Decision Support Tool Process Module for Municipal Solid Waste Processing for Developing Countries

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Current scenario:

- Most developing countries do not have existing infrastructure for processing of a municipal solid waste.
- Waste processed -Approximately 42% (World Bank, WHAT A WASTE 2.0, 2021),
- The decision support tools for developed countries do not apply well directly to developing countries.
  - Differences in default values and assumptions like 100 % waste collection, type of equipment and waste, the fraction of waste going to processing facilities, etc.

- An urgent need to develop decision support tools tailored for developing countries.

- Green house gas (GHG) Emission estimation, cost, and diesel consumption along with, processing facility design play a vital role in sustainable SWM.

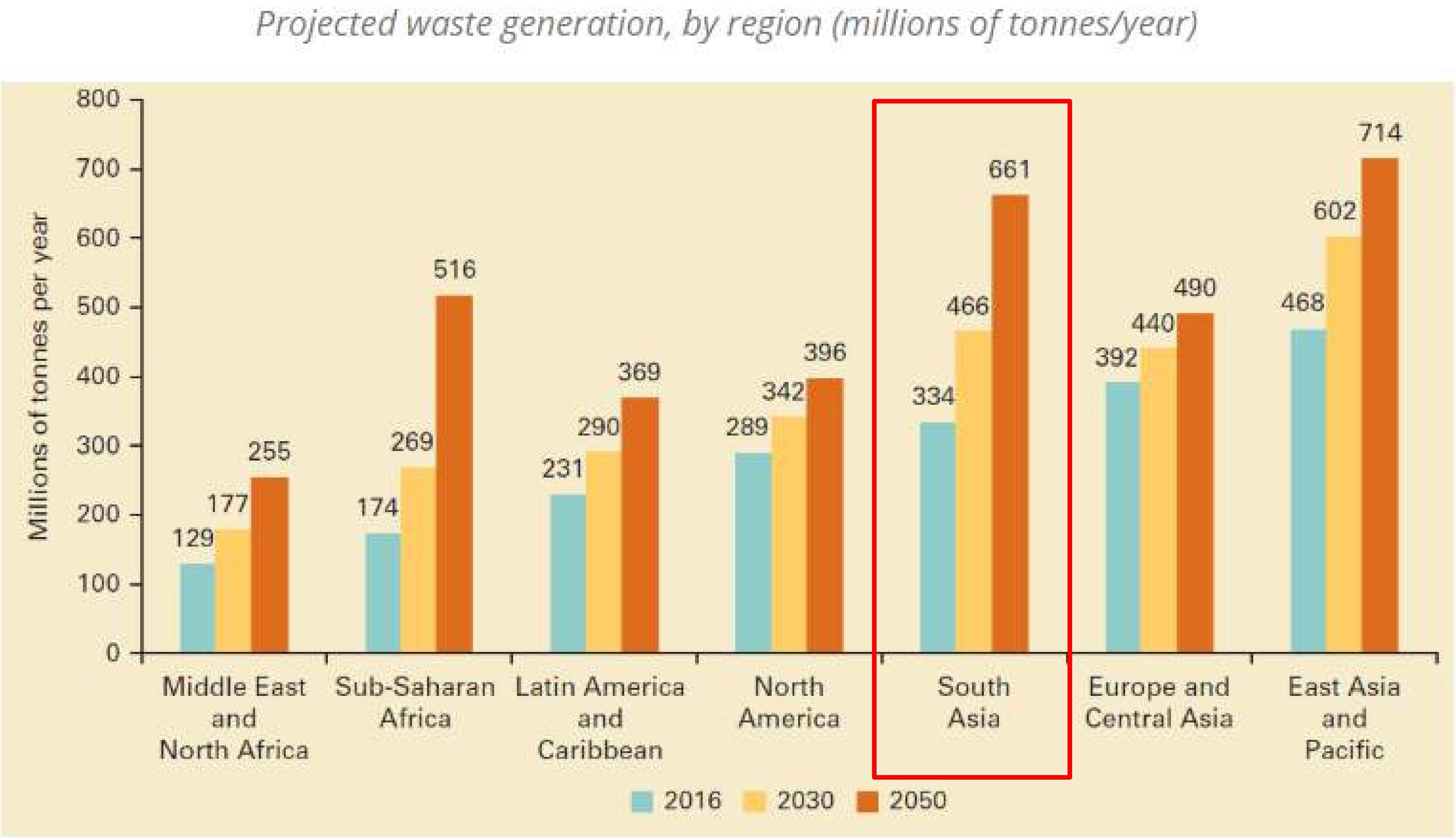
Health impacts of improper SWM

Improper waste management

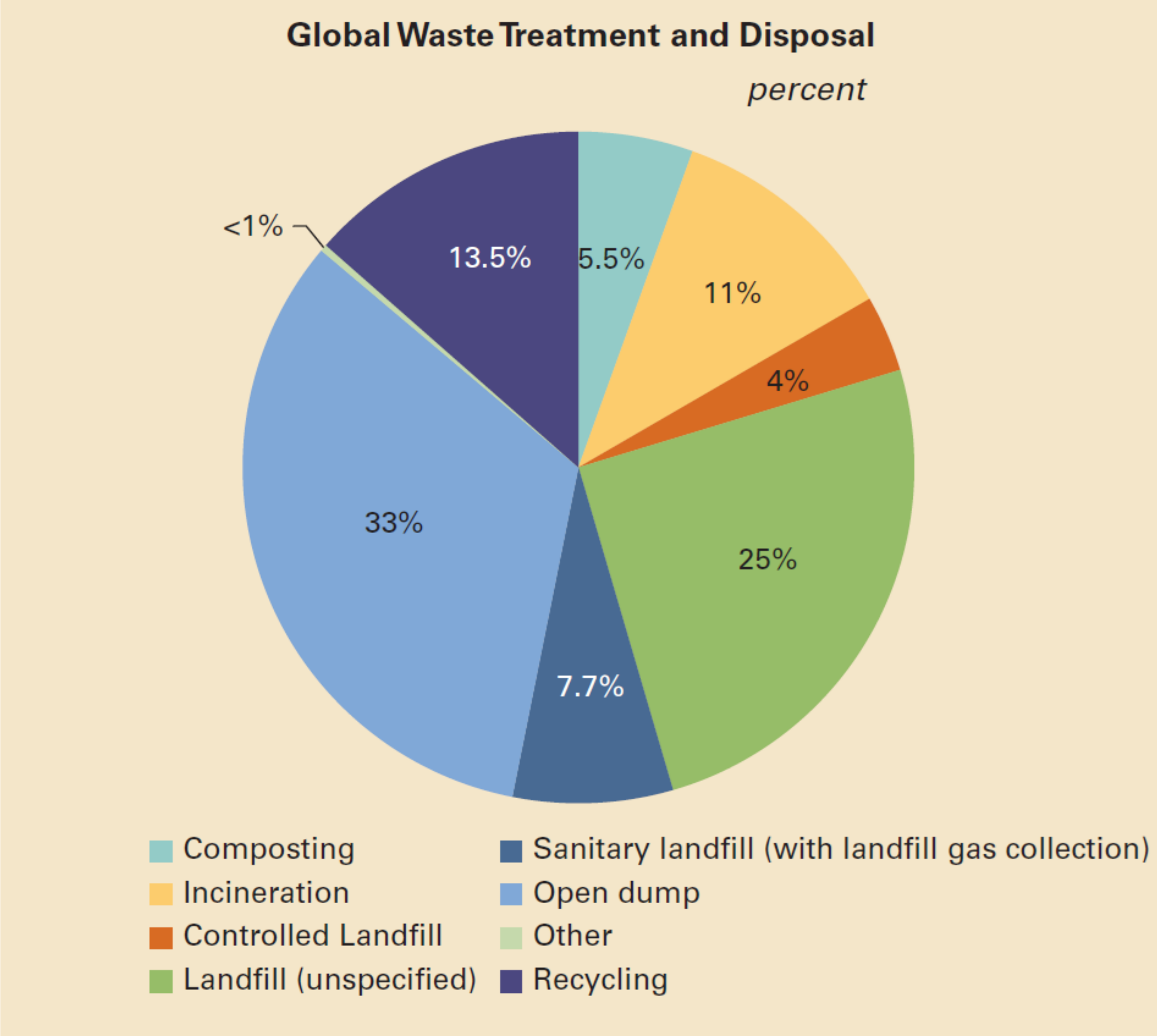
- **Public health:**
  - Asthma,
  - Birth defects,
  - Cancer,
  - Cardiovascular disease, etc.

- **Environmental hazards, polluting:**
  - Air
  - Groundwater
  - Surface water,
  - Soil, etc.

Global Waste Generation:



Source: World Bank, 2016



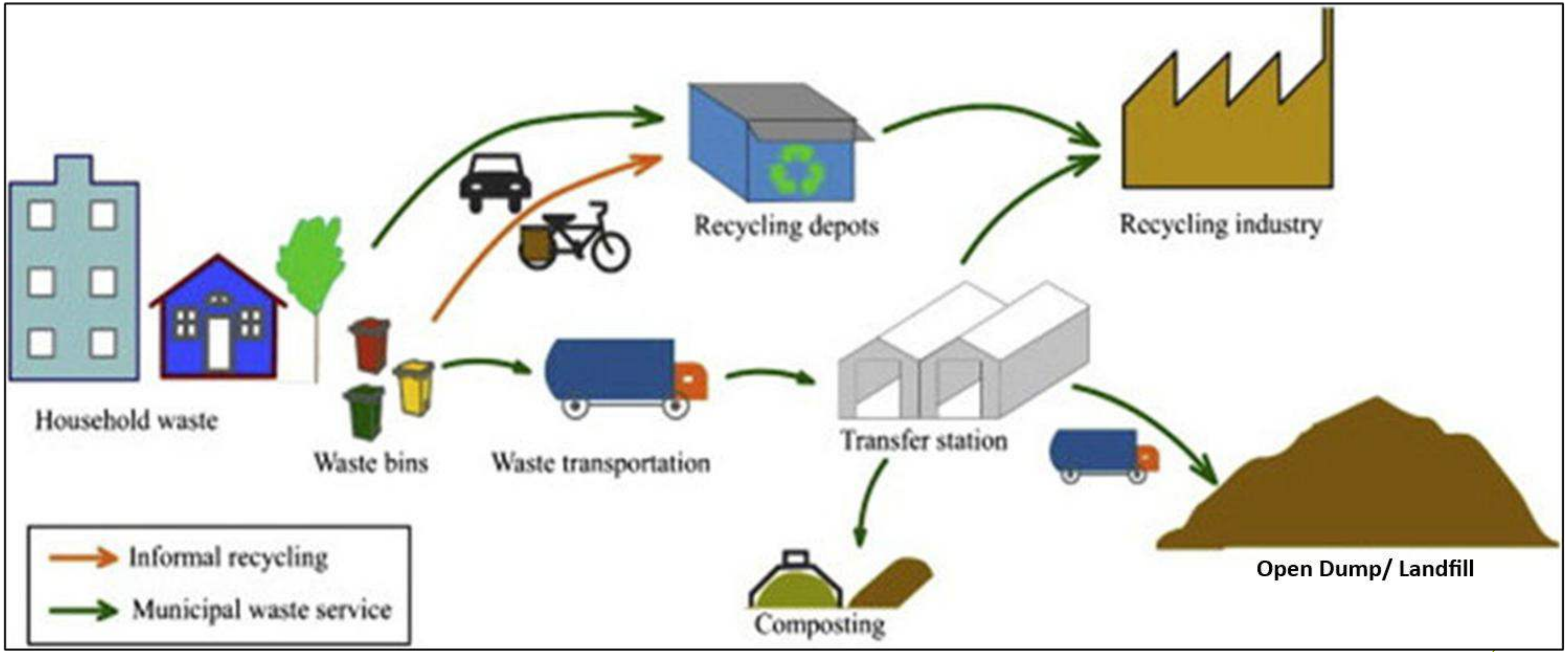
Ref: World Bank, WHAT A WASTE 2.0, 2021

SWEET – previously the only model designed for developing countries

Shortcomings and Limitations:

- Uses US-based default emission factors
- Targets short-lived climate pollutants only
- Does not estimate costs
- Does not include open dump burning to manage waste in developing countries.

Waste processing in developing countries:
Ahmedabad Municipal Corporation (AMC) Case study



Goals & Objectives

Goal:

- **To develop a Decision Support Tool Process Module for Municipal Solid Waste Processing for Developing Countries.**

Objectives:

1) To develop the Solid Waste Assessment Tool (SWAT), which will contain solid waste management Processing module prevalent in developing countries.

2) To use the processing module developed in Obj. 1, to compare case studies for 2 municipalities, Ahmedabad Municipal corporation (AMC) and Vapi Municipality (VM) in Gujarat State in India, including determining optimal waste management systems (types of waste processing) to minimize GHG emissions, costs, and diesel consumption.

Comparing and contrasting the two study communities

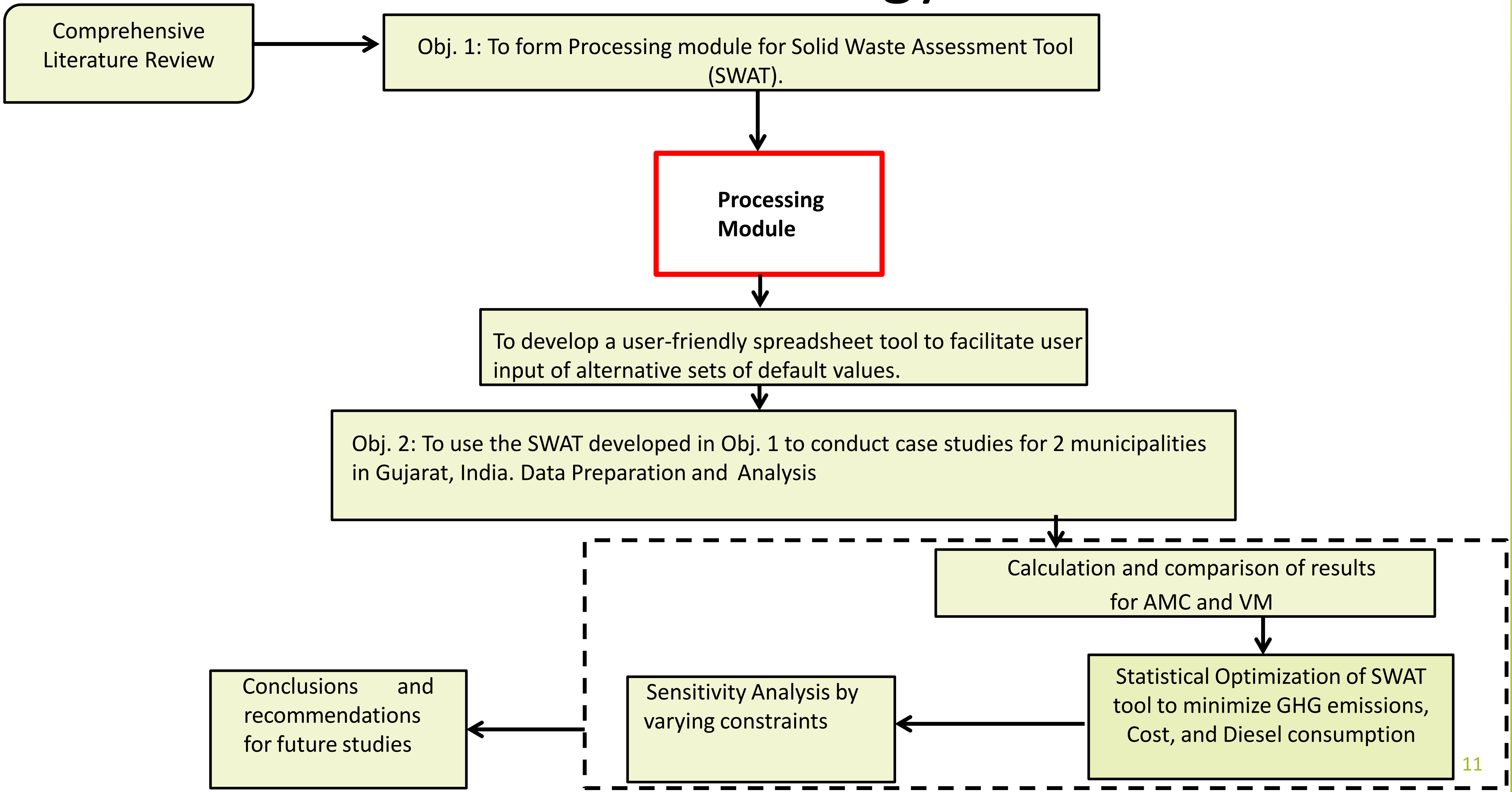
- Two case studies of urban cities were selected
  - Population of 300-400 thousand, Vapi Municipality (VM), and
  - Population of 5.5-6.5 Million, Ahmedabad Municipal Corporation (AMC)
- First application of a solid waste assessment tool using life-cycle assessment for SWM
- The process module in the tool divides processing areas into single-family, multi-family, and commercial sectors.
  - With sector-specific, user-defined characteristics, including population, waste generation rate, and waste composition.
- The data for the process module were collected from the State of Gujarat in western India.

List of officers and organizations contacted for the data and information

123 variables

Officers name	Title	Organization
Dr. Sunil Kumar	Senior Scientists	National Environmental Engineering Research Institute (NEERI)
Dr. Vijay Mistry	Deputy Director	Ahmedabad Municipal Corporation
Dr. P. U. Asnani	Expert on urban governance and an International Expert on Solid Waste Management	Urban Management Centre Global, India
Ms. Mona Khandhar, IAS	Mission Director	Swachh Bharat Mission-Urban Gujarat
Mr. Dhiren Siddh	Deputy Director and head of Chief officers of municipalities	Swachh Bharat Mission -Urban Gujarat
Mr. Ashwini Kumar, IAS	Managing Director	GUDC
Shika and Tarun Rokadiya	Senior Waste Analyst	Ernst and Young
Ms. Somya Jain	Senior Consultant	KPMG
Mr. Pranshu Jain	Senior Consultant	Deloitte
Ms. Manvita Baradi	CEO	Urban Management Centre
Mr. Nachiket Dhruva	Deputy Director-Western region	AIILSG
Mr. Rutger de Bruijn	Founder and CEO	Nexusnovus

Methodology



Vermi-composting Plant (VCP) Module Framework

No.	User Inputs		Outputs
1	Total compostable matter going to the VCP		Direct Emissions (kg of CO_2 eq/ton) (Operation + Degradation)
2	Composting efficiency		
3	Time spent in windrow		Capital Cost ($/ton)
4	Time spent between turns		
5	Operator hourly wages	**Vermi-composting Process Module**	Operating Cost ($/ton)
6	Manager hourly wages		
7	Woodchip cost		Diesel Use: Equipment Fuel Use (L/ton)
8	Amount of woodchip		
9	Saw dust cost		
10	Amount of saw dust added		
11	Value of compost produce		
12	VCP Facility Life		

VCP Emissions

Direct Emissions = Emissions $_{\text{Operational}}$ + Emission $_{\text{Degradation}}$

i) Emissions from equipment for turning the compost can be calculated as shown

$$\textbf{Emission}_{\textbf{Operation}} = \frac{\mathbf{F}}{\mathbf{W}} * \mathbf{E} * \mathbf{EF}$$

Where:

- *Emissions operation = Emissions from equipment used to turn the vermi-composting piles (kg CO_2/ton of waste handled)*
- *F: Fuel (L) = Fossil fuel consumption per month*
- *W: Waste (tons) = Organic waste utilization per month*
- *E: Energy (MJ/unit) = Energy content of the fossil fuel (e.g., Diesel 36.42 MJ/L)*
- *EF: CO_2 Emission Factor for the fuel (e.g., diesel: 0.074 kg CO_2/MJ)*

VCP GHG emissions from organic waste fraction biodegradation

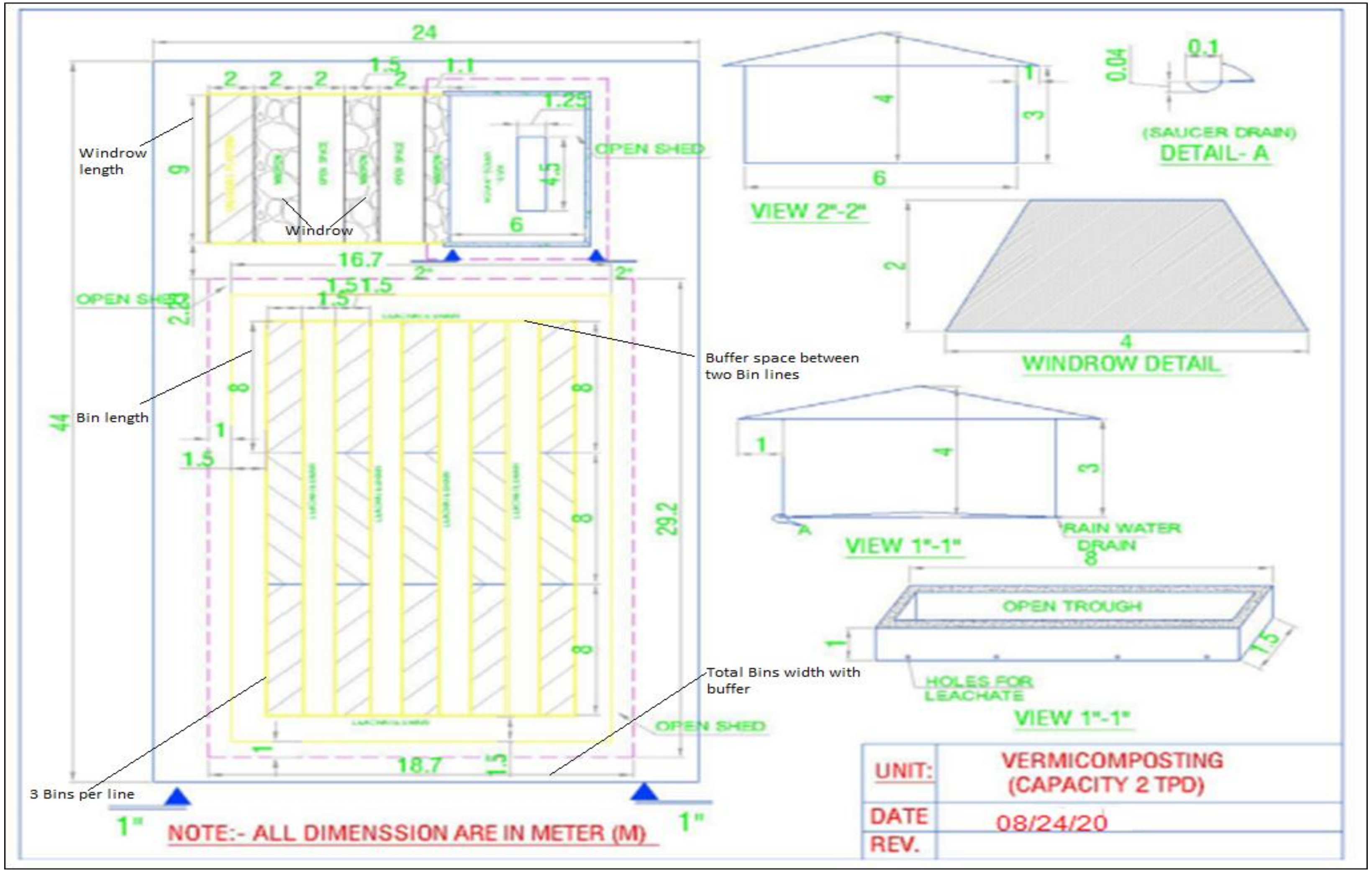
$$\textbf{Emissions}_{\text{Degradation}} = CO_2 + E_{CH_4} \times GWP_{CH_4} + E_{N_2O} \times GWP_{N_2O}$$

Where:

- *Emissions Degradation = Emissions from organic waste degradation (kg CO_2-equivalents/ton of organic waste)*
- **CO_2 -** *Emissions of CO_2 during waste degradation (kg of CO_2/ton of waste).*
- ***E_{CH_4}*** *- Emissions of methane (CH_4) during organic waste degradation (kg of CH_4/ton of waste).*
- ***GWP_{CH_4}*** *- Global warming potential of CH_4 (28 kg CO_2/kg of CH_4)*
- ***E_{N_2O}*** *- Emissions of N_2O during waste degradation (kg of N_2O/ton of waste).*
- ***GWP_{N_2O}*** *- Global warming potential of N_2O (310 kg CO_2/kg of N_2O)*

N.P.: Any volatilization of compounds from waste/compost was ignored.

Vermi-composting plant layout and costs



Plant capacity (TPD)	$/m^2 value of construction	Total plant costs ($)	$/Ton value
2	13.2	36,590	4.08
5	13	42,250	1.88
10	13	66,300	1.48
17.5	12.8	110,656	1.41
40	10	245,230	1.37

Source: Mazumdar, 2012

Equipment using diesel at a vermi-composting plant

No.	Equipment	Number of pieces of equipment required	Actual working hours per day (hours/equipment-day)	Diesel consumption (Liter/hr)
1	Windrow turner	1	7	10
2	Front End Loader	2	7	5
3	Skid-Steer	2	7	10
4	Post-screen	2	7	3
5	Water tanker	1	7	3

Source: Data of fuel consumption from manufacturers and number of equipment required from AMC Mechanical Workshop, Jan. 2020 during the site visit.

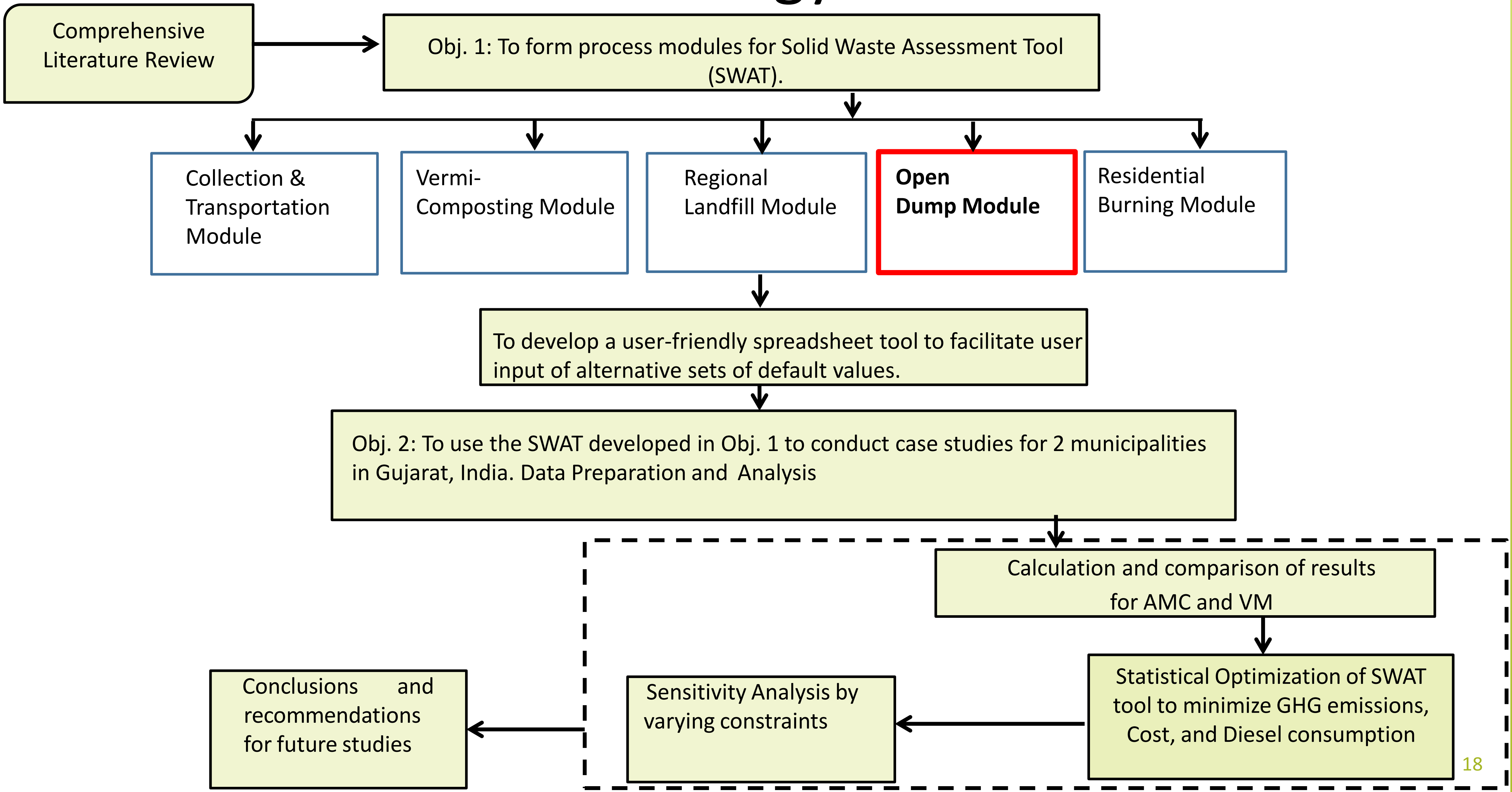
VCP Diesel Consumption

$$Diesel\ Use:\ Equipment\ Fuel\ Use = Total\ energy * Fuel\ consumption * Mass\ of\ Material\ turned * \left(\frac{Timespent\ in\ windrows}{Time\ between\ turns}\right)$$

Where:

Total energy	0.264 kWh/ton turned
Fuel consumption	0.127 L/kWh
Mass of Material turned	ton turned at each turn
Time spent in windrows	Windrow Active Composting: 45 days; Curing: 20 days
Time between turns	Windrow active composting: 3 days; Curing: 7 days
Source: SWOLF Document, 2013	

Methodology



Open Dumps Module Framework

PART-I: Open Dump conventional (without burning) module.			
No.	**User Inputs**		**Outputs**
1	Country and income level	**Open Dump Process Module - Part I**	Direct Emissions (kg/Ton)
2	Total amount of solid waste open dump		Capital Cost (\$/Ton) (Equipment)
3	Type of landfill		
4	Total years of operation		
5	Climatic condition/type for calculating decay rate constant (k)		Operating Cost (\$/Ton) (Equipment)
6	Operator/Driver hourly wages		Diesel Use: Equipment Fuel Use (L/Ton)
7	Laborer/Helper hourly wages		

PART-II: Open Dump (with burning) module.			
No.	**User Inputs**		**Outputs**
1	Population (P)	**Open Dump Process Module - Part II**	Direct Emissions (kg/Ton) from burning portion
2	Waste generation rate (MSW_b)		
3	Collection efficiency (ε)		Direct Emissions (kg/Ton) from non-burning portion
4	Burning fraction of the waste generated (B_f)		
5	Combustible fraction of the waste burned (λ_f)		
6	Oxidation efficiency (η)		

Emissions associated with open dumps:

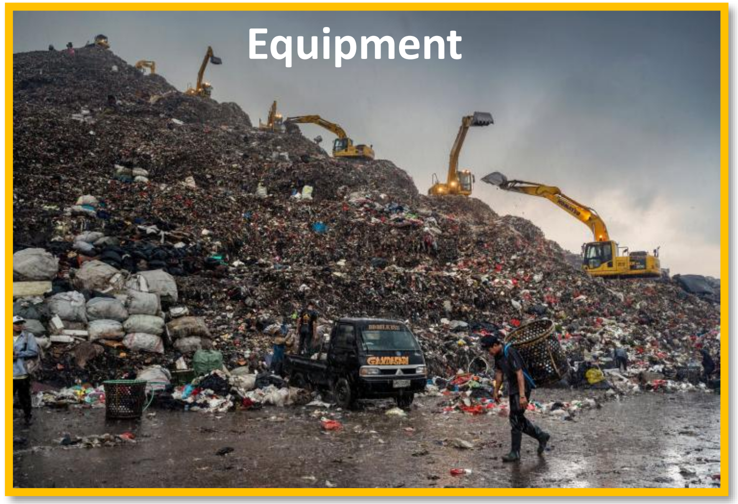
1) Equipment (same emission factors as regional landfill)

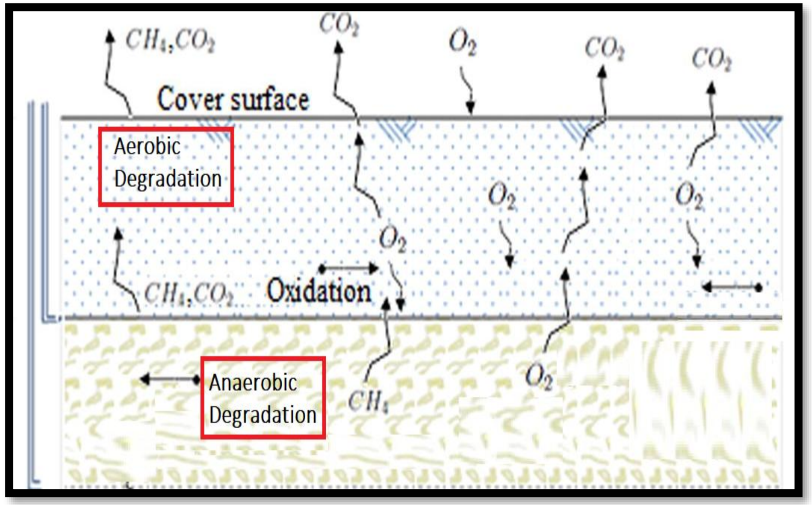
2) Anaerobic degradation of waste,

3) Aerobic degradation,

4) Waste volatilization, and

5) Waste burning/fires.





Emissions from anaerobic degradation of waste

Considering MCF as the type of landfill selected

Emissions from aerobic degradation of waste

Location	Country	CO_2 (kg/Ton)	References
Eskisehir	Turkey	147	Banar et al., 2009
Lahore	Pakistan	178	Manfredi and Christensen, 2009
Denmark	Denmark	131	Thanh and Matsui, 2013
Zhejiang	Province China	391	Guan et al., 2015

Volatile compounds from open dumps

Pollutant	Deonar; kg of CO_2 equivalent/ Ton	Malad; kg of CO_2 equivalent/ Ton	This study; kg of CO_2 equivalent/ Ton
Styrene	-	-	-
Benzene	1.3775	0.2320	0.8048
Carbon tetrachloride	0.1895	0.0297	0.1096
Chloroform	0.0012	0.0004	0.0008
Ethylbenzene	0.0019	0.0003	0.0011
Methylene chloride	0.0618	0.0020	0.0319
Xylene mixture	0.0009	0.0001	0.0005
Toluene	0.3375	0.1395	0.2385

Source: Majmudar et al., 2017

Emissions from waste burning

$$MSWb = P \times (MSWp) \times \varepsilon \times B_f \times \lambda_f \times \eta \times 365 \times 10^{-3}$$

Source: Das et al., 2018

Where;

MSW_b: amount of waste open burned, tons/yr

P: Population, persons

MSW_p: Per capita waste generation rate, kg/person/day

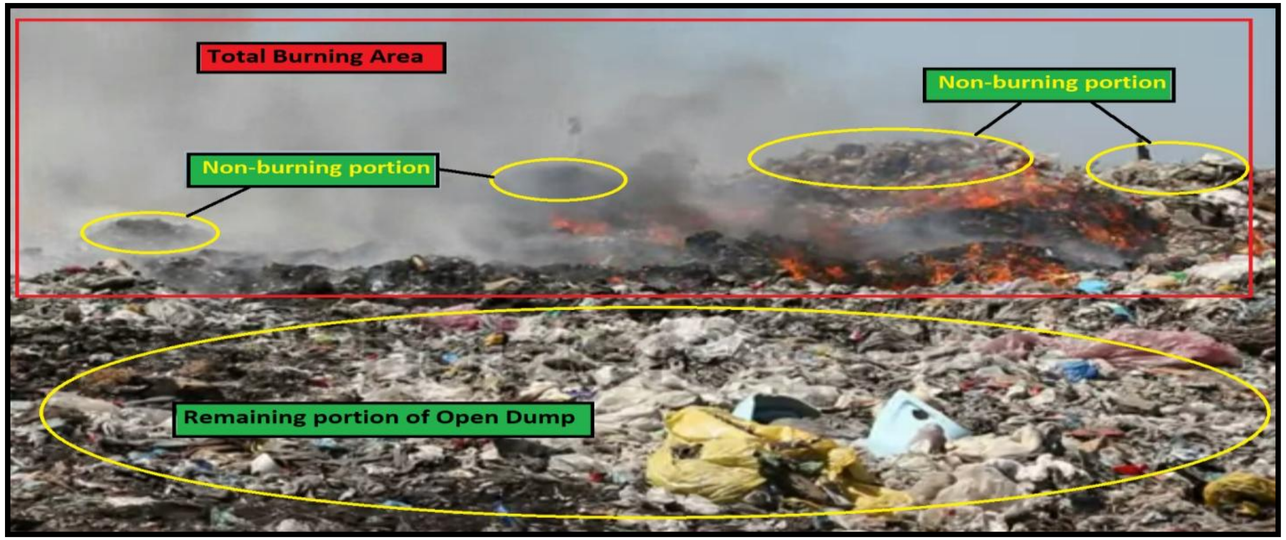
ε: Collection efficiency (fraction that is disposed/landfilled)

B_f: Fraction of the waste that is burned relative to the total amount of waste disposed of at a disposal site.

λ_f: fraction of combustible waste relative to the fraction of waste that is burned.

η: Fraction oxidized (some of the combustible fraction may not burn due to the temperature being too low)

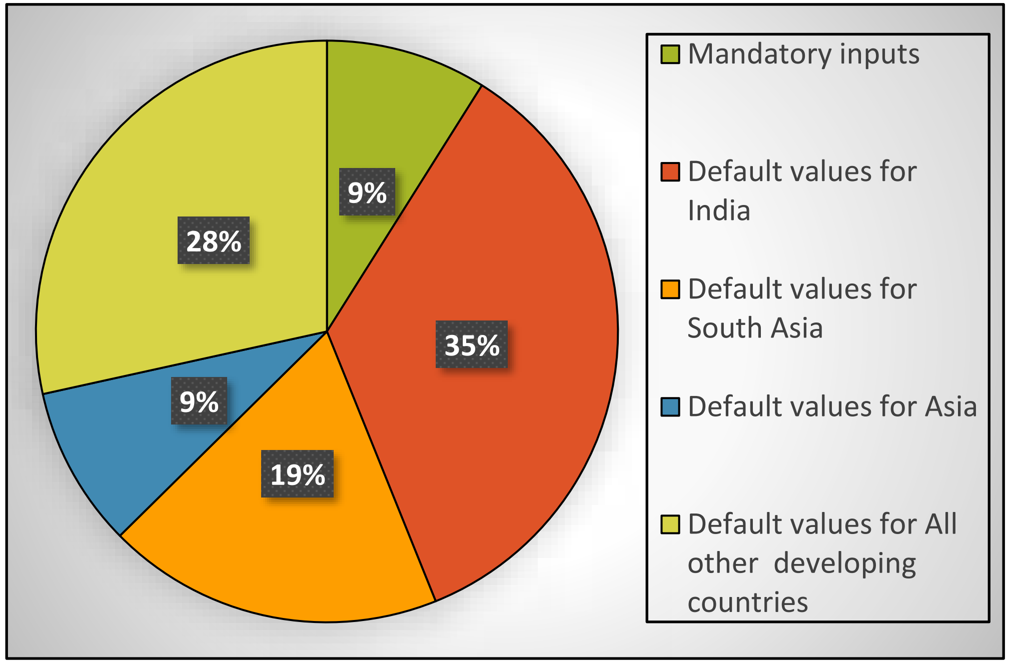
10^{-3}: conversion factor from kilograms to tons.



SWAT tool input variables

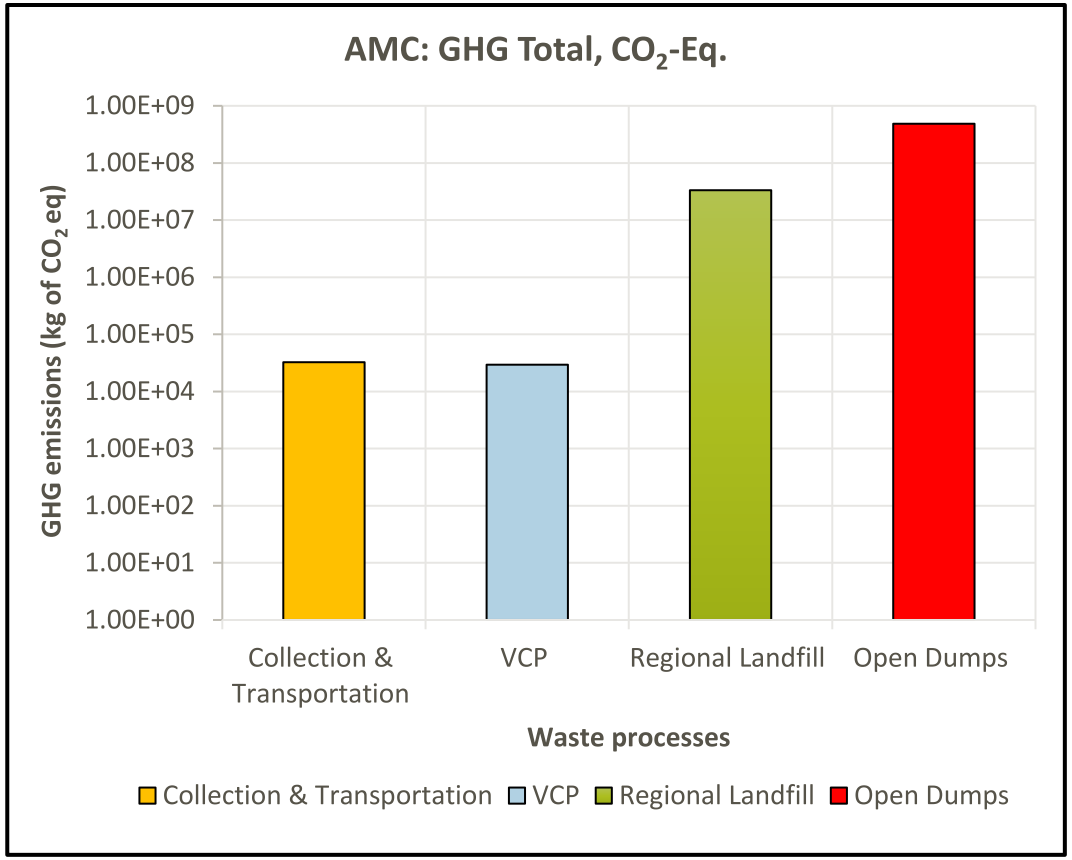
46 variables

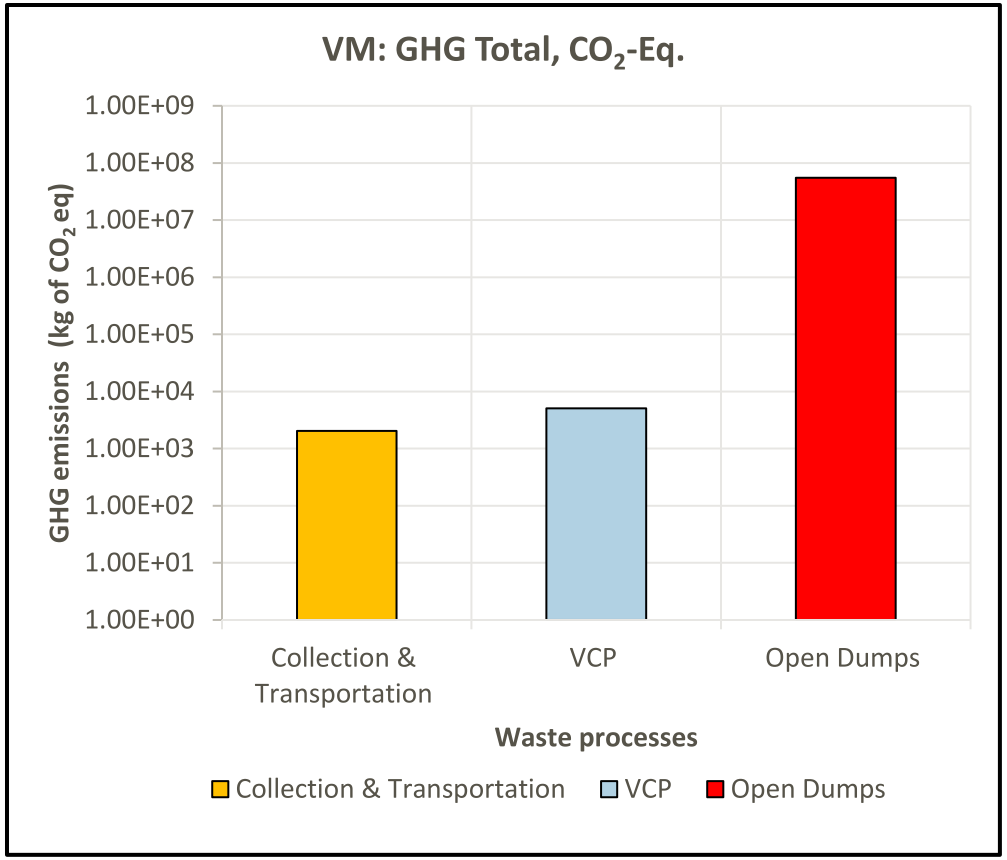
Module	Total input variables	Mandatory inputs	Optional input: Default provided for:			
			India	South Asia	Asia	All other developing countries
Vermi-Composting	30	1	12	9	2	6
Open Dump	16	3	4	1	2	6



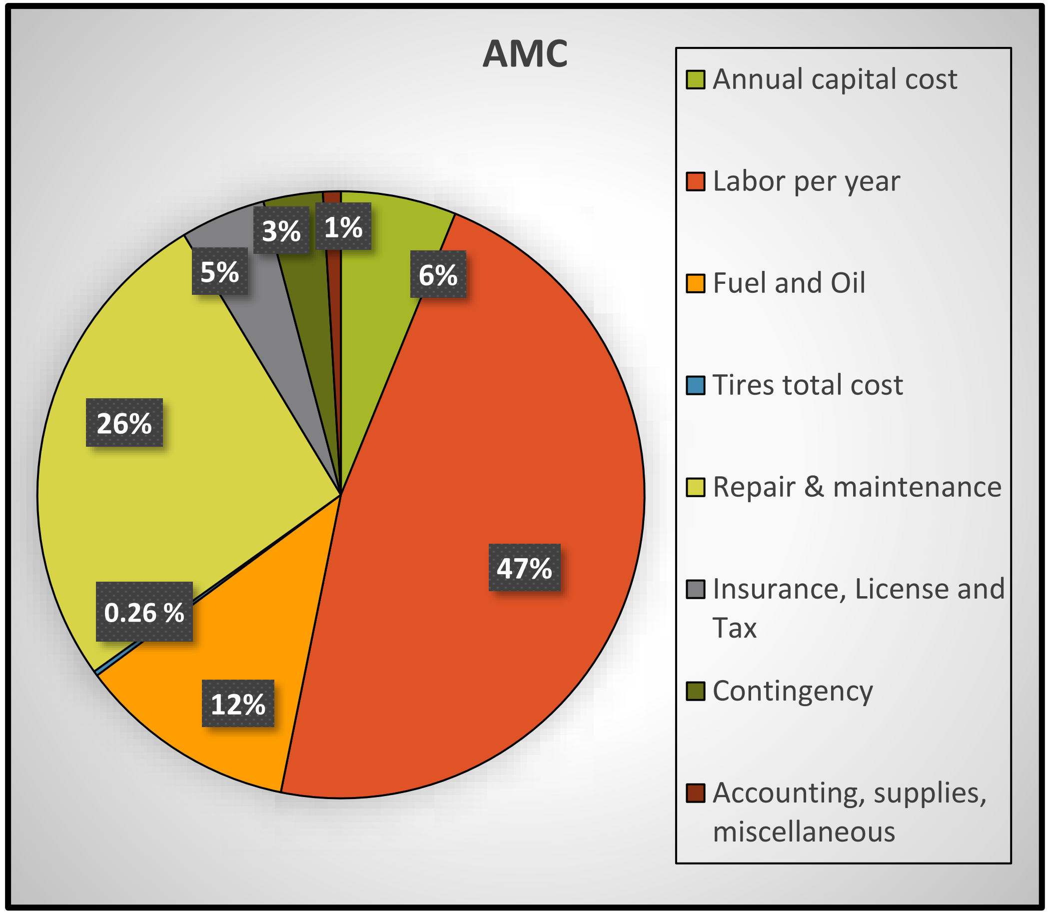
Spatial applicability of SWAT input variables

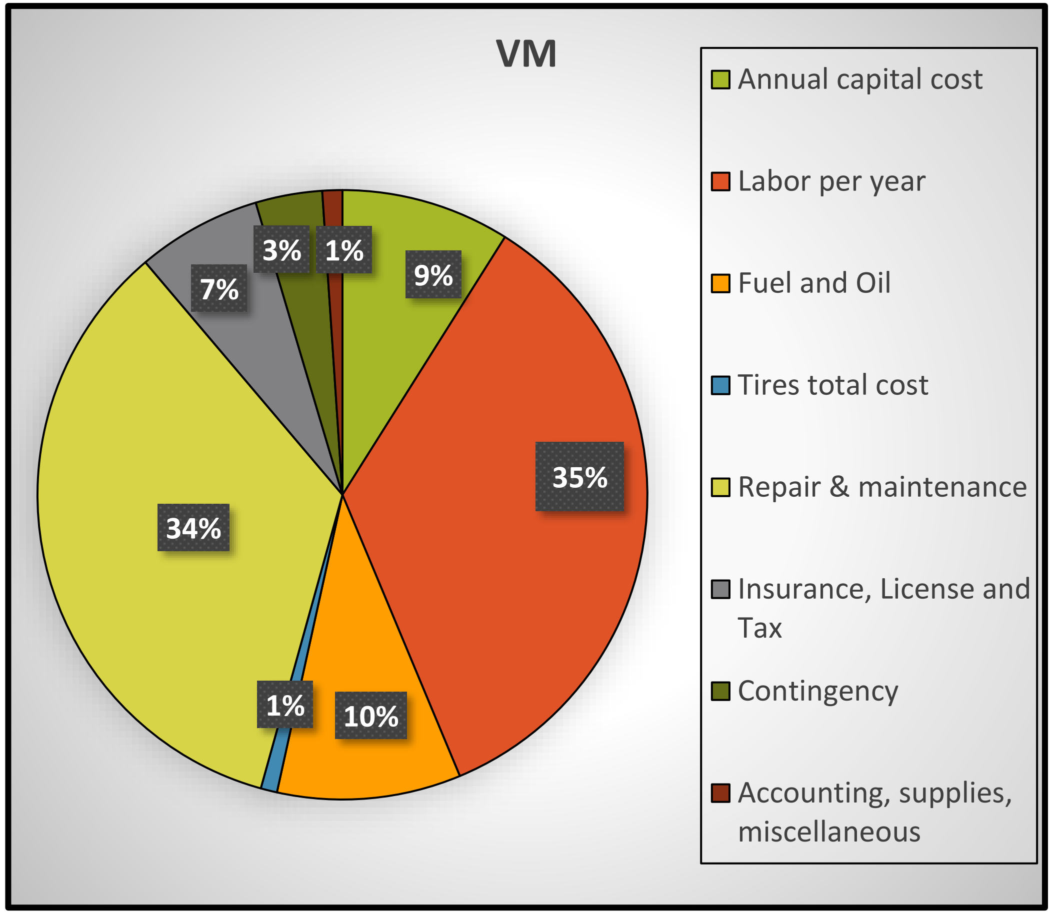
Comparison of GHG Emissions for



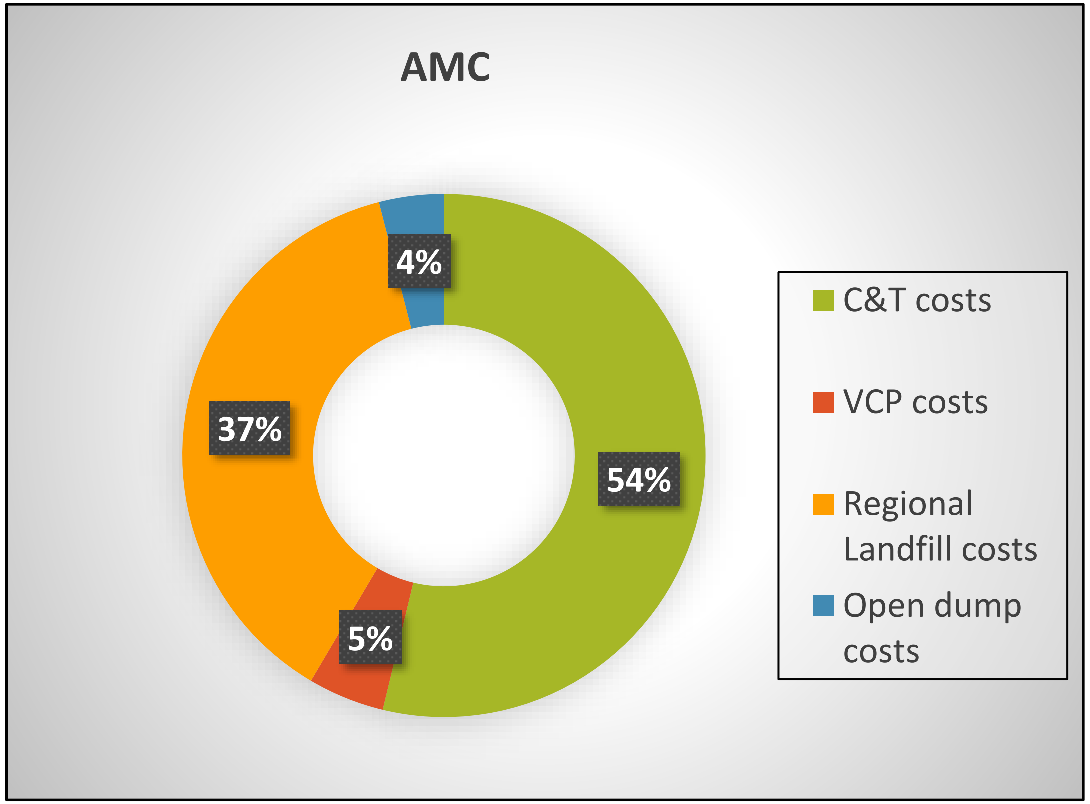


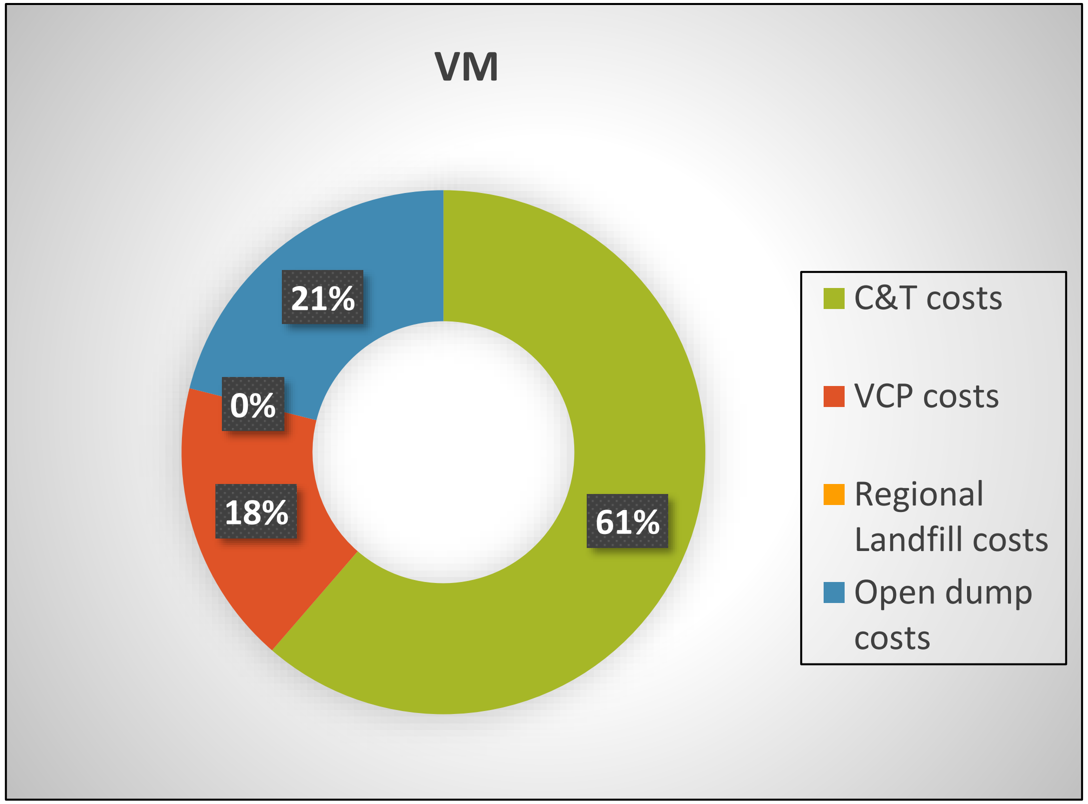
VCP cost results



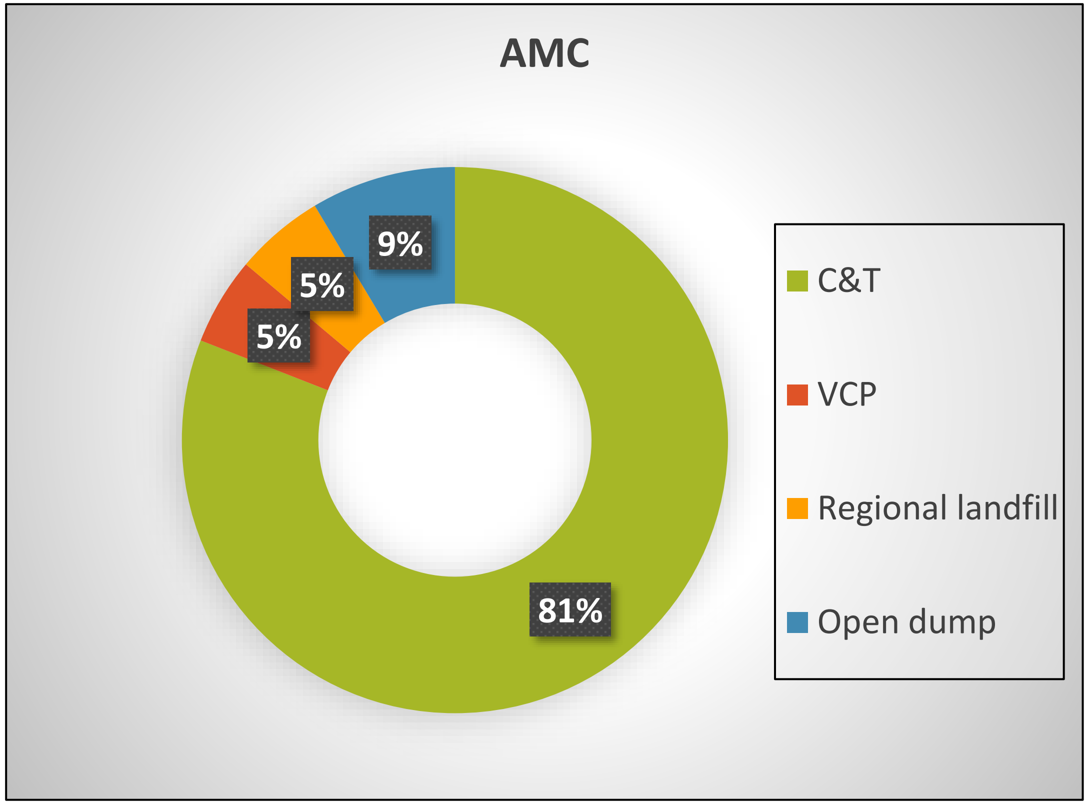


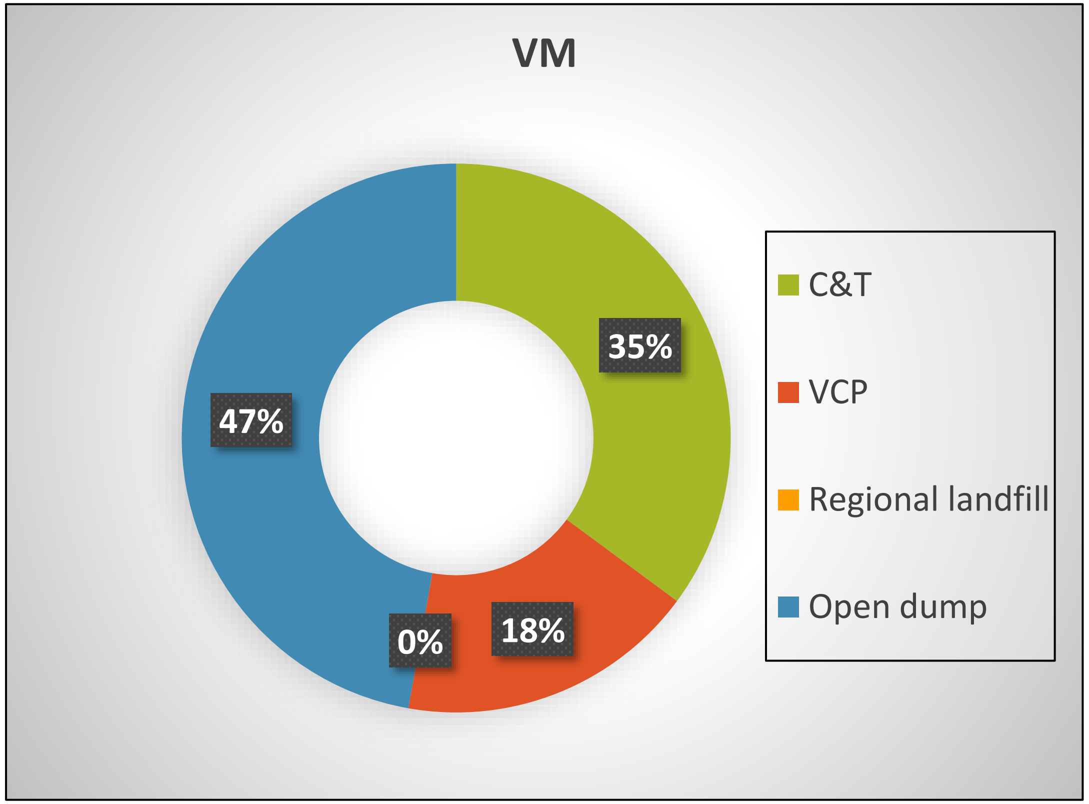
Comparison of Total Costs



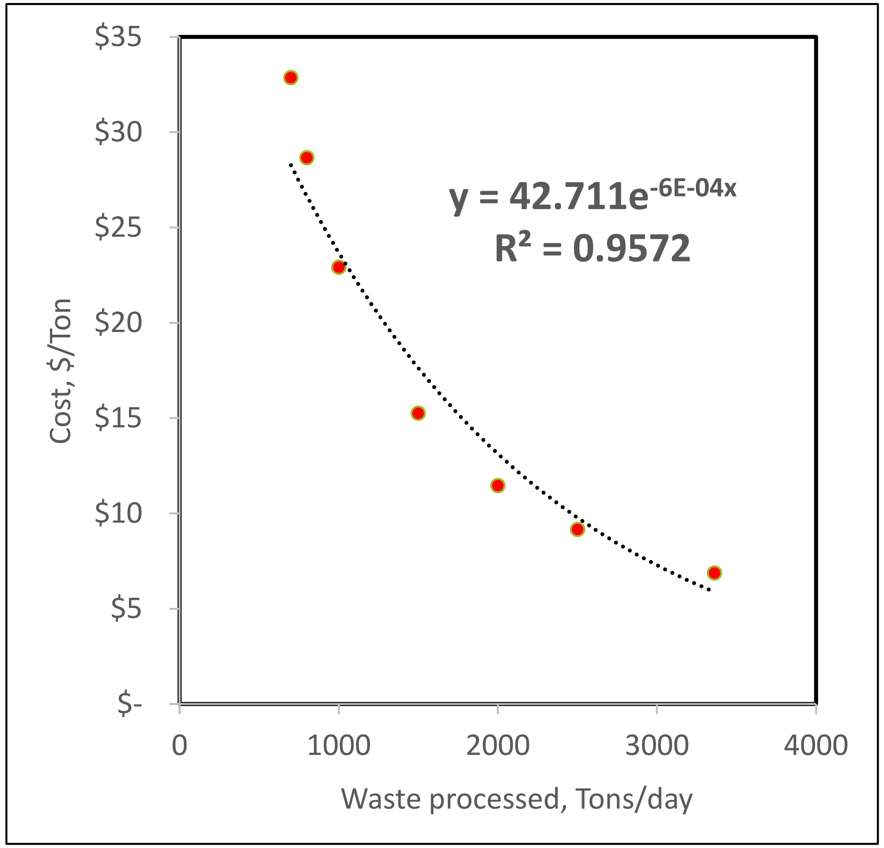


Comparison of Diesel Consumption





Predictor variables x and response variables Y for objective functions predicting costs, as functions of tons of waste processed



Cost vs. mass of waste open dumped for AMC

Objective function (Cost).:

Min ($Y_{C,AMC}$=(-9.22*Ln(x_{VCP})*x_{VCP} + 59.758*x_{VCP})+((42.711*(EXP(-6*10^-4*x_{OD})))*x_{OD})

Where;

Variable	Description	Units
Y_C	Total cost for processing/disposal	$
x_{CT}	Waste collected and transported	TPD
x_{VCP}	Waste going to the vermi composting plant	TPD
x_{OD}	Waste going to open dumps	TPD
Z_{RL}	Factor used in the tool to decide whether the waste % in less than 1,000 TPD or more	1 or 0

Similarly, objective functions were generated to obtain GHG emissions, and diesel consumption.
Total 6 objective functions for AMC and VM.

Summary of optimization for AMC and VM costs, GHG emissions, and diesel consumption

Optimization \ Scenario	AMC			VM		
	Cost ($)	GHG emissions (kg of CO_2 eq)	Diesel (Liters)	Cost ($)	GHG emissions (kg of CO_2 eq)	Diesel (Liters)
Cost	-29%	40%	-3%	-18%	64%	58%
GHG emissions	-1%	-51%	15%	25%	-44%	29%
Diesel	3%	-19%	-4%	3%	-19%	-10%

(-) shows decrease in value.

Optimization \ Scenario	AMC		VM	
	Diverts From	Diverts to	Diverts From	Diverts to
Cost	VCP	OD	VCP	OD
GHG emission	OD	RL	OD	RL
Diesel	OD/RL	VCP	OD	VCP

Conclusions

- The SWAT tool can be used to design or modify solid waste management systems in developing countries to reduce emissions of traditional air pollutants and greenhouse gases, costs, and diesel consumption.
- The capital and operating costs per ton for AMC were 9% and 5% lower than for VM, respectively, as expected due to economies of scale.
- The baseline scenario results for AMC and VM showed that the highest GHG emissions were obtained from open dumps for both AMC and VM.
- The AMC regional landfill emits the greatest amount of VOCs and NO_x, with the open dump emitting somewhat greater CO. For VM, since there is no regional landfill, open dumps emit the greatest amount of all non-GHG pollutants.
- The O&M cost for AMC was found to be 7.5 times the capital cost, while for VM it was found to be 6.28 times.

Conclusions (Cont'd)

- The SWAT study results suggest that proper optimization to reduce GHG emissions, cost, and diesel consumption would help decision making in the selection of type and number of vehicles or equipment for SWM in developing countries.
- More than 105 trials on SWAT tool found that when the cost was low, GHG emissions were high (e.g., OD), and when GHG emissions were low, diesel consumption was high (e.g., VCP) based on the scenarios selected, with few exceptional cases.
  - Considering these interdependencies can be helpful in selecting the preferred SWM option, based on community priorities.
  - While above conclusion was derived from a case study for particular conditions, the methodology used can be applied to similar projects.

Thank you!

Contact information:

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