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Life cycle assessment of municipal solid waste with regard to DPSIR framework: Evidence from India

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ABSTRACT

Life cycle assessment concepts and methods are being applied to evaluate integrated municipal solid waste management strategies in India. The aim of this article is to develop the integrated and dynamic relationship between DPSIR and LCA model. The DPSIR model is evaluate the driving forces of municipal solid waste generation, pressure on flora-fauna, state and impact on environment and responses of government and non-government sector which helps to make new strategies of integrated municipal solid waste management of India. The Life Cycle Assessment (LCA) model included with waste collection, transfer stations, recovery, composting, combustion and landfill. Additional unit processes included are electrical energy production, transportation and recycling. This article also includes the applications of such model for municipal solid management system in developing countries. DPSIR framework is integrated with LCA model, can be used as a best tool for assessing the environmental impact of municipal solid waste generation. The conceptual model helps to develop better and effective strategy of municipal solid waste in developing countries. It is a user-friendly model for the assessment of resource consumption and potential impacts for waste management systems in a life cycle perspective.

KEYWORDS

Life cycle assessment;
DPSIR model;
Municipal solid waste management;
Applications;
Developing countries.

INTRODUCTION

A large number of tools for assessing environmental impacts are available like Environmental Impact Assessment (EIA), System of Economic and Environmental Accounting (SEEA), Environmental Auditing (EA), Life Cycle Assessment (LCA) and Material Flow Analysis (MFA). Life cycle assessment is a tool for evaluating the environmental impacts and consumption of resources. In recent years LCA has frequently been used to evaluate the environmental issues associated with solid waste management[5]. Hence, a number of studies in the literature used LCA as a comparative tool for different management schemes[1, 2, 6]. The main advantage of using LCA on solid waste management system is a

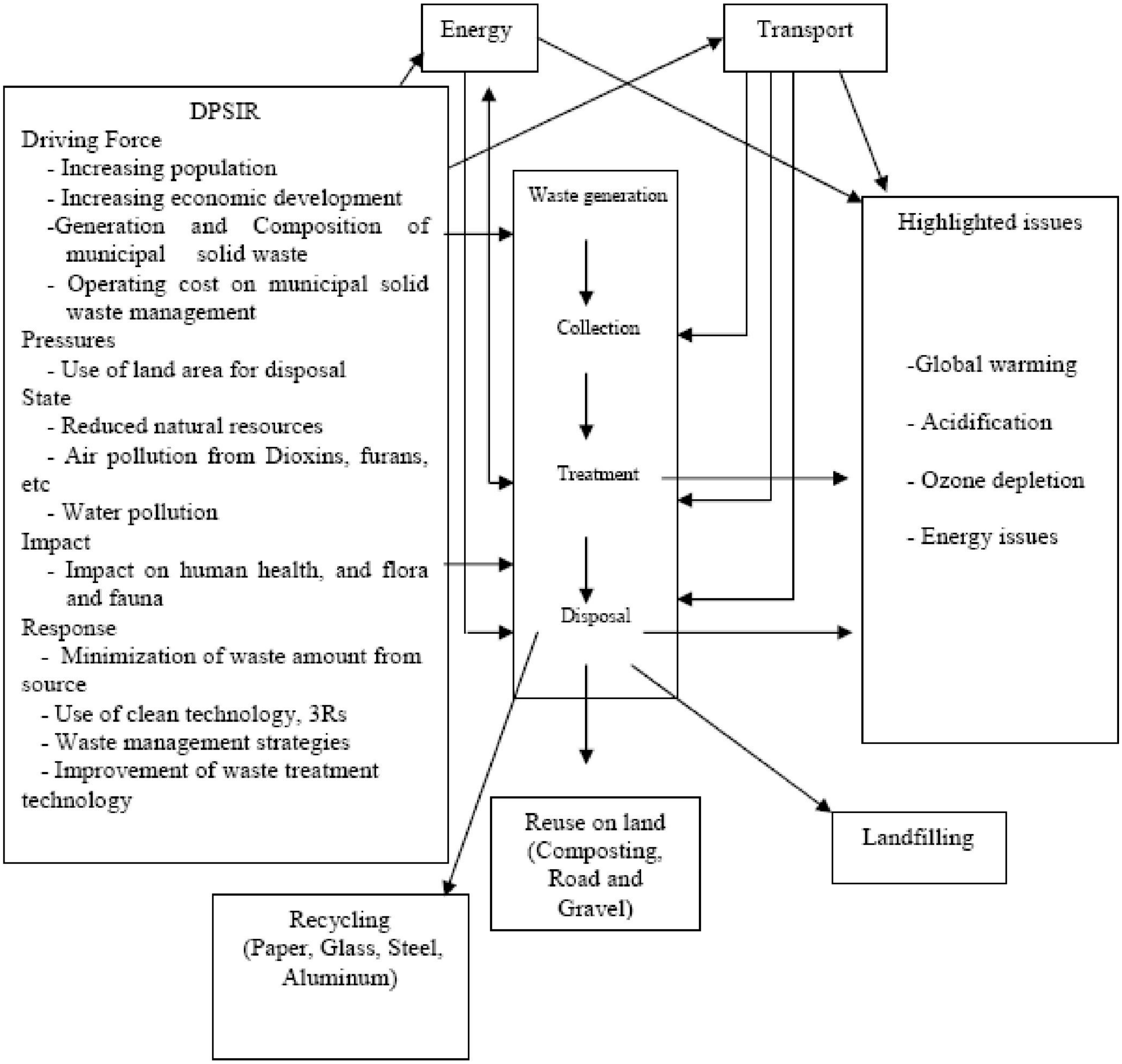

Figure 1 : Conceptual structure of DPSIR - LCA model.

systematic approach which covers all impacts of management system. It provides the capability of evaluating different treatment technologies with different patterns of energy consumption or production and material recovery.

This article develops as an integrated (DPSIR-LCA) model was establish, including waste generation, collection, transportation, treatment and disposal and accompanying external processes with the purpose of assessing the environmental impacts of the municipal solid waste management system of India.

CONCEPTUAL RELATIONSHIP OF DPSIR-LCA MODEL

Life Cycle Assessment (LCA) is a method to assess the environmental impacts and resources associated with the processes or products in a 'cradle to grave' fashion as throughout a product's life from raw material through production, use and disposal. LCA was taking into account issues not addressed by other environmental management tools such as statutory impact as-

TABLE 2 : Physical and chemical characteristics of municipal solid waste in Indian cities

Population range (in million)	No. of cities surveyed	Physical						Chemical				
		Paper	Rubber, leather and synthetics	Glass	Metal	Compostable matter	Inert material	Nitrogen as total nitrogen	Phosphorus as P_2O_5	Potassium as K_2O	C/N ratio	Calorific value kcal/kg
0.1–0.5	12	2.91	0.78	0.56	0.33	44.57	43.59	0.71	0.63	0.83	30.94	1009.89
0.5–1.0	15	2.95	0.73	0.56	0.32	40.04	48.38	0.66	0.56	0.69	21.13	900.61
1.0–2.0	9	4.71	0.71	0.46	0.49	38.95	44.73	0.64	0.82	0.72	23.68	980.05
2.0–5.0	3	3.18	0.48	0.48	0.59	56.57	49.07	0.56	0.69	0.78	22.45	907.18
5.0 and above	4	6.43	0.28	0.94	0.8	30.84	53.9	0.56	0.52	0.52	30.11	800.70

All values are in percentage and are calculated on wet weight basis. Source[7].

sessment, in terms of assessing environmental burdens associated with products or processes and choosing the least burdensome option[10]. An LCA results on the level of policy outcomes within the waste management process. In relation to DPSIR model, LCA will produce results on both pressure and impacts.

The scope and conceptual structure of DPSIR-LCA model is the functional unit with the identification of waste management with different system boundaries as global warming, acidification, ozone depletion and energy issues (Figure 1). The conceptual model is defined the waste management system from point of waste generation to disposal of waste residuals with environmental impact and response to the society.

TABLE 1 : Municipal solid waste generation in different states of India

S. No.	Name of the states	No. of cities	Municipal population	Municipal solid waste (tones/day)	Per capita generated (Kg/day)
1	Andhra Pradesh	32	10,845,907	3943	0.3
2	Assam	4	878,310	196	0.2
3	Bihar	17	5,278,361	1479	0.2
4	Gujarat	21	8,443,962	3805	0.4
5	Haryana	12	2,254,353	623	0.2
6	Himachal Pradesh	1	82,054	35	0.4
7	Karnataka	21	8,283,498	3118	0.3
8	Kerala	146	3,107,358	1220	0.3
9	Madhya Pradesh	23	7,225,833	2286	0.3
10	Maharashtra	27	22,727,186	8589	0.3
11	Manipur	1	198,535	40	0.2
12	Meghalaya	1	223,366	35	0.1
13	Mizoram	1	155,240	46	0.2
14	Orissa	7	1,766,021	646	0.3
15	Punjab	10	3,209,903	1001	0.3
16	Rajasthan	14	4,979,301	1768	0.3
17	Tamil Nadu	25	10,745,773	5021	0.4
18	Tripura	1	157,358	33	0.2
19	Uttar Pradesh	41	14,480,479	5515	0.3
20	West Bengal	23	13,943,445	4475	0.3
21	Chandigarh	1	504,094	200	0.3
22	Delhi	1	8,419,084	4000	0.4
23	Pondicherry	1	203,065	60	0.2

Source: Status of MSW generation, collection, treatment and disposal in class-I cities[3].

WASTE MANAGEMENT SYSTEM: EVIDENCE FROM INDIA

The municipal solid waste management system proceeds through the steps of waste generation, source separation and waste collection and finally treatment, utilization, recovery and disposal. In order to achieve environmental sustainability, the municipal solid waste management systems were compared in a LCA context, which considered the following components: collection and transportation of municipal solid waste, MRF/Transfer Station, Thermal (direct incineration) and biological (anaerobic digestion) treatment and landfilling.

Generation and composition

Municipal solid waste generation rate in small towns are lower than those of metro cities, and per capita generation rate ranges from 0.2 to 0.5 kg/day (TABLE 1). The per capita generation rate is high in some states of mega cities. It may occur due to high living standards, rapid economic growth and high level of urbanization in these cities.

The composition was determined on a wet weight basis and it mainly consists a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). The C/N ratio ranges between 20-30, and the lower calorific value ranges between 800-1000 kcal/kg. It has been noticed that the physical and chemical characteristics of municipal solid waste change with population density, as shown in TABLE 2.

Source separation, collection and storage

Separation of waste at source and storage is substantially lack because the bins are common for both decomposable and non-decomposable waste and waste is disposed at a communal disposal center. The predominant system of collection in most of the cities is through communal bins placed at various points along the roads and it leads to the creation of unauthorized open collection point. The average collection efficiency of municipal solid waste in Indian states is about 70% (TABLE 3).

TABLE 3 : Per capita disposal and percentage of collection efficiency of municipal solid waste of Indian states.

Name of States	Per capita disposal (g/cap/day)	Collection efficiency (%)
Andhra Pradesh	247	74
Bihar	242	59
Gujarat	182	61
Haryana	268	82
Karnataka	234	80
Kerala	201	82
Madhya Pradesh	167	73
Maharashtra	322	72
Orissa	184	61
Punjab	354	71
Rajasthan	322	62
Tamil Nadu	216	73
Uttar Pradesh	341	78
West Bengal	117	74

Source[8].

The present model was provide the modeling of source separation fractions with corresponding sorting efficiencies, which defines proportion of each material fraction that is led to sorting fraction. Another set of parameters defines the fuel consumption for transportation from the waste collection area to treatment or disposal facility.

Treatment and disposal

The different treatment technologies are material recovery facilities (MRF) for organic waste, MRFs for recyclables, reuse of paper, glass, iron etc., anaerobic digestion, composting, use of compost/digested biomass, incineration, bottom ash treatment, use of bottom ash and landfills for ashes and mixed waste. The present model provides information about within each treatment or disposal method the database includes a number of waste technologies that can be chosen in a scenario. The model calculates all environmental exchanges from all involved waste technologies including resource consumptions and emission load in the environment.

Material recovery facilities

Material recovery facilities (MRF) consist of mechanical sorting or pre-treatment prior to recycling or biological treatment. Pre-treated organic waste for biological treatment and residue for other treatment may be the products from MRF for organic wastes. Recyclable waste fractions (such as waste paper, glass, metal and plastic) may also be directed to a MRF that sorts the recyclable in different qualities for subsequent remanufacturing.

Composting

A pre-treatment or sorting of organic waste prior to composting may be performed in MRF organic. The ash content in waste remains constant throughout composting process. The outputs are composted waste and up to three residual fractions from post-treatment or sorting. The water content of composted waste can be controlled by composting process. The composted waste may be applied to agricultural soil and make it's more fertile

Incineration

Apart of the incineration in DPSIR model outputs as air emissions, bottom ash, fly ash and waste water. Additionally, the air emissions on the basis of total sulphur content in incoming waste, which typically is relevant for sulphur dioxide (SO_2) and sulphuric acid

(H_2S), both of which are waste specific in relation to the total sulphur input[4]. The energy production is calculated on the basis of energy content in waste, combined with energy recovery efficiencies for any relevant type of energy production (district heating and/or electricity).

Landfilling

The landfill module in DPSIR generates landfill gas, which is produced by decomposition of organic content and landfill leachate is produced by infiltration of water. The gas can either be collected for venting or combustion in an engine or it can migrate up through the top layer of landfill. The leachate can similarly either be collected and led to surface water or treated at a waste water treatment plant, or the leachate can migrate to groundwater through the bottom layer of landfill to the soil and groundwater beneath.

Recycle

The recycling and reuse module of DPSIR-LCA has the purpose the environmental impacts of remanufacture material. The module has same structure for all recyclable waste materials and waste material take into consideration to make new material during remanufacturing. Finally, a virgin product similar to remanufactured material, the substitution ratio will be subtracted from the environmental exchanges for remanufacturing processes.

MODEL APPLICATIONS

System boundaries

The system boundaries have largely been defined through the description of functional elements of DPSIR and processes of waste from generation to final disposal. Unlike traditional LCAs, however, integrates cost and environmental data and boundaries for each are slightly different as described below.

Boundaries for environmental analysis

Municipal solid waste from separation of materials, collection through transportation, treatment, recovery and disposal are included in environmental analysis. The material is recycled, resource and energy consumption are associated with manufacturing of a new products. This procedure also applies to energy recovery from other unit processes including combustion and landfill gas recovery.

Boundaries for cost analysis

Costs have also play a crucial role in integrated municipal solid waste management strategies. The system boundaries for cost analysis differ from that of environmental analysis because they are designed to provide a relative comparison of annual cost among alternative municipal solid waste management strategies by public sector. The cost analysis is intended to reflect cost associated with waste management alternatives based on U.S.EPA guidance[11]. The cost of waste disposal or treatment is included in cost analysis of management facility.

Energy issues

LCA of waste management system revealed the energy utilization as a key issue. This is due to direct energy recovery substituting for fossil-fuel-based energy production and indirect energy recovery by recycling of material fractions. If the energy content of waste is not efficiently utilized, the energy spent in collection can be a significant contribution to global warming.

CONCLUSIONS

DPSIR model is integrated with LCA model, can be used as a best tool for assessing the environmental impact of municipal solid waste management system. The conceptual model as an environmental tool can be successfully applied in an Integrated Solid Waste Management System (ISWMS) as a decision support tool which helps to develop better and effective strategy of municipal solid waste in developing countries. It is a user-friendly model for the assessment of resource consumption and potential impacts for waste management system in a life cycle perspective.

FUTURE PERSPECTIVES OF DPSIR-LCA MODEL

Environmental assessment with DPSIR model and holistic approach to LCA is very important for assessing the municipal solid waste management system. This model shows the new issues and sources for potential of socio-economic and environmental problems.

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