

WASTE

TO

CLIMATE ACTION

ASSESSING
GHG EMISSIONS
OF IMPROVED
SOLID WASTE
MANAGEMENT
INTERVENTIONS

*Insights from our work in the
Indian Himalayan Region*

WASTE WARRIORS
REDUCE RE-USE RECYCLE



Strategic Guidance

We acknowledge their strategic guidance and continued support throughout the development of this report.

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WASTE

TO

**CLIMATE
ACTION**

Aim

To Strengthen GHG Emissions Reporting on Waste Management interventions (reduced emissions) in Indian Himalayan Region.

Objective

To quantify reduced emissions (metric tons of carbon dioxide equivalent MTCO_{2e}) achieved through improved waste management practices by Waste Warriors (WW) and its effectiveness at reducing emissions across selected projects and report these for FY 2024–25 using the Waste Reduction Model (WARM) tool.

Context

The waste sector is a notable, yet often overlooked, contributor to climate change, accounting for 3–5% of global emissions of greenhouse gases (GHG). GHG such as methane and carbon dioxide (CO₂) cause the warming of the earth's surface. In the waste management sector, direct mitigation or reduction of GHG emissions can be achieved through composting, stopping open burning, and collecting landfill gases. Emissions can also be reduced through source reduction/prevention, recycling, energy recovery, carbon savings through 3Rs (Reduce, reuse, recycle) and promoting circular economy. Through these measures, the indirect mitigation potential can reach up to 20%.



Why This Matters

The Indian Himalayan Region (IHR) consists of unique ecosystems that are some of the most climate sensitive zones in the world. Though IHR contributes minimal GHG emissions, the region is susceptible to extreme climate impacts ranging from melting of glaciers, changed rainfall patterns, and extreme weather events resulting in natural disasters. These risks are often accelerated by unmanaged waste where open dumping and burning along steep terrain and riverbanks further chokes and degrades the fragile mountain ecosystems by releasing different pollutants (methane, black carbon).

Waste accumulation in small towns and rural areas (where there is no dedicated body for managing waste unlike urban areas) affects soil, water and air, indirectly weakening local resilience to climate change. The geographical conditions and associated logistics challenges of collection and transportation in mountainous regions, makes waste management a concern for both environment and adaptation.

Strengthening waste systems in these areas will have multi fold benefits: resource mobilization, improvement of ecosystem, stronger policy, financial solutions, accountability, climate action, community adaptation, resilience and reduction in GHG emissions further supporting missions like National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and the State Action Plans on Climate Change (SAPCCs).

Overview

The analysis compares greenhouse gas (GHG) emissions from two waste management scenarios with and without intervention by Waste Warriors:

- Baseline Waste Management Scenario (Open dumping & Burning)
- Alternative Waste Management Scenario (source reduction, recycling, composting, incineration/co processing in cement plants, and landfilling).
- This evaluates the potential for Green House Gases (GHGs) emissions reductions through improved waste management practices.

Scope of the Analysis

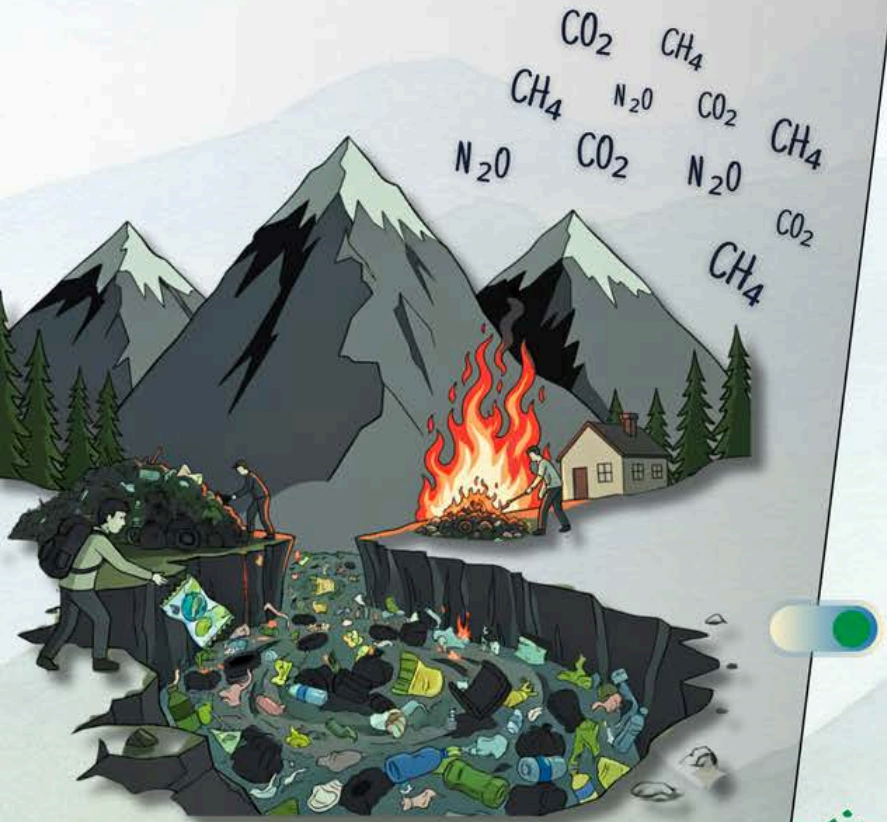
Assessment period: FY 2024–25.

- Data: Primary data collected from different project locations.
- Material Type: Paper, food waste, yard trimmings, mixed plastics, electronics, metals, glass, tires, mixed materials etc.
- Geographic scope: Nine project locations across Himachal Pradesh and Uttarakhand; two states of the Indian Himalayan Region.

From Waste

To Climate Action

The Waste Transformation Journey with Waste Warriors



Unmanaged Waste

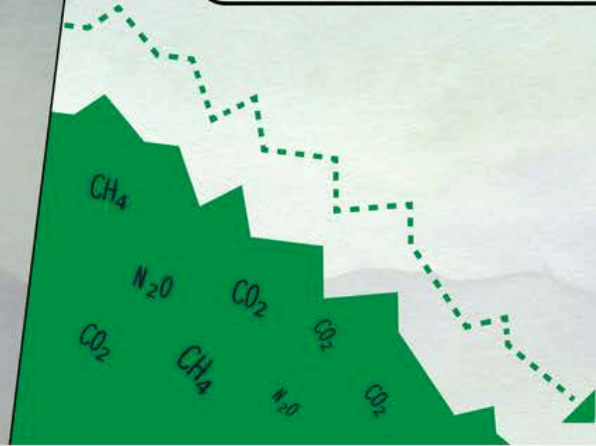
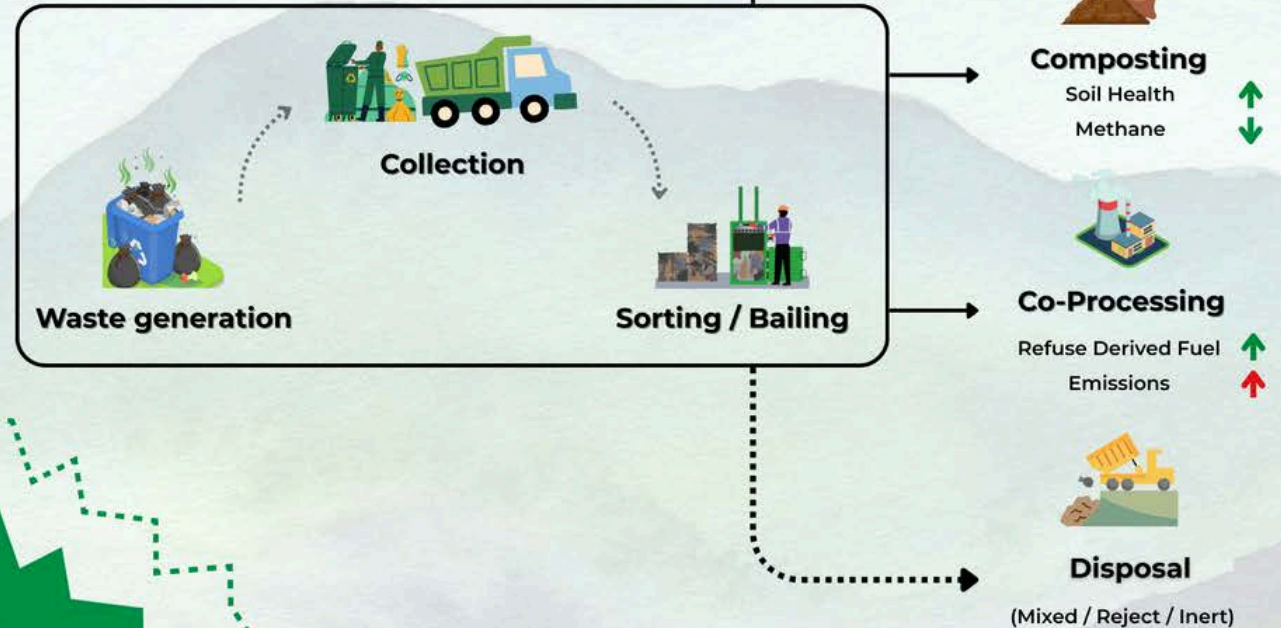
- ▶ Dumping ▶ Burning ▶ Littering
- ▶ High GHG Emissions ▶ Pollution
- ▶ Resource Loss

Reducing GHG Emissions through Improved Waste Management



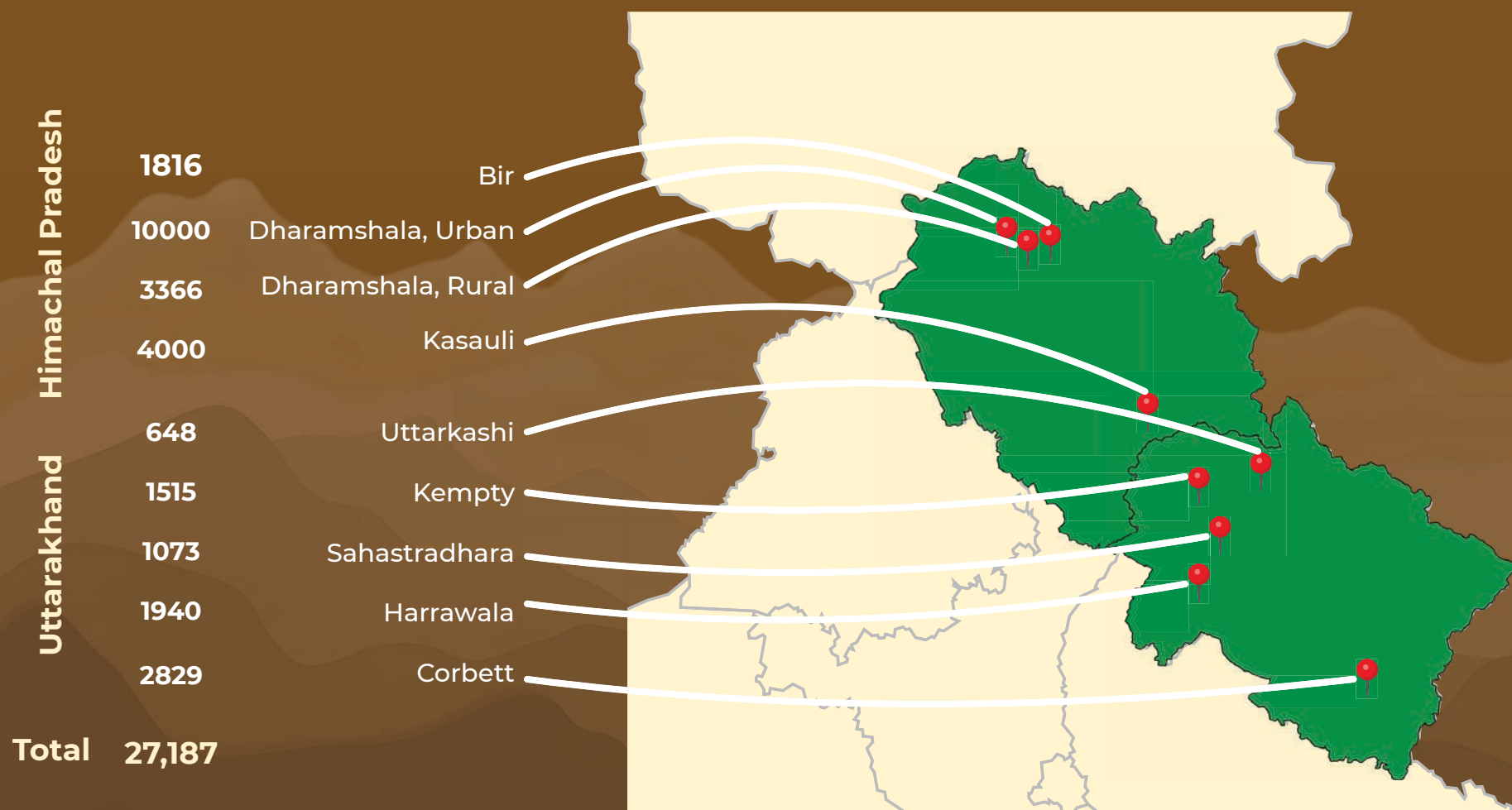
Managed Waste

- ▶ Systemic change
- ▶ Reduced open burning and dumping
- ▶ Lower emissions

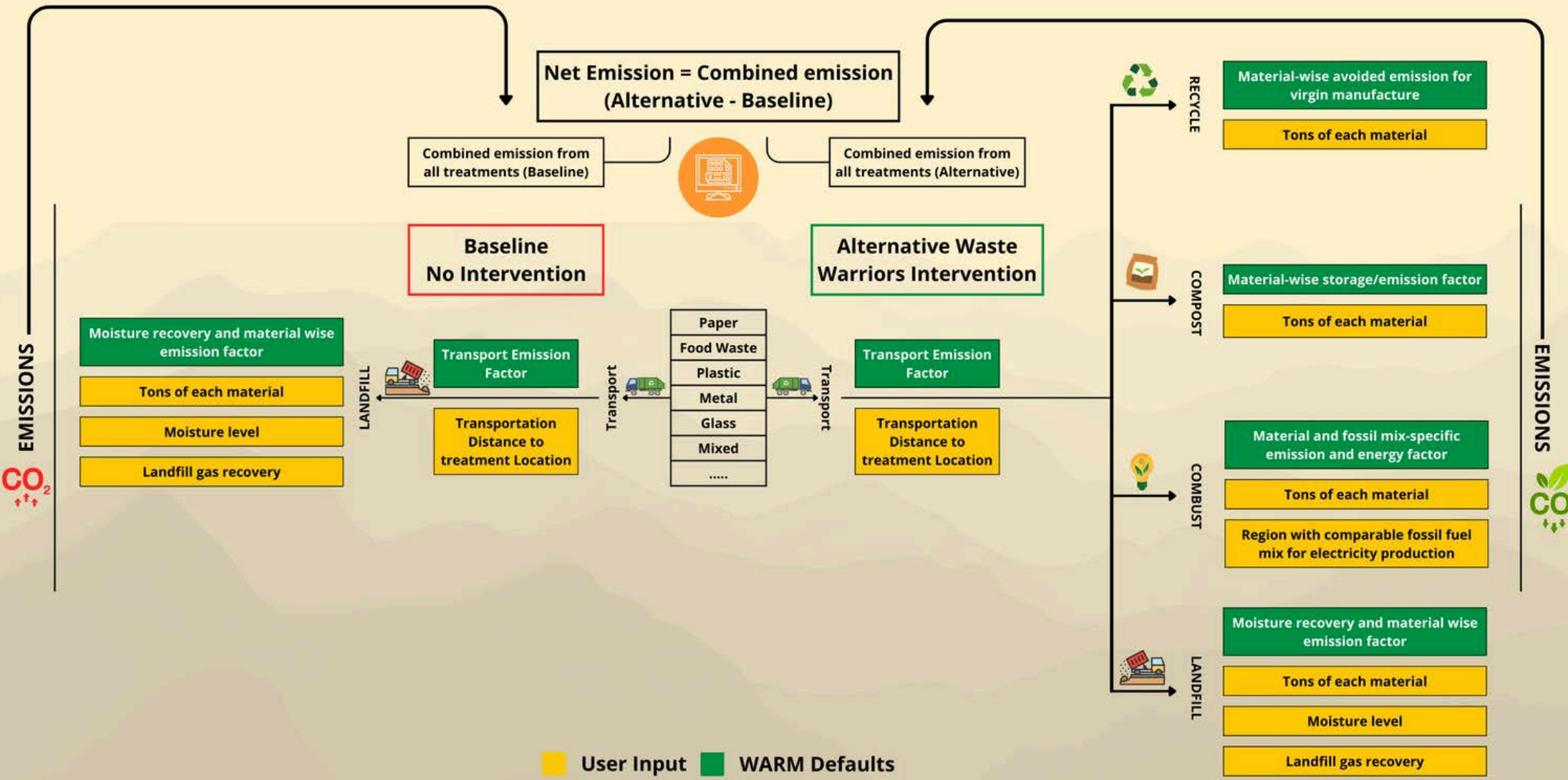


Coverage

(Households and Commercial establishment)



WARM Tool: Measurement Workflow



Material Mapping Comparison

Waste Warrior vs. WARM

WWS Material Categories	WARM Material Categories
Cardboard	Corrugated Containers
Newspaper	Newspaper
Paper	Office Paper
Millboard	Mixed Paper (general)
Pet-Plastic (Green, White, Mixed)	PET
E-Waste	Mixed Electronics
Aluminum Cans	Aluminum Cans
Metal-Iron, Metal-Tin	Mixed Metals
Glass (Green, White, Mixed, Broken)	Glass
Wet Waste	Mixed Organics
Textile Waste (Cloth), Used Beverage Cartons(Tetrapak)	Mixed Recyclables
Wastage, Rejected Waste, Inert, Sanitary Waste , Shoe Sole	Mixed MSW
Carry Bags, PP-Raffia, MLP , HDPE, LDPE, Thermocol, Mixed Plastics, Other low value plastics (LVP)	Mixed Plastics

*Note: Some of the material categories could not be directly mapped to WARM categories:
Multi-layered Plastics (MLP) / Used Beverage Cartons (Tetrapak) / Sanitary / Hazardous Waste*

Insights across different Locations

Overall, combining all the 9 locations in Uttarakhand and Himachal Pradesh, approximately 1,854 metric tonnes of solid waste were collected and processed by Waste Warriors (WW) during April 2024-March 2025.

In a Baseline scenario where there was no formal collection of waste, most of this waste would have been burnt, openly dumped, or likely to be found littered. Upon calculation with the WARM tool, this baseline scenario would result in GHG emissions of approximately 1,613 Metric Tons of CO₂ equivalent.

But, due to our interventions (Alternative scenario) which included recycling, composting and combustion (co-processing at cement factories), the resultant emissions are approximately -779 MTCO₂e. In other words, our intervention results in reduction of nearly 780 metric tons of CO₂ equivalent GHG emissions. Hence, the net effect of our intervention compared to the baseline scenario is the reduction of about 2,392 MTCO₂e (given in figure 1).

While our intervention reduced the emissions at all locations, Kasauli in Himachal Pradesh had the lowest change in emissions (23 MTCO₂e) and Harrawala in Uttarakhand had the highest reduction in emissions (nearly 1,400 MTCO₂e). These are explained by the quantum of waste processed at the two locations with about 16 tonnes at Kasauli (being the new location) and 965 tonnes at Harrawala (being the centralized hub and established location over years).

APRIL 2024

MAY 2025

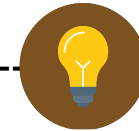
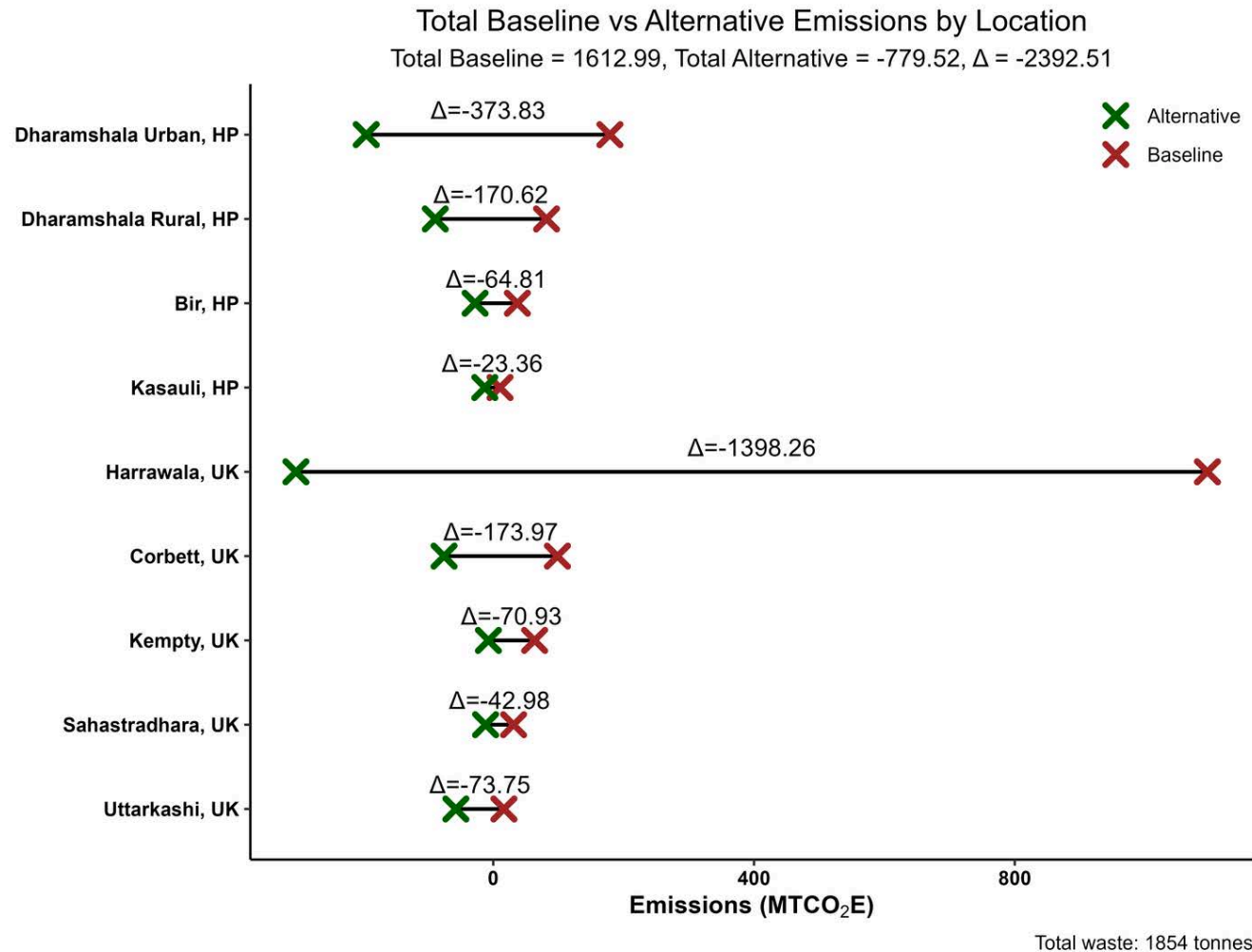
1,854 MT

Solid Waste Collected & Processed



2,392 MTCO₂e

Reduced Emissions



Kasauli being our newest location, reported lowest reduction in absolute emissions.

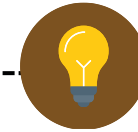
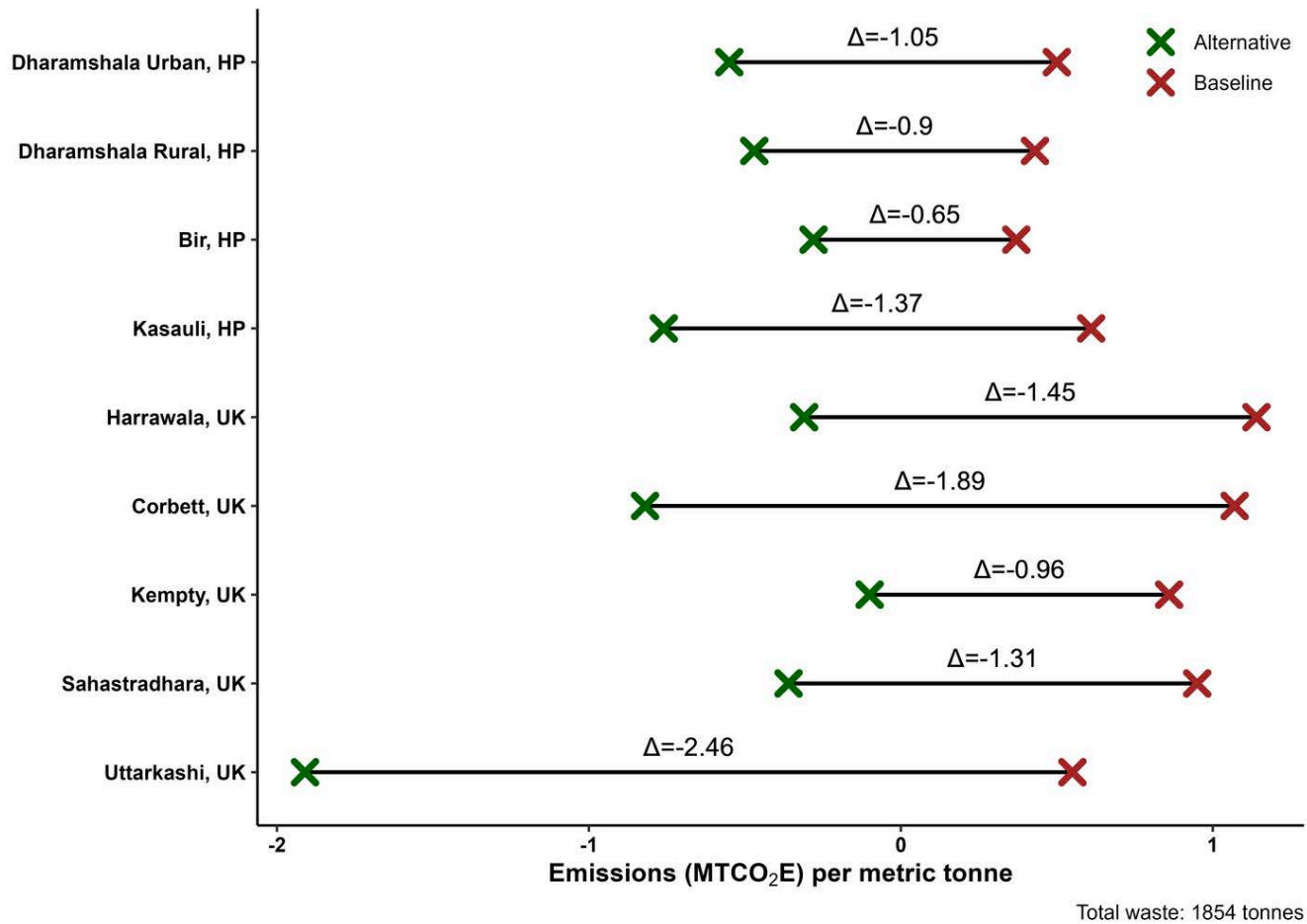
Harrawala (Dehradun) being a centralized hub and a model facility over years, reported highest reduction in absolute emissions.

Figure 1. Total emissions produced in the baseline and alternative scenarios as calculated using the WARM tool at each location. (Where: UK = Uttarakhand, HP = Himachal Pradesh). The net emissions reduced are given by Δ symbol and are calculated by measuring change (Alternative-Baseline) in metric tons of CO₂ equivalents (MTCO₂e).

Note: When waste is segregated, recycled, composted, and moved away from mixed dumping, the carbon footprint drops drastically. Even decentralized interventions in small hill towns create large climate benefits per ton of waste.

Comparison of Baseline vs Alternative Emissions per metric tonne of waste at each Location

Average Baseline = 0.71, Average Alternative = -0.54, $\Delta = -1.25$



Bir: High Co-processing of non-recyclables results in lower emissions reduction.

Corbett: higher recycling rates drive greater emissions reduction, highlighting the role of last-mile recycler linkages.

Kempty: Subpar recycling of mixed MSW results in lower emissions reduction.

Uttarkashi sees higher emissions reduction per ton, as most material is sent for informal recycling.

Figure 2. Emissions produced per tonne of waste processed at each location calculated by dividing the total emissions at each location by the total quantum of solid waste processed at that location.



Recycling > Co-processing (Cement Plants) > Landfilling (Post-processing) >> Composting (by Volume Handled)

High-value recyclables (PET, HDPE, LDPE, metals, glass, paper) are recycled with positive recovery value.

Low-value plastics (MLP, SUP, thin films) are co-processed in cement plants, typically without any monetary value.

Figure 3. The location-wise breakdown of percentage of waste subjected to different alternative interventions implemented under waste management. The total amount of waste (in tonnes) processed at each location is represented on the top of the bar.

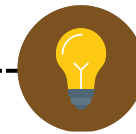
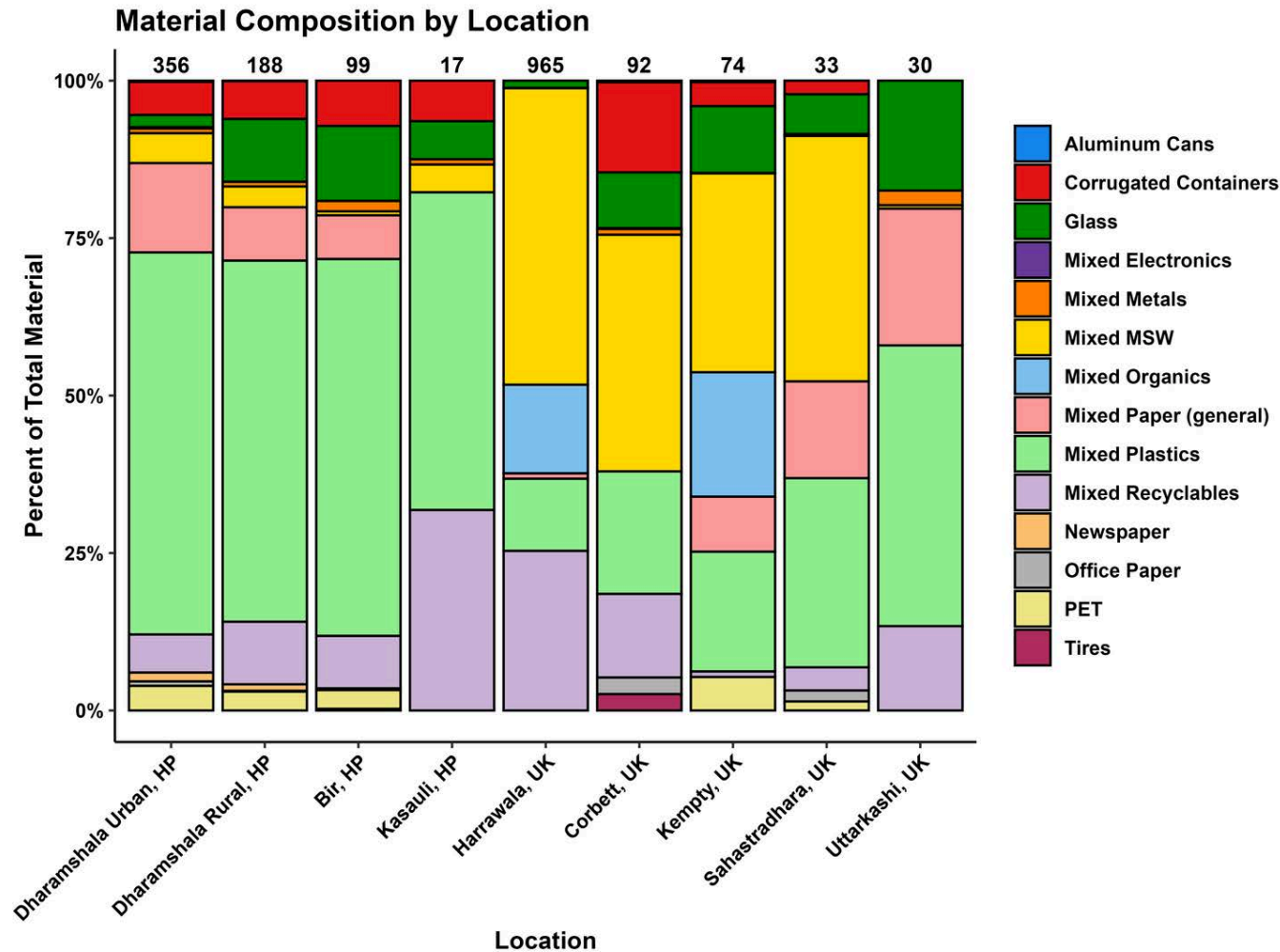
Note: Residual waste still flows to landfills, highlighting the need for better segregation and decentralized processing solutions
 Composting is present across locations but in smaller volumes, mainly limited by feedstock purity and operational capacity

Comparative analysis of emissions reduction per ton of waste (Figure 2)

- At all locations, the alternative scenario has **lower emissions** in comparison to the baseline scenario, resulting in net environmental benefit.
- While measuring effectiveness of reducing emissions per ton of waste (**Figure 2**), the **largest emission reduction ($\Delta = -2.46$ MTCO₂e/tonne)** is observed in **Uttarkashi (UK)**, while the **smallest reduction ($\Delta = -0.65$ MTCO₂e/tonne)** occurs in **Bir (HP)**.
- In general, the average emissions in the baseline emissions and alternative scenarios were roughly **0.71 and -0.54 MTCO₂e/tonne** respectively, resulting in an **average reduction of -1.25 MTCO₂e/tonne**.
- Implementing alternative waste management methods can bring about indirect mitigation potential by reducing emissions while the extent of benefit per tonne of waste processed varies across different locations and waste composition, quantity and treatment/processing methods followed.

Comparative analysis of different alternative interventions (Figure 3)

- Looking at the percentages of the waste subjected to different types of processing (Figure 3), it was found that most of the waste at Uttarkashi is **recycled**, explaining the high degree of effectiveness. However, Uttarkashi does not receive a large amount of waste, so it may not be a representative example.
- Among the larger processing sites, Harrawala and Corbett are quite effective on a per tonne basis, with about **-1.45 and -1.88 MTCO₂e** reduction of emissions, respectively.
- At first glance, this may reflect a trend that more effective reduction of emissions is related to a lower percentage of waste combusted from a particular location. However, Kasauli has a high percentage of waste combusted, but has a comparable reduction of **-1.42 MTCO₂e** due to high mixed recyclables.
- Among different alternate management scenarios, **composting** and **recycling** contributed as the most significant interventions to GHG reductions.



Depending upon the level of segregation, mixed plastics remain one of the dominant waste fractions across locations.

Harrawala (Dehradun) & Kemply collect segregated wet waste across residential & commercial.

Figure 4. The compositional percentage of different waste materials across locations along with the quantum of waste (in tonnes) processed at each location is represented on the top of the bar.

NOTE: Material composition is based on primary data collected by Waste Warriors through its SWM interventions. It is not representative of the total waste generated in the mentioned locations.

Higher percentage of mixed recyclables reduces emissions

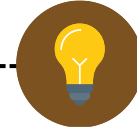
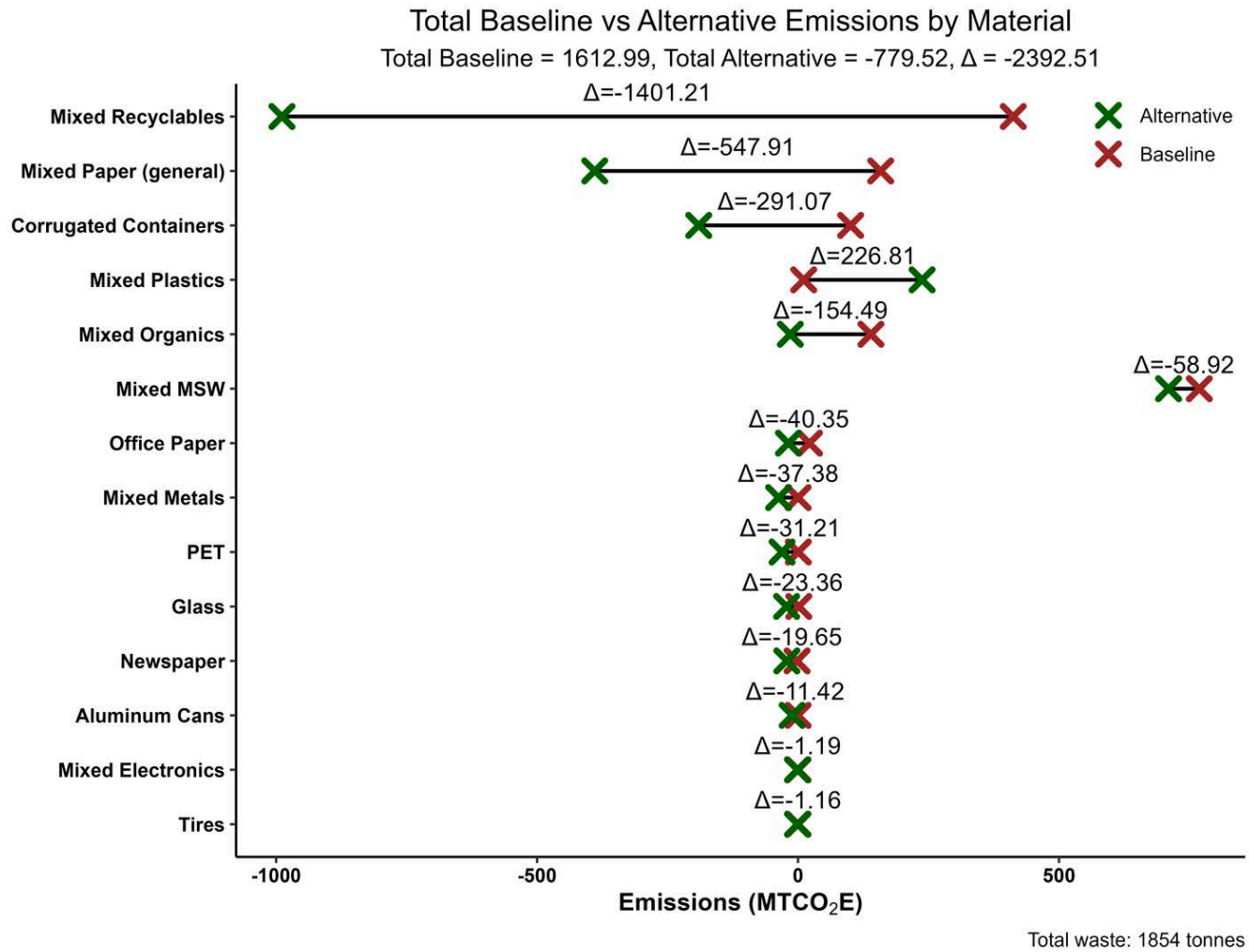
The nature of interventions at different locations may be related to the different percentages of materials of waste processed at these locations (Figure 4). Both Harrawala and Corbett, have a higher percentage of mixed MSW (municipal solid waste), while locations such as Dharamshala (urban and rural) and Bir which have a lower per tonne reduction of emissions have higher percentages of mixed plastics. At the same time, Kasauli also has a high percentage of mixed plastics and mixed recyclables as well. Clearly, processing mixed recyclables and MSW has a significantly positive effect on emissions reduction, while mixed plastics seem to have a negative impact on emissions reduction.



Combustion increases emissions but might offset fossil fuel use

Our interventions reduced emissions for most materials processed/treated across our MRFs (Figure 5). Sending the mixed recyclables for recycling results in the greatest reduction in emissions (about -1400 MTCO₂e). In contrast, the combustion of mixed plastics has resulted in an increase in emissions of about 227 MTCO₂. Mixed plastics are mostly sent for cement co-processing because of high quantum of low value plastics having low recyclability and high calorific value. Therefore, it can substitute for offsetting fossil fuel use and can be diverted toward Refuse-Derived Fuel (RDF) production and co-processing in cement/thermal plants.



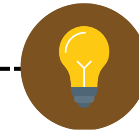
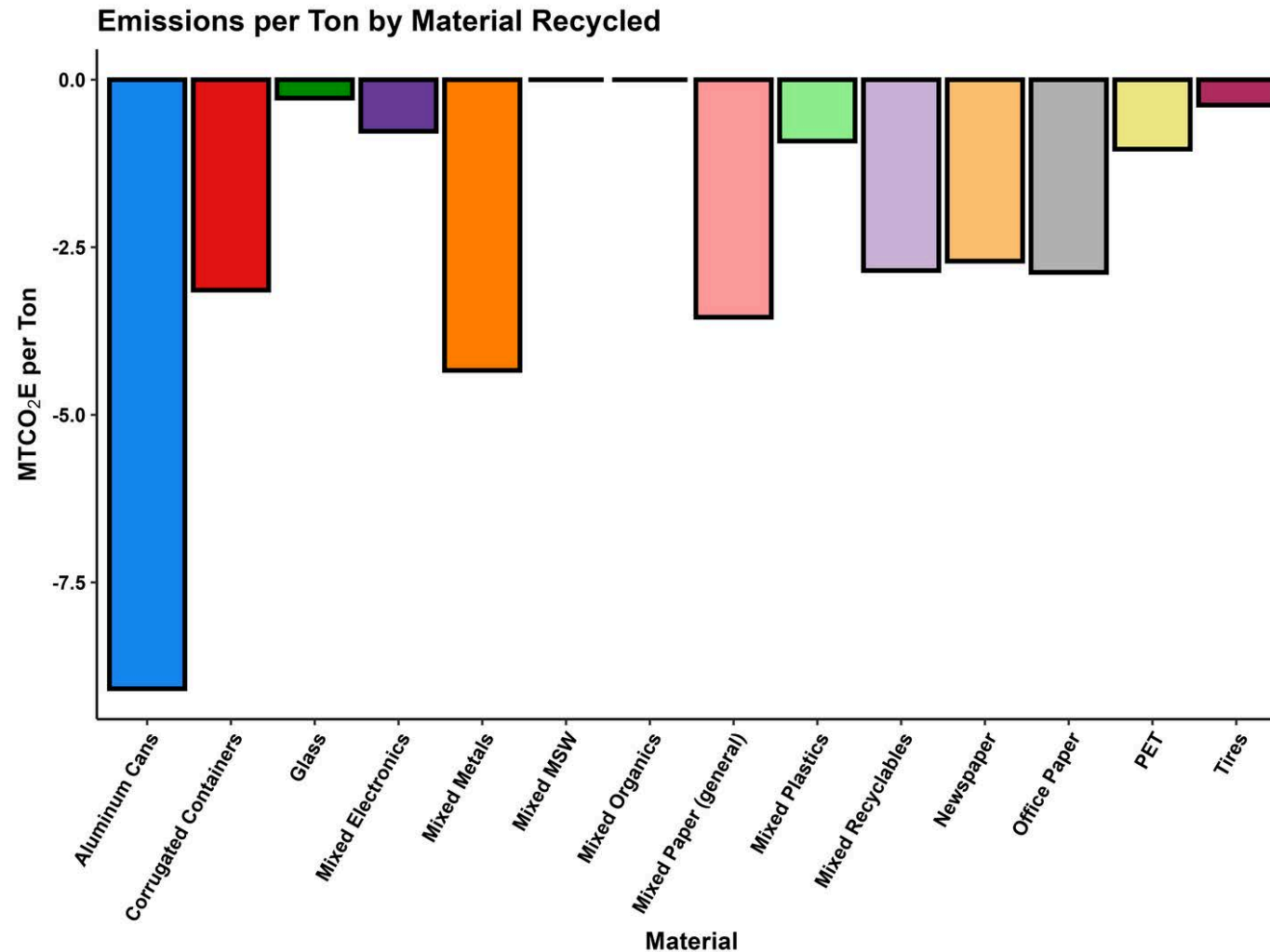


Managing non-recyclable materials like multi-layered and single-use plastics results in higher net emissions than the baseline scenario.

Mixed MSW causes high emissions with low reduction potential, making segregation a priority.

Figure 5. Emissions combined across all locations for each type of material.

GHG Emissions Reductions from Recycling Different Materials



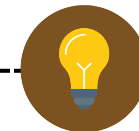
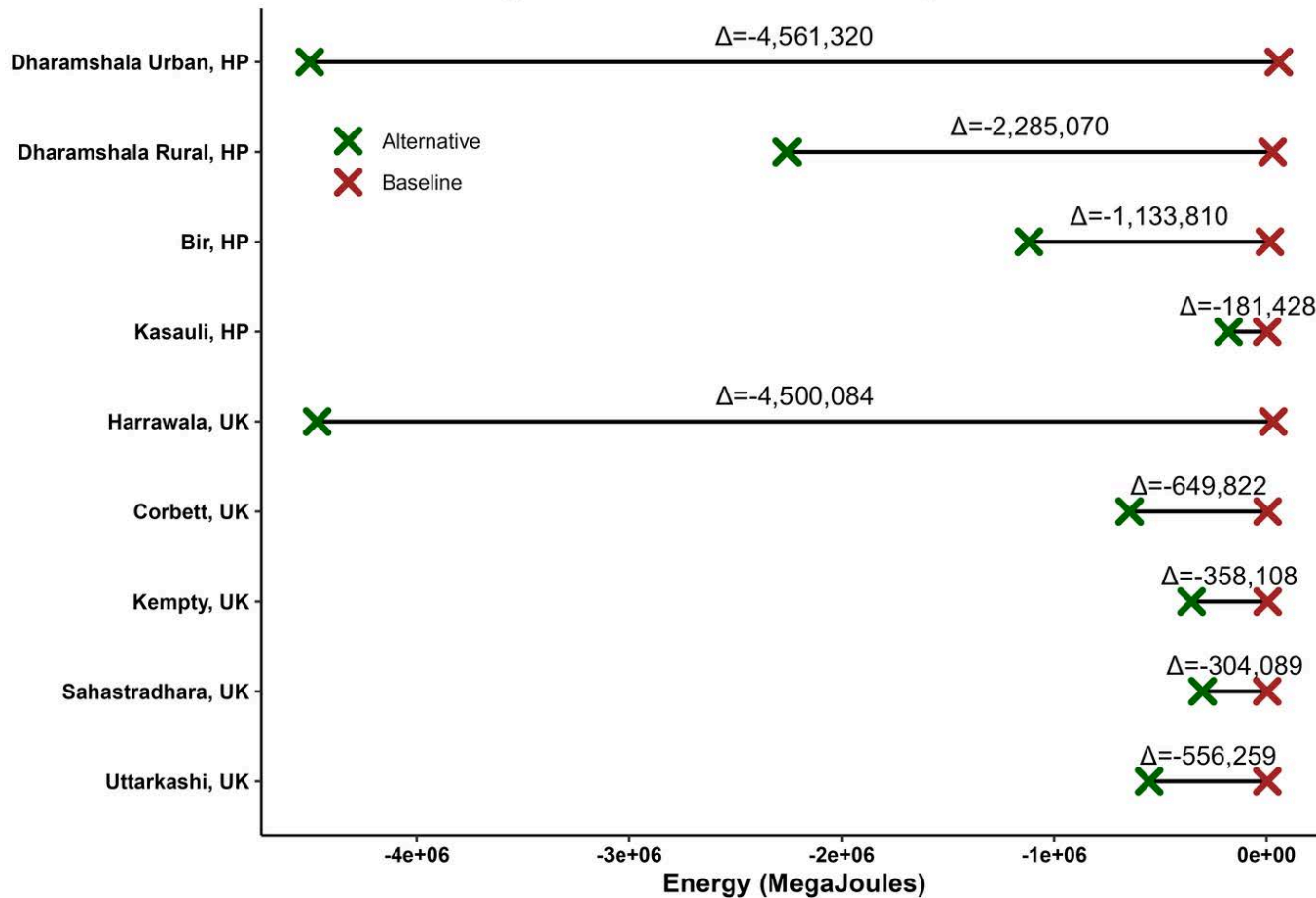
Aluminum recycling delivers the highest climate benefit, reducing ~9 MTCO₂e per ton due to energy-intensive primary production.

Paper, metals, and mixed recyclables also offer significant savings (2–5 MTCO₂e per ton).

Glass and tires show very small benefits

Note : Glass and tires show lower GHG benefits, as glass production is relatively energy-efficient and transport emissions are high. Recycling carbon-intensive materials should therefore be prioritized.

Total Baseline vs Alternative Energy (MegaJoules) by Location - Mixed Plastics
 Total Baseline Energy = 151,728, Total Alternative Energy = -14,378,263, $\Delta = -14,529,991$



Combustion of non-recyclables results in high emissions but leads to significant reductions in energy use assuming energy produced during the process leads to reduction in alternative fuel used for producing electricity.

Figure 6. Reduction in energy used (in Mega Joules) due to energy production from combustion of mixed plastics or from their recycling at each location.

Reduction in energy used (in Mega Joules) due to energy production from combustion of mixed plastics

We send a lot of our low value (non-recyclable) mixed plastics from different locations in Himachal Pradesh to cement co-processing plants for combustion. Sending to cement co-processing plants not only reduces the volume of this waste category that would otherwise have ended up in landfills (baseline scenario) but also produces a significant amount of energy. For example, the mixed plastics from Dharamshala Urban alone resulted in reduction of about 4.5 million joules of energy (Figure 6), that would otherwise have been mostly supplied by fossil fuels. This is equivalent to the annual energy consumption of 48 households or 744 barrels of oil, which we are substituting with this refuse derived fuel (RDF).



4,500,000 J

48 X



or



X 744

Critical insights across locations

Location	Problem	Solution
	Himachal Pradesh	
Bir	High volume of mixed plastics (65.44 MT) having low recyclability	Diversion as RDF to co- processing and replacing low value plastics with sustainable alternatives.
	Mixed MSW is being combusted due to poor source segregation, limiting recycling potential and increasing emissions.	Encouraging source segregation to divert and enhance recycling initiatives.
Dharmshala (Rural)	Mixed plastics (118.76 MT) dominate the waste stream.	Improving recyclability of MLPs, diverting it to cement plants as RDF.
	Mixed MSW (6.80 MT) being combusted.	Source segregation for resource recovery, enhancing better recycling through segregation.
Dharmshala (Urban)	Mixed plastics (237.75 MT) dominate the waste stream.	Improving recyclability of MLPs, diverting it to cement plants as RDF.
	Mixed MSW (18.52 MT) being combusted.	Source segregation should be practised.
Kasauli	Recent Scaled up project, yet similar pattern of high volumes of low value waste, mixed plastics (9.51 MT).	Having finite resources and plastics originating from non renewable energy, the design, manufacturing should see sustainable alternatives boosting the circular economy.
	Mixed MSW (0.83MT) reducing recycling potential.	Improved segregation can reduce the GHG emissions.

Uttarakhand

Corbett

Out of 19.82 MT, 3.75 MT is combusted. Recyclables not reaching the market due to poor linkage/network.

Better connectivity to retailers, recyclers and vendors enable better recycling initiatives.

Mixed MSW (38.27 MT) leading to positive emissions.

Source segregation is essential which can enable better alternative interventions lowering down emissions through reduction at source.

WardNo.97, Harrawala

A total of 965 MT of waste contains mixed MSW (500.84 MT) which could have been diverted to different better alternatives.

Source segregation would have led to better characterization of waste into its resultant segregated category that could offset the emissions if diverted correctly.

Kempty

Approximately 74 mT of waste only contains 15.50 MT of mixed plastics that cannot be upcycled.

Reduce the use of mixed plastics and use these as a substitute fuel keeping in mind the high calorific value.

Mixed MSW (25.74 MT) increasing positive emissions & reducing recycling potential.

Implement strict source segregation systems.

Sahastradhara

Mixed plastics (10.86 MT) are a concern unlike any other location.

Sustainable product, its manufacturing of MLPs, or better substitute

Mixed MSW (14.09 MT) have increased the emissions.

Strict rules and strengthening source level segregation to enhance recycling programs.

Uttarkashi

Mixed MSW is a major problem that is going to landfills, hence increasing emissions.

Source segregation is the key to ensure resource recovery, making recycling programs more efficient.

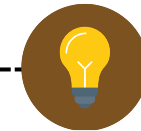
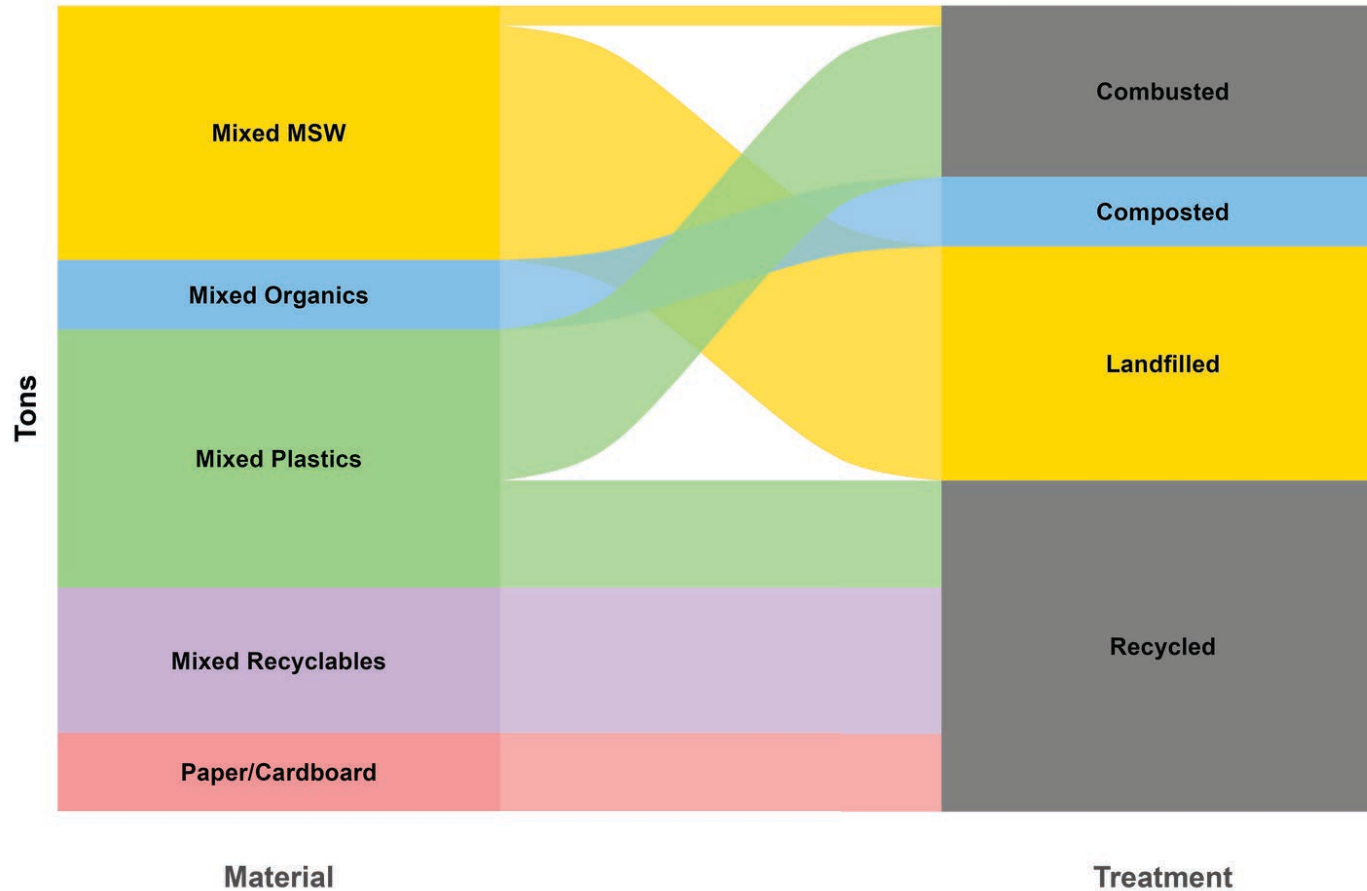


**Material x Alternative
Treatments:
A Deep-dive**

Material Flow Across Alternative Treatment Methods

Material Flow Towards Treatments (Alternative Scenario)

Each block shows category totals, with flows representing tonnage

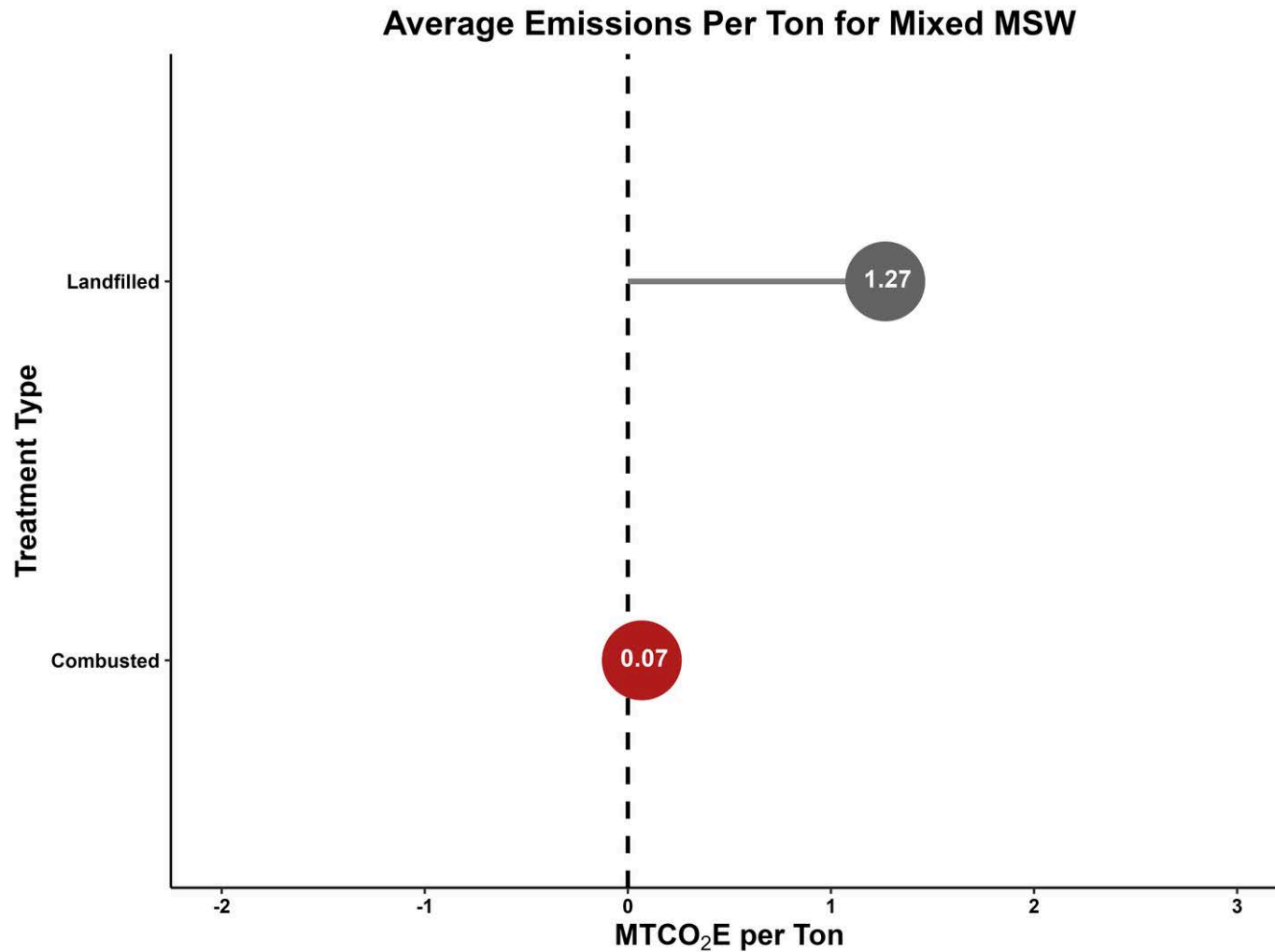


A significant proportion of mixed plastics (typically non-recyclable) are sent for combustion due to lack of alternative treatment methods.

Composting is present across locations but in smaller volumes, mainly limited by feedstock purity and operational capacity

Note: Most of the MSW ends up in landfills even after intervention due to high proportion of wet waste, making it unsuitable for combustion/recycling implying that - "Source segregation is essential"

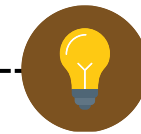
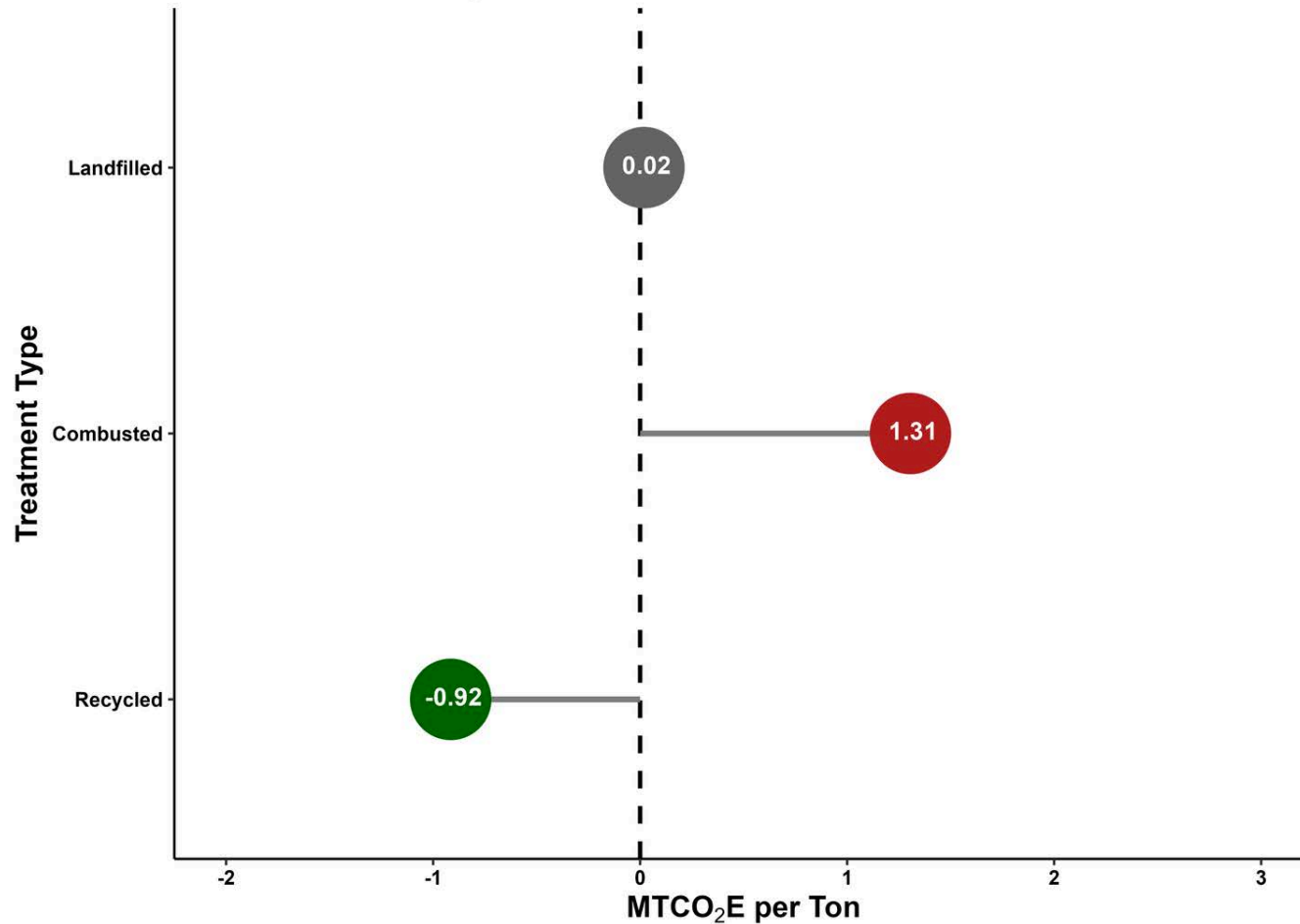
Mixed MSW Generates Higher Emissions in Landfills than in Combustion



Note: Mixed MSW typically contains a high proportion of biodegradable materials which produce the largest positive emissions when landfilled (newspaper being a notable exception).

Evaluating Treatment Pathways for Mixed Plastics

Average Emissions Per Ton for Mixed Plastics



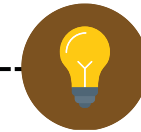
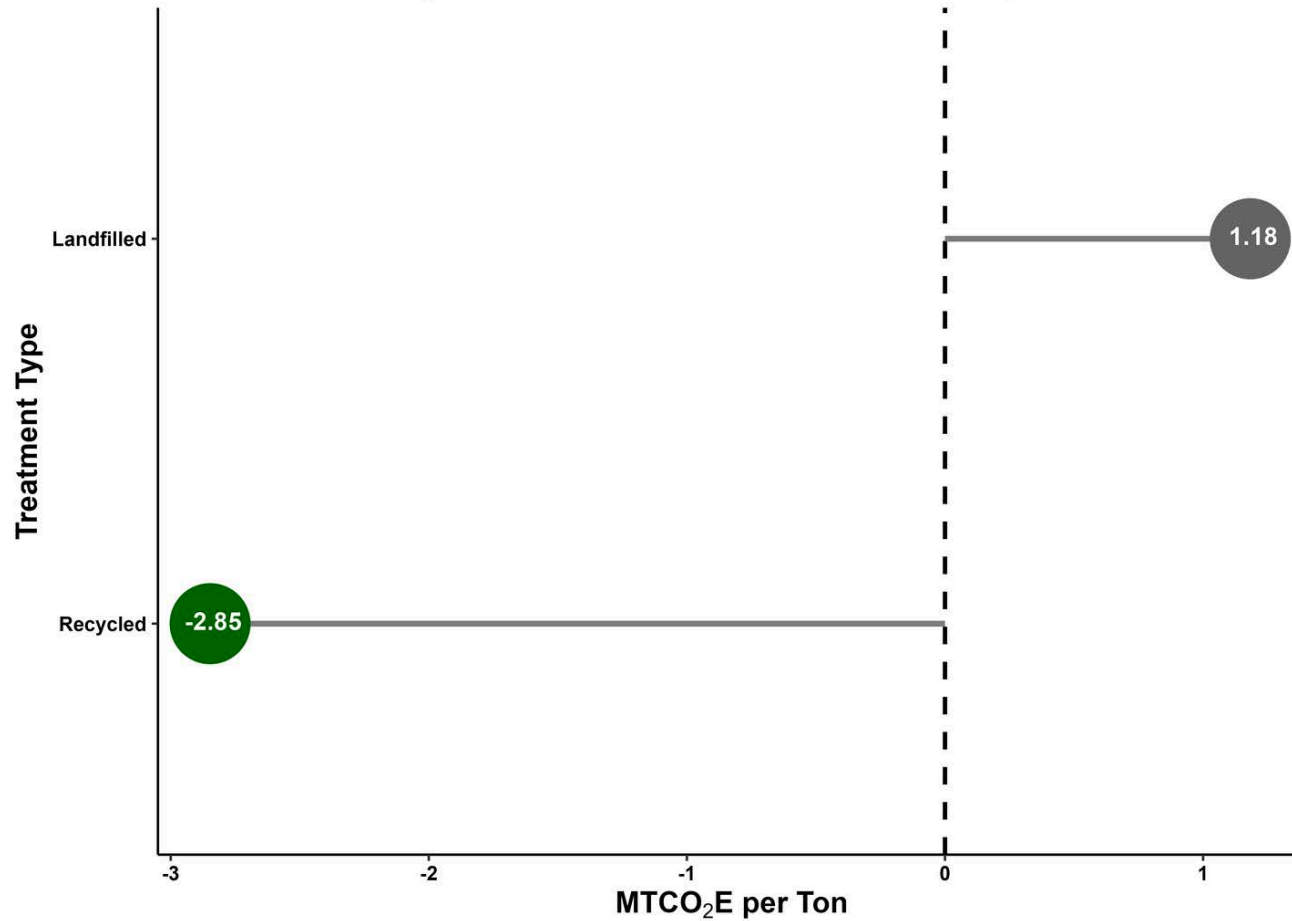
A high proportion of non-recyclables typically goes for combustion (co-processing), leading to a net increase in emissions, however, other economic impacts of this process are yet to be evaluated.

Or,

Scientific landfilling may be an alternative for the combustion of plastics if minimizing carbon emissions is the primary concern.

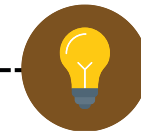
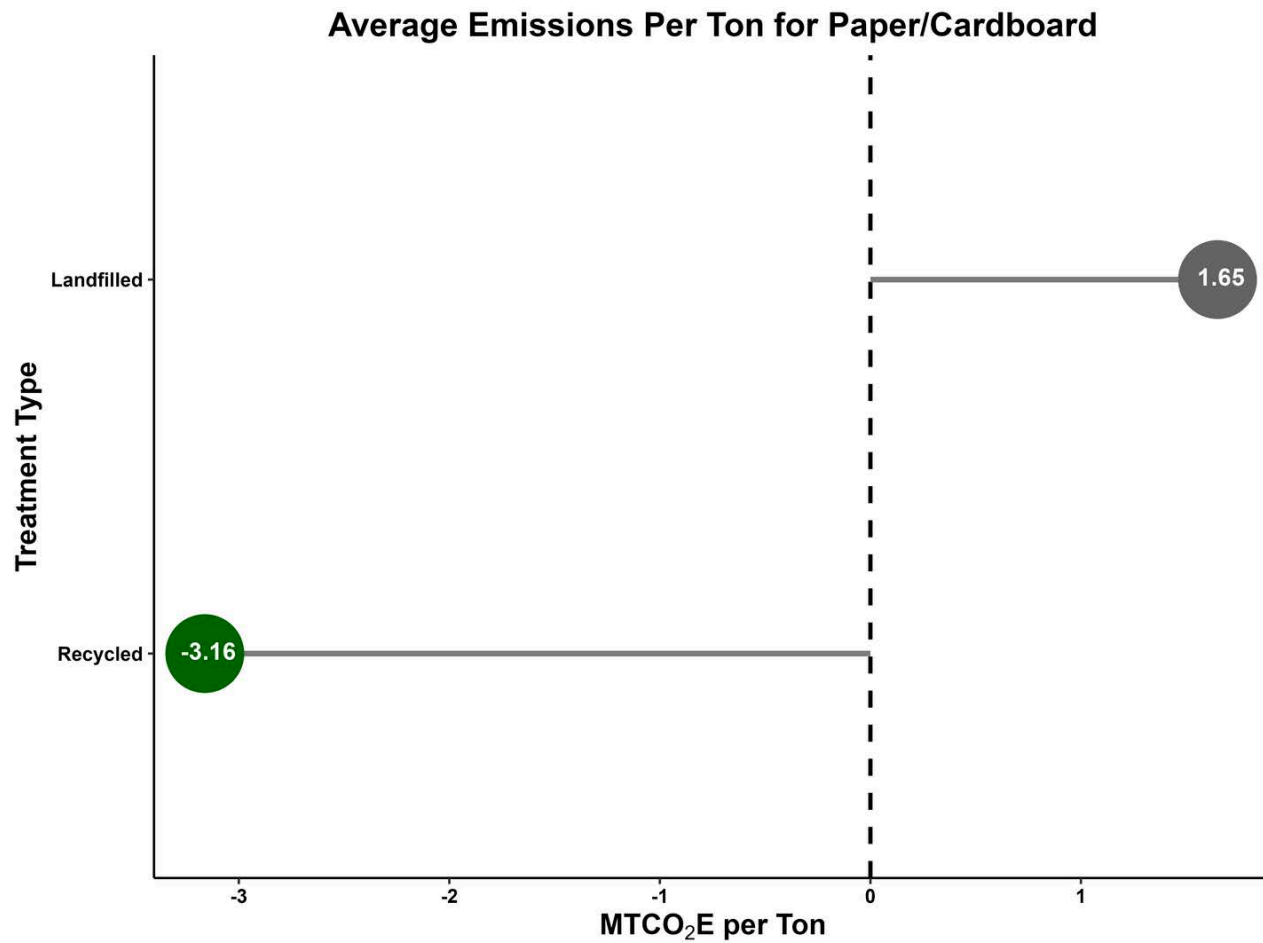
When Recycling is Most Effective

Average Emissions Per Ton for Mixed Recyclables



Mixed recyclables shows large emissions reduction between the baseline treatment (landfilling) and alternative treatment (recycling) among major waste categories.

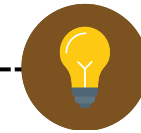
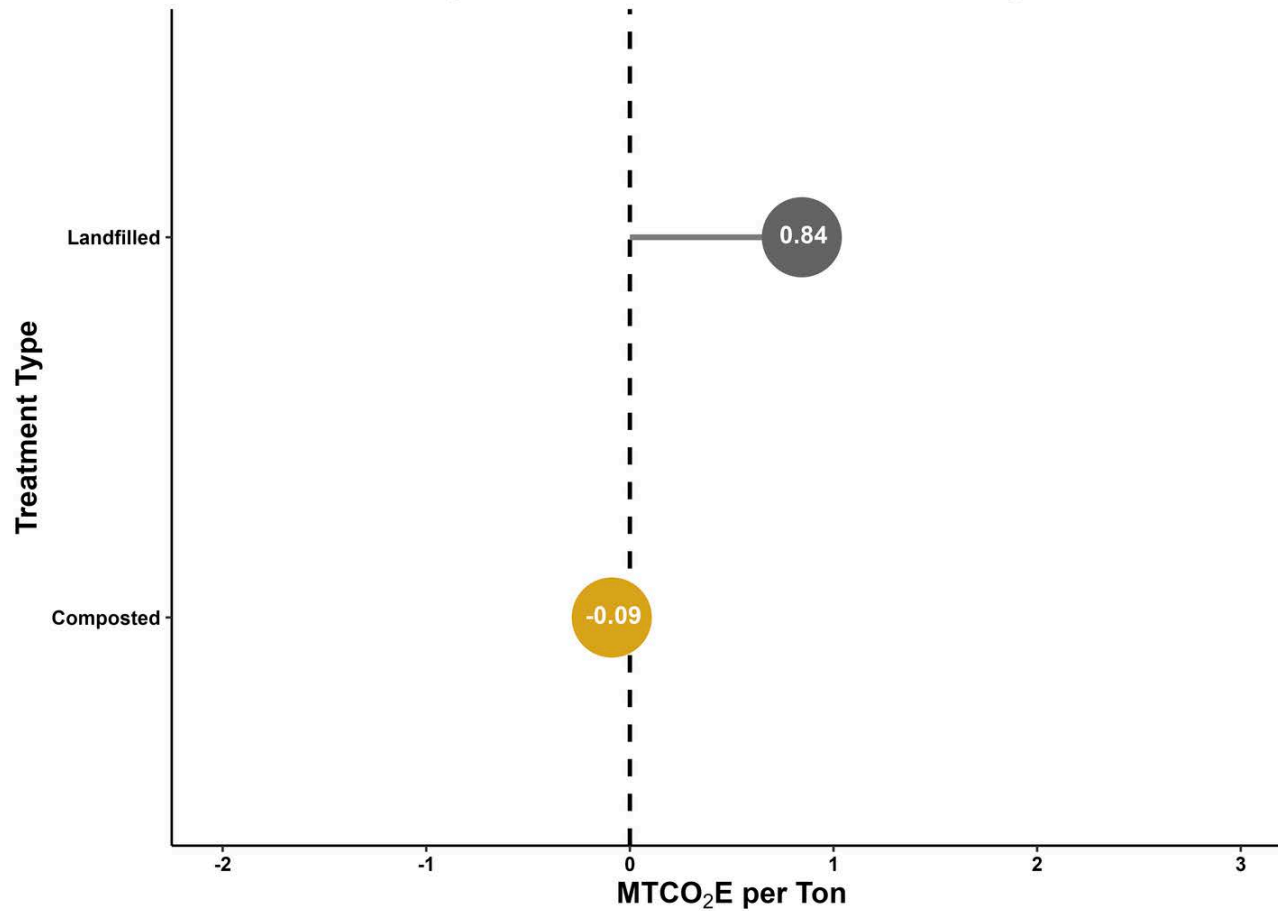
When Recycling is Most Effective (Cont.)



Paper also shows similarly large emissions reduction between the baseline treatment (landfilling) and alternative treatment (recycling) among major waste categories.

Evaluating Treatment Pathways for Mixed Organics

Average Emissions Per Ton for Mixed Organics

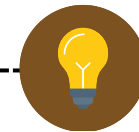
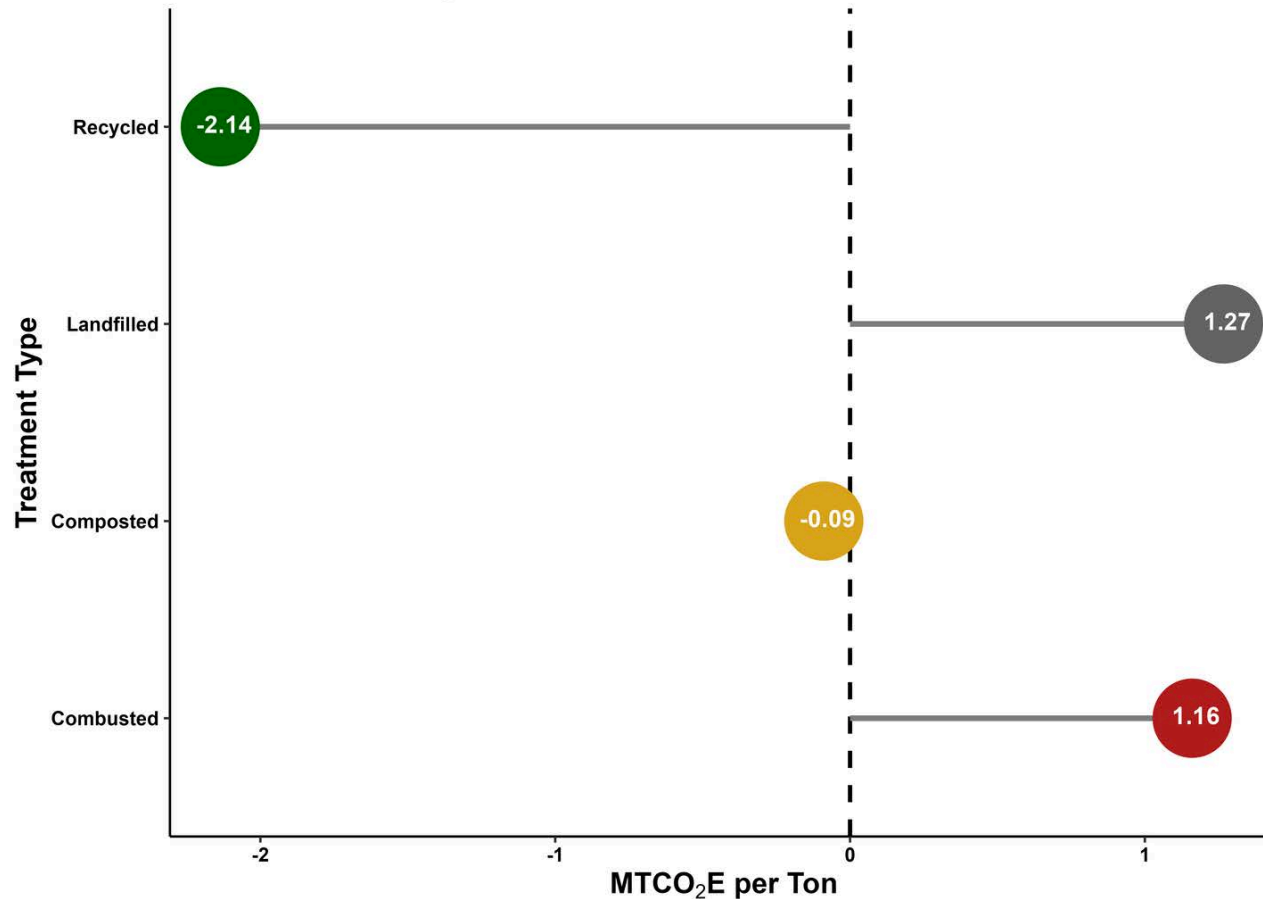


Landfilling organic waste produces GHGs like methane and Carbon dioxide due to anaerobic decomposition.

Whereas, Composting minimizes emissions through aerobic decomposition and can store carbon in soil, making it more climate friendly alternative.

Comparison of Emissions from Alternative Treatments

Average Emissions Per Ton across All Materials



Recycling remains the most effective method in terms of net emissions reduced per ton, as WARM accounts for reduced GHG emissions from producing an equivalent amount of material from virgin inputs.

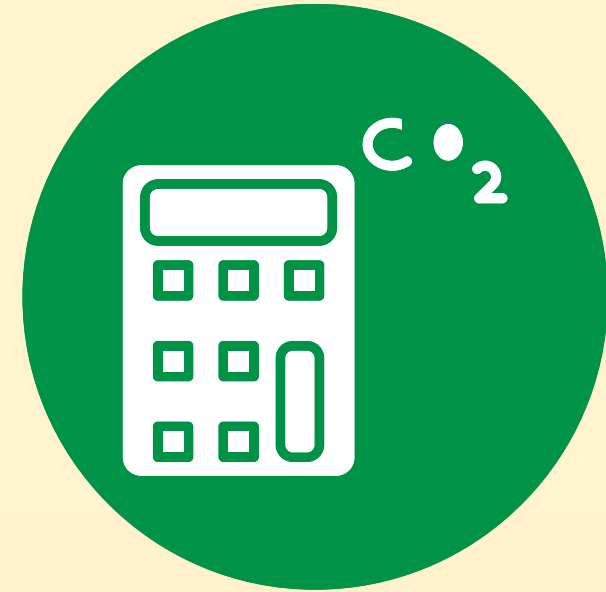
Landfilling & Combustion result in net positive emissions per ton, however, degree of emissions varies depending on the material type.

Combustion is often the only viable treatment option for most of the non-recyclables materials, further resulting in high net positive emissions.

Advantages

The Waste Reduction Model (WARM) was selected for this analysis, as:

- It is a credible and widely recognised tool which is developed by the U.S. Environmental Protection Agency (EPA) under Global Methane Initiative with the support of Climate and Clean Air Coalition; hence, results are robust and scientific.
- It has standard emission factors for bringing comparability across different waste management scenarios.
- It is open source, freely available, simple and user friendly (MS Excel based).
- It accounts total emissions from a life cycle assessment perspective enabling recording of direct and indirect mitigation potential benefits.



Assumptions

- Dumpsites were assumed as equivalent to landfills with no landfill gas recovery, no flaring and worst-case scenario.
- Default WARM factors assume recycling substitutes the need to produce fresh (virgin) products from raw material.
- To avoid electricity-related emissions, the national average was chosen by selecting West Virginia as a proxy region which is dominated by coal that closely resembles the electricity mix in India.
- For moisture conditions and associated bulk MSW decay rate (k), wet conditions (k=0.06) having greater than 40 inches of precipitation per year were selected as representative conditions at the landfill. Default values for cured digestate resulting from anaerobic digester before land application was assumed for wet digestion.
- Default values were assumed for type of vehicles, different fuels, idling time, mileage and distances.

Limitations in Indian Context

- It is a U.S. based tool, which may not truly reflect the Indian scenario.
- WARM considers mixed plastics as 40% HDPE & 60% PET; whereas in our case mixed plastics contain majorly the low value waste/mixed plastics (SLPs and MLPs) with negligible fraction of PET and HDPE.
- Certain types of waste like sanitary waste, hazardous waste, inert waste are missing. Also, material like LLDPE falls under the broader category of polyethylene but has no defined resin identification code to know and label its recycling potential.
- Alternative interventions like co-processing, open burning, home composting or in-vessel composting, mixed waste stream and informal recycling are not fully accounted for.
- It does not truly reflect different processes and equipment used in Material Recovery Facilities, climatic & geographical conditions and dumpsites etc. existing at national and regional level.
- Reporting GHG emissions through these reduced emissions brought by alternative initiatives include waste management components of state and local climate change action plans which can assume efficiencies that may differ from on-ground reality and results obtained can be indicative not definitive unless localised emission factors are modelled.

Roadmap to Accurate Emissions Measurement

- India-specific emission factors for electricity, transportation, landfilling, recycling, and composting should be developed.
- Development of India-specific material life cycle assessment (LCA) methodologies is important to gauge effectiveness of waste management practices
- The tool should incorporate India-specific material composition and include mapping of certain materials, such as sanitary waste and non-recyclable materials
- Local context in relation to geography, climate and waste management practices should be considered in emissions calculations



Ultimately, we are seeking an Indian equivalent of the WARM tool!

About Us

Waste Warriors Society, a non-profit organisation, operates as a catalyst for systemic change to address the pressing waste management crisis in the Indian Himalayan Region (IHR). Situated amid the stunning yet challenging landscapes of Uttarakhand and Himachal Pradesh, our team of 190+ Warriors is dedicated to developing effective waste management solutions in urban and rural areas, with a particular emphasis on eco-sensitive and tourist regions. Our mission spans climate change, biodiversity habitat conservation, and creation of dignified livelihoods.

The integrated approach involves collaborating with government bodies and encompasses a Zero Waste Program, Research and Advocacy, Community Activation, and Livelihood Development. Our project locations, including Kasauli, Dharamshala, Bir-Billing, Manali, Kempton, Dehradun, Sahasradhara, Uttarkashi and Corbett Tiger Reserve, are strategically chosen to have a significant impact on the IHR's diverse ecosystem.

The IHR comprises snow-covered peaks and glaciers feeding perennial rivers which provide water to a third of India's population and hosts over 10,000 plants, 300 mammals, 977 birds, 281 herpetofauna, 269 fishes, several species of invertebrates and microorganisms, many of which have global conservation significance. The ecosystem faces exponential degradation due to improper waste disposal practices, impacting high-altitude wildlife food chain, soil health and rivers, thus reducing agricultural yield and water quality.

Waste Warriors actively combats this challenge by promoting source segregation, bridging infrastructure gaps, and raising awareness through Information, Education, and Communication (IEC) initiatives. Our work contributes to waste mitigation and aids in conserving vulnerable and endangered species, maintaining the delicate balance of the IHR ecosystems. Waste Warriors seeks to usher in a sustainable and harmonious coexistence between communities and the environment through these efforts.



Call for Collaboration

We invite collaborations from climate experts, researchers and ecosystem partners to co-develop a robust, India specific tool to estimate reduced emissions from solid waste management. Let's co-create robust emissions estimation framework for waste sector.

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