM) due to the shortage of financial resources and technology, and lacking in sustainable planning and execution. MSWM effectiveness in a city should keep pace with the growth of that city [9, 10]. Increase in waste generation in Indian cities makes the management of MSW and its handling a critical problem. This needs targeted action from key stakeholders involved in the management of MSW in any city including Municipal Corporation of city, MSW generators i.e., public and private institutions (offices, hotels, restaurants, markets and other commercial sectors), non-governmental organizations (NGOs) and private contractors. Waste generated in large quantity requires a system of collection, segregation, storage, transportation, treatment, and disposal. There are several MSWM method to cut down the volume of the waste such as its minimization from source itself, waste 3 R's ("Reduce, Reuse and Recycle") strategy, incineration, composting and anaerobic digestion (AD); however, unscientific or unsanitary landfilling is the most adopted approach for MSW disposal nationwide as it has been a relatively simple and economical mode of MSW disposal [11, 12].

Figure 1 shows a four-tiered integrated solid waste management hierarchy to guide MSWM decision-making according to the type of waste. Knowledge of composition of MSW is important for selecting the suitable waste processing and disposal practices since MSW volume and its composition differs considerably with the places having changes in food habits, cultural traditions, lifestyles, socio-economic conditions, and climate [4, 13]. Integrated MSWM based on varying MSW composition is required to recover materials, compost and renewable energy from MSW and residues to reduce the quantity of MSW reaching landfill sites [12].

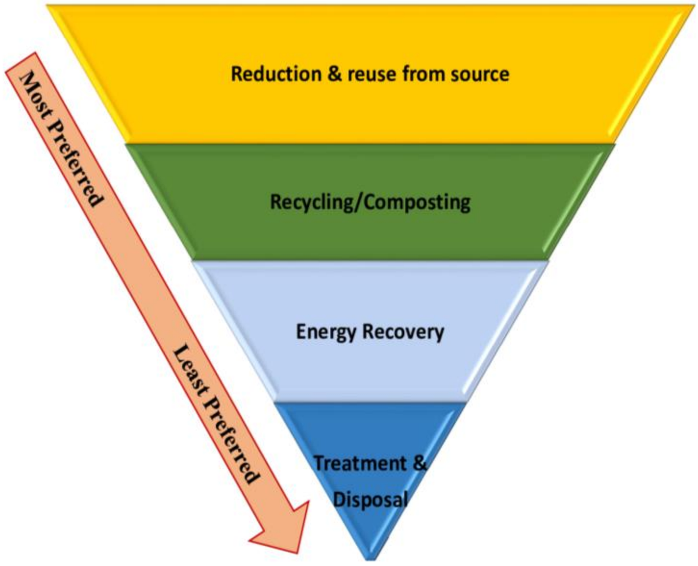


Figure 1. Integrated solid waste management hierarchy [14]

This study reviews the present status of MSWM for Indian cities more broadly and specifically for Jaipur city and provides recommendations for improvement. Further, the study provides the list of waste management technologies adopted in the other cities of India as well as around the globe to convert the waste to energy. The review further compares these technologies in terms of energy potential and economic feasibility. The life cycle assessment (LCA) and optimization done by other studies have also been summarized to elaborate the applicability of these tools for predicting the most suitable method for implementing the waste conversion technologies resulting in highest energy yield with minimum emission and cost. This review would enable regulatory bodies such as the State Pollution Control Board (SPCB), Urban Development Authority and Municipal Corporation to improve the waste management processes in the Jaipur city and tackle the issues in systems. Moreover, this study may also be helpful for the other cities of developing countries around the world which

Formatted: Centered

are facing the similar issues to tackle the accumulating waste due to lack of proper treatment method as well as policies regarding them.

2. Current scenario of MSW in India

***'**Solid waste'* includes solid or semi-solid domestic waste, sanitary waste, commercial waste, institutional waste, catering and market waste, and other non-residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture, dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-waste, battery waste, and radioactive waste" [15]. MSW (Management and Handling) Rules, 2000 issued by Ministry of Environment and Forests (MoEF), Government of India, regulates appropriate collection, segregation, transportation, treatment and disposal of solid waste. Under these rules, Municipalities are authorized to implement measures for improving MSW and submit annual reports to the Central Pollution Control Board (CPCB). Parameters such as the quality of ambient air and groundwater, leachate, compost and standards of incineration are required to comply with respective standards and monitored by CPCB as well as SPCB. Currently there is a gap between regulation and enforcement in most Indian cities. [10, 16, 17].

Key features in revised rules i.e. solid waste management rules 2016, extended to urban and industrial areas, are mandating the solid waste source segregation to have its recovery, reuse and recycle; integration of informal system i.e. unauthorized rag pickers and waste dealers into the formal system; prohibition of waste throwing, burning, and burying in public spaces, if violation of rules found, generator will have to pay 'spot fine'; manufactures of sanitary products should provide the suitable wrapping material with it for its safe disposal; introducing partnership concept for bulk waste producers (hotels, institutions, restaurants, event organizers, new townships and societies) to segregate, sort and handle the generated waste by associating with local bodies; all brand owners or manufactures shall have to provide the required financial aid to local authorities for MSWM; non-recyclable waste (Calorific Value >= 1500kcal/kg) should be used directly for energy production or as input for generating refused derived fuel (RDF) [15].

Being one of the fastest growing economies and the second most populated country in the world, India is facing the upsurge in MSW generation in the cities. With changing lifestyles, Indian cities are now generating more MSW with an estimated increase of 1-1.33% per annum. Currently in India, only 15-20% of MSW is segregated, 21.45% of MSW is processed or treated and remaining 78.55% MSW disposed at unsanitary landfills. Open dumping was 90% in 2008 and showed only 11.45% waste diversion from open dumping in last decade [10, 18]. Moreover, the projection of MSW generation for urban inhabitants revealed that the MSW generation rate (kg/capita/day) is approximately two times of the urban agglomeration rate [19].

MSW contains 50-60% organic fraction composed of majorly food waste and its untreated disposal i.e., uncontrolled decomposition causes rotting, severe impacts on local public health and foul odor due to methane generation which is a GHG [20,21]. Reliable characterization of MSW requires a large number of MSW samples being analyzed over the cities of India. Physical composition of MSW for Indian scenario is shown in Table 1. MSW collected from different cities of India contains approximately 40-62% biodegradable content and 11-24% recyclable content [17]. Average household MSW composition consists of around 70% organic fraction [22-24].

Table 1: Physical composition (%) of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio

1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	45	12	43	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

MSW generations in major~~35~~ metro cities of India are reported by CPCB are shown in Figure 2. It exhibits trend of waste generation per day in last 10~~5~~ years (in the year of 2004-05~~, 2010-11~~ and 2015-16) in major~~35~~ metro cities. Larger metro cities such as Mumbai and Delhi have a very high rate of waste generation and are currently leading in waste generation with up to 11000 and 8700 TPD waste generation respectively. In Delhi, openly dumped MSW was observed to be the highest in the low socio-economic neighborhood with 61 kg per capita per person per year [25].

Socio-economic conditions i.e., education level, family income, occupation and household size play significant role in MSW generation in the society. A study performed in Dhanbad city, India regarding these factors divided society into five socio-economic group (SEG) based on above mentioned four factors. It concluded that middle and lower middle SEG has the highest per capita waste generation due to comparatively more family members. Comprehensive study of waste composition in different SEGs shows high food and plastics wastes generation from higher SEG, whereas lower SEG generates lesser food waste due to different standard of living [267]. Impact of socio-economic factors on MSW generation in Bangalore city shows positive relation with family income, whereas negative relation with education level and household size [23].

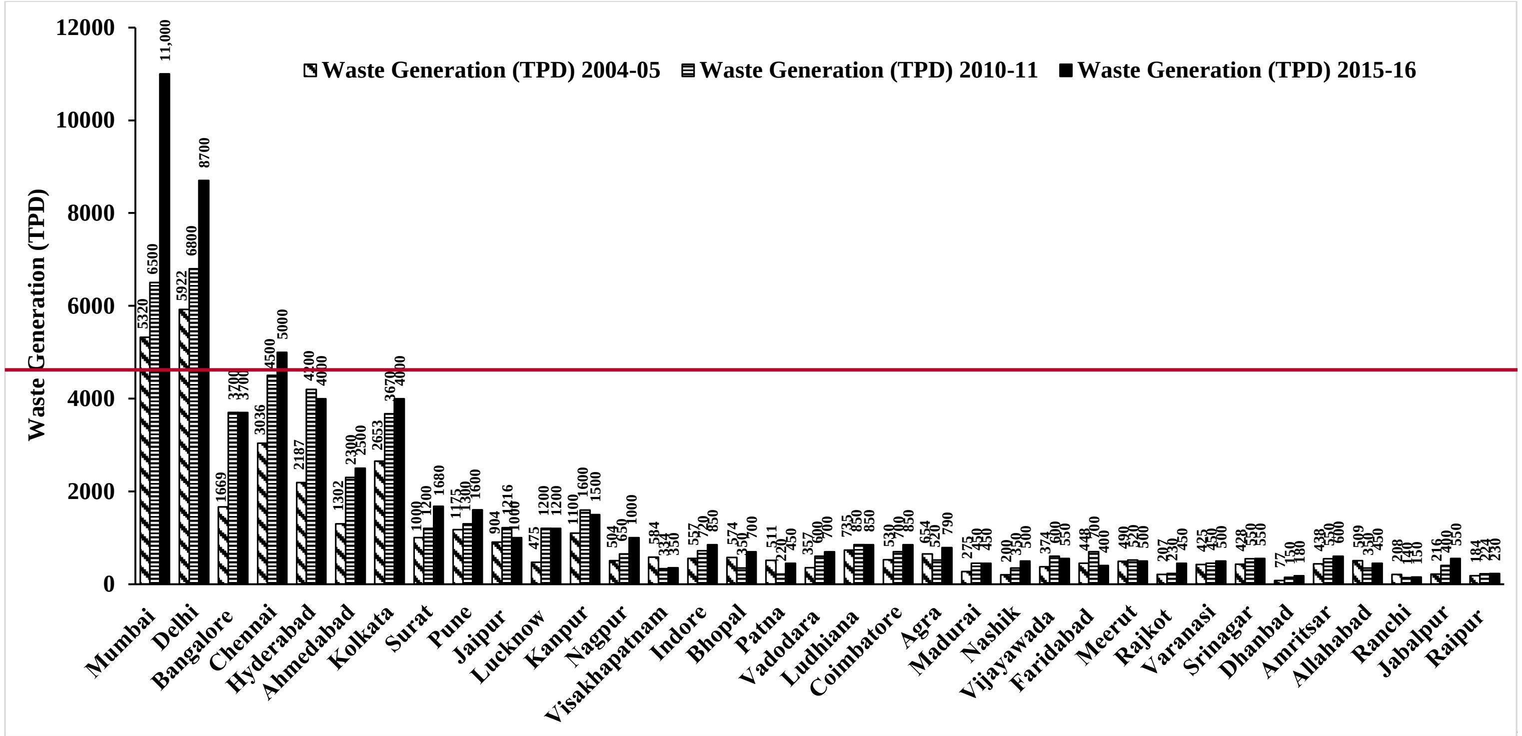
In Indian system, the residential solid waste in the household is stored in a single plastic container (16-20 L capacity) in a mixed form including both dry and wet waste. The collected waste is then dumped by the residents to the nearby community bins (4.5-6 m^3 capacity, metallic or concrete) without segregation. The door-to-door collection is practiced only in few wards of metro cities, through handcarts or tricycle with the help of NGOs. Residential and market waste is also dumped on the open roads either due to negligence of waste generator or inadequate presence and capacity of community bins. All street and road wastes are collected by sweepers using wheelbarrows and thereafter dumped it into nearby community bin. Community bins are mostly uncovered i.e., easily accessible to rag pickers and animals, they litter the waste around the bin in the search of recyclable waste and food respectively, thereby dispersed waste on the street and creating the unhygienic conditions. The dispersed waste sometimes reaches to the nearby drainage system causing it to be blocked. The major problem for municipality arises from low and middle-income residential areas where the waste is dumped on narrow streets, or behind houses instead of putting it in nearby bins [24, 278, 289]. Due to this poor-practice, these areas remain inaccessible to waste collecting workers for some days.

Private contractors are involved in metro cities for transportation of MSW from community bins to dumping sites. Tractors, ordinary trucks, pay loader, compactors, tippers and dumper placer vehicles are usually used for waste transportation. Though many of them are outlived which run with low efficiency and high fuel consumption [19, 2930, 301].

Except few cities like Delhi, Pune and Hyderabad, all Indian cities transport MSW to the dumping sites where uncontrolled landfilling is practiced (Table 2).

Current management strategies adopted for handling MSW in some major Indian cities are highlighted in Table 2. Almost all cities have no source segregation of MSW while some cities perform MSW segregation by engaging workers. Few cities have poor collection efficiency and no source segregation is performed except Bangalore and Pune. Composting and unsanitary landfilling is a very common strategy practiced for waste management in most of the Indian cities. Pune is the only city where waste management practice is appreciably effective by integrating segregation, composting, waste to energy plants and scientific landfilling. There are less significant research updates regarding MSWM of Northeast Indian cities. In Dibrugarh town of Assam, open dumping site is located near the Brahmaputra river contaminating the river ecosystem as well as affecting the health of humans and animals. The health hazards become more severe during rainy seasons causing water pollution and water-borne diseases [2930].

229


Waste Generation (TPD)
12000
10000
8000
6000
4000
2000
0
Waste Generation (TPD) 2004-05
Waste Generation (TPD) 2010-11
Waste Generation (TPD) 2015-16
Mumbai
Delhi
Bangalore
Chennai
Hyderabad
Ahmedabad
Kolkata
Surat
Pune
Jaipur
Lucknow
Kanpur
Nagpur
Visakhapatnam
Indore
Bhopal
Patna
Vadodara
Ludhiana
Coimbatore
Agra
Madurai
Nashik
Vijayawada
Faridabad
Meerut
Rajkot
Varanasi
Srinagar
Dhanbad
Amritsar
Allahabad
Ranchi
Jabalpur
Raipur

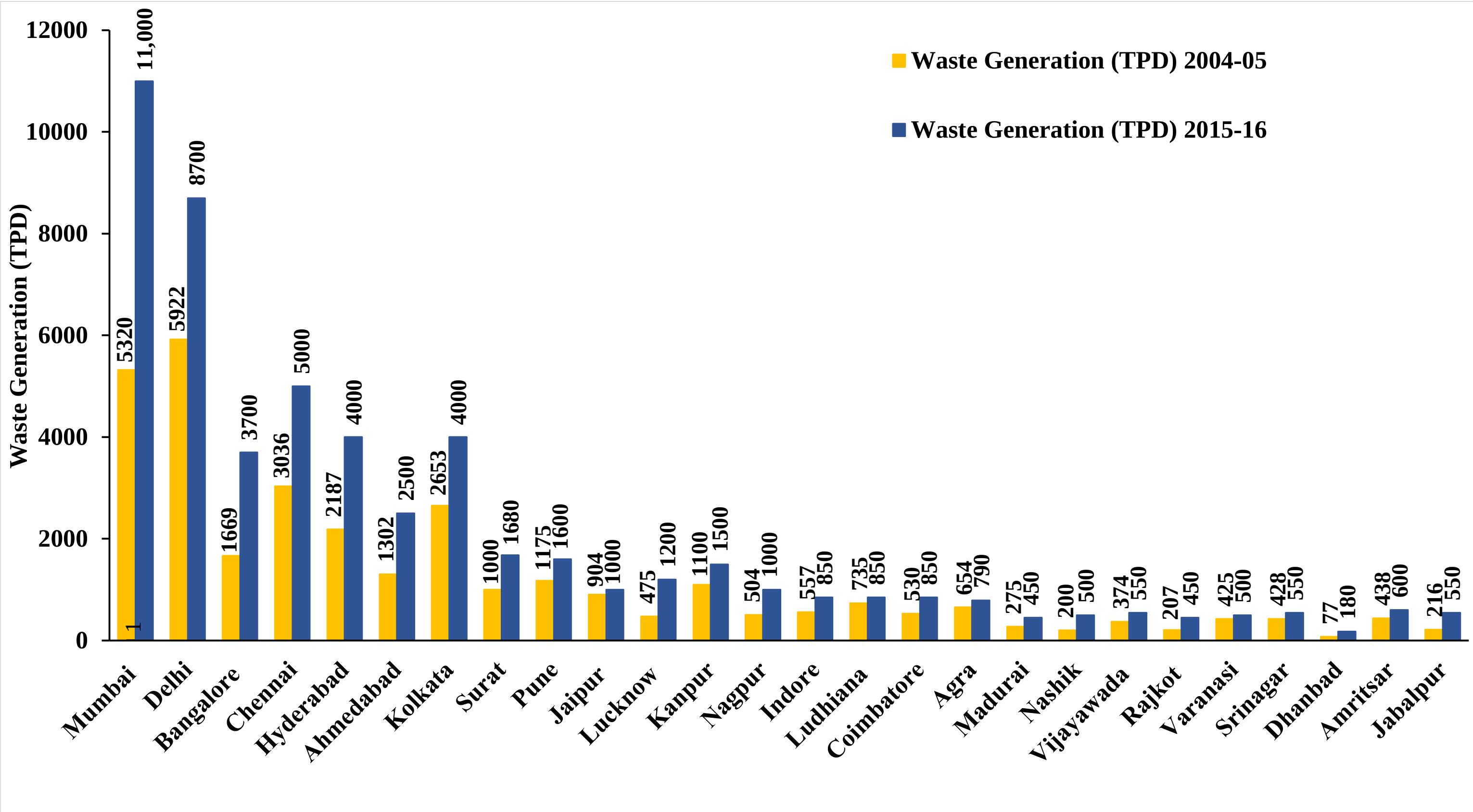


Figure 2. MSW generation trend in major Indian cities [7]

Formatted: Normal, Line spacing: Double

Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,278]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,312]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R’s hierarchy of management and waste to energy technology	[323]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[334,345]

Delhi	Y	Y	Y	R-Informal, C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[356,367]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[378,389]
Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[3940]
Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[401]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[412]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[423]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[434,445]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[456]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]

Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[467]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[478]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[312,489]
Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[4950]
Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[312]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[312,501]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,267]

Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective strategy, (no.) –number in the bracket represents the number of respective facilities.

3. Municipal waste management in Jaipur city

The previous section provided status of waste management in some of the significant cities of India. The waste management strategies followed by these cities are largely based on the MSW composition which in turn vary according to the lifestyle and eating habits of citizens, food resources as well as the climate of the city [51]. While, these studies of other cities of India are helpful in solving the specific waste management issues; the MSWM model of one city cannot be implemented as it is to another city of India due to varying climate conditions and lifestyle which changes drastically in India.

Jaipur city, capital of Rajasthan the largest state of India, is one of the future smart cities of India and famous for its tourism and hospitality. In 2019, the city has been declared as UNESCO world heritage site. As shown in Figure 2, It is also a major city in north India along with Delhi, Kanpur and Lucknow with high waste generation rate. With an area of 467 km^2 and the entire city is divided into 91 wards. Since 2011, the wards are distributed in 8 Municipal Corporation zones: Vidhyadhar Nagar, Civil Lines, Mansarovar, Sanganer, Moti Dungri, Hawa Mahal East, Hawa Mahal West and Amer. Jaipur Municipal Corporation (JMC) has the constitutional responsibility of collection, transportation, treatment and safe disposal of MSW generated in the city. Currently, Jaipur city has MSW flow in its management process as shown in Figure 3.

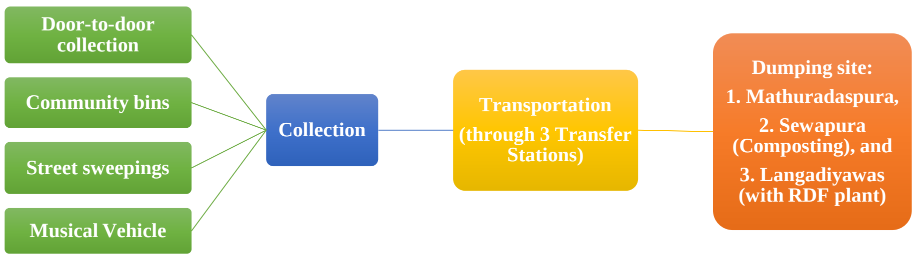


Figure 3. MSW flow in Jaipur [278]

3.1. MSW composition and characteristics

MSW in Jaipur comprises three key components [334, 52]:

1. Biodegradable (organic waste): Food waste, garden waste (grass, fallen leaves and tree trimmings), wood etc.
2. Recyclable waste: Paper (paper is classified as organic only when it is tainted by organic material), cardboard, plastics, metals, glass etc.
3. Inert and other wastes: Textiles, leather, paints, rubber, multi-laminates, medicines, sanitary products and inert materials (stones, silt, ash and inorganic material).

MSW composition and chemical characteristics viz. moisture content, volatile solids (VS), calorific value and elemental composition etc. of MSW in Jaipur city are shown in Figure 4 and Table 3 respectively. As shown in Figure 4, approximately 45% portion of MSW collected in Jaipur was reported in 2018 to be biodegradable while 43% content was composed of ash and fine earth particles [17].

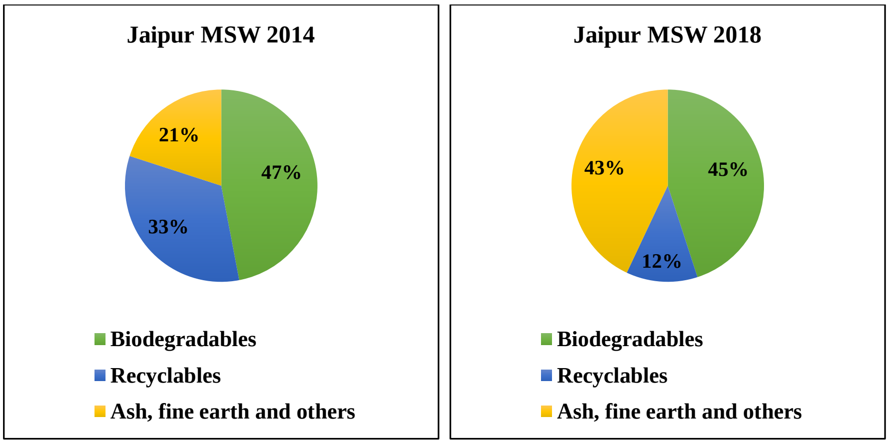


Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

Table 3: Chemical characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV (kCal/kg)	C	H	N	S	O	P (P_2O_5)	Potash K_2O
Values (%)*	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

*Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids, CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen, P=Phosphorus.

3.2.Cleaning and collection

The door-to-door waste collection method is not adopted in Jaipur city by JMC, and rather some wards are implementing it through informal sectors by paying them reasonable amount per month. Sometimes, a portion of MSW left unattended and remained as open dumped waste. Jaipur city has collection efficiency of MSW around 85% [11, 12]. In this collected MSW, 18-24% contents are recyclable including paper, plastic, rubber, ferrous and non-ferrous metals. However, 15% out of total recyclable waste is collected by rag pickers for their livelihood and traded to scrap buyer informally [10].

JMC staff require more health inspectors and sweepers for respective wards as per a study conducted [11]. Permanent and temporary street sweepers on daily wage basis are deployed for cleaning the city. Street sweeping and community bins are the primary collection methods of the waste. Total 1794 community bins of 3 sizes i.e., 1.1 m^3, 3 m^3 and 7 m^3 capacity have been installed [11]. Still, many wards are left without having any garbage container causing more disorder with respect to waste collection.

It has been observed that the city~~town~~ does not segregate the waste at source and dump it into the municipal bins, open spaces and drains. Many of the community bin's waste are scattered around by animals which causes unhygienic conditions. Some ward's road cleaning is performed daily while remaining wards are cleaned periodically i.e., once or twice a week.

Street waste cleaning, de-silting the surface drains and collection tasks performed by sweepers using a wheelbarrow and transferred to community bins. Since recyclable waste segregation is not practiced, it is usually found mixed in the community bins [11].

3.3. Transfer station and transportation

The collected garbage from community bins is transported to the secondary storage points or transfer station and then to the disposal sites using dumper placer and compactor vehicles. Currently, Jaipur has 3 transfer station at Lal Dungri, Vidhyadhar, and Jhalana having capacity of 400, 250, and 150 TPD respectively. Uncovered or open body type trucks tend to spill waste gradually on the road causing unhygienic conditions on the roads. A vehicle's waste collection frequency is around 2-4 times daily due to lack of transfer stations in other zones. Therefore, 3 more transfer stations are proposed in Mansarover, Bambala Pulia and Sushilpura to cover the zones which are far away from disposal sites and to minimize the time, money and fuel consumption during waste transportation. Transportation system alone consumes more than 60% funding from the total fund assigned for the MSWM [11, 12].

3.4. Treatment and disposal facilities

For MSW disposal, Jaipur city has currently 3 dumping sites: Mathuradaspura, Langadiyawas, and Sewapura as shown in Figure 5 on Jaipur map and main features are discussed below [11, 12].

1. Mathuradaspura dumping site: It is located at 17 km distance from the main city, having capacity up to 400 TPD of MSW with total area 0.285 km^2.
2. Sewapura dumping site: It is situated at 20 km from the city, with site area 0.324 km^2 having a capacity of 300 TPD. It has a compost processing facility of 350 TPD operated by Infrastructure Leasing & Financial Services Limited.
3. Langadiyawas dumping site: It has a total area of 0.782 km^2 out of which 0.065 km^2 is allotted for RDF processing facility and 0.16 km^2 for Sanitary Landfilling (under

construction). M/s Grasim Industries constructed an RDF processing facility producing 150 TPD RDF from 500 TPD MSW at Langadiyawas and transported to a company UltraTech Cement Limited in Neemuch, Madhya Pradesh, to generate energy for cement production.

MSW undergoes many transformations before converting to RDF such as removal of dangerous and large items (i.e., big stones, batteries, dead animals, machines) by workers and then load into pre shedder to have granular size of 0-200 mm. Subsequently, the shredded waste is sent into an integrated conveyor installed magnetic separator removing all metals from waste. Further separation of sand and grit from organic waste is carried out by trommel screen. The heavier pieces like glass and ceramics are passed through the ballistic separator. Thereafter, organic portions are sent for further size reduction up to 0-50 mm, resulting in mixed waste as raw materials for RDF. This garbage for RDF has low calorific value, so plastics purchased from Sainath Enterprises are added. This RDF application in cement plant brings carbon credit to the firm and 9-15% saving of coal burning. This facility recovers 5-6% RDF instead of 30% from MSW received because of the inadequate technology and mixing of construction debris with the MSW [278].

Figure 5. The landfill locations in Jaipur city [11, 12]

Currently, total 500 MSW TPD i.e., 50% of total MSW treated either as composting or converted into RDF. JMC proposed a waste to energy plant in Mathuradaspura site for remaining MSW which is being disposed unscientifically at this moment [11]. Uncontrolled dumping is practiced in all of 3 disposal sites, prone to leachate production which can cause ground and ground water pollution and may create vectors for propagating various diseases. Moreover, these sites are without pollution monitoring facilities, proper fencing and fly control [12]. Ground water from eight sites near Mathuradaspura were sampled and some of them show high content of naturally available fluoride and total dissolved solid which may cause fluorosis and gastro intestinal irritation respectively to the nearby residents [11, 12].

3.5.Private-public partnership (PPP)

JMC has been using PPPs model to sub-contract some of its MSWM responsibilities to individual corporations (NGOs or private companies). Two private companies are handling composting and RDF treatment facility in Jaipur MSWM [11]. Two NGOs the Centre for Communication Development (CDC) and Satya were engaged on MSWM related activities.

Satya provided labor in Jaipur to lead a successful program in handling the waste and dumping the MSW. Satya was also engaged in door-to-door collection in Vaishali Nagar, Chitrakoot and ward no.20 with charging INR 20-30 a household per month in 2005-07. However, due to poor facilitation from JMC, difficulties in payments, inadequacy in management, the partnership was discontinued after two years of the contract. Another NGO, CDC started few projects for better urban MSWM regarding collection and transportation. Again, JMC could not support their projects financially and hence CDC ceased their work and focused on other social services in Jaipur city [27~~8~~].

3.6. Case studies

Singh [12] carried out a survey of two regions of Jaipur city viz. Tonk Phatak and Malviya Nagar and concluded that stronger social network or high-income areas have better MSWM or living condition than low-income societies. Here, social network means friendship, social contacts and interactions among the influencing people and common people. Dissatisfaction level found to be high in Tonk Phatak area as a result of lack of community bins and waste collection system with respect to MSWM. While, Malviya Nagar was found to be more socially connected and where MSW was carried away daily. Tonk Phatak area people were willing to pay some money to get their locality clean and hygienic. On the other hand, Malviya Nagar locality somewhat disagreed for the same. The survey in these two areas found that 90% people~~s~~ do not have awareness~~ among people~~ about the fate of waste.

A case study performed by Gandhi et al. [20] in Jaipur metropolitan revealed the amount of food waste generated from hotel sectors. The study reported that food waste (14.9 kg/day) generation from 4-5 star rated hotels is almost threefold as compared to 2-3-1 star rated and unrated hotels. Only 34% hotels out of surveyed 70 hotels perform segregation of food waste, out of which 84% are of 3-5 rated hotels. An educational institute survey study revealed that MSW generated from the campus consisted of food waste, plastics, paper, metal, glass, and garden trimming etc [53]. Total collected waste was directly transported to the city's dumping site. Segregation was not performed and waste treatment facility have not been adopted within the campus [53]. A feasibility study of organic waste energy potential in another institutional campus shows that the mixed food and green waste has biogas potential of 400-660 mL/g VS of mixed substrate [54]. The study suggested that there was a need for developing composting and AD plant for the organic waste generated within the campus, with segregation of recyclable waste. Another study performed the multi feed anaerobic co digestion of mung bean husk and wheat straw with organic fraction of MSW. The co-digestion was observed to increase 37% methane production with respect to AD of organic fraction of MSW only [55].

4. Challenges pertaining to MSWM in Jaipur

The main difficulties with MSWM in Jaipur city are firstly the social negligence from public side to have segregation and proper disposal of solid waste due to either lack of knowledge of its long-term harmful impacts on habitats and environment or their irresponsibility towards their fundamental duty of protecting environment. The second major challenge is governance as the municipal corporation continues to practice waste dumping at the outskirts of the city with no planning and safe waste treatment practices. Unlined and uncovered landfilling is the worst option when accounting its groundwater contamination, land degradation and environmental and health impacts causing from breeding infectious diseases majorly due to leachate and landfill gas. Sometimes, Jaipur city also faces burning of MSW piled in streets or grounds, producing highly toxic gases composed of dioxins, CO, hydrocarbons, volatile organic compounds, oxides of sulfur, and hazardous fumes etc. Municipality and public have not been sensitized about the increasing adverse effects of wastes on local environment i.e., contaminating air, water and land making hard for living beings to survive [17, 56].

Major technical problem for MSW treatment is mixed MSW i.e., non-segregation of organic waste for its utilization into biogas and compost production which is the most suitable waste management technique for Indian Scenario. In 2008, India's installed energy recovery from waste was 86.32 MW and currently in 2021, it is 168.64 MW, which is very less in comparison to MSW generation rate within the same time period [57, 58]. Biomass power generation (4831.33 MW in March 2016 to 10145.92 MW in March 2021) by combustion route and biomass cogeneration in sugar mills in India is highly progressive. On the other hand, there is no substantial focus on waste to energy conversion techniques in last 13 years even though MSW increment rate has been high [57, 58]. Even many installed composting, RDF and waste to energy plants have been failed due to insufficient waste segregation, inefficient management, operational problems like deficient logistical planning and adequate financing. Other problems in prospects of energy recovery facility are feasible technologies, inadequate financial support and quality of waste i.e., contamination occurs during collection and transportation, lack of appropriate storage facility, and lack of expertise in government. These problems were listed and recognized after consultation with urban local bodies (ULBs), industries, and academics [20, 59]. Since most of the Indian cities are rapidly developing, there is a pressing need of effective and sustainable waste management practices in every city.

5. Recommendations

Various feasible and well-practiced techniques in some cities of India as well as at global scale are recommended in this section to tackle challenges of Jaipur city as well as other Indian cities having similar scenario of MSW quantity and composition.

5.1. Awareness campaigns to increase public participation

A most prominent stakeholder is community or public and their inclusion at various levels of waste management process will lead to effective as well as efficient MSWM [301]. In general, "Waste" is supposed to be not useful for people which need to be thrown away. Therefore, the opinion on waste needs to be changed and it should be considered as a resource rather than waste [278]. For this, firstly JMC needs to organize awareness programs assisted from NGOs and educational institutes for reducing the MSW at source, making residents aware of waste categories i.e., organic, recyclable, non-biodegradable and other hazardous waste, so that community would start segregating domestic MSW into biodegradable and non-biodegradable waste. Further, people can be encouraged to start home composting for gardening purpose along with educating them with potential health impacts from poor MSW management. Awareness programs can be arranged through public group meetings, seminar, workshops, newspapers, media, radio, and television networks involving active participation from local bodies [12, 389].

Food waste generation in different hospitality sectors at hotels and restaurants is high in a city like Jaipur which is well known for tourism and hospitality. Strategies for mitigating food waste from hospitality sector include: making customers and staff aware through showing signage and posters regarding reducing the food wastage, imposing fine over food leftovers (possibly well-mentioned in the food menu), management of serving size, serving smaller plates that avoids people to take extra food, serving again leftovers if food is not spoiled, often revising the menu based on most of the food leftovers and offering the non-consumed food to food banks and low-income communities through support of NGOs. Segregated food waste provides the chance to recover energy from it such as biogas and compost production. Food waste management from hospitality sector also needs to be improved in terms of reducing food waste and its handling i.e., segregation, and effective subsequent utilization [20].

Door-to-door collection in pre-organized time slots with gentle alarming sound, is essential even though this will require more manpower and wheel barrows or handcarts containing 2-3 different colored bins. Door-to-door collection must be stringent and should strictly collect the properly segregated waste. Once household waste collection is improved, concepts like “Bin free city” or “Zero dustbin city” may be introduced in Jaipur which have been successfully implemented in Ambikapur city of Chhattisgarh. Similarly, Maharashtra’s Nagpur city has also reduced the community bins number to 80% of total to encourage door-to-door collection of MSW [22, 29~~30~~]. Government can introduce the competitions and winning rewards in different zones in the same city for sanitation and cleanliness which would encourage the public participation. Moreover, MSW collectors and sweepers should be provided training, steady disinfection of the dhalaos (transfer station), safety uniforms, and equipments and regular monthly wages. They must be provided with personal protective equipment like gloves, shoes and air filter masks while cleaning and handling the wastes to prevent eosinophilia, respiratory disorders and infection or contagious diseases [50~~1~~, 60].

A study in Jaipur highlights that the placement of community bins should be equitable in terms of regional coverage and not just be based on social connections [12]. Bigger bins must be placed near the party venues, marriage halls and institutions, which generate larger volumes of MSW in a day. All community bins must be covered so that it would be accessible to humans only avoiding waste dispersion by animals. ~~Transportation of MSW is energy intensive with significant emissions.~~ For transportation, o~~O~~ld and inefficient vehicles should be ~~avoided/~~discarded and~~ also transporting vehicles should be~~ covered properly to prevent waste scattering on roads.

5.2. Improvement in existing composting and landfill facilities

The biological conversion of organic fraction existing in MSW into a compost/humus through bacterial activity i.e., oxidizing the organic compounds in the presence of air, is called composting. In anaerobic composting, microorganisms break down the organic compounds in the absence of air through reduction process while metabolizing the nutrients [61]. This compost has good fertilizer quality for agriculture application. Many metro cities have MSW composting capacity between 150-500 TPD. Vermicomposting is also practiced in Mumbai, Bangalore and Faridabad where organic waste is decomposed by aerobic microorganisms followed by disintegration through earthworms [10]. Similar measures can be adopted for Jaipur city as well. Organic feedstocks in vermicomposting are generally animal, agricultural, food waste, and sewage waste. The processing periods for vermicomposting may be ranged between 28-120 days and conditions for the process can be varied between 18-67^{o}C temperature, 5.9-8.3 pH and moisture content 11-80%, yielding compost as bio-fertilizer rich in nitrogen, phosphorous and potassium [62].

Many studies highlighted the irreparable damage caused through uncontrolled open landfilling sites and suggested sanitary landfill for final MSW disposal [323, 401, 63]. Jaipur city must have sanitary landfill provisions for safe disposal of MSW by either transforming the existing open landfills to sanitary landfill or establishing waste to energy plant [301]. Sanitary landfill design must follow the procedures of MSW 2016 guidelines regarding site selection, environmental examination i.e., environmental impact assessment-, near to the treatment facility if possible, and away from dwelling areas and water bodies. There must be urgent cessation of existing dumping sites near rivers or any water storage facility like well, pond, lakes.

Advancement in landfill technology may lead to the development of bioreactor landfilling (BLF), which serves as storage as well as treatment of waste. BLF facilitates rapid degradation of organic waste through microbial action due to increase in moisture content via leachate recirculation. The process may achieve faster landfill gas generation to have energy production from it. This type of landfilling also enhances the waste stabilization and its features such as waste degradation, storage, landfill gas collection and faster stabilization make it an environmentally sound landfill as compared to other landfill systems. Diversion of MSW streams to recycling, composting and waste to energy technologies may avoid the possibility or development of landfill gas recovery (LFGR) system as no organic waste reaches to landfill site avoiding biological actions for gas production [19, 63].

5.3. Informal sector integration and public private partnerships

The efficient MSWM in Jaipur city also calls for the provisions of a governing body to administer rag pickers and scrap dealers. The rag pickers can be integrated with the formal system by providing training and facility of precautionary measures as well as the regular monthly wages along with preventing the scrap dealers to take any advantage of rag pickers. Their incorporation with the formal system would enhance the recovery of the recyclable materials [12, 50~~1~~]. Recently, a study in Brazil has advocated the socio-economic inclusion of scavengers for addressing the challenge of MSW management through their active participation in waste collection and increasing their quality of life through income generation as well as ensured health and safety at work [64].

Due to lack of investment and experts in waste treatment field, responsibilities like collection, transportation, treatment and disposal can be shared between NGOs, private companies and municipality. For instance, collection and segregation can be handled by NGOs~~, using resources provided by municipality while~~ transportation~~ can be handled~~ by municipality and~~. Similarly,~~ design, construction and operation of treatment and disposal facilities~~y~~ ~~may be handled~~ by ~~a~~ private companies~~y~~. This model has been followed by Delhi by collaborating with 3 different companies for MSWM in six zones of Delhi [27~~8~~]. PPP model is a significant way and profitable business for private investors which have adequate planning, experts and infrastructures to have well-organized MSWM. For instance, Praj Industries Ltd, Pune has introduced the safer production of biodiesel, fuel ethanol, bio-CNG (Compressed Natural Gas) and liquid manure from the organic content of MSW by solvent extraction, fermentation, and biomethanation in an integrated manner [44~~5~~].

Circular resource efficiency can be achieved by using recyclables from MSW as raw materials for recycled new products. Increasing cost of new materials and non-renewable energy makes that case for recovery of material from waste as an economical and sustainable way for recycling. Recyclables can include newspapers, plastics, glass, aluminium, metals, construction and demolition debris. Recovery of recycling materials mainly consists of screening of undersize material and shredding followed by magnetic separation for ferrous metal. Getting some revenue from recyclables may ease the waste management budget as well as cut down the cost regarding its treatment and disposal, thereby reducing the landfill burden. ~~Engagement of private sector into manufacturing industry has huge potential in having recyclables as input raw materials. This can be a perfect trade mechanism for generating job opportunities as well as minimizing the dependence on non-renewable resources.~~ Overall, recycling alone is the most economical and energy efficient process that avoids the enormous embodied energy of a virgin new material and also evades the GHGs emissions due to the virgin material energy consumption [9, 19].

5.4. Adoption of waste to energy techniques

For a developing country like India, rapid economic development requires energy and resources to progress. With depleting fossil reserves, future energy demand can be addressed through the alternative sources of energy i.e., renewable energy. At present, India has 2554 MW potential as renewable energy potential from waste generated i.e., MSW and waste water [33~~4~~, 65]. Waste to energy can play effective role in production of renewable and sustainable energy. In Jaipur, the MSW consisting organic and inorganic portions may be utilized for biofuel and power generation.

MSW's quantity, characteristics, composition, physical properties, land availability, environmental safety, financing, stakeholder's involvement, and capability of organizations are major criteria for selection of appropriate technology. Cities alone generating more than 1000 TPD (like Jaipur) should opt for waste to energy technologies as it would be sustainable as well as economical. If the thermal route is to be adopted, the enhanced calorific value of waste should be ensured by proper segregation of MSW [66]. The recovery of energy from waste offers many additional benefits i.e., total waste quantity gets reduced by 60-90% depending upon the waste composition and adopted technology; demand for land for landfilling would reduce; the cost of transportation to far-away landfill sites would reduce; and most importantly net environmental pollution would be minimized [11]. Further, the pros and cons of individual waste to energy technologies are shown in Table 5. Recommendations for making waste to energy technologies viable in Indian cities are to introduce contracts for waste collections and deliveries, control on storage sites preventing contamination, increase the public participation by educating and making aware, more funds to ULBs or municipality authority to support waste to energy projects [59].

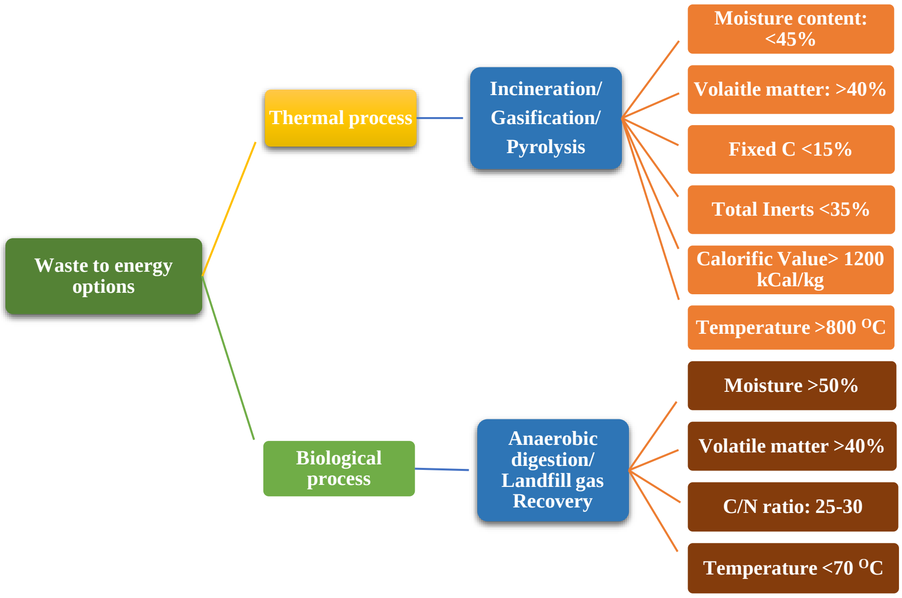


Figure 6. Waste to energy options with operating parameter's desired ranges [18]

5.4.1. Thermal conversion

Thermal conversion process entails thermal decomposition of MSW to produce either heat energy or fuel oil or gas. The objectives of thermal waste to energy are recovering the energy potential from the waste, destroying toxic substances in organic and inorganic waste, saving the natural energy resources for energy production, reducing the waste quantities for disposal and transforming the residuals into reusable secondary products to save material resources. Thermal treatment plants require high installation and operational cost as well as the experts in the field [10]. It is convenient to have waste as a fuel resource containing a high percentage of non-biodegradable matter and low moisture content. The main technological options under this category include incineration, pyrolysis and gasification. Main operating parameters during thermal conversion to energy require desired ranges for proper functioning are shown in Figure 6. Moisture content, volatile content and temperature are the crucial parameters for incineration, pyrolysis, gasification and AD as well. Though the thermal conversion techniques require much higher temperature (>800ºC) as compared to biological conversion method. The volatile matter in the waste should be at least 40% in order to be feasible for waste to energy conversion.

5.4.1.1.Incineration

Incineration is a similar process like the combustion i.e., complete burning of solid waste in presence of sufficient air at 980 to 2000^{o}C, converting MSW's chemical energy into heat energy and generating electricity through turbine-generator system [10, 11]. Raw MSW is generally preferred. Incineration depends on the characteristics of waste which in turn affected by the socio-cultural, seasonal and demographic differences [67]. However, segregated combustible non-biodegradable waste having calorific value greater than 1000 kcal/kg should be selected for this treatment. Moisture content and inert waste reduce the calorific value of MSW and affect its combustibility. Stages in incineration process are - drying, incineration, energy recovery from combustion, and flue gas cleaning for air pollution control. Ash produced, in the end, can be utilized in road construction and building materials like fly ash brick. Through this treatment process, incineration of 1 tonne of MSW is capable of generating 544 kWh of energy and 180 kg of solid residues [68]. In General, around 0.7-1.2 mg CO_2 is released from incineration of 1 mg MSW incineration [69]. Though, it may be different for Indian MSW incineration scenario due to dissimilar compositions. Indian cities hardly practice this technique due to undesirable characteristics i.e., high moisture content, high inert content and low calorific value of MSW [10, 18].

5.4.1.2.Gasification

Gasification is the combustion of solid waste into gas mixture (H_2, CO, CO_2, CH_4, H_2O and inert gases) under deficient oxygen conditions at high temperature 800-900^{o}C. Syngas (majorly H_2 and CO), the main product of gasification, can be used to produce renewable energy and as a feedstock for production of chemicals like methanol and liquid fuels. This system mainly includes the gasifier, gas cleaning configuration and energy recovery system. Generally, it is installed for agricultural residues and forest wastes in India. However, it can also be used for MSW by drying, inert removal and chopping prior to gasification of MSW [10, 33~~4~~, 70]. Its integration with combined cycle, where conversion of gaseous fuel to electricity by gas turbine have overall high conversion efficiency ranges 40-50% for 30-60 MW capacity plant [71]. The process is widely used in Japan with 85 MSW operating gasification plants as well as at a smaller scale in USA, Germany, Norway, UK and Italy [68]. This technology is comparably better than incineration in terms of cost, flue gas cleaning and output products and can be explored for MSW management in Jaipur city.

5.4.1.3.Pyrolysis

Pyrolysis is another thermal conversion technology in which biomass converted to liquid (bio-oil or bio-crude) and gases, in devoid of oxygen at 400-800^{o}C temperature range. The process parameters are temperature, the rate of heating, residence time, waste composition, and waste particle size. Lower temperature pyrolysis products are pyrolysis oil, wax and tar. However, quality pyrolysis gases (CO, H_2, H_2O, N_2, hydrocarbons) are produced at a higher temperature (>700^{o}C). Some developed countries like Japan, UK and France are operating MSW pyrolysis plants successfully. Integration of MSW pyrolysis with a gas turbine for energy recovery may lead to a net conversion efficiency of 28-30% [68].

5.4.2. Biological conversion

The biological conversion process is based on the enzymatic decomposition of organic matter by microbial action to produce biofuel i.e., biogas, bioethanol, and bio-diesel. Biological processes are preferred for waste having a high percentage of biodegradable matter and high level of moisture content, which aids microbial activity. The main technological options under this category are AD (or bio-methanation) to produce biogas and fermentation to produce biofuel like ethanol [11, 18].

5.4.2.1. Anaerobic Digestion

Organic matter is degraded by bacteria in controlled anaerobic conditions to generate biogas i.e., mixture of CH_4 and CO_2 and traces of water vapor, H_2S, NH_3, etc. The AD process is composed of series of 4 stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis [72]. Controlling parameters are volatile content, temperature, pH, and carbon to nitrogen (C/N) ratio. The lignocellulosic organic matter is undesirable for AD process without adequate pretreatment, as its hydrolysis is difficult due to the presence of lignin [66, 73, 74]. It is capable of generating 300-400 m^3 biogas per tonne of VS of organic fraction of MSW [18]. One tonne of MSW composed of 60% organic matter and remaining is moisture which may produce 150 kg of methane through AD process. Purified biogas after removing CO_2 and H_2S gas can be used as transportation fuel, called as Bio-CNG [68]. AD of untainted food waste has attractive option of management, nutrient recycling and bio-methanation having potential of 410-530 ml biogas/g VS of food waste [75].

5.4.2.2.Landfill Gas Recovery

Complex biological and chemical decomposition of organic matter of MSW dumped results in landfill gas production. Landfill gas emissions composed of mainly methane and carbon dioxide gases. Waste composition (primly organic fraction), moisture content, waste age, ash content, temperature and precipitation are major factors affecting the rate of methane gas production. Landfill gas has methane potential of 100 m^3/tonne of organic fraction of MSW which is capable of being trapped and utilized as green energy production [76]. Landfill accounts for 13% of global CH_4 emission considered as one of the major anthropogenic methane emissions [289]. Its reduction and recovery consequently reduce GHG emission. If landfill gas could be recovered, it is capable of generating 72 MW of electricity in India [5]. Since most of the landfill sites are not designed considering recovery of landfill gas, it is infeasible to trap landfill gas and therefore its on-site burning is chosen [289,76,77].

Standard protocols used internationally for landfill gas estimation are first order decomposition models i.e., LandGEM, mass balance model, modified triangular method developed by Intergovernmental Panel on Climate Change. These models need to incorporate meteorology data for site specific estimation. The on-field methods are flux chamber technique, vertical radial plume mapping and differential absorption LiDAR techniques [77,78]. Flux chamber method has been used for estimating CH_4 and CO_2 emission fluxes which are 68 and 92 mg/min/m^2 respectively, which are severe in summer in comparison to winter season for northeast city Guwahati [77]. A specific model has been developed for methane estimation from landfill sites in Indian climatic conditions, which is validated in three different climatic cities: Shillong, Jaipur and Kolkata [78].

RDF, waste to energy and LFGR methods involve renewable energy recovery from MSW through clean development mechanism projects, as they can result into 40,308-1,252,206 tonne of CO_2 equivalent reduction in GHG emission, which will bring carbon credits and make the projects financially attractive [79].

5.4.3. Energy and economic aspects of waste to energy techniques

The specific energy potential of waste to energy technologies have been summarized in Table 4 [55, 68, 80]. On the basis of these energy potentials, further calculations were done to estimate the total saving of diesel fuel as well as GHG emissions for using the energy from these plants to replace the diesel for power generation. As reported by Prajapati et al. [55], 1 tonne of organic fraction of MSW has the potential to generate 192.582 m^3 biogas through AD. 1 m^3 of biogas generates 2.04 kWh electricity with 35% efficiency [80]. Utilizing diesel for heat and power generation results in GHG emissions of 2.68 kg CO_2 per L of diesel burned [81]. These emissions can be saved by replacing the diesel from biofuel generated from organic fraction of municipal waste. Similarly, GHG emission from landfill of MSW is

1230 kg of CO_2 per tonne of MSW [82]. These GHG emissions from landfills can be saved by using waste to energy technology.

Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy Technologies

Technology	Specific Energy potential (kWh_e/tonne)	GHG emissions and cost savings				
		Diesel Fuel saved (L)	USD ($)	GHG from Diesel Generator (kg of CO2)	GHG from landfill (kg/tonne)	Total GHG (kg of CO_2) saved
AD	393*	90.36	106.62	242.16	1230.00	1472.16
Incineration / RDF	544	125.12	147.64	335.32	1230.00	1565.32
Gasification	400	92.00	108.56	246.56	1230.00	1476.56
LFGR	163	37.54	44.29	100.60	1230.00	1331.60

*kWh/tonne of Organic fraction of MSW

For cost analysis of these technologies, the key parameters to be considered are: cost of land acquisition, technology installation, feedstock, operation and maintenance cost as well as labor cost. From economic assessment perspective, incineration technique is the more suitable choice as compared to complex gasification technology as it requires low cost for implementation and installation. Gasification has the operational cost of around 0.250 million USD/day. Still, gasification is the most attractive technology considering environmental assessment as it can reduce more than 3208 TPD of carbon emissions [83]. In India, most of the gasifiers uses coal, agricultural, and agro-industrial waste. Therefore, the MSW with similar energy content can also be used as a co-fuel in appropriate blend for energy production. However, further research and optimization of this strategy is required to reduce its capital cost. Hybrid technologies can also be explored for combining MSW conversion with other renewable energy technologies for making MSW viable as fuel. A recent study suggested a hybrid solar-biomass system in which AD of MSW was combined with concentrated photovoltaic to generate heat and power form the system [84].

A biomass RDF plant feasibility was evaluated with net present value as profitability method and also sensitivity analysis performed to evaluate critical factors like pellet price, capacity utilization and annual working hours for plant economy. The study concluded a minimum selling price as USD 120 per tonne of pellet for plant feasibility [85].

In developing countries like India, the economic viability of waste to energy technology requires comprehensive study of cost parameters for initial investment, cash inflow and outflow estimation as well as sensitivity analysis of influencing parameters. There is a scope of techno-economic evaluation of waste to energy technologies using economic metrics net present value and levelized cost of energy considering economic value of produced electricity, thermal energy and products, and specially accounting ecological benefits, reduction in current MSWM costs.

Table 5: Pros and cons of different waste to energy techniques [10, 334, 68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	• Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume	• Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	• Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning	• Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	• Production of fuel oil	• Heterogeneity in MSW • Char removal is important • Yield stream is complex

		• Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent)	
Biological conversion	AD	• Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer • Control GHG emissions, with net environmental gains are positive • Potential for co-digestion with agricultural and industrial organic wastes • Less monitoring is required • Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill	• Requires organic waste segregation • Not suitable for complex organics, oily, or lignocellulosic materials • GHGs, fouling, and fire threats if leakage is present
	LFGR	• Least cost option • Collected gas can be used power generation, and thermal application • Reduce environmental and health impact, reduce GHG emissions	• Expertise and monitoring required • Higher transportation cost and need larger land area • Leachate problem if landfill is not scientific

5.5. Application of optimization models

Mathematical and optimization models robustly used for planning and optimizing the MSWM infrastructure to make MSWM as sustainable management reducing usage of fossil fuels. Extrapolation of past data is inaccurate and unreliable way for forecasting of waste generation rate, as it greatly affected by socioeconomic factors whose selection should be significant to the local situation. Mathematical modeling methods of solid waste streams for the precise prediction of waste generation and its rate have been benefitted the MSWM in terms of viable future planning. Models concerning generation of waste having key variables of socioeconomic factors like household size, waste volume, education level of households, income level of households, and environmental awareness, etc. in a district area, and in a similar way over the country. Linear regression technique is used to develop model the forecasting of biodegradable and non-biodegradable waste generation rate and also analyzing the accountable variables in Dhanbad city [86]. Waste collection streams data: mixed waste, source separated waste, and treatment decisions also used for modeling of waste prediction. Models include mostly correlation and regression models, single regression analysis and multiple regression analysis, system dynamic, and artificial intelligent system (genetic algorithm, artificial neural network, and fuzzy logic) for multivariable analysis [87].

Nganda [88] developed a mathematical model actings as a technique to optimize the use of management facilities (like number of trucks, incineration plants, landfill capacity, etc.) to reduce total waste management cost and ensuring optimal use of resources. It results to provide suitable information in decision-making to have a planned and efficient waste management system. Same model was used in Hong Kong, waste streams between collection centers, replacement truck warehouse, incinerators, and landfill were formulated using mixed integer programming for identifying the number of trucks required between two points and same in the whole system and waste amount reduced by 42% in landfill with their present strategy [89]. In a similar way, management facilities can be minimized by using mathematical models in Jaipur scenario with existing operating facilities.

An integrated model of geographic information systems (GIS), equation-based model and agent-based model effectively used to minimize collection cost by 11.3%, by reducing travel length and time making efficient collection and transportation system [90]. Das and Bhattacharyya [91] proposed an effective MSWM in Bidhan Nagar municipality under metropolitan Kolkata city, by optimizing length route in its transportation using travelling salesman problem. Travelling salesman problem can be robustly used for optimizing the path length for waste transportation amongst the waste source, collection points, transfer stations, treatment facility or landfill, will majorly reduce the management cost and emissions from the transportation part. Cost effective collection and transportation process considering the locations of dustbin, transfer station, road network, composting unit and dumping site, is optimized with help of GIS and remote sensing in Vellore city of India, and achieving 59.12% reduction in travel distance in the transportation [92]. Thus, reducing natural resource consumption and making the management as sustainable approach.

5.6. Application of life cycle assessment tools

Different MSWM strategies can be compared and evaluated by using LCA tool which helps in determining the environmental implications, energy consumption and cost of the different combination of management strategies [93-95]. LCA makes it easier to identify the processes which have a significant impact on the environment. SimaPro, GaBi, WISARDTM and EASEWASTE are widely used software for LCA.

Babu et al. [63] evaluated 4 disposal scenarios in Bangalore city: open dumping, landfilling without gas recovery, landfilling with gas recovery and BLF to find out sustainable and economical disposal using LCA tool. The study revealed BLF as best option with least Global Warming Potential (3335 kg CO_2) and photochemical ozone creation potential (0.379 kg) per tonne of waste, and faster waste stabilization inducing more energy recovery from MSW and also with lesser payback period (50 years) than others. Another study assessed the cost and environmental impacts of 4 management options under LCA tool in the selected wards of Bangalore: 1. Existing system i.e., recycling, composting and rest of MSW transported to landfill site; 2. With optimal route transportation; 3. Vermicomposting of 62% MSW (biodegradable) and rest landfilling; 4. Incineration of entire waste. The results of the study showed that the second option with optimal route transportation and least amount required USD 409750 per annum was the best on the basis of ecological, economic and social aspects [96].

LCA performed for integrated MSWM in Delhi concluded that the recycling facility has negligible emissions and energy consumption. Landfilling has comparatively less negative environmental impacts in the beginning year as compared to incinerators. However, it produces highest GHG emissions among all MSWM afterwards [367]. For the same city, Bohra et al. [97] compared 12 different integrated MSWM scenarios involving RDF, AD, composting and sanitary landfilling including existing MSWM i.e., 9% composting and rest to landfill site as baseline scenario. While the global warming potential (226.92 kg CO_2 eq.) was revealed to be least for the scenario having major diversion of organic waste from landfilling to treatment facilities to RDF pelletisation (16%), AD (16%) and composting (10%).

A study in Mumbai city compared six different scenarios including the current practice of open dumping with partial BLF and other five integrated approaches of different combinations of recycling, AD, composting, incineration and landfilling with 50% gas recovery. The study reported least GHG (930.01 kg CO2 eq. per tonne) emission for the combination of recycling, AD and landfilling [323]. LCA study carried out in non-metro city Dhanbad compared four management strategies of collection + transportation + landfilling;

recycling + open burning + open dumping + landfilling without energy recovery (LFWER); composting + LFWER; and recycling, composting and LFWER. It concluded that the management strategies comprising recycling, composting and landfilling without energy recovery had the least environmental impacts (global warming potential - 3430 kg CO_2; terrestrial ecotoxicity - 0.872 kg C_2H_4 eq.; acidification - 4.63 kg SO_2 and eutrophication 1.99 kg PO_4^{3-} per tonne of MSW) as recyclables, organic and inert materials subjected to respective treatment or disposal facility [56].

The outcomes of the environmental evaluation of different MSWM scenarios in a city provides crucial information to decision makers when planning sustainable waste management strategies. LCA study of MSWM in Jaipur city will greatly help to identify and quantify the environmental impacts caused either by waste or different treatment processes. This may help the managing authorities to choose the best and environmentally appropriate process among the possible treatments.

6. Conclusions

Jaipur city faces significant problems including unregulated landfilling, inability to enforce MSW (management and handling) regulations and insufficient public involvement in the management process. The study inferred that composting and unsanitary landfilling are the most prevalent method for waste disposal in Jaipur as well as other Indian cities with no proper installed facilities for waste conversion. Even the installed facilities are less suitable and inefficient due to the lack of segregation of waste during collection.

On the basis of this review, the key conclusions and recommendations for MSW management for Jaipur cities can be summarized as below:

- Different stakeholders (municipality, private sectors, public and informal sectors) are required to work together by taking specific responsibility in MSWM stages aiming to have maximum material and energy recovery from MSW.

- There is a need to actively work with local communities to raise awareness for waste segregation processes.
- There is a large scope and urgent need of development of recycling plants, feasible waste to energy technology and scientific landfill in Jaipur complying environmental standards regarding emissions.
- The mathematical or optimization model can be applied in Jaipur MSWM robustly, which would optimize the resource utilization, minimize management facilities, time and expenditure.
- LCA study in Jaipur city of practicing or possible MSWM scenarios would be helpful to identify the technology or treatment process having least impact on the environment which should be favored first.
- More research is required regarding the economic and environmental gains from recycling and energy generation facilities in the context of Jaipur city.

Acknowledgements

Authors are thankful to Department of Science and Technology, (Grant No: Grant No. ECR/2016/000989) and Department of Biotechnology (Grant No. BT/RLF/Re-entry/04/2013) Government of India for providing the financial support to carry out the present study. The fourth author is also grateful to the Royal Academy of Engineering, BBOXX and UCL for supporting her five-year fellowship.

Conflict of interest:

The authors declare that they have no conflict of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Cheela VS, Ranjan VP, Goel S, John M, Dubey B. Pathways to sustainable waste management in Indian Smart Cities. J Urban Manag 2021 (In press). https://www.sciencedirect.com/science/article/pii/S2226585621000364#sec4

[2] Yadav P, Samadder SR. A global prospective of income distribution and its effect on life cycle assessment of municipal solid waste management: a review. Environ Sci Pollut Res 2017;24(10):9123-41.

[3] Shekdar AV. Sustainable solid waste management: an integrated approach for Asian countries. Waste Manag 2009;29(4):1438-48.

[4] Mboowa D, Quereshi S, Bhattacharjee C, Tonny K, Dutta S. Qualitative determination of energy potential and methane generation from municipal solid waste (MSW) in Dhanbad (India). Energy 2017;123:386-91.

[5] Planning Commission Report. Reports of the task force on waste to energy (Vol-I) (in the context of Integrated MSW management). 2014. http://164.100.161.239/reports/genrep/rep_wte1205.pdf (Accessed 05 June 2021).

[6] Annual Review Report 2014-15. Implementation of Municipal solid wastes (Management and Handling) Rules, 2000. Central Pollution control board, Ministry of Environment, Forest and Climate Change, Government of India. April 2016. https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2014-15.pdf (Accessed on 05 June 2021).

[7] Municipal solid waste, Central Pollution control board, Ministry of Environment, Forest and Climate Change, Government of India. https://cpcb.nic.in/uploads/MSW/trend_46_cities_list.pdf (Accessed 05 June 2021).

[8] Population Census 2011, India, http://www.census2011.co.in/.

[9] Nandan A, Yadav BP, Baksi S, Bose D. Recent scenario of solid waste management in India. World Sci News 2017;66:56-74.

[10] Sharholy M, Ahmad K, Mahmood G, Trivedi RC. Municipal solid waste management in Indian cities–A review. Waste Manag 2008;28(2):459-67.

[11] Feasibility for Integrated Municipal solid waste management project for Jaipur Municipal Corporation. Report by InfraEn (India) Pvt. Ltd. Jaipur Municipal Corporation; 2015.

[12] Singh A. Municipal Solid Waste Management in Jaipur: Current Status and Way forward. Intern Report. Rajasthan State Pollution Control Board. June 2011. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.467.3019&rep=rep1&type=pdf (Accessed in 05 May 2021).

[13] Yay AS. Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya. J Clean Prod 2015;94:284-93.

[14] Waste management hierarchy and homeland security incidents, https://www.epa.gov/homeland-security-waste/waste-management-hierarchy-and-homeland-security-incidents (Accessed on 05 May 2021).

[15] SWM 2016, Solid waste management rule, Government of India; 2016. https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf (Accessed 05 May 2021).

[16] Municipal solid waste (management and handling) rules 2000. Ministry of Environment and Forests (MoEF), Government of India, New Delhi, India. 2000. https://www.mpcb.gov.in/sites/default/files/solid-waste/MSWrules200002032020.pdf

[17] Kumar A, Agrawal A. Recent trends in solid waste management status, challenges, and potential for the future Indian cities–A review. Curr Res Environ Sustain 2020;2:100011.

[18] Dhar H, Kumar S, Kumar R. A review on organic waste to energy systems in India. Bioresour Technol 2017;245:1229-37.

[19] Kaushal RK, Varghese GK, Chabukdhara M. Municipal solid waste management in India-current state and future challenges: a review. Int J Eng Sci Technol 2012;4(4):1473-89.

[20] Gandhi P, Kumar S, Paritosh K, Pareek N, Vivekanand V. Hotel generated food waste and its biogas potential: a case study of Jaipur city, India. Waste Biomass Valor 2019;10:1459-68.

[21] Ganapathy N. In India: waste that saves lives. The Straits Times.2013 http://www.straitstimes.com/asia/in-india-waste-that-saves-lives. (Accessed 20 February 18).

[22] Solid waste management feasibility study for Nagpur. Report for municipal solid waste management in Nagpur city. Arcadis Germany GmbH. http://www.unescap.org/sites/default/files/Report_IN_Nagpur_SolidWasteManagement_ArcadisGermanyGmbH_2017.pdf; 2017. (Accessed 13 March 2018).

[23] Ramachandra TV, Bharath HA, Kulkarni G, Han SS. Municipal solid waste: generation, composition and GHG emissions in Bangalore, India. Renew Sustain Energy Rev 2018;82:1122-36.

[24] Yadav P, Samadder SR. Assessment of applicability index for better management of municipal solid waste: a case study of Dhanbad, India. Environ Technol 2018;39(12):1481-96.

[25] Nagpure AS. Assessment of quantity and composition of illegal dumped municipal solid waste (MSW) in Delhi. Resour Conserv Recy 2019;141:54-60.

~~[26] Sharma KD, Jain S. Overview of municipal solid waste generation, composition, and management in India. J Environ Eng 2019;145(3):04018143.~~

Formatted: Indent: Left: 0.5", No bullets or

~~[27]~~[26] Khan D, Kumar A, Samadder SR. Impact of socioeconomic status on municipal solid waste generation rate. Waste Manag 2016;49:15-25.

~~[28]~~[27] Olivier L. The solid waste management system of Jaipur: an overview and analysis. independent study project (ISP) collection. 2011. https://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=2069&context=isp_collection (Accessed in 05 May 2021)

~~[29]~~[28] Joshi R, Ahmed S. Status and challenges of municipal solid waste management in India: A review. Cogent Environ Sci 2016;2(1):1139434.

~~[30]~~[29] Choudhury M, Dutta J. A comparative study of municipal solid waste management status for three major towns of upper Assam-India. Int J Waste Resour 2017;7(3):1-8.

~~[31]~~[30] Ghatak TK. Municipal solid waste management in India: a few unaddressed issues. Procedia Environ Sci 2016;35:169-75.

~~[32]~~[31] Status of municipal solid waste management in southern states. Report by Central Pollution Control Board Zonal office (South), Bengaluru. 2011.

~~[33]~~[32] Sharma BK, Chandel MK. Life cycle assessment of potential municipal solid waste management strategies for Mumbai, India. Waste Manag Res 2017;35(1):79-91.

~~[34]~~[33] Kalyani KA, Pandey KK. Waste to energy status in India: a short review. Renew Sustain Energy Rev 2014;31:113-20.

~~[35]~~[34] Das S, Bhattacharyya BK. Municipal solid waste characteristics and management in Kolkata, India. In The 19th International Conference on Industrial Engineering and Engineering Management. Springer, Berlin, Heidelberg. 2013; 1399-1409.

~~[36]~~[35] Gupta B, Arora SK. A study on management of municipal solid waste in Delhi. J Environ Waste Manag 2016;3(1):130-8.

~~[37]~~[36] Srivastava AK, Nema AK. Life cycle assessment of integrated solid waste management system of Delhi. Towards life cycle sustainability management. Springer, Dordrecht. 2011, p. 267-276.

~~[38]~~[37] Francis RC, Singh LP, Prakash EV. Solid waste management and characteristics in Lucknow, Uttar Pradesh, India. Int J Sci Eng Res 2013;4(11):1645-8.

~~[39]~~[38] Archana, Ali D, Yunus M, Dutta V. Assessment of the status of municipal solid waste management (MSWM) in Lucknow – Capital city of Uttar Pradesh, India. IOSR J Environ Sci Toxicol Food Technol. 2014;8(5)II:41-9.

~~[40]~~[39] Mohanty CR, Mishra U, Beuria PR. Municipal solid waste management in Bhubaneswar, India—a review. Int J Latest Trends Eng Technol 2014;3(3):303-12.

~~[41]~~[40] Gogoi L. Municipal solid waste disposal: a case study in Guwahati city to mitigate the man-made disaster. IOSR J Humanities Soc Sci 2013;9(3):55-60.

~~[42]~~[41] Mahongnao M. Urban solid waste management in Imphal, Manipur. J Ind Pollut Control 2017;33(1):696-701.

~~[43]~~[42] Late A, Mule MB. Composition and characterization study of solid waste from Aurangabad city. Univers J Environ Res Technol 2013;3(1):55-60.

~~[44]~~[43] Mundhe N, Jaybhaye R, Dorik B. Assessment of municipal solid waste management of Pune city using geospatial tools. Int J Computer Appl 2014;100(10):24-32.

~~[45]~~[44] Soni AK, Patil D, Argade K. Municipal solid waste management. Procedia Environ Sc 2016;35:119-26.

~~[46]~~[45] Status of municipal solid waste management in Jodhpur city. Report by Central Pollution Control Board, Central zonal Office, Bhopal. 2011. https://cpcb.nic.in/displaypdf.php?id=em9iaG9wYWwvTVNXX0pvZGhwdXIucGRm

~~[47]~~[46] Status of municipal solid waste management in Gwalior city. Report by Central Pollution Control Board, Central zonal Office, Bhopal. 2011. https://cpcb.nic.in/displaypdf.php?id=em9iaG9wYWwvTVNXX0d3YWxpb3IucGRm.

~~[48]~~[47] Srivastava R, Krishna V, Sonkar I. Characterization and management of municipal solid waste: a case study of Varanasi city, India. Int J Curr Res Acad Rev 2014;2(8):10-6.

~~[49]~~[48] Jampala S, Gellu A, Kala DS. Current scenario on urban solid waste with respect to Hyderabad city. Int J Res Studies Sci Eng Technol 2016;3(12):10-13.

~~[50]~~[49] Rajendra A, Ramu. Assessment of municipal solid waste management in Mysore city. Int J Appl Innov Eng Manag 2014;3(4):134-8.

~~[51]~~[50] Kandasamy SP, Akolkar AB, Manoharan A, Paranji S. Municipal solid waste management at Chennai in southern India–an occupational health perspective. Int J Health Promot Edu 2013;51(1):50-61.

[51] Abdel-Shafy HI, Mansour MS. Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egyp J Pet 2018;27(4):1275-90.

[52] Hoornweg D, Bhada-Tata P. What a waste: a global review of solid waste management. World Bank Report. 2012.

[53] Upadhyay V, Jethoo AS, Poonia MP. Solid waste collection and segregation: a case study of MNIT campus, Jaipur. Int J Eng Innov Technol 2012;1(3):144-9.

[54] Paritosh K, Mathur S, Pareek N, Vivekanand V. Feasibility study of waste (d) potential: co-digestion of organic wastes, synergistic effect and kinetics of biogas production. Int J Environ Sci Technol 2018;15(5):1009-18.

[55] Prajapati KK, Pareek N, Vivekanand V. Pretreatment and multi-feed anaerobic co-digestion of agro-industrial residual biomass for improved biomethanation and kinetic analysis. Front Energy Res 2018;6:111.

[56] Yadav P, Samadder SR. Environmental impact assessment of municipal solid waste management options using life cycle assessment: a case study. Environ Sci Pollut Res 2018;25(1):838-54.

[57] Kumar A, Kumar K, Kaushik N, Sharma S, Mishra S. Renewable energy in India: current status and future potentials. Renew Sustain Energy Rev 2014;14(8):2434-42.

[58] All India Installed Capacity. Central Electricity Authority (CEA), Government of India. https://cea.nic.in/installed-capacity-report/?lang=en . (Accessed on 05 May 2021).

[59] Nixon JD, Dey PK, Ghosh SK. Energy recovery from waste in India: An evidence-based analysis. Sustain Energy Technol Assess 2017;21:23-32.

[60] Sharma R. Municipal solid waste management in Ajmer city, Rajasthan: an overview. Nat Environ Pollut Technol 2008;7(4):639-42.

[61] Gupta N, Yadav KK, Kumar V. A review on current status of municipal solid waste management in India. J Environ Sci 2015;37:206-17.

[62] Manyuchi MM, Phiri A. Vermicomposting in solid waste management: a review. Int J Sci Eng Technol 2013;2(12):1234-42.

[63] Babu GS, Lakshmikanthan P, Santhosh LG. Life cycle analysis of municipal solid waste (MSW) land disposal options in Bangalore city. ICSI: Creating Infrastructure for a sustainable world. In: Proceedings of the 2014 international conference on sustainable infrastructure. 2014, p. 795-806.

[64] Fidelis R, Marco-Ferreira A, Antunes LC, Komatsu AK. Socio-productive inclusion of scavengers in municipal solid waste management in Brazil: practices, paradigms and future prospects. Resour Conserv Recy 2020;154:104594.

[65] Waste to energy potential in India. Annual Report 2017. Ministry of New and Renewable Energy, Government of India, 2017. https://mnre.gov.in/img/documents/uploads/file_f-1608050046985.pdf (Accessed on 05 May 2021)

[66] The national action plan for municipal solid waste management. In compliance with Hon'ble National Green Tribunal, CPCB. India, 2015. https://cpcb.nic.in/uploads/MSW/Action_plan.pdf (Accessed on 05 May 2021)

[67] Sebastian RM, Kumar D, Alappat BJ. A technique to quantify incinerability of municipal solid waste. Resour Conserv Recy 2019;140:286-96.

[68] Kumar A, Samadder SR. A review on technological options of waste to energy for effective management of municipal solid waste. Waste Manag 2017;69:407-22.

[69] Johnke B. Emissions from waste incineration. In Background paper for expert meeting on good practice in inventory preparation: emissions from waste. IPCC/OECD/IEA National Greenhouse Gas Inventories Programme, (Unpublished–TSU, Japan). 1999. https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_3_Waste_Incineration.pdf

[70] Yap HY, Nixon JD. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. Waste Manag 2015;46:265-77.

[71] Kumar A, Kumar N, Baredar P, Shukla A. A review on biomass energy resources, potential, conversion and policy in India. Renew Sustain Energy Rev 2015;45:530-9.

[72] Zamri MF, Hasmady S, Akhiar A, Ideris F, Shamsuddin AH, Mofijur M, Fattah IR, Mahlia TM. A comprehensive review on anaerobic digestion of organic fraction of municipal solid waste. Renew Sustain Energy Rev 2021;137:110637.

[73] Paritosh K, Yadav M, Kesharwani N, Pareek N, Karthyikeyan OP, Balan V, Vivekanand V. Strategies to improve solid state anaerobic bioconversion of lignocellulosic biomass an overview. Bioresour Technol 2021;331:125036.

[74] Kumar S, Paritosh K, Pareek N, Chawade A, Vivekanand V. De-construction of major Indian cereal crop residues through chemical pretreatment for improved biogas production: An overview. Renew Sustain Energy Rev 2018;90:160-70.

[75] Paritosh K, Kushwaha SK, Yadav M, Pareek N, Chawade A, Vivekanand V. Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. BioMed Res Int 2017;2017:2370927.

[76] Thomas P, Soren N, Rumjit NP, James JG, Saravanakumar MP. Biomass resources and potential of anaerobic digestion in Indian scenario. Renew Sustain Energy Rev 2017;77:718-30.

[77] Gollapalli M, Kota SH. Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. Environ Pollut 2018;234:174-80.

[78] Kumar S, Nimchuk N, Kumar R, Zietsman J, Ramani T, Spiegelman C, Kenney M. Specific model for the estimation of methane emission from municipal solid waste landfills in India. Bioresour Technol 2016;216:981-7.

[79] Unnikrishnan S, Singh A. Energy recovery in solid waste management through CDM in India and other countries. Resour Conserv Recy 2010;54(10):630-40.

[80] Seo YC, Alam MT, Yang WS. Gasification of municipal solid waste. Gasif. Low-Grade Feedstock. IntechOpen, 2018.

[81] Yadav M, Paritosh K, Pareek N, Vivekanand V. Coupled treatment of lignocellulosic agricultural residues for augmented biomethanation. J Clean Prod 2019;213:75-88.

[82] Xin C, Zhang T, Tsai SB, Zhai YM, Wang J. An empirical study on greenhouse gas emission calculations under different municipal solid waste management strategies. Appl Sci 2020;10(5):1673.

[83] Hameed Z, Aslam M, Khan Z, Maqsood K, Atabani AE, Ghauri M, et al. Gasification of municipal solid waste blends with biomass for energy production and resources recovery: Current status, hybrid technologies and innovative prospects. Renew Sustain Energy Rev 2021;136:110375.

[84] Calise F, Cappiello FL, d'Accadia MD, Vicidomini M. Concentrating photovoltaic/thermal collectors coupled with an anaerobic digestion process: dynamic simulation and energy and economic analysis. J Clean Prod 2021;311:127363.

[85] Pradhan P, Gadkari P, Arora A, Mahajani SM. Economic feasibility of agro waste pelletization as an energy option in rural India. Energy Procedia 2019;158:3405-10.

[86] Kumar A, Samadder SR. An empirical model for prediction of household solid waste generation rate–a case study of Dhanbad, India. Waste Manag 2017;68:3-15.

[87] Kolekar KA, Hazra T, Chakrabarty SN. A review on prediction of municipal solid waste generation models. Procedia Environ Sci 2016;35:238-44.

[88] Nganda MK. Mathematical models in municipal solid waste management. Thesis for the Degree of Licentiate of Philosophy. 2007. http://www.math.chalmers.se/Math/Research/Preprints/2007/6.pdf

[89] Lee CK, Yeung CL, Xiong ZR, Chung SH. A mathematical model for municipal solid waste management–a case study in Hong Kong. Waste Manag 2016;58:430-41.

[90] Nguyen-Trong K, Nguyen-Thi-Ngoc A, Nguyen-Ngoc D, Dinh-Thi-Hai V. Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model. Waste Manag 2017;59:14-22.

[91] Das S, Bhattacharyya BK. Optimization of municipal solid waste collection and transportation routes. Waste Manag 2015;43:9-18.

[92] Lella J, Mandla VR, Zhu X. Solid waste collection/transport optimization and vegetation land cover estimation using geographic information system (GIS): a case study of a proposed smart-city. Sustain Cities Soc 2017;35:336-49.

[93] ISO 14040. Environmental management – life cycle assessment – general principles and framework. International Organization for Standardisation, Geneva, 2006.

[94] Istrate IR, Iribarren D, Gálvez-Martos JL, Dufour J. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. Resour Conserv Recy 2020;157:104778.

[95] Wang D, He J, Tang YT, Higgitt D, Robinson D. Life cycle assessment of municipal solid waste management in Nottingham, England: past and future perspectives. J Clean Prod 2020;251:119636.

[96] Basavaraj I, Prakash SM. Comparative life cycle assessment of different municipal solid waste management options in selected wards of Bangalore. Int J Civil Eng Technol 2017;8(2):300–8.

[97] Bohra A, Nema AK, Ahluwalia P. Global warming potential of waste management options: case study of Delhi. Int J Environ Technol Manag 2012;15(3-6):346-62.

An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations

Kishan Kumar Prajapati[1], Monika Yadav[1], Rao Martand Singh[2], Priti Parikh[3], Nidhi Pareek[4], Vivekanand Vivekanand[1]

[1]Centre for Energy and Environment, Malaviya National Institute of Technology, Jaipur 302017, Rajasthan, India.

[2]Department of Civil and Environmental Engineering, Norwegian University of Science & Technology (NTNU), Trondheim 7034, Norway

[3]Engineering for International Development Centre, Department of Civil, Environmental and Geomatic Engineering, University College London, Chadwick Building, Gower Street, London, WC1E6BT, United Kingdom.

[4]Department of Microbiology, School of Life Sciences, Central University of Rajasthan, Bandarsindri, Kishangarh, Ajmer, Rajasthan 305801, India

*Corresponding author. Tel.: + 91 141 2713573 E-mail: vivekanand.cee@mnit.ac.in

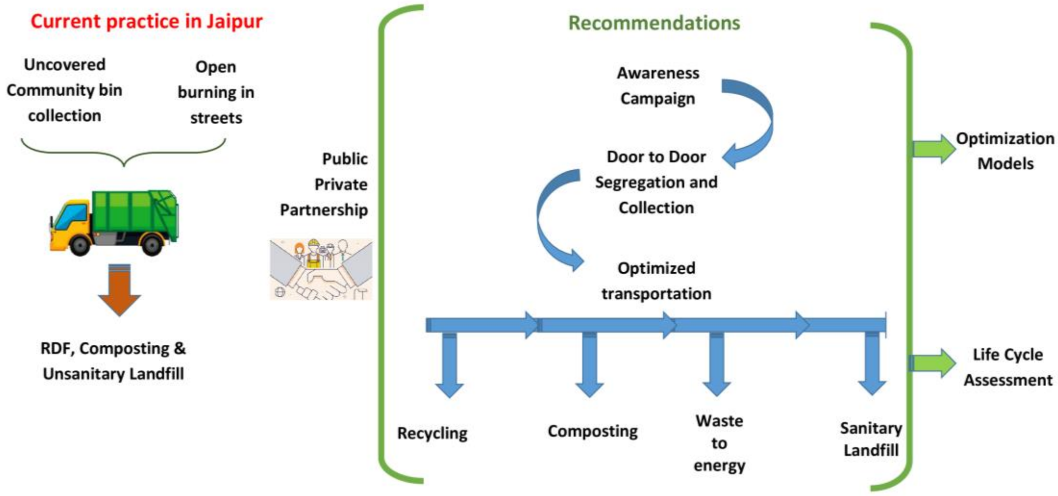
ABSTRACT

In developing countries, urbanization and rapid population growth has resulted in a substantial increase in generation of Municipal Solid Waste (MSW). Safe collection, transportation and treatment of MSW are among the major issues for Indian cities. Poor MSW management practices have negative impact on public health, environment and climate change. India currently only treats 21% of MSW while the remainder disposed in unsanitary landfill sites with no recycling and treatment technologies. This paper reviews the existing MSW management practices, challenges and provides recommendations for improving MSW management for the city of Jaipur in Rajasthan, India.

Despite being the state capital as well as the top tourist destination in northern part of India, there is no detailed study which reviews the waste management strategies of this city along with identifying the key challenges. The study reveals that the major challenges for MSW management in Jaipur include uncontrolled landfilling, inadequate public participation as well as failings of implementation of MSW legislation and waste conversion. Recommendations for improvement include public awareness campaigns, public-private partnership, investment in lined landfills, recycling and waste to energy techniques. Optimization models and life cycle assessment tools should be employed to minimize cost and the environmental impact of MSW management. This study will provide policy makers and private sector stakeholders to develop strategies for future planning, investment and execution of improved MSW management in Indian cities.

Keywords: Municipal solid waste; Waste to energy; Landfill; Anaerobic digestion; Optimization models; Life cycle assessment

Graphical Abstract



List of abbreviations

AD	Anaerobic digestion
BLF	Bioreactor landfilling
CPCB	Central Pollution Control Board
CDC	Centre for Communication Development
GIS	Geographic information systems
GHG	Greenhouse gas
JMC	Jaipur Municipal Corporation
LFGR	Landfill gas recovery
LCA	Life cycle assessment
MoEF	Ministry of Environment and Forests
MSW	Municipal solid waste
MSWM	Municipal solid waste management
NGO	Non-governmental organizations
PPP	Private-public partnership
RDF	Refused derived fuel
SEG	Socio-economic group
SPCB	State Pollution Control Board
TPD	Tonne per day
ULB	Urban local bodies
VS	Volatile solid

1. Introduction

Rapid urbanization, industrialization, and population growth have resulted in substantial increase in rates of solid waste generation in urban centers. As per United Nations, the 52% population of world was urban in 2011 and it is estimated to reach to 67.2% till 2050 [1]. This increase will transform the social structure, living standards, resource utilization as well as waste generation by people. The generation rate of municipal solid waste (MSW) can be directly correlated to the economic growth of a country i.e., gross domestic product and population density [2, 3]. Annual worldwide total solid waste generation is approximately 17 billion tonne per year, and this sector contributes to 16% greenhouse gas (GHG) emissions responsible for global warming [2, 4].

In developing countries such as India, typical per capita, MSW generation rate is about 0.49 kg/day which is lower than the 1-2.5 kg/day waste generation rates in developed countries. In future, waste consumption and generation patterns in developing countries will replicate those in developed nations. Currently, India handles 62 million tonne MSW per year [5]. However, the collection and treatment efficiency of the country is around 90% and 27% respectively. Remaining untreated MSW at present itself is a major problem which would sustain in a disastrous way [6]. Jaipur city having 3.04 million population, is the capital of Rajasthan state where a rise in infrastructure development and living standards has led to waste generation amounting to 1000 tonne per day (TPD) [7, 8]. This quantity of waste is one-third of the total waste generated by entire Rajasthan state.

Most of the Indian cities failed to have the desired level of municipal solid waste management (MSWM) due to the shortage of financial resources and technology, and lacking in sustainable planning and execution. MSWM effectiveness in a city should keep pace with the growth of that city [9, 10]. Increase in waste generation in Indian cities makes the management of MSW and its handling a critical problem. This needs targeted action from key stakeholders involved in the management of MSW in any city including Municipal Corporation of city, MSW generators i.e., public and private institutions (offices, hotels, restaurants, markets and other commercial sectors), non-governmental organizations (NGOs) and private contractors. Waste generated in large quantity requires a system of collection, segregation, storage, transportation, treatment, and disposal. There are several MSWM method to cut down the volume of the waste such as its minimization from source itself, waste 3 R's ("Reduce, Reuse and Recycle") strategy, incineration, composting and anaerobic digestion (AD); however, unscientific or unsanitary landfilling is the most adopted approach for MSW disposal nationwide as it has been a relatively simple and economical mode of MSW disposal [11, 12].

Figure 1 shows a four-tiered integrated solid waste management hierarchy to guide MSWM decision-making according to the type of waste. Knowledge of composition of MSW is important for selecting the suitable waste processing and disposal practices since MSW volume and its composition differs considerably with the places having changes in food habits, cultural traditions, lifestyles, socio-economic conditions, and climate [4, 13]. Integrated MSWM based on varying MSW composition is required to recover materials, compost and renewable energy from MSW and residues to reduce the quantity of MSW reaching landfill sites [12].

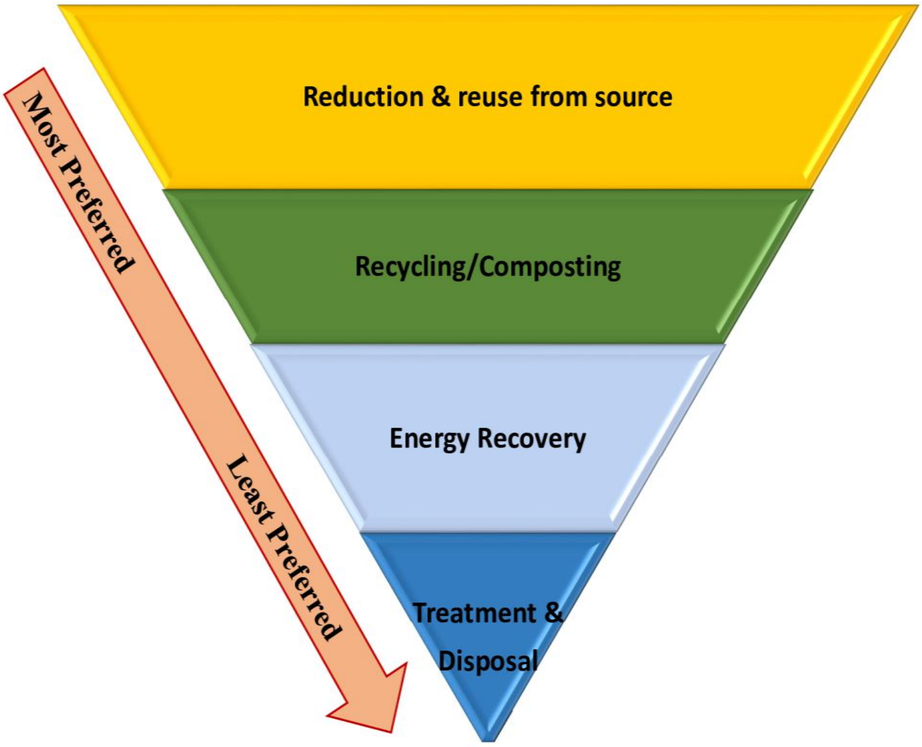


Figure 1. Integrated solid waste management hierarchy [14]

This study reviews the present status of MSWM for Indian cities more broadly and specifically for Jaipur city and provides recommendations for improvement. Further, the study provides the list of waste management technologies adopted in the other cities of India as well as around the globe to convert the waste to energy. The review further compares these technologies in terms of energy potential and economic feasibility. The life cycle assessment (LCA) and optimization done by other studies have also been summarized to elaborate the applicability of these tools for predicting the most suitable method for implementing the waste conversion technologies resulting in highest energy yield with minimum emission and cost. This review would enable regulatory bodies such as the State Pollution Control Board (SPCB), Urban Development Authority and Municipal Corporation to improve the waste management processes in the Jaipur city and tackle the issues in systems. Moreover, this study may also be helpful for the other cities of developing countries around the world which are facing the similar issues to tackle the accumulating waste due to lack of proper treatment method as well as policies regarding them.

2. Current scenario of MSW in India

'Solid waste' includes solid or semi-solid domestic waste, sanitary waste, commercial waste, institutional waste, catering and market waste, and other non-residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture, dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-waste, battery waste, and radioactive waste" [15]. MSW (Management and Handling) Rules, 2000 issued by Ministry of Environment and Forests (MoEF), Government of India, regulates appropriate collection, segregation, transportation, treatment and disposal of solid waste. Under these rules, Municipalities are authorized to implement measures for improving MSW and submit annual reports to the Central Pollution Control Board (CPCB). Parameters such as the quality of ambient air and groundwater, leachate, compost and standards of incineration are required to comply with respective standards and monitored by CPCB as well as SPCB. Currently there is a gap between regulation and enforcement in most Indian cities. [10, 16, 17].

Key features in revised rules i.e. solid waste management rules 2016, extended to urban and industrial areas, are mandating the solid waste source segregation to have its recovery, reuse and recycle; integration of informal system i.e. unauthorized rag pickers and waste dealers into the formal system; prohibition of waste throwing, burning, and burying in public spaces, if violation of rules found, generator will have to pay 'spot fine'; manufactures of sanitary products should provide the suitable wrapping material with it for its safe disposal; introducing partnership concept for bulk waste producers (hotels, institutions, restaurants, event organizers, new townships and societies) to segregate, sort and handle the generated waste by associating with local bodies; all brand owners or manufactures shall have to provide the required financial aid to local authorities for MSWM; non-recyclable waste (Calorific Value >= 1500kcal/kg) should be used directly for energy production or as input for generating refused derived fuel (RDF) [15].

Being one of the fastest growing economies and the second most populated country in the world, India is facing the upsurge in MSW generation in the cities. With changing lifestyles, Indian cities are now generating more MSW with an estimated increase of 1-1.33% per annum. Currently in India, only 15-20% of MSW is segregated, 21.45% of MSW is processed or treated and remaining 78.55% MSW disposed at unsanitary landfills. Open dumping was 90% in 2008 and showed only 11.45% waste diversion from open dumping in last decade [10, 18]. Moreover, the projection of MSW generation for urban inhabitants revealed that the MSW generation rate (kg/capita/day) is approximately two times of the urban agglomeration rate [19].

MSW contains 50-60% organic fraction composed of majorly food waste and its untreated disposal i.e., uncontrolled decomposition causes rotting, severe impacts on local public health and foul odor due to methane generation which is a GHG [20,21]. Reliable characterization of MSW requires a large number of MSW samples being analyzed over the cities of India. Physical composition of MSW for Indian scenario is shown in Table 1. MSW collected from different cities of India contains approximately 40-62% biodegradable content and 11-24% recyclable content [17]. Average household MSW composition consists of around 70% organic fraction [22-24].

Table 1: Physical composition (%) of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio

1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	45	12	43	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

MSW generations in major metro cities of India are reported by CPCB are shown in Figure 2. It exhibits trend of waste generation per day in last 10 years (in the year of 2004-05 and 2015-16) in major metro cities. Larger metro cities such as Mumbai and Delhi have a very high rate of waste generation and are currently leading in waste generation with up to 11000 and 8700 TPD waste generation respectively. In Delhi, openly dumped MSW was observed to be the highest in the low socio-economic neighborhood with 61 kg per capita per person per year [25].

Socio-economic conditions i.e., education level, family income, occupation and household size play significant role in MSW generation in the society. A study performed in Dhanbad city, India regarding these factors divided society into five socio-economic group (SEG) based on above mentioned four factors. It concluded that middle and lower middle SEG has the highest per capita waste generation due to comparatively more family members. Comprehensive study of waste composition in different SEGs shows high food and plastics wastes generation from higher SEG, whereas lower SEG generates lesser food waste due to different standard of living [26]. Impact of socio-economic factors on MSW generation in Bangalore city shows positive relation with family income, whereas negative relation with education level and household size [23].

In Indian system, the residential solid waste in the household is stored in a single plastic container (16-20 L capacity) in a mixed form including both dry and wet waste. The collected waste is then dumped by the residents to the nearby community bins (4.5-6 m^3 capacity, metallic or concrete) without segregation. The door-to-door collection is practiced only in few wards of metro cities, through handcarts or tricycle with the help of NGOs. Residential and market waste is also dumped on the open roads either due to negligence of waste generator or inadequate presence and capacity of community bins. All street and road wastes are collected by sweepers using wheelbarrows and thereafter dumped it into nearby community bin. Community bins are mostly uncovered i.e., easily accessible to rag pickers and animals, they litter the waste around the bin in the search of recyclable waste and food respectively, thereby dispersed waste on the street and creating the unhygienic conditions. The dispersed waste sometimes reaches to the nearby drainage system causing it to be blocked. The major problem for municipality arises from low and middle-income residential areas where the waste is dumped on narrow streets, or behind houses instead of putting it in nearby bins [24, 27, 28]. Due to this poor-practice, these areas remain inaccessible to waste collecting workers for some days.

Private contractors are involved in metro cities for transportation of MSW from community bins to dumping sites. Tractors, ordinary trucks, pay loader, compactors, tippers and dumper placer vehicles are usually used for waste transportation. Though many of them are outlived which run with low efficiency and high fuel consumption [19, 29, 30]. Except few cities like Delhi, Pune and Hyderabad, all Indian cities transport MSW to the dumping sites where uncontrolled landfilling is practiced (Table 2).

Current management strategies adopted for handling MSW in some major Indian cities are highlighted in Table 2. Almost all cities have no source segregation of MSW while some cities perform MSW segregation by engaging workers. Few cities have poor collection efficiency and no source segregation is performed except Bangalore and Pune. Composting and unsanitary landfilling is a very common strategy practiced for waste management in most of the Indian cities. Pune is the only city where waste management practice is appreciably effective by integrating segregation, composting, waste to energy plants and scientific landfilling. There are less significant research updates regarding MSWM of Northeast Indian cities. In Dibrugarh town of Assam, open dumping site is located near the Brahmaputra river contaminating the river ecosystem as well as affecting the health of humans and animals. The health hazards become more severe during rainy seasons causing water pollution and water-borne diseases [29].

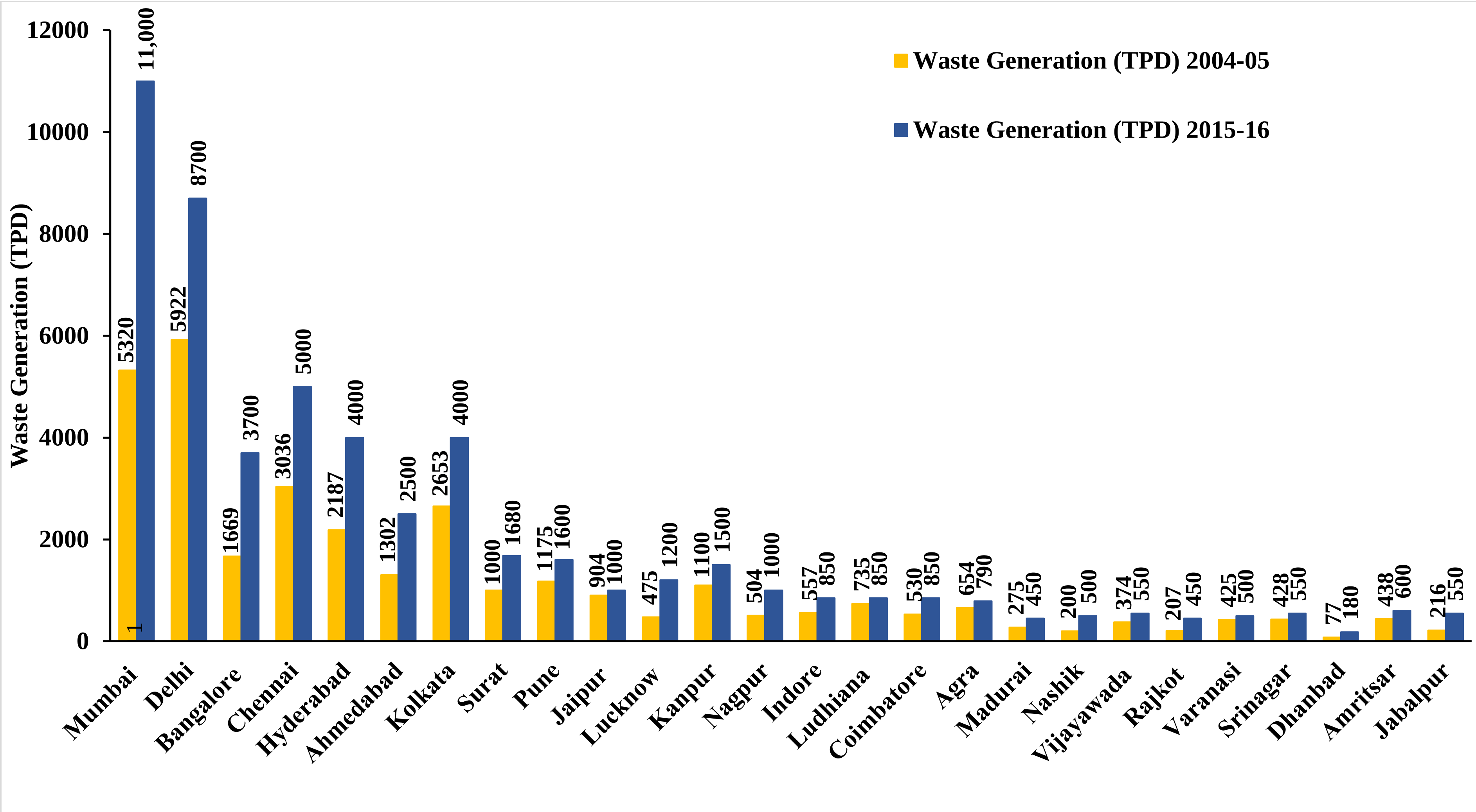


Figure 2. MSW generation trend in major Indian cities [7]

Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,27]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,31]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R's hierarchy of management and waste to energy technology	[32]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[33,34]
Delhi	Y	Y	Y	R-Informal, C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[35,36]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[37,38]
Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[39]

Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[40]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[41]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[42]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[43,44]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[45]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]
Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[46]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[47]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[31,48]
Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[49]

Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[31]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[31,50]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,26]

Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective strategy, (no.) –number in the bracket represents the number of respective facilities.

3. Municipal waste management in Jaipur city

The previous section provided status of waste management in some of the significant cities of India. The waste management strategies followed by these cities are largely based on the MSW composition which in turn vary according to the lifestyle and eating habits of citizens, food resources as well as the climate of the city [51]. While, these studies of other cities of India are helpful in solving the specific waste management issues; the MSWM model of one city cannot be implemented as it is to another city of India due to varying climate conditions and lifestyle which changes drastically in India.

Jaipur city, capital of Rajasthan the largest state of India, is one of the future smart cities of India and famous for its tourism and hospitality. In 2019, the city has been declared as UNESCO world heritage site. As shown in Figure 2, It is also a major city in north India along with Delhi, Kanpur and Lucknow with high waste generation rate. With an area of 467 km^2 and the entire city is divided into 91 wards. Since 2011, the wards are distributed in 8 Municipal Corporation zones: Vidhyadhar Nagar, Civil Lines, Mansarovar, Sanganer, Moti Dungri, Hawa Mahal East, Hawa Mahal West and Amer. Jaipur Municipal Corporation (JMC) has the constitutional responsibility of collection, transportation, treatment and safe disposal of MSW generated in the city. Currently, Jaipur city has MSW flow in its management process as shown in Figure 3.

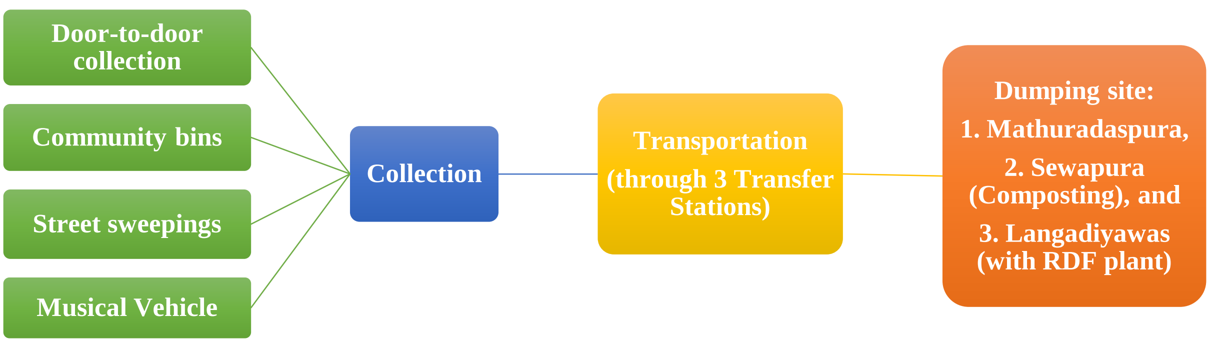


Figure 3. MSW flow in Jaipur [27]

3.1. MSW composition and characteristics

MSW in Jaipur comprises three key components [33, 52]:

1. Biodegradable (organic waste): Food waste, garden waste (grass, fallen leaves and tree trimmings), wood etc.
2. Recyclable waste: Paper (paper is classified as organic only when it is tainted by organic material), cardboard, plastics, metals, glass etc.
3. Inert and other wastes: Textiles, leather, paints, rubber, multi-laminates, medicines, sanitary products and inert materials (stones, silt, ash and inorganic material).

MSW composition and chemical characteristics viz. moisture content, volatile solids (VS), calorific value and elemental composition etc. of MSW in Jaipur city are shown in Figure 4 and Table 3 respectively. As shown in Figure 4, approximately 45% portion of MSW collected in Jaipur was reported in 2018 to be biodegradable while 43% content was composed of ash and fine earth particles [17].

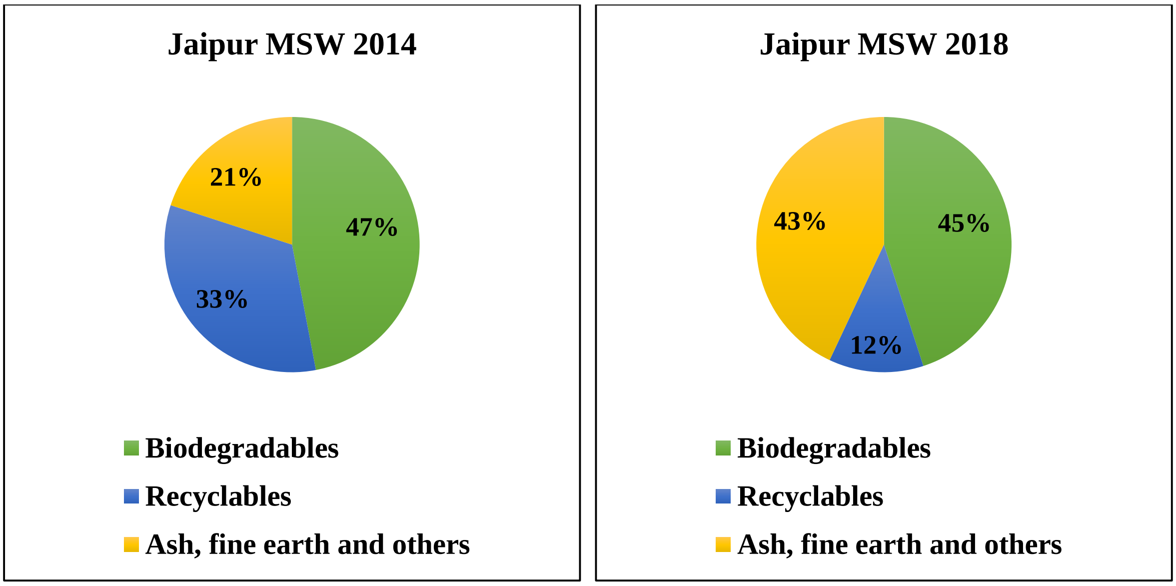


Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

Table 3: Chemical characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV (kCal/kg)	C	H	N	S	O	P (P_2O_5)	Potash K_2O
Values (%)*	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

*Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids, CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen, P=Phosphorus.

3.2. Cleaning and collection

The door-to-door waste collection method is not adopted in Jaipur city by JMC, and rather some wards are implementing it through informal sectors by paying them reasonable amount per month. Sometimes, a portion of MSW left unattended and remained as open dumped waste. Jaipur city has collection efficiency of MSW around 85% [11, 12]. In this collected MSW, 18-24% contents are recyclable including paper, plastic, rubber, ferrous and non-ferrous metals. However, 15% out of total recyclable waste is collected by rag pickers for their livelihood and traded to scrap buyer informally [10].

JMC staff require more health inspectors and sweepers for respective wards as per a study conducted [11]. Permanent and temporary street sweepers on daily wage basis are deployed for cleaning the city. Street sweeping and community bins are the primary collection methods of the waste. Total 1794 community bins of 3 sizes i.e., 1.1 m^3, 3 m^3 and 7 m^3 capacity have been installed [11]. Still, many wards are left without having any garbage container causing more disorder with respect to waste collection.

It has been observed that the city does not segregate the waste at source and dump it into the municipal bins, open spaces and drains. Many of the community bin’s waste are scattered around by animals which causes unhygienic conditions. Some ward’s road cleaning is performed daily while remaining wards are cleaned periodically i.e., once or twice a week.

Street waste cleaning, de-silting the surface drains and collection tasks performed by sweepers using a wheelbarrow and transferred to community bins. Since recyclable waste segregation is not practiced, it is usually found mixed in the community bins [11].

3.3. Transfer station and transportation

The collected garbage from community bins is transported to the secondary storage points or transfer station and then to the disposal sites using dumper placer and compactor vehicles. Currently, Jaipur has 3 transfer station at Lal Dungri, Vidhyadhar, and Jhalana having capacity of 400, 250, and 150 TPD respectively. Uncovered or open body type trucks tend to spill waste gradually on the road causing unhygienic conditions on the roads. A vehicle's waste collection frequency is around 2-4 times daily due to lack of transfer stations in other zones. Therefore, 3 more transfer stations are proposed in Mansarover, Bambala Pulia and Sushilpura to cover the zones which are far away from disposal sites and to minimize the time, money and fuel consumption during waste transportation. Transportation system alone consumes more than 60% funding from the total fund assigned for the MSWM [11, 12].

3.4. Treatment and disposal facilities

For MSW disposal, Jaipur city has currently 3 dumping sites: Mathuradaspura, Langadiyawas, and Sewapura as shown in Figure 5 on Jaipur map and main features are discussed below [11, 12].

1. Mathuradaspura dumping site: It is located at 17 km distance from the main city, having capacity up to 400 TPD of MSW with total area 0.285 km^2.
2. Sewapura dumping site: It is situated at 20 km from the city, with site area 0.324 km^2 having a capacity of 300 TPD. It has a compost processing facility of 350 TPD operated by Infrastructure Leasing & Financial Services Limited.
3. Langadiyawas dumping site: It has a total area of 0.782 km^2 out of which 0.065 km^2 is allotted for RDF processing facility and 0.16 km^2 for Sanitary Landfilling (under

construction). M/s Grasim Industries constructed an RDF processing facility producing 150 TPD RDF from 500 TPD MSW at Langadiyawas and transported to a company UltraTech Cement Limited in Neemuch, Madhya Pradesh, to generate energy for cement production.

MSW undergoes many transformations before converting to RDF such as removal of dangerous and large items (i.e., big stones, batteries, dead animals, machines) by workers and then load into pre shedder to have granular size of 0-200 mm. Subsequently, the shredded waste is sent into an integrated conveyor installed magnetic separator removing all metals from waste. Further separation of sand and grit from organic waste is carried out by trommel screen. The heavier pieces like glass and ceramics are passed through the ballistic separator. Thereafter, organic portions are sent for further size reduction up to 0-50 mm, resulting in mixed waste as raw materials for RDF. This garbage for RDF has low calorific value, so plastics purchased from Sainath Enterprises are added. This RDF application in cement plant brings carbon credit to the firm and 9-15% saving of coal burning. This facility recovers 5-6% RDF instead of 30% from MSW received because of the inadequate technology and mixing of construction debris with the MSW [27].

Figure 5. The landfill locations in Jaipur city [11, 12]

Currently, total 500 MSW TPD i.e., 50% of total MSW treated either as composting or converted into RDF. JMC proposed a waste to energy plant in Mathuradaspura site for remaining MSW which is being disposed unscientifically at this moment [11]. Uncontrolled dumping is practiced in all of 3 disposal sites, prone to leachate production which can cause ground and ground water pollution and may create vectors for propagating various diseases. Moreover, these sites are without pollution monitoring facilities, proper fencing and fly control [12]. Ground water from eight sites near Mathuradaspura were sampled and some of them show high content of naturally available fluoride and total dissolved solid which may cause fluorosis and gastro intestinal irritation respectively to the nearby residents [11, 12].

3.5.Private-public partnership (PPP)

JMC has been using PPPs model to sub-contract some of its MSWM responsibilities to individual corporations (NGOs or private companies). Two private companies are handling composting and RDF treatment facility in Jaipur MSWM [11]. Two NGOs the Centre for Communication Development (CDC) and Satya were engaged on MSWM related activities.

Satya provided labor in Jaipur to lead a successful program in handling the waste and dumping the MSW. Satya was also engaged in door-to-door collection in Vaishali Nagar, Chitrakoot and ward no.20 with charging INR 20-30 a household per month in 2005-07. However, due to poor facilitation from JMC, difficulties in payments, inadequacy in management, the partnership was discontinued after two years of the contract. Another NGO, CDC started few projects for better urban MSWM regarding collection and transportation. Again, JMC could not support their projects financially and hence CDC ceased their work and focused on other social services in Jaipur city [27].

3.6. Case studies

Singh [12] carried out a survey of two regions of Jaipur city viz. Tonk Phatak and Malviya Nagar and concluded that stronger social network or high-income areas have better MSWM or living condition than low-income societies. Here, social network means friendship, social contacts and interactions among the influencing people and common people. Dissatisfaction level found to be high in Tonk Phatak area as a result of lack of community bins and waste collection system with respect to MSWM. While, Malviya Nagar was found to be more socially connected and where MSW was carried away daily. Tonk Phatak area people were willing to pay some money to get their locality clean and hygienic. On the other hand, Malviya Nagar locality somewhat disagreed for the same. The survey in these two areas found that 90% people do not have awareness about the fate of waste.

A case study performed by Gandhi et al. [20] in Jaipur metropolitan revealed the amount of food waste generated from hotel sectors. The study reported that food waste (14.9 kg/day) generation from 4-5 star rated hotels is almost threefold as compared to 2-3-1 star rated and unrated hotels. Only 34% hotels out of surveyed 70 hotels perform segregation of food waste, out of which 84% are of 3-5 rated hotels. An educational institute survey study revealed that MSW generated from the campus consisted of food waste, plastics, paper, metal, glass, and garden trimming etc [53]. Total collected waste was directly transported to the city's dumping site. Segregation was not performed and waste treatment facility have not been adopted within the campus [53]. A feasibility study of organic waste energy potential in another institutional campus shows that the mixed food and green waste has biogas potential of 400-660 mL/g VS of mixed substrate [54]. The study suggested that there was a need for developing composting and AD plant for the organic waste generated within the campus, with segregation of recyclable waste. Another study performed the multi feed anaerobic co digestion of mung bean husk and wheat straw with organic fraction of MSW. The co-digestion was observed to increase 37% methane production with respect to AD of organic fraction of MSW only [55].

4. Challenges pertaining to MSWM in Jaipur

The main difficulties with MSWM in Jaipur city are firstly the social negligence from public side to have segregation and proper disposal of solid waste due to either lack of knowledge of its long-term harmful impacts on habitats and environment or their irresponsibility towards their fundamental duty of protecting environment. The second major challenge is governance as the municipal corporation continues to practice waste dumping at the outskirts of the city with no planning and safe waste treatment practices. Unlined and uncovered landfilling is the worst option when accounting its groundwater contamination, land degradation and environmental and health impacts causing from breeding infectious diseases majorly due to leachate and landfill gas. Sometimes, Jaipur city also faces burning of MSW piled in streets or grounds, producing highly toxic gases composed of dioxins, CO, hydrocarbons, volatile organic compounds, oxides of sulfur, and hazardous fumes etc. Municipality and public have not been sensitized about the increasing adverse effects of wastes on local environment i.e., contaminating air, water and land making hard for living beings to survive [17, 56].

Major technical problem for MSW treatment is mixed MSW i.e., non-segregation of organic waste for its utilization into biogas and compost production which is the most suitable waste management technique for Indian Scenario. In 2008, India's installed energy recovery from waste was 86.32 MW and currently in 2021, it is 168.64 MW, which is very less in comparison to MSW generation rate within the same time period [57, 58]. Biomass power generation (4831.33 MW in March 2016 to 10145.92 MW in March 2021) by combustion route and biomass cogeneration in sugar mills in India is highly progressive. On the other hand, there is no substantial focus on waste to energy conversion techniques in last 13 years even though MSW increment rate has been high [57, 58]. Even many installed composting, RDF and waste to energy plants have been failed due to insufficient waste segregation, inefficient management, operational problems like deficient logistical planning and adequate financing. Other problems in prospects of energy recovery facility are feasible technologies, inadequate financial support and quality of waste i.e., contamination occurs during collection and transportation, lack of appropriate storage facility, and lack of expertise in government. These problems were listed and recognized after consultation with urban local bodies (ULBs), industries, and academics [20, 59]. Since most of the Indian cities are rapidly developing, there is a pressing need of effective and sustainable waste management practices in every city.

5. Recommendations

Various feasible and well-practiced techniques in some cities of India as well as at global scale are recommended in this section to tackle challenges of Jaipur city as well as other Indian cities having similar scenario of MSW quantity and composition.

5.1. Awareness campaigns to increase public participation

A most prominent stakeholder is community or public and their inclusion at various levels of waste management process will lead to effective as well as efficient MSWM [30]. In general, "Waste" is supposed to be not useful for people which need to be thrown away. Therefore, the opinion on waste needs to be changed and it should be considered as a resource rather than waste [27]. For this, firstly JMC needs to organize awareness programs assisted from NGOs and educational institutes for reducing the MSW at source, making residents aware of waste categories i.e., organic, recyclable, non-biodegradable and other hazardous waste, so that community would start segregating domestic MSW into biodegradable and non-biodegradable waste. Further, people can be encouraged to start home composting for gardening purpose along with educating them with potential health impacts from poor MSW management. Awareness programs can be arranged through public group meetings, seminar, workshops, newspapers, media, radio, and television networks involving active participation from local bodies [12, 38].

Food waste generation in different hospitality sectors at hotels and restaurants is high in a city like Jaipur which is well known for tourism and hospitality. Strategies for mitigating food waste from hospitality sector include: making customers and staff aware through showing signage and posters regarding reducing the food wastage, imposing fine over food leftovers (possibly well-mentioned in the food menu), management of serving size, serving smaller plates that avoids people to take extra food, serving again leftovers if food is not spoiled, often revising the menu based on most of the food leftovers and offering the non-consumed food to food banks and low-income communities through support of NGOs. Segregated food waste provides the chance to recover energy from it such as biogas and compost production. Food waste management from hospitality sector also needs to be improved in terms of reducing food waste and its handling i.e., segregation, and effective subsequent utilization [20].

Door-to-door collection in pre-organized time slots with gentle alarming sound, is essential even though this will require more manpower and wheel barrows or handcarts containing 2-3 different colored bins. Door-to-door collection must be stringent and should strictly collect the properly segregated waste. Once household waste collection is improved, concepts like “Bin free city” or “Zero dustbin city” may be introduced in Jaipur which have been successfully implemented in Ambikapur city of Chhattisgarh. Similarly, Maharashtra’s Nagpur city has also reduced the community bins number to 80% of total to encourage door-to-door collection of MSW [22, 29]. Government can introduce the competitions and winning rewards in different zones in the same city for sanitation and cleanliness which would encourage the public participation. Moreover, MSW collectors and sweepers should be provided training, steady disinfection of the dhalaos (transfer station), safety uniforms, and equipments and regular monthly wages. They must be provided with personal protective equipment like gloves, shoes and air filter masks while cleaning and handling the wastes to prevent eosinophilia, respiratory disorders and infection or contagious diseases [50, 60].

A study in Jaipur highlights that the placement of community bins should be equitable in terms of regional coverage and not just be based on social connections [12]. Bigger bins must be placed near the party venues, marriage halls and institutions, which generate larger volumes of MSW in a day. All community bins must be covered so that it would be accessible to humans only avoiding waste dispersion by animals. For transportation, old and inefficient vehicles should be discarded and covered properly to prevent waste scattering on roads.

5.2. Improvement in existing composting and landfill facilities

The biological conversion of organic fraction existing in MSW into a compost/humus through bacterial activity i.e., oxidizing the organic compounds in the presence of air, is called composting. In anaerobic composting, microorganisms break down the organic compounds in the absence of air through reduction process while metabolizing the nutrients [61]. This compost has good fertilizer quality for agriculture application. Many metro cities have MSW composting capacity between 150-500 TPD. Vermicomposting is also practiced in Mumbai, Bangalore and Faridabad where organic waste is decomposed by aerobic microorganisms followed by disintegration through earthworms [10]. Similar measures can be adopted for Jaipur city as well. Organic feedstocks in vermicomposting are generally animal, agricultural, food waste, and sewage waste. The processing periods for vermicomposting may be ranged between 28-120 days and conditions for the process can be varied between 18-67^{o}C temperature, 5.9-8.3 pH and moisture content 11-80%, yielding compost as bio-fertilizer rich in nitrogen, phosphorous and potassium [62].

Many studies highlighted the irreparable damage caused through uncontrolled open landfilling sites and suggested sanitary landfill for final MSW disposal [32, 40, 63]. Jaipur city must have sanitary landfill provisions for safe disposal of MSW by either transforming the existing open landfills to sanitary landfill or establishing waste to energy plant [30]. Sanitary landfill design must follow the procedures of MSW 2016 guidelines regarding site selection, environmental examination i.e., environmental impact assessment, near to the treatment facility if possible, and away from dwelling areas and water bodies. There must be urgent cessation of existing dumping sites near rivers or any water storage facility like well, pond, lakes.

Advancement in landfill technology may lead to the development of bioreactor landfilling (BLF), which serves as storage as well as treatment of waste. BLF facilitates rapid degradation of organic waste through microbial action due to increase in moisture content via leachate recirculation. The process may achieve faster landfill gas generation to have energy production from it. This type of landfilling also enhances the waste stabilization and its features such as waste degradation, storage, landfill gas collection and faster stabilization make it an environmentally sound landfill as compared to other landfill systems. Diversion of MSW streams to recycling, composting and waste to energy technologies may avoid the possibility or development of landfill gas recovery (LFGR) system as no organic waste reaches to landfill site avoiding biological actions for gas production [19, 63].

5.3. Informal sector integration and public private partnerships

The efficient MSWM in Jaipur city also calls for the provisions of a governing body to administer rag pickers and scrap dealers. The rag pickers can be integrated with the formal system by providing training and facility of precautionary measures as well as the regular monthly wages along with preventing the scrap dealers to take any advantage of rag pickers. Their incorporation with the formal system would enhance the recovery of the recyclable materials [12, 50]. Recently, a study in Brazil has advocated the socio-economic inclusion of scavengers for addressing the challenge of MSW management through their active participation in waste collection and increasing their quality of life through income generation as well as ensured health and safety at work [64].

Due to lack of investment and experts in waste treatment field, responsibilities like collection, transportation, treatment and disposal can be shared between NGOs, private companies and municipality. For instance, collection and segregation can be handled by NGOs, transportation by municipality and design, construction and operation of treatment and disposal facilities by private companies. This model has been followed by Delhi by collaborating with 3 different companies for MSWM in six zones of Delhi [27]. PPP model is a significant way and profitable business for private investors which have adequate planning, experts and infrastructures to have well-organized MSWM. For instance, Praj Industries Ltd, Pune has introduced the safer production of biodiesel, fuel ethanol, bio-CNG (Compressed Natural Gas) and liquid manure from the organic content of MSW by solvent extraction, fermentation, and biomethanation in an integrated manner [44].

Circular resource efficiency can be achieved by using recyclables from MSW as raw materials for recycled new products. Increasing cost of new materials and non-renewable energy makes that case for recovery of material from waste as an economical and sustainable way for recycling. Recyclables can include newspapers, plastics, glass, aluminium, metals, construction and demolition debris. Recovery of recycling materials mainly consists of screening of undersize material and shredding followed by magnetic separation for ferrous metal. Getting some revenue from recyclables may ease the waste management budget as well as cut down the cost regarding its treatment and disposal, thereby reducing the landfill burden. Overall, recycling alone is the most economical and energy efficient process that avoids the enormous embodied energy of a virgin new material and also evades the GHGs emissions due to the virgin material energy consumption [9, 19].

5.4. Adoption of waste to energy techniques

For a developing country like India, rapid economic development requires energy and resources to progress. With depleting fossil reserves, future energy demand can be addressed through the alternative sources of energy i.e., renewable energy. At present, India has 2554 MW potential as renewable energy potential from waste generated i.e., MSW and waste water [33, 65]. Waste to energy can play effective role in production of renewable and sustainable energy. In Jaipur, the MSW consisting organic and inorganic portions may be utilized for biofuel and power generation.

MSW's quantity, characteristics, composition, physical properties, land availability, environmental safety, financing, stakeholder's involvement, and capability of organizations are major criteria for selection of appropriate technology. Cities alone generating more than 1000 TPD (like Jaipur) should opt for waste to energy technologies as it would be sustainable as well as economical. If the thermal route is to be adopted, the enhanced calorific value of waste should be ensured by proper segregation of MSW [66]. The recovery of energy from waste offers many additional benefits i.e., total waste quantity gets reduced by 60-90% depending upon the waste composition and adopted technology; demand for land for landfilling would reduce; the cost of transportation to far-away landfill sites would reduce; and most importantly net environmental pollution would be minimized [11]. Further, the pros and cons of individual waste to energy technologies are shown in Table 5. Recommendations for making waste to energy technologies viable in Indian cities are to introduce contracts for waste collections and deliveries, control on storage sites preventing contamination, increase the public participation by educating and making aware, more funds to ULBs or municipality authority to support waste to energy projects [59].

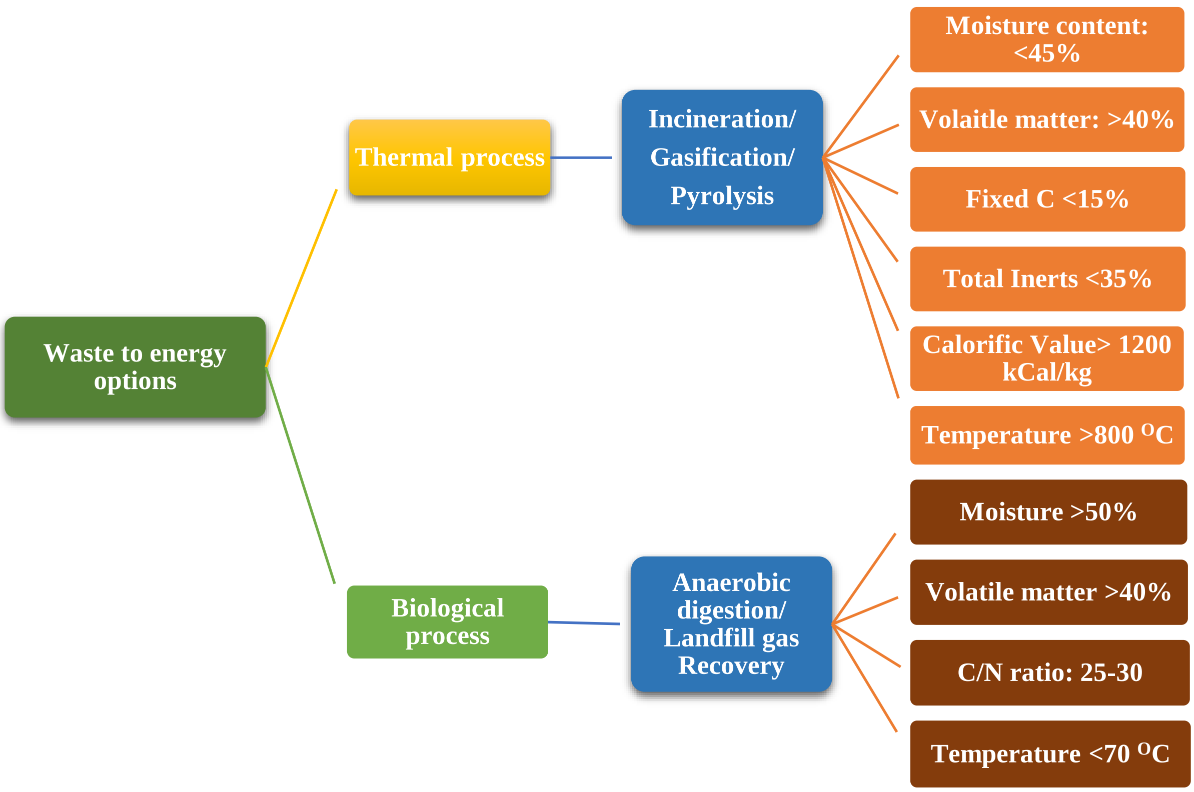


Figure 6. Waste to energy options with operating parameter's desired ranges [18]

5.4.1. Thermal conversion

Thermal conversion process entails thermal decomposition of MSW to produce either heat energy or fuel oil or gas. The objectives of thermal waste to energy are recovering the energy potential from the waste, destroying toxic substances in organic and inorganic waste, saving the natural energy resources for energy production, reducing the waste quantities for disposal and transforming the residuals into reusable secondary products to save material resources. Thermal treatment plants require high installation and operational cost as well as the experts in the field [10]. It is convenient to have waste as a fuel resource containing a high percentage of non-biodegradable matter and low moisture content. The main technological options under this category include incineration, pyrolysis and gasification. Main operating parameters during thermal conversion to energy require desired ranges for proper functioning are shown in Figure 6. Moisture content, volatile content and temperature are the crucial parameters for incineration, pyrolysis, gasification and AD as well. Though the thermal conversion techniques require much higher temperature (>800ºC) as compared to biological conversion method. The volatile matter in the waste should be at least 40% in order to be feasible for waste to energy conversion.

5.4.1.1.Incineration

Incineration is a similar process like the combustion i.e., complete burning of solid waste in presence of sufficient air at 980 to 2000ºC, converting MSW's chemical energy into heat energy and generating electricity through turbine-generator system [10, 11]. Raw MSW is generally preferred. Incineration depends on the characteristics of waste which in turn affected by the socio-cultural, seasonal and demographic differences [67]. However, segregated combustible non-biodegradable waste having calorific value greater than 1000 kcal/kg should be selected for this treatment. Moisture content and inert waste reduce the calorific value of MSW and affect its combustibility. Stages in incineration process are -

drying, incineration, energy recovery from combustion, and flue gas cleaning for air pollution control. Ash produced, in the end, can be utilized in road construction and building materials like fly ash brick. Through this treatment process, incineration of 1 tonne of MSW is capable of generating 544 kWh of energy and 180 kg of solid residues [68]. In General, around 0.7-1.2 mg CO_2 is released from incineration of 1 mg MSW incineration [69]. Though, it may be different for Indian MSW incineration scenario due to dissimilar compositions. Indian cities hardly practice this technique due to undesirable characteristics i.e., high moisture content, high inert content and low calorific value of MSW [10, 18].

5.4.1.2.Gasification

Gasification is the combustion of solid waste into gas mixture (H_2, CO, CO_2, CH_4, H_2O and inert gases) under deficient oxygen conditions at high temperature 800-900^{o}C. Syngas (majorly H_2 and CO), the main product of gasification, can be used to produce renewable energy and as a feedstock for production of chemicals like methanol and liquid fuels. This system mainly includes the gasifier, gas cleaning configuration and energy recovery system. Generally, it is installed for agricultural residues and forest wastes in India. However, it can also be used for MSW by drying, inert removal and chopping prior to gasification of MSW [10, 33, 70]. Its integration with combined cycle, where conversion of gaseous fuel to electricity by gas turbine have overall high conversion efficiency ranges 40-50% for 30-60 MW capacity plant [71]. The process is widely used in Japan with 85 MSW operating gasification plants as well as at a smaller scale in USA, Germany, Norway, UK and Italy [68]. This technology is comparably better than incineration in terms of cost, flue gas cleaning and output products and can be explored for MSW management in Jaipur city.

5.4.1.3.Pyrolysis

Pyrolysis is another thermal conversion technology in which biomass converted to liquid (bio-oil or bio-crude) and gases, in devoid of oxygen at 400-800^{o}C temperature range. The process parameters are temperature, the rate of heating, residence time, waste composition, and waste particle size. Lower temperature pyrolysis products are pyrolysis oil, wax and tar. However, quality pyrolysis gases (CO, H_2, H_2O, N_2, hydrocarbons) are produced at a higher temperature (>700°C). Some developed countries like Japan, UK and France are operating MSW pyrolysis plants successfully. Integration of MSW pyrolysis with a gas turbine for energy recovery may lead to a net conversion efficiency of 28-30% [68].

5.4.2. Biological conversion

The biological conversion process is based on the enzymatic decomposition of organic matter by microbial action to produce biofuel i.e., biogas, bioethanol, and bio-diesel. Biological processes are preferred for waste having a high percentage of biodegradable matter and high level of moisture content, which aids microbial activity. The main technological options under this category are AD (or bio-methanation) to produce biogas and fermentation to produce biofuel like ethanol [11, 18].

5.4.2.1. Anaerobic Digestion

Organic matter is degraded by bacteria in controlled anaerobic conditions to generate biogas i.e., mixture of CH_4 and CO_2 and traces of water vapor, H_2S, NH_3, etc. The AD process is composed of series of 4 stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis [72]. Controlling parameters are volatile content, temperature, pH, and carbon to nitrogen (C/N) ratio. The lignocellulosic organic matter is undesirable for AD process without adequate pretreatment, as its hydrolysis is difficult due to the presence of lignin [66, 73, 74]. It is capable of generating 300-400 m^3 biogas per tonne of VS of organic fraction of MSW [18]. One tonne of MSW composed of 60% organic matter and remaining is moisture which may produce 150 kg of methane through AD process. Purified biogas after removing CO_2 and H_2S gas can be used as transportation fuel, called as Bio-CNG [68]. AD of untainted food waste has attractive option of management, nutrient recycling and bio-methanation having potential of 410-530 ml biogas/g VS of food waste [75].

5.4.2.2. ***Landfill Gas Recovery***

Complex biological and chemical decomposition of organic matter of MSW dumped results in landfill gas production. Landfill gas emissions composed of mainly methane and carbon dioxide gases. Waste composition (primly organic fraction), moisture content, waste age, ash content, temperature and precipitation are major factors affecting the rate of methane gas production. Landfill gas has methane potential of 100 m^3/tonne of organic fraction of MSW which is capable of being trapped and utilized as green energy production [76]. Landfill accounts for 13% of global CH_4 emission considered as one of the major anthropogenic methane emissions [28]. Its reduction and recovery consequently reduce GHG emission. If landfill gas could be recovered, it is capable of generating 72 MW of electricity in India [5]. Since most of the landfill sites are not designed considering recovery of landfill gas, it is infeasible to trap landfill gas and therefore its on-site burning is chosen [28,76,77].

Standard protocols used internationally for landfill gas estimation are first order decomposition models i.e., LandGEM, mass balance model, modified triangular method developed by Intergovernmental Panel on Climate Change. These models need to incorporate meteorology data for site specific estimation. The on-field methods are flux chamber technique, vertical radial plume mapping and differential absorption LiDAR techniques [77,78]. Flux chamber method has been used for estimating CH_4 and CO_2 emission fluxes which are 68 and 92 mg/min/m^2 respectively, which are severe in summer in comparison to winter season for northeast city Guwahati [77]. A specific model has been developed for methane estimation from landfill sites in Indian climatic conditions, which is validated in three different climatic cities: Shillong, Jaipur and Kolkata [78].

RDF, waste to energy and LFGR methods involve renewable energy recovery from MSW through clean development mechanism projects, as they can result into 40,308-1,252,206 tonne of CO_2 equivalent reduction in GHG emission, which will bring carbon credits and make the projects financially attractive [79].

5.4.3. Energy and economic aspects of waste to energy techniques

The specific energy potential of waste to energy technologies have been summarized in Table 4 [55, 68, 80]. On the basis of these energy potentials, further calculations were done to estimate the total saving of diesel fuel as well as GHG emissions for using the energy from these plants to replace the diesel for power generation. As reported by Prajapati et al. [55], 1 tonne of organic fraction of MSW has the potential to generate 192.582 m^3 biogas through AD. 1 m^3 of biogas generates 2.04 kWh electricity with 35% efficiency [80]. Utilizing diesel for heat and power generation results in GHG emissions of 2.68 kg CO_2 per L of diesel burned [81]. These emissions can be saved by replacing the diesel from biofuel generated from organic fraction of municipal waste. Similarly, GHG emission from landfill of MSW is 1230 kg of CO_2 per tonne of MSW [82]. These GHG emissions from landfills can be saved by using waste to energy technology.

Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy Technologies

Technology	Specific Energy potential (kWh_e/tonne)	GHG emissions and cost savings

		Diesel Fuel saved (L)	USD ($)	GHG from Diesel Generator (kg of CO2)	GHG from landfill (kg/tonne)	Total GHG (kg of CO_2) saved
AD	393*	90.36	106.62	242.16	1230.00	1472.16
Incineration / RDF	544	125.12	147.64	335.32	1230.00	1565.32
Gasification	400	92.00	108.56	246.56	1230.00	1476.56
LFGR	163	37.54	44.29	100.60	1230.00	1331.60

*kWh/tonne of Organic fraction of MSW

For cost analysis of these technologies, the key parameters to be considered are: cost of land acquisition, technology installation, feedstock, operation and maintenance cost as well as labor cost. From economic assessment perspective, incineration technique is the more suitable choice as compared to complex gasification technology as it requires low cost for implementation and installation. Gasification has the operational cost of around 0.250 million USD/day. Still, gasification is the most attractive technology considering environmental assessment as it can reduce more than 3208 TPD of carbon emissions [83]. In India, most of the gasifiers uses coal, agricultural, and agro-industrial waste. Therefore, the MSW with similar energy content can also be used as a co-fuel in appropriate blend for energy production. However, further research and optimization of this strategy is required to reduce its capital cost. Hybrid technologies can also be explored for combining MSW conversion with other renewable energy technologies for making MSW viable as fuel. A recent study suggested a hybrid solar-biomass system in which AD of MSW was combined with concentrated photovoltaic to generate heat and power form the system [84].

A biomass RDF plant feasibility was evaluated with net present value as profitability method and also sensitivity analysis performed to evaluate critical factors like pellet price, capacity utilization and annual working hours for plant economy. The study concluded a minimum selling price as USD 120 per tonne of pellet for plant feasibility [85].

In developing countries like India, the economic viability of waste to energy technology requires comprehensive study of cost parameters for initial investment, cash inflow and outflow estimation as well as sensitivity analysis of influencing parameters. There is a scope of techno-economic evaluation of waste to energy technologies using economic metrics net present value and levelized cost of energy considering economic value of produced electricity, thermal energy and products, and specially accounting ecological benefits, reduction in current MSWM costs.

Table 5: Pros and cons of different waste to energy techniques [10, 33, 68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	• Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume	• Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	• Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning	• Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	• Production of fuel oil	• Heterogeneity in MSW • Char removal is important • Yield stream is complex

		• Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent)	
Biological conversion	AD	• Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer • Control GHG emissions, with net environmental gains are positive • Potential for co-digestion with agricultural and industrial organic wastes • Less monitoring is required • Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill	• Requires organic waste segregation • Not suitable for complex organics, oily, or lignocellulosic materials • GHGs, fouling, and fire threats if leakage is present
	LFGR	• Least cost option • Collected gas can be used power generation, and thermal application • Reduce environmental and health impact, reduce GHG emissions	• Expertise and monitoring required • Higher transportation cost and need larger land area • Leachate problem if landfill is not scientific

5.5. Application of optimization models

Mathematical and optimization models robustly used for planning and optimizing the MSWM infrastructure to make MSWM as sustainable management reducing usage of fossil fuels. Extrapolation of past data is inaccurate and unreliable way for forecasting of waste generation rate, as it greatly affected by socioeconomic factors whose selection should be significant to the local situation. Mathematical modeling methods of solid waste streams for the precise prediction of waste generation and its rate have been benefitted the MSWM in terms of viable future planning. Models concerning generation of waste having key variables of socioeconomic factors like household size, waste volume, education level of households, income level of households, and environmental awareness, etc. in a district area, and in a similar way over the country. Linear regression technique is used to develop model the forecasting of biodegradable and non-biodegradable waste generation rate and also analyzing the accountable variables in Dhanbad city [86]. Waste collection streams data: mixed waste, source separated waste, and treatment decisions also used for modeling of waste prediction. Models include mostly correlation and regression models, single regression analysis and multiple regression analysis, system dynamic, and artificial intelligent system (genetic algorithm, artificial neural network, and fuzzy logic) for multivariable analysis [87].

Nganda [88] developed a mathematical model acting as a technique to optimize the use of management facilities (like number of trucks, incineration plants, landfill capacity, etc.) to reduce total waste management cost and ensuring optimal use of resources. It results to provide suitable information in decision-making to have a planned and efficient waste management system. Same model was used in Hong Kong, waste streams between collection centers, replacement truck warehouse, incinerators, and landfill were formulated using mixed integer programming for identifying the number of trucks required between two points and same in the whole system and waste amount reduced by 42% in landfill with their present strategy [89]. In a similar way, management facilities can be minimized by using mathematical models in Jaipur scenario with existing operating facilities.

An integrated model of geographic information systems (GIS), equation-based model and agent-based model effectively used to minimize collection cost by 11.3%, by reducing travel length and time making efficient collection and transportation system [90]. Das and Bhattacharyya [91] proposed an effective MSWM in Bidhan Nagar municipality under metropolitan Kolkata city, by optimizing length route in its transportation using travelling salesman problem. Travelling salesman problem can be robustly used for optimizing the path length for waste transportation amongst the waste source, collection points, transfer stations, treatment facility or landfill, will majorly reduce the management cost and emissions from the transportation part. Cost effective collection and transportation process considering the locations of dustbin, transfer station, road network, composting unit and dumping site, is optimized with help of GIS and remote sensing in Vellore city of India, and achieving 59.12% reduction in travel distance in the transportation [92]. Thus, reducing natural resource consumption and making the management as sustainable approach.

5.6. Application of life cycle assessment tools

Different MSWM strategies can be compared and evaluated by using LCA tool which helps in determining the environmental implications, energy consumption and cost of the different combination of management strategies [93-95]. LCA makes it easier to identify the processes which have a significant impact on the environment. SimaPro, GaBi, WISARDTM and EASEWASTE are widely used software for LCA.

Babu et al. [63] evaluated 4 disposal scenarios in Bangalore city: open dumping, landfilling without gas recovery, landfilling with gas recovery and BLF to find out sustainable and economical disposal using LCA tool. The study revealed BLF as best option with least Global Warming Potential (3335 kg CO_2) and photochemical ozone creation potential (0.379 kg) per tonne of waste, and faster waste stabilization inducing more energy recovery from MSW and also with lesser payback period (50 years) than others. Another study assessed the cost and environmental impacts of 4 management options under LCA tool in the selected wards of Bangalore: 1. Existing system i.e., recycling, composting and rest of MSW transported to landfill site; 2. With optimal route transportation; 3. Vermicomposting of 62% MSW (biodegradable) and rest landfilling; 4. Incineration of entire waste. The results of the study showed that the second option with optimal route transportation and least amount required USD 409750 per annum was the best on the basis of ecological, economic and social aspects [96].

LCA performed for integrated MSWM in Delhi concluded that the recycling facility has negligible emissions and energy consumption. Landfilling has comparatively less negative environmental impacts in the beginning year as compared to incinerators. However, it produces highest GHG emissions among all MSWM afterwards [36]. For the same city, Bohra et al. [97] compared 12 different integrated MSWM scenarios involving RDF, AD, composting and sanitary landfilling including existing MSWM i.e., 9% composting and rest to landfill site as baseline scenario. While the global warming potential (226.92 kg CO_2 eq.) was revealed to be least for the scenario having major diversion of organic waste from landfilling to treatment facilities to RDF pelletisation (16%), AD (16%) and composting (10%).

A study in Mumbai city compared six different scenarios including the current practice of open dumping with partial BLF and other five integrated approaches of different combinations of recycling, AD, composting, incineration and landfilling with 50% gas recovery. The study reported least GHG (930.01 kg CO2 eq. per tonne) emission for the combination of recycling, AD and landfilling [32]. LCA study carried out in non-metro city Dhanbad compared four management strategies of collection + transportation + landfilling;

recycling + open burning + open dumping + landfilling without energy recovery (LFWER); composting + LFWER; and recycling, composting and LFWER. It concluded that the management strategies comprising recycling, composting and landfilling without energy recovery had the least environmental impacts (global warming potential - 3430 kg CO_2; terrestrial ecotoxicity - 0.872 kg C_2H_4 eq.; acidification - 4.63 kg SO_2 and eutrophication 1.99 kg PO_4^{3-} per tonne of MSW) as recyclables, organic and inert materials subjected to respective treatment or disposal facility [56].

The outcomes of the environmental evaluation of different MSWM scenarios in a city provides crucial information to decision makers when planning sustainable waste management strategies. LCA study of MSWM in Jaipur city will greatly help to identify and quantify the environmental impacts caused either by waste or different treatment processes. This may help the managing authorities to choose the best and environmentally appropriate process among the possible treatments.

6. Conclusions

Jaipur city faces significant problems including unregulated landfilling, inability to enforce MSW (management and handling) regulations and insufficient public involvement in the management process. The study inferred that composting and unsanitary landfilling are the most prevalent method for waste disposal in Jaipur as well as other Indian cities with no proper installed facilities for waste conversion. Even the installed facilities are less suitable and inefficient due to the lack of segregation of waste during collection.

On the basis of this review, the key conclusions and recommendations for MSW management for Jaipur cities can be summarized as below:

- Different stakeholders (municipality, private sectors, public and informal sectors) are required to work together by taking specific responsibility in MSWM stages aiming to have maximum material and energy recovery from MSW.

- There is a need to actively work with local communities to raise awareness for waste segregation processes.
- There is a large scope and urgent need of development of recycling plants, feasible waste to energy technology and scientific landfill in Jaipur complying environmental standards regarding emissions.
- The mathematical or optimization model can be applied in Jaipur MSWM robustly, which would optimize the resource utilization, minimize management facilities, time and expenditure.
- LCA study in Jaipur city of practicing or possible MSWM scenarios would be helpful to identify the technology or treatment process having least impact on the environment which should be favored first.
- More research is required regarding the economic and environmental gains from recycling and energy generation facilities in the context of Jaipur city.

Acknowledgements

Authors are thankful to Department of Science and Technology, (Grant No: Grant No. ECR/2016/000989) and Department of Biotechnology (Grant No. BT/RLF/Re-entry/04/2013) Government of India for providing the financial support to carry out the present study. The fourth author is also grateful to the Royal Academy of Engineering, BBOXX and UCL for supporting her five-year fellowship.

Conflict of interest:

The authors declare that they have no conflict of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Cheela VS, Ranjan VP, Goel S, John M, Dubey B. Pathways to sustainable waste management in Indian Smart Cities. J Urban Manag 2021 (In press). https://www.sciencedirect.com/science/article/pii/S2226585621000364#sec4

[2] Yadav P, Samadder SR. A global prospective of income distribution and its effect on life cycle assessment of municipal solid waste management: a review. Environ Sci Pollut Res 2017;24(10):9123-41.

[3] Shekdar AV. Sustainable solid waste management: an integrated approach for Asian countries. Waste Manag 2009;29(4):1438-48.

[4] Mboowa D, Quereshi S, Bhattacharjee C, Tonny K, Dutta S. Qualitative determination of energy potential and methane generation from municipal solid waste (MSW) in Dhanbad (India). Energy 2017;123:386-91.

[5] Planning Commission Report. Reports of the task force on waste to energy (Vol-I) (in the context of Integrated MSW management). 2014. http://164.100.161.239/reports/genrep/rep_wte1205.pdf (Accessed 05 June 2021).

[6] Annual Review Report 2014-15. Implementation of Municipal solid wastes (Management and Handling) Rules, 2000. Central Pollution control board, Ministry of Environment, Forest and Climate Change, Government of India. April 2016. https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2014-15.pdf (Accessed on 05 June 2021).

[7] Municipal solid waste, Central Pollution control board, Ministry of Environment, Forest and Climate Change, Government of India. https://cpcb.nic.in/uploads/MSW/trend_46_cities_list.pdf (Accessed 05 June 2021).

[8] Population Census 2011, India, http://www.census2011.co.in/.

[9] Nandan A, Yadav BP, Baksi S, Bose D. Recent scenario of solid waste management in India. World Sci News 2017;66:56-74.

[10] Sharholy M, Ahmad K, Mahmood G, Trivedi RC. Municipal solid waste management in Indian cities–A review. Waste Manag 2008;28(2):459-67.

[11] Feasibility for Integrated Municipal solid waste management project for Jaipur Municipal Corporation. Report by InfraEn (India) Pvt. Ltd. Jaipur Municipal Corporation; 2015.

[12] Singh A. Municipal Solid Waste Management in Jaipur: Current Status and Way forward. Intern Report. Rajasthan State Pollution Control Board. June 2011. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.467.3019&rep=rep1&type=pdf (Accessed in 05 May 2021).

[13] Yay AS. Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya. J Clean Prod 2015;94:284-93.

[14] Waste management hierarchy and homeland security incidents, https://www.epa.gov/homeland-security-waste/waste-management-hierarchy-and-homeland-security-incidents (Accessed on 05 May 2021).

[15] SWM 2016, Solid waste management rule, Government of India; 2016. https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf (Accessed 05 May 2021).

[16] Municipal solid waste (management and handling) rules 2000. Ministry of Environment and Forests (MoEF), Government of India, New Delhi, India. 2000. https://www.mpcb.gov.in/sites/default/files/solid-waste/MSWrules200002032020.pdf

[17] Kumar A, Agrawal A. Recent trends in solid waste management status, challenges, and potential for the future Indian cities–A review. Curr Res Environ Sustain 2020;2:100011.

[18] Dhar H, Kumar S, Kumar R. A review on organic waste to energy systems in India. Bioresour Technol 2017;245:1229-37.

[19] Kaushal RK, Varghese GK, Chabukdhara M. Municipal solid waste management in India-current state and future challenges: a review. Int J Eng Sci Technol 2012;4(4):1473-89.

[20] Gandhi P, Kumar S, Paritosh K, Pareek N, Vivekanand V. Hotel generated food waste and its biogas potential: a case study of Jaipur city, India. Waste Biomass Valor 2019;10:1459-68.

[21] Ganapathy N. In India: waste that saves lives. The Straits Times.2013 http://www.straitstimes.com/asia/in-india-waste-that-saves-lives. (Accessed 20 February 18).

[22] Solid waste management feasibility study for Nagpur. Report for municipal solid waste management in Nagpur city. Arcadis Germany GmbH. http://www.unescap.org/sites/default/files/Report_IN_Nagpur_SolidWasteManagement_ArcadisGermanyGmbH_2017.pdf; 2017. (Accessed 13 March 2018).

[23] Ramachandra TV, Bharath HA, Kulkarni G, Han SS. Municipal solid waste: generation, composition and GHG emissions in Bangalore, India. Renew Sustain Energy Rev 2018;82:1122-36.

[24] Yadav P, Samadder SR. Assessment of applicability index for better management of municipal solid waste: a case study of Dhanbad, India. Environ Technol 2018;39(12):1481-96.

[25] Nagpure AS. Assessment of quantity and composition of illegal dumped municipal solid waste (MSW) in Delhi. Resour Conserv Recy 2019;141:54-60.

[26] Khan D, Kumar A, Samadder SR. Impact of socioeconomic status on municipal solid waste generation rate. Waste Manag 2016;49:15-25.

[27] Olivier L. The solid waste management system of Jaipur: an overview and analysis. independent study project (ISP) collection. 2011. https://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=2069&context=isp_collection (Accessed in 05 May 2021)

[28] Joshi R, Ahmed S. Status and challenges of municipal solid waste management in India: A review. Cogent Environ Sci 2016;2(1):1139434.

[29] Choudhury M, Dutta J. A comparative study of municipal solid waste management status for three major towns of upper Assam-India. Int J Waste Resour 2017;7(3):1-8.

[30] Ghatak TK. Municipal solid waste management in India: a few unaddressed issues. Procedia Environ Sci 2016;35:169-75.

[31] Status of municipal solid waste management in southern states. Report by Central Pollution Control Board Zonal office (South), Bengaluru. 2011**.**

[32] Sharma BK, Chandel MK. Life cycle assessment of potential municipal solid waste management strategies for Mumbai, India. Waste Manag Res 2017;35(1):79-91.

[33] Kalyani KA, Pandey KK. Waste to energy status in India: a short review. Renew Sustain Energy Rev 2014;31:113-20.

[34] Das S, Bhattacharyya BK. Municipal solid waste characteristics and management in Kolkata, India. In The 19th International Conference on Industrial Engineering and Engineering Management. Springer, Berlin, Heidelberg. 2013; 1399-1409.

[35] Gupta B, Arora SK. A study on management of municipal solid waste in Delhi. J Environ Waste Manag 2016;3(1):130-8.

[36] Srivastava AK, Nema AK. Life cycle assessment of integrated solid waste management system of Delhi. Towards life cycle sustainability management. Springer, Dordrecht. 2011, p. 267-276.

[37] Francis RC, Singh LP, Prakash EV. Solid waste management and characteristics in Lucknow, Uttar Pradesh, India. Int J Sci Eng Res 2013;4(11):1645-8.

[38] Archana, Ali D, Yunus M, Dutta V. Assessment of the status of municipal solid waste management (MSWM) in Lucknow – Capital city of Uttar Pradesh, India. IOSR J Environ Sci Toxicol Food Technol. 2014;8(5)II:41-9.

[39] Mohanty CR, Mishra U, Beuria PR. Municipal solid waste management in Bhubaneswar, India—a review. Int J Latest Trends Eng Technol 2014;3(3):303-12.

[40] Gogoi L. Municipal solid waste disposal: a case study in Guwahati city to mitigate the man-made disaster. IOSR J Humanities Soc Sci 2013;9(3):55-60.

[41] Mahongnao M. Urban solid waste management in Imphal, Manipur. J Ind Pollut Control 2017;33(1):696-701.

[42] Late A, Mule MB. Composition and characterization study of solid waste from Aurangabad city. Univers J Environ Res Technol 2013;3(1):55-60.

[43] Mundhe N, Jaybhaye R, Dorik B. Assessment of municipal solid waste management of Pune city using geospatial tools. Int J Computer Appl 2014;100(10):24-32.

[44] Soni AK, Patil D, Argade K. Municipal solid waste management. Procedia Environ Sc 2016;35:119-26.

[45] Status of municipal solid waste management in Jodhpur city. Report by Central Pollution Control Board, Central zonal Office, Bhopal. 2011. https://cpcb.nic.in/displaypdf.php?id=em9iaG9wYWwvTVNXX0pvZGhwdXIucGRm

[46] Status of municipal solid waste management in Gwalior city. Report by Central Pollution Control Board, Central zonal Office, Bhopal. 2011. https://cpcb.nic.in/displaypdf.php?id=em9iaG9wYWwvTVNXX0d3YWxpb3IucGRm.

[47] Srivastava R, Krishna V, Sonkar I. Characterization and management of municipal solid waste: a case study of Varanasi city, India. Int J Curr Res Acad Rev 2014;2(8):10-6.

[48] Jampala S, Gellu A, Kala DS. Current scenario on urban solid waste with respect to Hyderabad city. Int J Res Studies Sci Eng Technol 2016;3(12):10-13.

[49] Rajendra A, Ramu. Assessment of municipal solid waste management in Mysore city. Int J Appl Innov Eng Manag 2014;3(4):134-8.

[50] Kandasamy SP, Akolkar AB, Manoharan A, Paranji S. Municipal solid waste management at Chennai in southern India–an occupational health perspective. Int J Health Promot Edu 2013;51(1):50-61.

[51] Abdel-Shafy HI, Mansour MS. Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egyp J Pet 2018;27(4):1275-90.

[52] Hoornweg D, Bhada-Tata P. What a waste: a global review of solid waste management. World Bank Report. 2012.

[53] Upadhyay V, Jethoo AS, Poonia MP. Solid waste collection and segregation: a case study of MNIT campus, Jaipur. Int J Eng Innov Technol 2012;1(3):144-9.

[54] Paritosh K, Mathur S, Pareek N, Vivekanand V. Feasibility study of waste (d) potential: co-digestion of organic wastes, synergistic effect and kinetics of biogas production. Int J Environ Sci Technol 2018;15(5):1009-18.

[55] Prajapati KK, Pareek N, Vivekanand V. Pretreatment and multi-feed anaerobic co-digestion of agro-industrial residual biomass for improved biomethanation and kinetic analysis. Front Energy Res 2018;6:111.

[56] Yadav P, Samadder SR. Environmental impact assessment of municipal solid waste management options using life cycle assessment: a case study. Environ Sci Pollut Res 2018;25(1):838-54.

[57] Kumar A, Kumar K, Kaushik N, Sharma S, Mishra S. Renewable energy in India: current status and future potentials. Renew Sustain Energy Rev 2014;14(8):2434-42.

[58] All India Installed Capacity. Central Electricity Authority (CEA), Government of India. https://cea.nic.in/installed-capacity-report/?lang=en . (Accessed on 05 May 2021).

[59] Nixon JD, Dey PK, Ghosh SK. Energy recovery from waste in India: An evidence-based analysis. Sustain Energy Technol Assess 2017;21:23-32.

[60] Sharma R. Municipal solid waste management in Ajmer city, Rajasthan: an overview. Nat Environ Pollut Technol 2008;7(4):639-42.

[61] Gupta N, Yadav KK, Kumar V. A review on current status of municipal solid waste management in India. J Environ Sci 2015;37:206-17.

[62] Manyuchi MM, Phiri A. Vermicomposting in solid waste management: a review. Int J Sci Eng Technol 2013;2(12):1234-42.

[63] Babu GS, Lakshmikanthan P, Santhosh LG. Life cycle analysis of municipal solid waste (MSW) land disposal options in Bangalore city. ICSI: Creating Infrastructure for a sustainable world. In: Proceedings of the 2014 international conference on sustainable infrastructure. 2014, p. 795-806.

[64] Fidelis R, Marco-Ferreira A, Antunes LC, Komatsu AK. Socio-productive inclusion of scavengers in municipal solid waste management in Brazil: practices, paradigms and future prospects. Resour Conserv Recy 2020;154:104594.

[65] Waste to energy potential in India. Annual Report 2017. Ministry of New and Renewable Energy, Government of India, 2017. https://mnre.gov.in/img/documents/uploads/file_f-1608050046985.pdf (Accessed on 05 May 2021)

[66] The national action plan for municipal solid waste management. In compliance with Hon'ble National Green Tribunal, CPCB. India, 2015. https://cpcb.nic.in/uploads/MSW/Action_plan.pdf (Accessed on 05 May 2021)

[67] Sebastian RM, Kumar D, Alappat BJ. A technique to quantify incinerability of municipal solid waste. Resour Conserv Recy 2019;140:286-96.

[68] Kumar A, Samadder SR. A review on technological options of waste to energy for effective management of municipal solid waste. Waste Manag 2017;69:407-22.

[69] Johnke B. Emissions from waste incineration. In Background paper for expert meeting on good practice in inventory preparation: emissions from waste. IPCC/OECD/IEA National Greenhouse Gas Inventories Programme, (Unpublished–TSU, Japan). 1999. https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_3_Waste_Incineration.pdf

[70] Yap HY, Nixon JD. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. Waste Manag 2015;46:265-77.

[71] Kumar A, Kumar N, Baredar P, Shukla A. A review on biomass energy resources, potential, conversion and policy in India. Renew Sustain Energy Rev 2015;45:530-9.

[72] Zamri MF, Hasmady S, Akhiar A, Ideris F, Shamsuddin AH, Mofijur M, Fattah IR, Mahlia TM. A comprehensive review on anaerobic digestion of organic fraction of municipal solid waste. Renew Sustain Energy Rev 2021;137:110637.

[73] Paritosh K, Yadav M, Kesharwani N, Pareek N, Karthyikeyan OP, Balan V, Vivekanand V. Strategies to improve solid state anaerobic bioconversion of lignocellulosic biomass an overview. Bioresour Technol 2021;331:125036.

[74] Kumar S, Paritosh K, Pareek N, Chawade A, Vivekanand V. De-construction of major Indian cereal crop residues through chemical pretreatment for improved biogas production: An overview. Renew Sustain Energy Rev 2018;90:160-70.

[75] Paritosh K, Kushwaha SK, Yadav M, Pareek N, Chawade A, Vivekanand V. Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. BioMed Res Int 2017;2017:2370927.

[76] Thomas P, Soren N, Rumjit NP, James JG, Saravanakumar MP. Biomass resources and potential of anaerobic digestion in Indian scenario. Renew Sustain Energy Rev 2017;77:718-30.

[77] Gollapalli M, Kota SH. Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. Environ Pollut 2018;234:174-80.

[78] Kumar S, Nimchuk N, Kumar R, Zietsman J, Ramani T, Spiegelman C, Kenney M. Specific model for the estimation of methane emission from municipal solid waste landfills in India. Bioresour Technol 2016;216:981-7.

[79] Unnikrishnan S, Singh A. Energy recovery in solid waste management through CDM in India and other countries. Resour Conserv Recy 2010;54(10):630-40.

[80] Seo YC, Alam MT, Yang WS. Gasification of municipal solid waste. Gasif. Low-Grade Feedstock. IntechOpen, 2018.

[81] Yadav M, Paritosh K, Pareek N, Vivekanand V. Coupled treatment of lignocellulosic agricultural residues for augmented biomethanation. J Clean Prod 2019;213:75-88.

[82] Xin C, Zhang T, Tsai SB, Zhai YM, Wang J. An empirical study on greenhouse gas emission calculations under different municipal solid waste management strategies. Appl Sci 2020;10(5):1673.

[83] Hameed Z, Aslam M, Khan Z, Maqsood K, Atabani AE, Ghauri M, et al. Gasification of municipal solid waste blends with biomass for energy production and resources recovery: Current status, hybrid technologies and innovative prospects. Renew Sustain Energy Rev 2021;136:110375.

[84] Calise F, Cappiello FL, d'Accadia MD, Vicidomini M. Concentrating photovoltaic/thermal collectors coupled with an anaerobic digestion process: dynamic simulation and energy and economic analysis. J Clean Prod 2021;311:127363.

[85] Pradhan P, Gadkari P, Arora A, Mahajani SM. Economic feasibility of agro waste pelletization as an energy option in rural India. Energy Procedia 2019;158:3405-10.

[86] Kumar A, Samadder SR. An empirical model for prediction of household solid waste generation rate–a case study of Dhanbad, India. Waste Manag 2017;68:3-15.

[87] Kolekar KA, Hazra T, Chakrabarty SN. A review on prediction of municipal solid waste generation models. Procedia Environ Sci 2016;35:238-44.

[88] Nganda MK. Mathematical models in municipal solid waste management. Thesis for the Degree of Licentiate of Philosophy. 2007. http://www.math.chalmers.se/Math/Research/Preprints/2007/6.pdf

[89] Lee CK, Yeung CL, Xiong ZR, Chung SH. A mathematical model for municipal solid waste management–a case study in Hong Kong. Waste Manag 2016;58:430-41.

[90] Nguyen-Trong K, Nguyen-Thi-Ngoc A, Nguyen-Ngoc D, Dinh-Thi-Hai V. Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model. Waste Manag 2017;59:14-22.

[91] Das S, Bhattacharyya BK. Optimization of municipal solid waste collection and transportation routes. Waste Manag 2015;43:9-18.

[92] Lella J, Mandla VR, Zhu X. Solid waste collection/transport optimization and vegetation land cover estimation using geographic information system (GIS): a case study of a proposed smart-city. Sustain Cities Soc 2017;35:336-49.

[93] ISO 14040. Environmental management – life cycle assessment – general principles and framework. International Organization for Standardisation, Geneva, 2006.

[94] Istrate IR, Iribarren D, Gálvez-Martos JL, Dufour J. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. Resour Conserv Recy 2020;157:104778.

[95] Wang D, He J, Tang YT, Higgitt D, Robinson D. Life cycle assessment of municipal solid waste management in Nottingham, England: past and future perspectives. J Clean Prod 2020;251:119636.

[96] Basavaraj I, Prakash SM. Comparative life cycle assessment of different municipal solid waste management options in selected wards of Bangalore. Int J Civil Eng Technol 2017;8(2):300–8.

[97] Bohra A, Nema AK, Ahluwalia P. Global warming potential of waste management options: case study of Delhi. Int J Environ Technol Manag 2012;15(3-6):346-62.

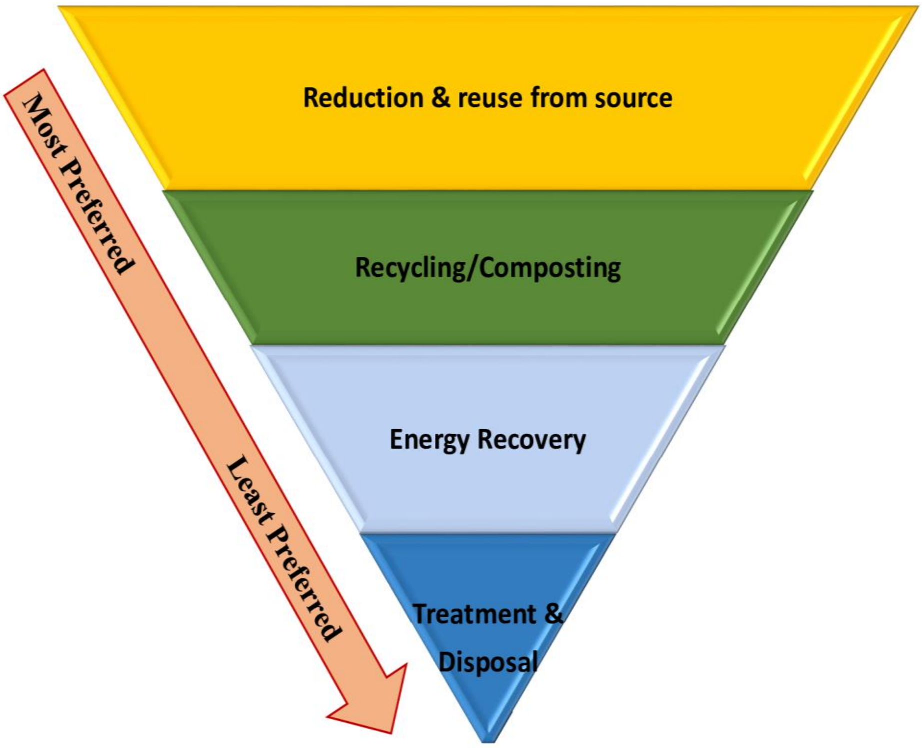


Figure 1. Integrated solid waste management hierarchy [14]

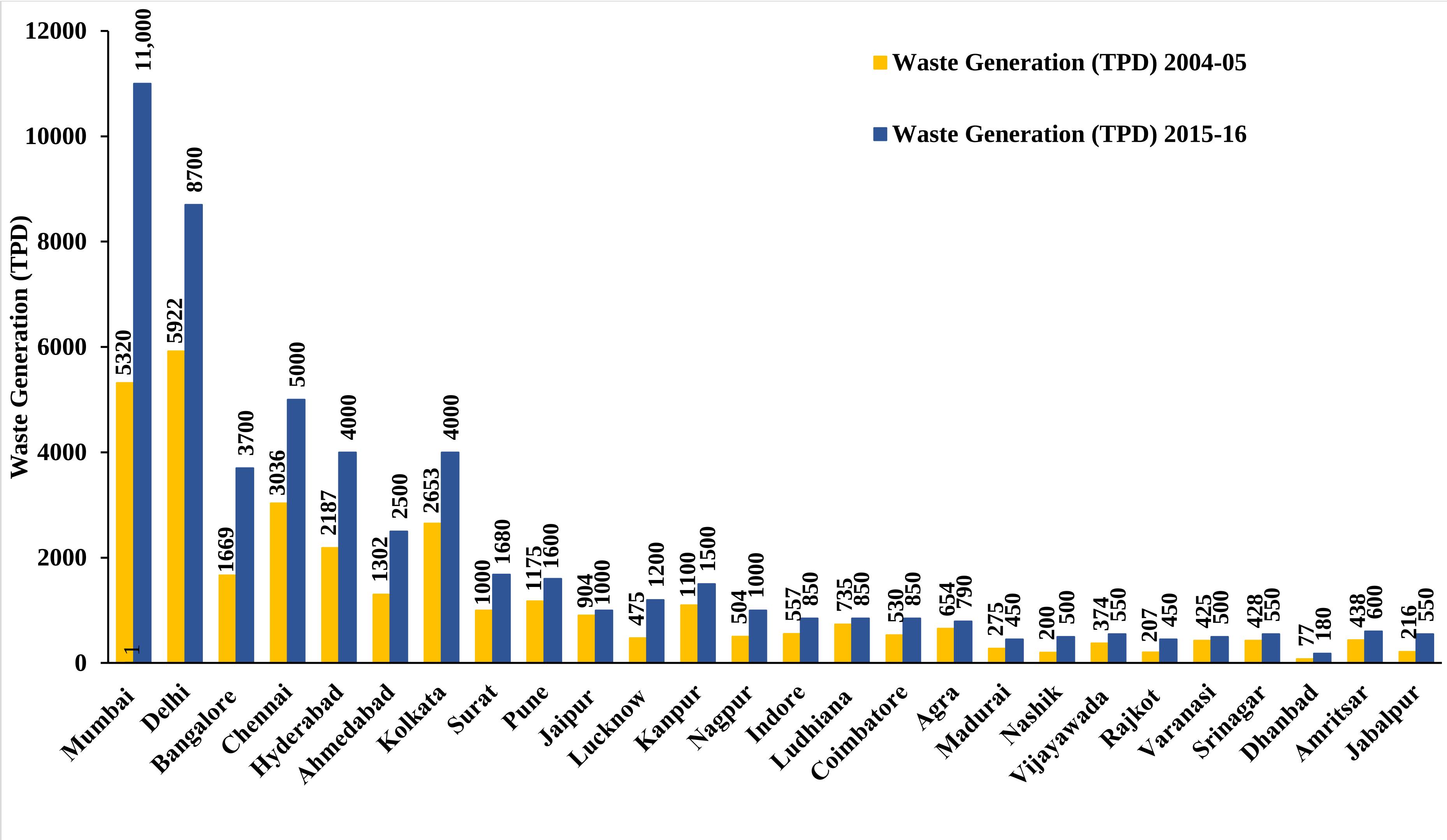


Figure 2. MSW generation trend in major Indian cities [7]

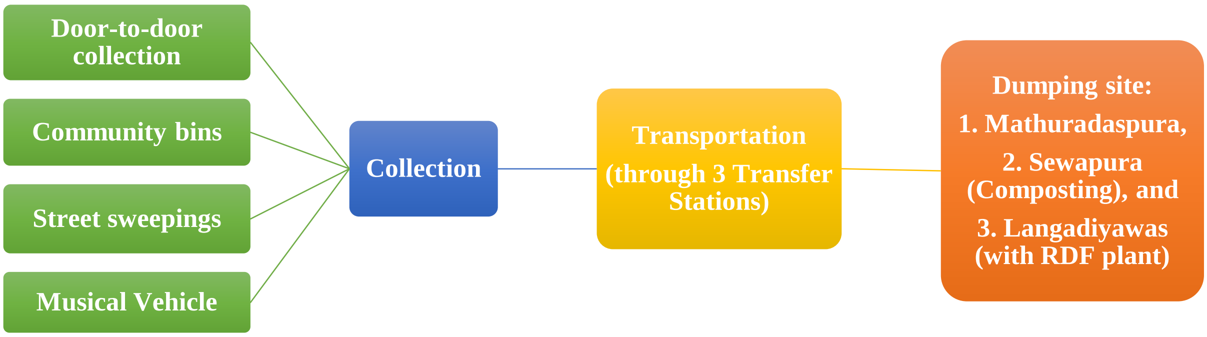


Figure 3. MSW flow in Jaipur [27]

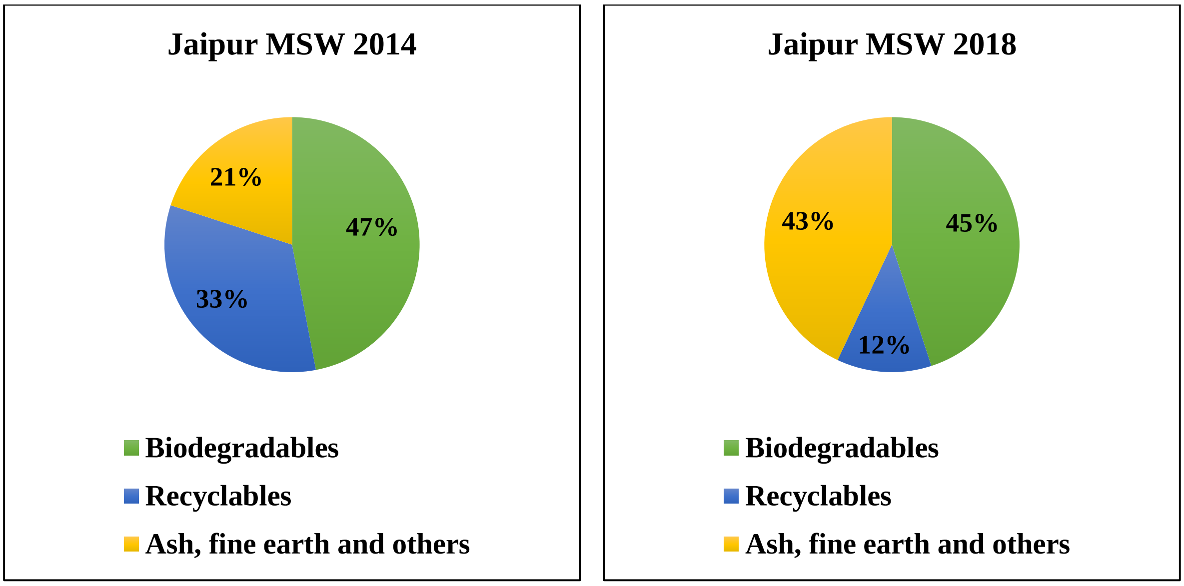


Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

Figure 5. The landfill locations in Jaipur city, India [11, 12].

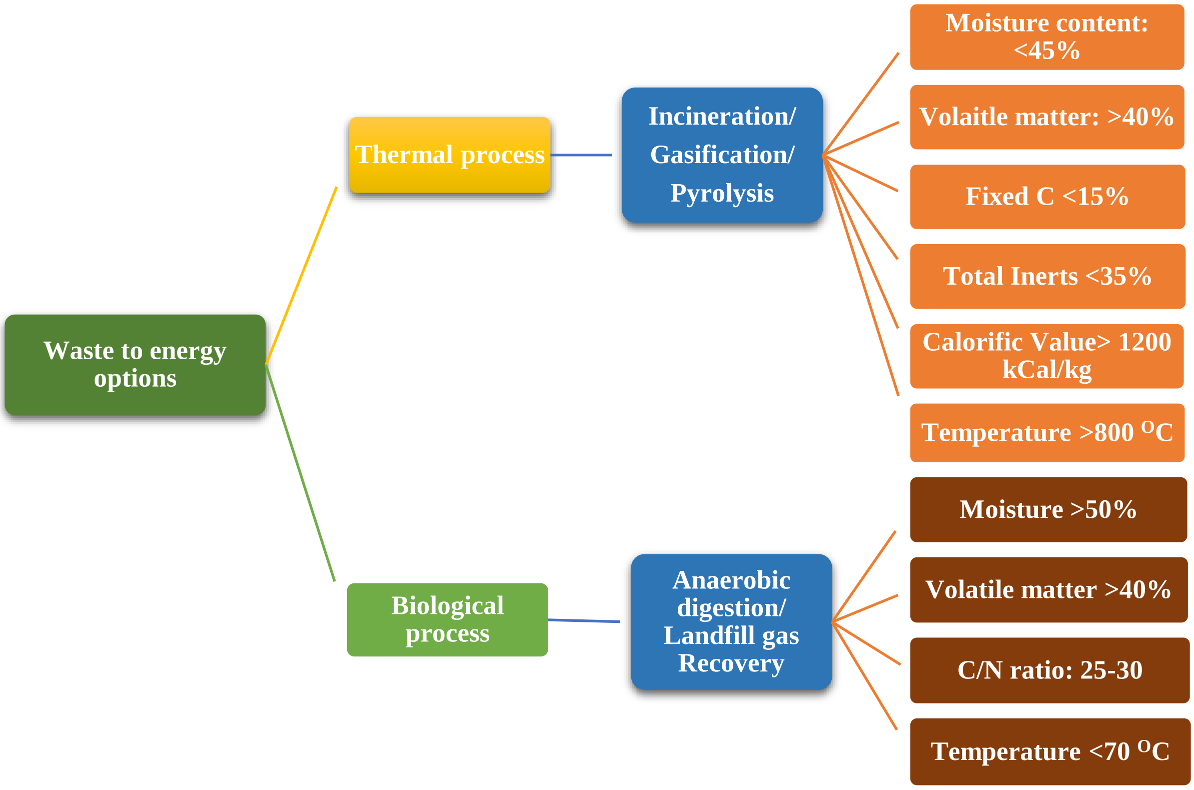


Figure 6. Waste to energy options with operating parameter's desired ranges [18]

Table 1: Physical composition of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio
1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	46	12	42	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,27]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,31]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R's hierarchy of management and waste to energy technology	[32]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[33,34]
Delhi	Y	Y	Y	R-Informal, C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[35,36]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[37,38]

Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[39]
Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[40]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[41]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[42]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[43,44]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[45]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]
Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[46]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[47]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[31,48]

Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[49]
Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[31]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[31,50]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,26]

Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective strategy, (N.) –number in the bracket represents the number of respective facilities

Table 3: Chemical Characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV (kCal/kg)	C	H	N	S	O	P (P_2O_5)	Potash K_2O
Values (%) *	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

*Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids, CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen, P=Phosphorus.

Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy Technologies

Technology	Specific Energy potential (kWh_e/tonne)	GHG emissions and cost savings				
		Diesel Fuel saved (L)	USD ($)	GHG from Diesel Generator (kg of CO2)	GHG from landfill (kg/ tonne)	Total GHG (kg of CO_2) saved
AD	393*	90.36	106.62	242.16	1230.00	1472.16
Incineration / RDF	544	125.12	147.64	335.32	1230.00	1565.32
Gasification	400	92.00	108.56	246.56	1230.00	1476.56
LFGR	163	37.54	44.29	100.60	1230.00	1331.60

Table 5: Pros and cons of different waste to energy techniques [10,33,68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	• Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume	• Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	• Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning	• Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	• Production of fuel oil	• Heterogeneity in MSW • Char removal is important • Yield stream is complex

		• Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent)	
Biological conversion	AD	• Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer • Control GHG emissions, with net environmental gains are positive • Potential for co-digestion with agricultural and industrial organic wastes • Less monitoring is required • Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill	• Requires organic waste segregation • Not suitable for complex organics, oily, or lignocellulosic materials • GHGs, fouling, and fire threats if leakage is present
	LFGR	• Least cost option • Collected gas can be used power generation, and thermal application • Reduce environmental and health impact, reduce GHG emissions	• Expertise and monitoring required • Higher transportation cost and need larger land area • Leachate problem if landfill is not scientific

Highlights

- In Jaipur city 50% MSW is treated while rest is subjected to unsanitary landfilling.
- Indian cities have inadequate MSW management practices treating only 21% of MSW.
- Lack of public participation, proper treatment techniques and sanitary landfill in the city.
- Recycling facilities, waste to energy techniques and sanitary landfilling is required.
- Role of optimization and LCA models in planning suitable MSW management practices.

Declaration of interest statement

The authors declare that there is **No Conflict of interests** for the submitted manuscript.

Sincerely,
Vivekanand (on behalf of all authors)

Dr Vivekanand (PhD IIT Roorkee)
Assistant Professor
Ramalingaswami Re-Entry Fellow (DBT-Govt of India)
Centre for Energy and Environment
Malaviya National Institute of Technology Jaipur
Jawaharlal Nehru Marg,
Jaipur-302 017, Rajasthan
INDIA
vivekanand.cee@mnit.ac.in