Semiconductor Optoelectronics, *Vol. 41 No. 12 (2022), 1709-1724*
https://bdtgd.cn/

Semiconductor Optoelectronics ISSN: 1001-5868

INTELLIGENT WASTE MANAGEMENT: A COMPUTER AIDED SYSTEM'S APPROACH

Manoj Panwar, Kavita Rathi*
Deenbandhu Chhotu Ram University of Science and Technology, Murthal (India)
manojpanwar.arch@dcrustm.org, kavitarathipanwar@dcrustm.org
***corresponding author: Kavita Rathi**

Abstract. Urban settlements offer various benefits to their residents and their region. Solid waste is one byproduct of the processes occurring in urban space. Management of waste poses severe problems for the development of any city. After critically analysing the available waste management techniques, the author identified Waste to Energy (WtE) as a promising solution for increasing waste and decreasing its ill effects along with power generation. Various techniques within Waste to Energy have been analysed in isolation. System Dynamic technique is a holistic approach with a strong base for analysing the overall impacts of proposed policy changes. The author considered Delhi, the capital city of India, as a system and analysed the role of Waste to Energy as an essential mechanism for solving issues of increasing waste, environmental problems, and adding clean energy. The authors used the system dynamic modelling technique to develop an integrated model by considering demographic, electrical power, economy, and municipal solid waste subsystem models. The developed model is validated and used to project the landfill site's increased capacity, electrical energy from solid waste contributing to renewable energy, recyclables, compost and construction aggregates for 2031 A.D. for different waste management techniques. The forecasted population of the NCT of Delhi is 25,127,921 and 28,708,386 in 2026 and 2031 and is predicted to produce 19,471.13 MT/day and 23,729.61 MT/day of Municipal Solid Waste in 2026 and 2031, respectively. The total amount of energy recovered from WtE using Bio-methanation and Plasma Arc Gasification possibilities can be 9.18 MU/day and 11.19 MU/day. Timely action in the direction of sustainable solid waste management in Delhi by using Waste to Energy as a mandatory step has the potential to avoid unsanitary landfills, pollution, and the production of energy and materials for utilisation for further development. The paper concludes with plausible recommendations.

1. Introduction

Urbanisation is an index of the transformation of economies from rural to industrial and service [1]. Urban settlements contribute to more than 80% of the total Gross Domestic Product (GDP) and provide concentrated public amenities for the residents for overall development. The urban settlements have a few negative effects, one of which is generating municipal solid waste (MSW) in concentrated form. Increased per capita income leads to lifestyle changes, higher energy consumption, and solid waste generation [1]. The number and size of urban settlements in India are increasing for harvesting the opportunities of urban settlements. Urbanisation, population growth and changes in lifestyle due to migration and increased per capita income will fuel energy demand and MSW generation [2]. More than 70% of India's urban population is concentrated in urban settlements with more than a million population. Urban settlements with a population higher than 0.1 million contribute to more than 70% of the total solid waste generated in India. The per capita waste generation in Indian cities ranges between 0.2 and 0.6 kg per day, with a growth rate of 1.3% per year [3]. Waste production and energy demand are forecasted to increase [4]. The landfill sites in most metro cities are already exhausted. The increase in waste already requires several landfill sites. Lack of land availability because of environmental framework and agitation by the affected population makes it extremely difficult for the city administration to identify new sites. We are dumping the solid waste in already exhausted landfill sites. Further, the dumping of the collected solid waste collected is without any treatment. Emissions of toxic pollutants, greenhouse gases, and seepage from waste disposal sites pollute groundwater and watercourses, and the concentration of heavy metals and solvents in waste represents a severe threat to humans, animals and vegetation [5] [6].

The author critically analysed waste processing techniques for handling accumulated waste and further in-line at city landfill sites, and presented MSW handling techniques with their advantages, disadvantages, size reduction in MSW by the particular method and energy generation potential compiled from different sources in Table 1.

Table 1. Contemporary methods of MSW handling in India

Sr. No.	Method	Advantages	Limitations	Size reduction	Power generation per tonne MSW	Remarks
1	Landfill					
1. a	Unsanitary landfills and open burning	Cheap & No site supervision required	Emissions of harmful gases and rise in temperature, site setting rate is increased by burning	20-30%	Nil	Highly detrimental for air and abutting watercourses
1. b	Landfills that do not capture CH4	Cheap & No site supervision required	Environmental degradation, slow setting rate	10-15%	Nil	CH4 has 21 times more heating potential than CO2
1. c	Landfill recovering and	Recovery of CH4 can generate energy	The volume of waste remains high after recovery.	10%	0.086 W per m^3 of CH4	Comparative reduction in environmental pollution

	using CH4				recov ered	
2	Waste to Energy	Highly environment-friendly, reduces the volume of MSW and helps in heat recovery in the form of energy. Depending upon the process adopted, plant cost and technology, moisture and calorific value of waste.				
2. a	Pyrolysis	Highly environmen t-friendly, produce power	Unsuccessful in high moisture and low calorific value waste.	50-70%	571 KWh$	Source-separated dry waste only unless combined with cleaning
2. b	Refused Derived Fuel	Produce power and reduce the load on landfill	The comparative operating cost of the RDF plant is high.	50-70%	544 KWh$	
2. c	Gasificat ion	Decrease pollution and increase heat recovery. Char can be used at the site or for industrial fuel.	Used only on Carbon-based materials	50-70%	685–816 KWh $	The thermal conversion process and products are adopted from [7]
2.d	Incinerat ion	Reduction in waste size, environmen tal benefits	It can't be used in high organic matter and high moisture content	50-70%	544 KWh$	If waste has high dampness or a low calorific value, incineration is only feasible with the help of extra fuel.
2. e	Plasma Arc Gasificat ion	Most efficient energy recovery	It can only be used with high calorific value waste	60% - 70%	45 KW#/ 100t/d ay	
3	Compost ing	Production of compost and Gas: Compost may contain harmful materials, which can become part of the food chain.				
3. a	Aerobic Compost ing*	Abutting agricultural activities	Source segregation is a must, as	10-20%		

		can consume the compost.	composting time is comparatively high.			
3.b	Windrow Composting	Compost and gas as a product.	Source segregation is a must.	20-30%	5.34-17.1 KWh	from MSW with 40-60% organic matter
3.c	vermicomposting	Compost and gas as a product.	Source segregation is a must, a fast process	20-30%	5.34-17.1 KWh	from MSW with 40-60% organic matter
3.d	Anaerobic Composting*	Compost and gas as a product.	Source segregation is a must; composting time is comparatively low.	20-30%	5.34-17.1 KWh	from MSW with 40-60% organic matter
4	Recycling	No emission, new products	Labour intensive, health impacts on informal waste pickers.	10-20%	-	Waste is ready for further processing.
4.a	Informal Recycling	No emission, new products, or waste reach the site and source of income for the informal sector	Labour intensive	10-20%	-	Segregation next to a source, in addition to economic and social value, helps pre-processing [8].
4.b	Recycling	No emission, new products	Labour intensive	10-20%		Segregation at a landfill site.
5	Waste Reduction	No emissions	Needs grassroots involvement	Depending on practice	Direct saving from healthy practices	Most beneficial

* Only for source-separated organics;** power generation capacity from WtE processes is from [9] and is given in table 2; @ Calculation has been done on total waste considering inert waste non-reducible.

Sources: [10]; $ [7] [11]; # [9] [2]

The quantity of waste generated is increasing at an unprecedented rate. We dump more than 80 per cent of the total waste generated directly on landfill sites [3] [10] [12]. Most of the sites were planned with a life of 30-50 years and have been already exhausted in metro cities. This increase in MSW has led to the focus on future site identification or application of methods prevailing in developed countries at existing sites to increase the life of the landfill site [12][7].

Composting (50 per cent) and anaerobic digestion (30 per cent), followed by palletisation 10 per cent, and Sanitary landfill 10 per cent, are the techniques of waste handling in India [7]. Biodegradable waste, inert matter and recyclable waste are the significant components of waste generally found in MSW of India. Biodegradable waste includes food and kitchen waste, green waste (vegetables, flowers, leaves, fruits) and paper. Inert Waste Matter contains C&D, dirt, and debris. Recyclable matter contains paper, glass, bottles, cans, metals, and certain plastics. Mixed waste has waste clothing, tetra packs, and plastics such as toys, domestic hazardous waste and toxic waste [13] [14].

Landfill disposal has a large share of greenhouse gas emissions; therefore alternative policy analysis for handling construction and demolition waste [15]. Classification of Municipal Solid Waste as a policy will lead to savings in greenhouse gas emissions and the identification of proper management and treatment techniques [16]. The factors impacting various processes involved in municipal solid waste management also influence the overall management [6].

A change in population density leads to a change in municipal solid waste's physical and chemical composition. Composite materials decrease with the increase in the socio-economic status of the city[10]. The calorific value of MSW goes down with an increase in population due to a decrease in the share of rubber, leather and synthetic materials [10]. As recorded by researchers, 80 to 95 per cent of the budget for solid waste management goes into the collection and transportation of MSW.

The advent of new technology in the form of Waste to Energy has made it possible to handle this waste sustainably and generate resources in different conditions [11]. The application of recent developments in waste handling by Waste to Energy has many benefits [17]. On the one hand, it is a non-conventional, environment-friendly procedure of energy production, and it helps reduce the waste quantity on landfill sites, leading to an increase in the city's health, on the other [11] [17]. Waste to Energy (WtE) is little explored in India and has enormous potential due to its benefits [18]. In the current state, India needs to be more utilised in the potential electricity generation from MSW.

The government of India provided incentives for setting up WtE plants under the National Programme on Energy Recovery from urban and industrial waste [19]. The author presented energy potential from WtE processes in Table 2. The energy recovery potential depends on the waste's quantity and quality (physical and chemical characteristics) [13]. Modelling of municipal solid waste requires percentages of recyclable waste (Paper, Leather, plastic, metal and glass), compostable matter with calorific value and inert matter for forecasting the potential of recycling, energy production, and aggregates to be used in buildings or infrastructure. Proper handling of MSW increases the quality of life and saves the economy and resources [14]. Effective waste reduction and recycling are predicated upon credible data on refuse generation and disposal [20]. Lack of data and inconsistency in available data is a significant hurdle in the study.

Table 2. WtE Process-based Energy generation potential

Sr. No	WtE Process	Energy generation potential (/100 t/day MSW)	Residue from the waste fed for WtE
1	Bio-methanation	1.9 MW	30-40%
2	Mass Burn Incineration	1.2 MW	20-30%
3	Refuse Derived Fuel (RDF)	3.0 MW	10-25%
4	Gasification	2.0 MW	10-20%
5	Pyrolysis	2.0 MW	10-20%
6	Plasma Arc Gasification	4.5 MW	05-15%

Source: [9]

The research aimed to analyse recent waste handling techniques for material and energy recovery and their environmental impact. The objectives are to examine the relative reduction of waste in a landfill site, the production of energy and other valuable products for investing in GDP and reduce GHG emissions using different waste handling techniques at landfill sites. The author collected data from scientific literature, existing databases, and observations made during visits to Delhi. The author considered Delhi, the capital city of India, as a system and analysed the role of waste to energy as an essential mechanism for solving waste management, energy demand and environmental problems of the city. Existing system conditions for the population, GDP, electricity consumption and MSW subsystems are analysed. The author used system dynamic modelling to develop integrated demographic, energy, economy, and solid waste subsystem models. The developed model is validated and used for projecting the increased capacity of the landfill sites, power from solid waste contributing to renewable energy and saving in GHG emissions for 2031 A.D for different waste management techniques.

2. A Brief Profile of the Study Area

The study area under consideration in this study is a State, the National Capital Territory of Delhi, an Urban Territory, and India's capital city. Haryana, Uttar Pradesh and the Rajasthan States surround the geographical area of 1484 sq. km of the NCT of Delhi. Delhi attracts in-migration from the entire nation for employment opportunities as it is India's political centre and central economic hub. Delhi is growing in almost all aspects. The author presented the population, urban area, built-up area, households, literacy rate, GDP and per capita income of the study area from 1991 to 2014 in Table 3. Considering Delhi's typical energy consumption pattern from conventional energy sources, exploring alternative clean fuel technology becomes very important to improve the environment viz-a-viz for energy recovery and GSDP.

Table 3. The scenario of population, urban area, built-up area, number of households, literacy rate, GDP and per capita income of NCT of Delhi from the year 1991 to 2014

Year	Population (in Lakh)	Urban Area (Sq. Km)	Built-up Area	No. of Household	Literacy rate	State GDP	Per Capita Income
1991	95.50	685.4		2446143	75.29%	-	-
2001	134.60	924.7	404.75	3379956	81.67%	61575.01	43751

2011	168.96	1113.6	542.16	4605555	86.20%	287106.9	161446
2014	182.47	1113.6	606.61	4973235 *	86.20%	451153.7	240849

Source: [22] [23][24][25][26][27] and extrapolated data*.

Delhi is one of the fastest-growing economies in India and produces huge MSW. Approximately 94 per cent of the generated MSW in Delhi is supplied to landfill sites [1]. The first incineration plant was set up in Timarpur in 1987, having a capacity of 300 t/day, but was forced to shut down because of high moisture content. The plant in Okhla generates 16 MW of electricity by combusting 1350 MT MSW/day. 40 MW WtE plants are now operational from 2016 in Delhi. Delhi has a potential of 111 MW energy recovery from solid waste [2]. So, the possibility of MSW still needs to be utilised. As per MSW rules 2002, Ministry of Environment and Forest, Government of India, incineration must be done to solve the problem of increasing waste, which is harmful to the environment even when authorities are not getting any energy recovered [12]. The author presented the total quantity of MSW generated in Delhi, mentioned by other researchers in Table 4, and the waste characteristics in Table 5.

Table 4. Quantity of MSW generated in Delhi chronological referenced.

Reference	Year	MSW generated in Delhi
[10]	1995	4000 MT/day
[19]	2001	5922 MT/day
[9]	2004	5922 MT/day
[1]	2009	6800 MT/day
[9]	2011, 2015, 2021 (Modelled)	11873.06, 13304.83 and 15326.68 MT/day, respectively

Table 5. Characteristics of Municipal Solid Waste in Metro Cities and Delhi

Description	Paper	Rubber, leather and synthetics	Glass	Metal	Compostable Matter	Inert Material	Calorific Value (Kcal/kg)
For Cities with a Population > 5.0 Mn	6.43	0.28	0.94	0.8	30.83	53.9	800.7
Delhi (1995)	6.6	6.1	1.2	2.5	31.78	51.5	1802
Delhi (2004)		Recyclable 16%			31.78	51.82	1802

Source: [10] [7] [9]

The data regarding MSW generation in Delhi could be more consistent. Gupta et al. [21] reported that the reclamation of sites in Delhi is impossible and a grave threat to the citizens of Delhi. The authors have used recyclables as 09 per cent, inert materials as 30 per cent, out of the remaining 61 per cent, 30 per cent is organic, and the remaining 31 per cent is combustible. The author used this composition to analyse different recoverables from Municipal Solid Waste for the NCT of Delhi.

3. Method used (Systems Approach)

4. System Concept

A system functions as a whole with the interaction of several subsystems. All the subsystems of the system are interlinked and interdependent to each other, forming a system. Suppose one of the subsystems is defunct or partly functions or functions with a higher degree (taking a lead role) during its operation. In that case, its effects can be visualised in the entire system over a while. Sometimes, the system may not function at all in some cases, while in some cases, the system may function, but with a lot of disturbances or the smooth functioning of the system may be paralysed.

5. System Dynamic Modelling

The system dynamic modelling approach helps formulate, validate and forecast the challenges of decision-making and policy formulation by planners, policymakers and managers for the development of the system. It represents the critical feedback structures in the system. Simulating the model under various alternative conditions helps in visualisation and explaining the effect of the system structures on policy interventions. System dynamic modelling is a problem evaluation approach based on the premise that the system's design generates its behaviour based on the feedback loop of various components [28]. Creating a simulation model helps the researcher with resource management problems, model assumptions and how the system works. System dynamic modelling best analyses issues whose behaviour is governed by feedback relationships having a long time horizon [29]. The significant advantage of this model is its ability to simulate the effects of any proposed actions on the problem. The capability of handling the complexity of non-linear and independent systems makes System Dynamics a critical tool for analysing various scenarios developed by proposed policy changes. The multiple variables used in System Dynamics models are level, rate and auxiliary variables (Figure. 1).

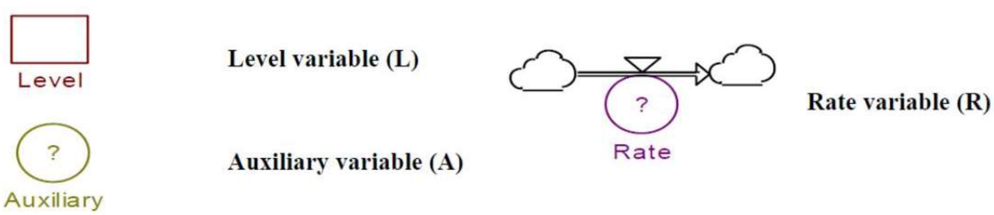

Figure 1. Notations Adopted in Modelling

6. Application of Theory

The investigator considered MSW, an integral part of an urban system, as an opportunity for clean energy and building material production, which will function as the catalyst for the development of the system, along with the system's functions. System dynamic modelling is highly recommended for analysing alternative scenarios, specifically for social sciences subjects like waste management [15] [16]. The necessity of various alternative management techniques in all stages of Solid Waste Management can be appropriately analysed for forecasting the accurate picture by using System Dynamics [30]. System Dynamic modelling provides a comprehensive view of all resources, locations, costs and policies for municipal solid waste management [31]. The System Dynamic approach has been used for policy development on Municipal Solid Waste Management for Dhaka [32], Jabalpur [13], Ahmedabad [33], Delhi [34], Haridwar [19], State of NJ [35], Bangkok [36], Campania [37], and many other cities by various researchers by considering different parameters. An appropriate Justification of System Dynamics in Municipal Solid Waste Management applications with a brief of multiple available software for modelling the same on the computer is presented in [38]. A few common dependency diagrams of Municipal Solid Waste Management using the System's Approach are presented in [39]. However, no research has modelled the dependency of municipal solid waste management on population, GDP and energy demand in the system's approach.

The investigator employed system theory and chose the NCT of Delhi (Urban Territory and Capital of India) as the study area for considering the system boundary. The author modelled Population, GDP, Energy and Municipal Solid Waste as critical subsystems based on the literature review. The present investigation rests on the causal loop diagram for the population, GDP, energy and MSW developed by the investigator presented in Figure. 2.

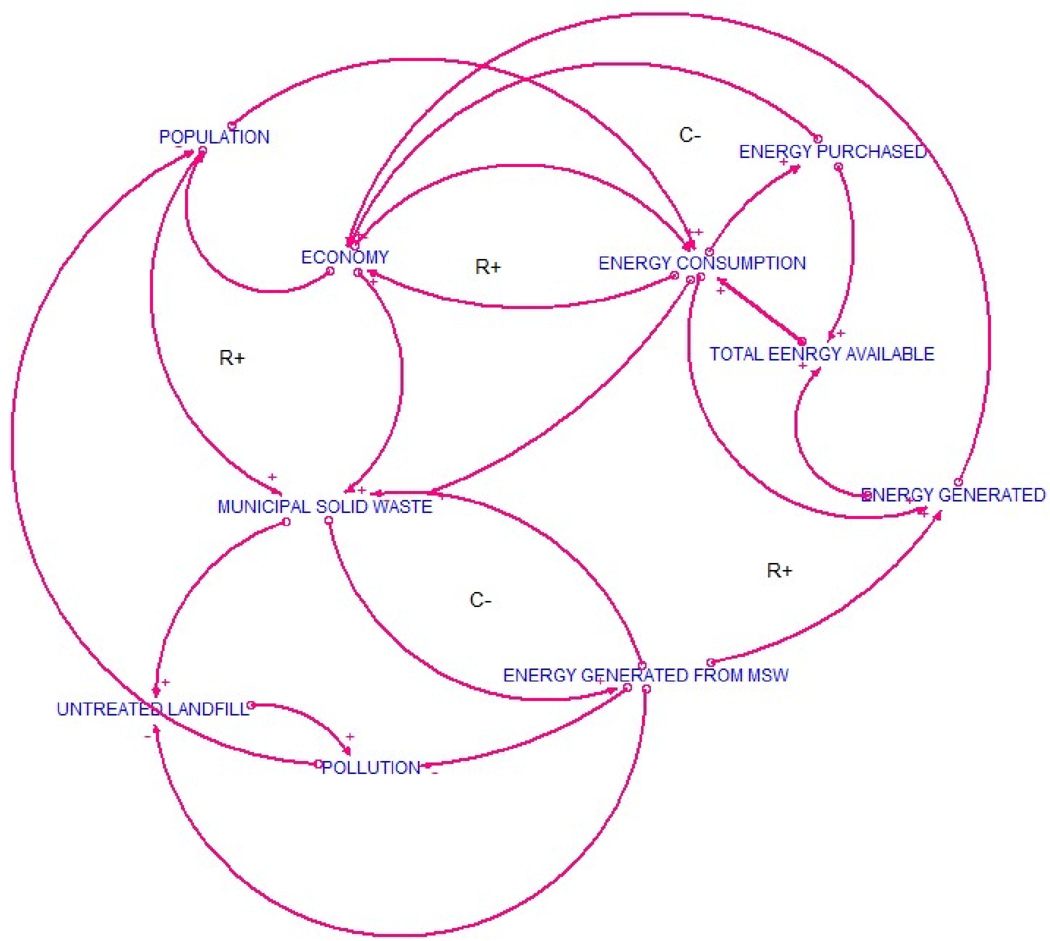

Figure 2. Causal loop diagram for population, GDP, energy, MSW showing WtE impact (Authors)

7. Model development

Authors have first proposed an MSW handling model for zero landfilling (Figure 3). The model is in addition to the model proposed by [17]. The acquisition is in the form of using the inert material for making stone aggregates, paving tiles or pure earth filling for construction sites (primarily roads), which will keep the topography intact and avoid the creation of hillocks.

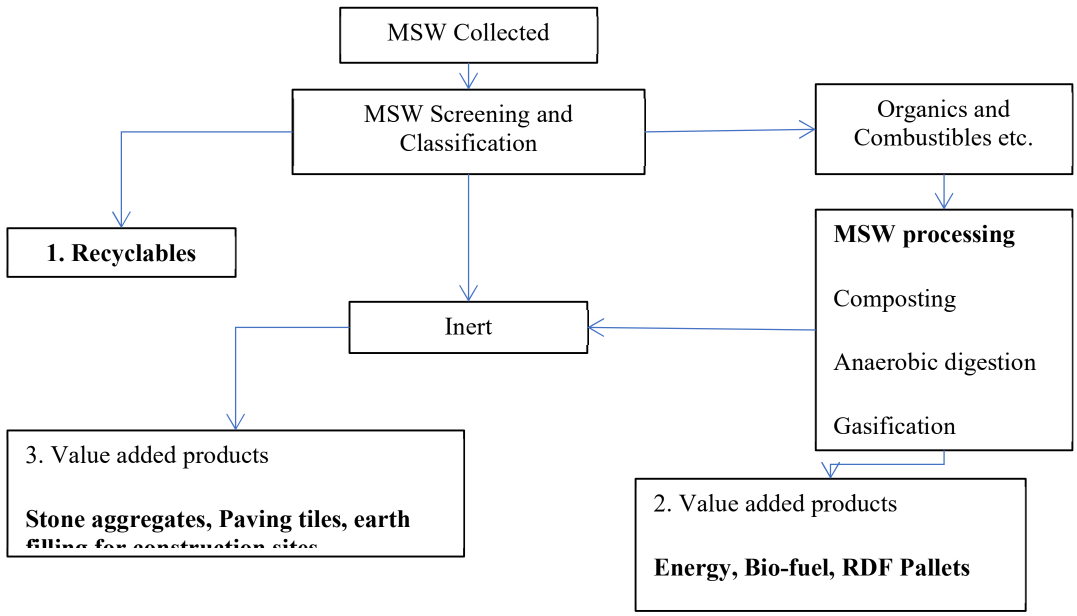

Figure 3. Facilities, the material flow of the proposed MSW handling model for zero landfills.

The authors developed the proposed model in Stella (Figures. 4 & 5), integrating population, GDP and energy subsystems to analyse the system's dynamics and quantify energy and mass from the proposed process. The author suggests the release of the gases into the atmosphere after treatment following EURO standards.

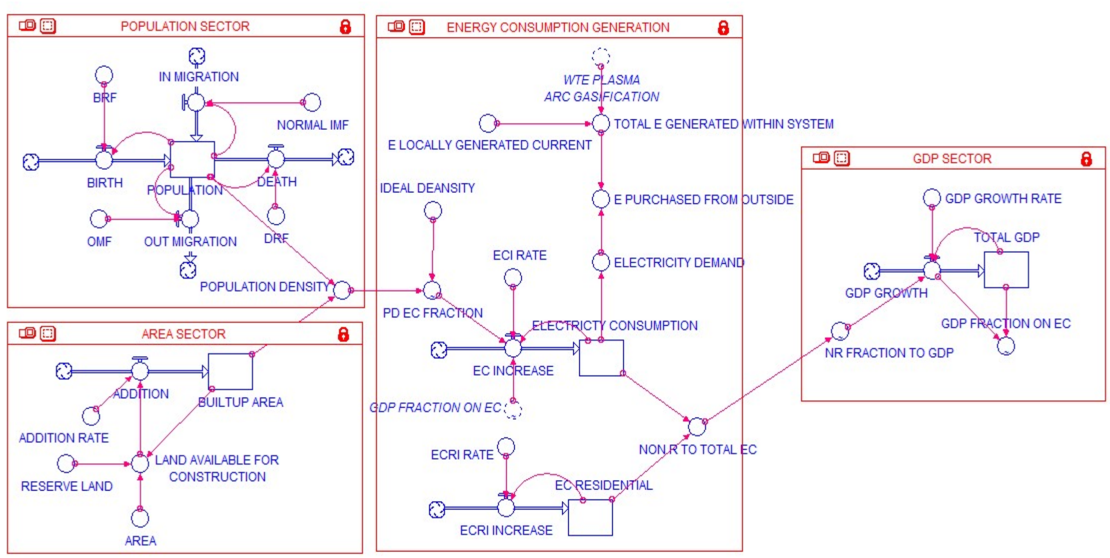

Figure 4. System Dynamic model for population, Area, Energy consumption and generation, and GDP

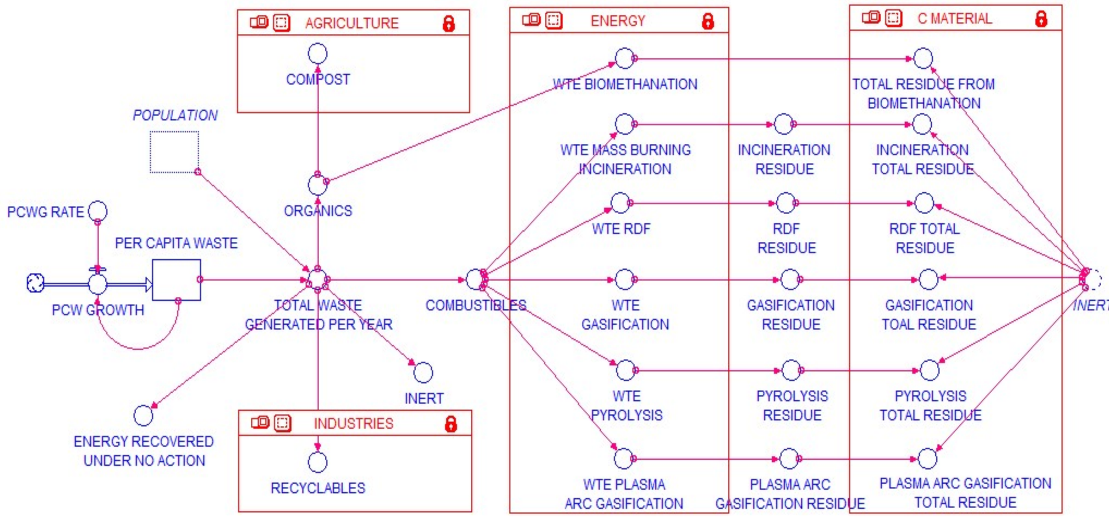

Figure 5. The Proposed flow of produced MSW to recyclables, compost, energy and residue for construction materials

8. Model Validation

The authors analysed the behaviour of the proposed model by considering Delhi as a system and 2011 as the base year. The model is validated for 2014 data for population, GDP, Area, Electricity consumption and MSW produced per day and is presented in Table 6.

Table 6. Model results and validation by using 2014 data.

Sr. No.	Variables	2011	2014	Modelled data for 2014	% variation from actual
1	Population (No.)	16896000	18247000	18252032	0.0003
2	GDP (Crore Rs.)	287106.9	451153.7	439,340.10	-0.0262
3	Built-up Area (Sq. Km)	542.16	606.61	598.89	-0.0127
4	Electricity Consumption (Million Units)	21700	25111	26,260.45	0.0458
5	Municipal Solid Waste Generated (MT/day)	11873	12947	12,112.46	-0.0645

The variations in the modelled data and actual data are within acceptable standards. The changes in modelled solid waste data and data by [9] are because of the variation in the base year data. The base year modelled data using 0.600 kg/person/day is 10757.04 tonnes/day, whereas as recorded by [9] is 11873.00 tonnes/day.

9. Results and Discussions

The validated model is used to forecast the MSW, which is then used to predict the energy and material through the proposed MSW handling model for zero landfilling and energy recovery. The comparative energy recovery forecasted using different techniques of WtE is presented in Table 7. Based on energy generation from segregated solid waste, bio-methanation in Delhi can produce 798 MUs, 973 MUs and 1186 MUs of energy from the biodegradable matter from solid waste in 2021, 2026 and 2031, respectively. Out of the identified scientific waste treatment techniques, i.e., Mass Burning Incineration, Pyrolysis, Gasification, Refuse Derived Fuel, and Plasma Arc Gasification, Plasma Arc Gasification can recover the highest energy from municipal solid waste in Delhi. The forecasted power recovered from municipal solid waste in Delhi using Plasma Arc Gasification is 1954 MUs, 2381 MUs and 2902 MUs for 2021, 2026 and 2031 respectively. The model results show that a combination of biomethanation with other WtE techniques plasma arc gasification, can be used to recover maximum energy. The overall results of the validated system dynamic model used in the proposed municipal solid waste management model are presented in Table 8.

Table 7. Comparative energy recovery forecasted using techniques of WtE (Million Units)

Year	MSW per day	Mass Burning Incineration	Bio - methanation	Pyrolysis	Gasification	Refuse Derived Fuel	Plasma Arc Gasification
2021	15,976.87	521	798	868	868	1303	1954
2026	19,471.13	635	973	1058	1058	1587	2381
2031	23,729.61	774	1186	1290	1290	1935	2902

Table 8. The forecasted output of integrated system dynamic and proposed zero waste model from MSW.

Year	Population	MSW (tonnes/day)	Recyclables (tonnes/day)	Compost (tonnes/day)	WtE from bio methanation and Plasma Arc Gasification (MU/day)	Aggregates (tonnes/day)
2021	21,994,006	15,976.87	1,437.92	1,437.92	7.53	4,793.06
2026	25,127,921	19,471.13	1,752.40	1,752.40	9.18	5,841.34
2031	28,708,386	23,729.61	2,135.66	2,135.66	11.19	7,118.88

The population in the NCT of Delhi is forecasted to be 21,994,006, 25,127,921 and 28,708,386 in 2021, 2026 and 2031, respectively. This population is predicted to produce 15,976.87 MT/day, 19,471.13 MT/day, and 23,729.61 MT/day of Municipal Solid Waste in 2021, 2026 and 2031, respectively. The total amount of energy recovered from WtE using Bio-methanation and Plasma Arc Gasification would be 7.53 MU/day, 9.18 MU/day and 11.19

MU/day. The already stated assumptions of 9 per cent recyclables, 9 per cent compost and 30 per cent aggregates would lead to the production of thousands of tonnes of recyclables, compost and inert materials, which can be again fed into the system as a resource for agricultural and as material for road and building construction. The resources generated increase the life of waste landfills and save the environment.

10. Recommendations

- Timely action in the direction of sustainable solid waste management in Delhi by using waste to energy as a mandatory step has the potential to avoid pollution, unsanitary landfills, and the production of energy and materials for utilisation for further development.
- Scientific SWM: Handling municipal solid waste in Delhi requires scientific processing.
- Investment in different processes of SWM: The government needs to invest heavily in spreading the negative impacts of increasing municipal solid waste and the benefits of segregation, treatment process and the output of treatment processes to encourage society to invest for its own.
- Waste Segregation: The segregation of waste produced must be encouraged at all steps of solid waste management. The segregation of recyclables can save approximately 30 per cent of the total waste generated, reaching further waste processing and finally to the landfill site. The technical methods must be used for waste segregation at treatment sites, and the waste needs to be classified into the categories, explicitly keeping the treatment technologies in mind.
- Decentralised small WtE plants: The waste generated must be collected and transported to the sites demarcated for scientific trash treatment. The transportation must be done in covered containers. The vehicle of solid waste to the four designated areas in Delhi is very problematic and consumes many economic and human resources. 80 to 95 per cent of the budget for solid waste management goes into the collection and transportation of MSW. The development of waste-to-energy plants reduces pollution and ensures maximum reduction in the quantity of solid waste. Implementing smaller Waste to Energy plants in decentralised will reduce transportation costs and support centralised infrastructure. The location and size feasibility of WtE plants can be decided on detailed analysis.
- Selection of WtE technique: Bio-methanation and Plasma Arc Gasification may require higher resources than the output, but these processes need time to avoid harmful impacts on the environment and ecology of Delhi.
- The products in the form of recyclables, compost and inert aggregates should be made available at cheaper prices to encourage their usage to neighbouring states if they remain underutilised in Delhi.
- Plantation around Landfill sites: The solid waste treatment process sites release harmful gases into the atmosphere in Treatment sites must be thoroughly surrounded by thick plantations to avoid any form of deleterious impacts generated from treatment facilities to the neighbourhoods.

11. Conclusion

The techniques of WtE already exist and now have Indian experience. Considering the benefits in the dense urban fabric of Indian cities, WtE is not only a viable solution for decreasing the load of landfill sites and improving the environment but also the necessity of time. Using inert material from landfill sites will reduce the existing waste hillocks. This paper attempts to explain municipal solid waste generation, energy consumption, energy generated from municipal solid waste, the total energy available, and energy purchased in Delhi using the dynamic system approach. An integrated model considering municipal solid waste generation, population, area, power, WtE technique, and residual construction material. The developed model is validated and applied in this investigation. Forecasting has been done for 2021, 2026, and 2031 to quantify the municipal solid waste generation per day and its associated variable, including mass burning incineration, biomethanation, pyrolysis, gasification, refused derived fuel and plasma arc gasification, and the research concluded with the plausible recommendations. Policies related to recyclables composition, waste composition, the impact of socio-economic changes on the design of waste, and environmental benefits can be attempted for alternative analysis using the quantification of the mentioned.

References

[1] Vij D 2012 Urbanization and Solid Waste Management in India: Present Practices and Future Challenges *Procedia - Soc. Behav. Sci.* **37** 437–47

[2] Kalyani K A and Pandey K K 2014 Waste to energy status in India: A short review *Renew. Sustain. Energy Rev.* **31** 113–20

[3] Zia H and Devadas V 2008 Urban solid waste management in Kanpur: Opportunities and perspectives *Habitat Int.* **32** 58–73

[4] Chen D M C, Bodirsky B L, Krueger T, Mishra A and Popp A 2020 The world's growing municipal solid waste: trends and impacts *Environ. Res. Lett.* **15**

[5] Bruvoll A and Ibenholt K 1997 Future waste generation Forecasts on the basis of a macroeconomic model *Resour. Conserv. Recycl.* **19** 137–49

[6] Abarca L, Maas G and Hogland W 2013 Solid waste management challenges for cities in developing countries *Waste Manag.* **33** 220–32

[7] Singh R P, Tyagi V V., Allen T, Ibrahim M H and Kothari R 2011 An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario *Renew. Sustain. Energy Rev.* **15** 4797–808

[8] Wilson D C, Velis C and Cheeseman C 2006 Role of informal sector recycling in waste management in developing countries *Habitat Int.* **30** 797–808

[9] Saini S, Rao P and Patil Y 2012 City Based Analysis of MSW to Energy Generation in India, Calculation of State-Wise Potential and Tariff Comparison with EU *Procedia - Soc. Behav. Sci.* **37** 407–16

[10] Sharholy M and Ahmad K 2008 Municipal solid waste management in Indian cities – A review **28** 459–67

[11] Annepu R K 2012 Sustainable Solid Waste Management in India *Dep. Earth Environ. Eng. Columbia Univ.* 1–189

[12] Unnikrishnan S and Singh A 2010 Energy recovery in solid waste management through CDM in India and other countries *Resour. Conserv. Recycl.* **54** 630–40

[13] Agrawal P C and Yadav V 2012 Evaluation of Potential of Energy from Jabalpur Municipal Solid waste (MSW) for Eco-Sustainability *Int. J. Sci. Eng. Technol.* **1** 197–202

[14] Rajkumar J and Sirajuddin A 2016 Status and challenges of municipal solid waste management in India : A review *Cogent Environ. Sci.* **2** 1–18

[15] Liu J, Liu Y and Wang X 2020 An environmental assessment model of construction and demolition waste based on system dynamics: a case study in Guangzhou *Environ. Sci. Pollut. Res.* **27** 37237–59

[16] Wang W jing and You X yi 2021 Benefits analysis of classification of municipal solid waste based on system dynamics *J. Clean. Prod.* **279**

[17] Ng W P Q, Lam H L, Varbanov P S and Klemeš J J 2014 Waste-to-Energy (WTE) network synthesis for Municipal Solid Waste (MSW) *Energy Convers. Manag.* **85** 866–74

[18] Ministry of Power G 2016 *All India Installed Capacity (in Mw) of Power Stations*

[19] Jain S and Sharma M P 2011 Power generation from MSW of Haridwar city: A feasibility study *Renew. Sustain. Energy Rev.* **15** 69–90

[20] Chowdhury M 2009 Searching quality data for municipal solid waste planning *Waste Manag.* **29** 2240–7

[21] Gupta S, Mohan K, Prasad R, Gupta S and Kansal A 1998 Solid waste management in India : options and opportunities *Resour. , Conserv. Recycl.* **24** 137–54

[22] Delhi Development Authority 2007 *Master Plan for Delhi - 2021* (New Delhi)

[23] GNCT of Delhi 2005 *Economic Survey of Delhi 2005-06*

[24] GNCT of Delhi 2015 *Economic Survey of Delhi 2014-15*

[25] GNCT of Delhi 2018 *Economic Survey of Delhi 2017-18*

[26] GNCT of Delhi 2014 *Delhi Statistical Hand Book 2014*

[27] GNCT of Delhi 2017 *Delhi Statistical Hand Book 2017*

[28] Sterman J D 2000 *Business Dynamic: System Thinking and Modeling for a Complex World* (Lusir, USA: McGraw-Hill Higher Education)

[29] Bérard C 2010 Group model building using system dynamics: An analysis of methodological frameworks *Electron. J. Bus. Res. Methods* **8** 35–45

[30] Rafew S M and Rafizul I M 2021 Application of system dynamics model for municipal solid waste management in Khulna city of Bangladesh *Waste Manag.* **129** 1–19

[31] Pinha A C H and Sagawa J K 2020 A system dynamics modelling approach for municipal solid waste management and financial analysis *J. Clean. Prod.* **269**

[32] Sufian M A and Bala B K 2007 Modeling of urban solid waste management system : The case of Dhaka city *Waste Manag.* **27** 858–68

[33] Sharholy M and Ahmad K 2007 Municipal solid waste characteristics and management in Allahabad, India *Waste Manag.* **27** 490–6

[34] Ahmad K 2012 A System Dynamics Modeling of Municipal Solid Waste Management Systems in Delhi *Int. J. Res. Eng. Technol.* **1** 628–41

[35] Kollikkathara N, Feng H and Yu D 2010 A system dynamic modeling approach for evaluating municipal solid waste generation , landfill capacity and related cost management issues *Waste Manag.* **30** 2194–203

[36] Sukholthaman P and Sharp A 2016 A system dynamics model to evaluate effects of source separation of municipal solid waste management : A case of Bangkok , Thailand *Waste Manag.* **In press**

[37] Federica M, Nola D, Escapa M and Ansah J P 2018 Modelling solid waste management solutions : The case of Campania , Italy *Waste Manag.* **78** 717–29

[38] Popli K, Sudibya G L and Kim S 2017 A Review of Solid Waste Management using System Dynamics Modeling *Int. J. Environ. Sci.* **26** 1185–200

[39] Pai R R, Rodrigues L L R, Mathew A O and Hebbar S 2014 Impact of Urbanization on Municipal Solid Waste Management : A System Dynamics Approach *Int. J. Renew. Energy Environ. Eng.* **02** 31–7