www.rsd.tfbor.bg.ac.rs

Recycling and Sustainable Development

RSD

Online ISSN 2560-3132
Print ISSN 1820-7480

Transitioning to Sustainable Waste Management in Selected Western Balkan Countries: Climate Benefits of Integrated Waste Management Interventions

Dejan Ubavin #, Dušan Milovanović, Miodrag Živančev, Goran Vujić

University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

ARTICLE INFO

Received 31 August 2026
Accepted 02 November 2026

Scientific article

Keywords:
Waste Management
Greenhouse Gas Emission
Composting
Anaerobic Digestion

Citation: Ubavin D., Milovanović D., Živančev M., Vujić G., Transitioning to Sustainable Waste Management in Selected Western Balkan Countries: Climate Benefits of Integrated Waste Management Interventions, Recycling and Sustainable Development, 19 (2), 2026, 49-67.

https://doi.org/10.30544/RSD120

Copyright: © 2025 CC BY 4.0 by Authors
Creative Commons License

ABSTRACT

Municipal solid waste management in Southeast Europe relies heavily on uncontrolled landfills, resulting in substantial greenhouse gas emissions, particularly methane. To address this critical environmental challenge, this study evaluates the potential for greenhouse gas emission reductions in municipal solid waste systems across Serbia, Bosnia and Herzegovina, North Macedonia, and Montenegro. Employing a quantitative, scenario-based approach using the Solid Waste Emissions Estimation Tool (SWEET), the research models emissions from 2026 to 2050. The analysis compares a Business-As-Usual usual baseline with three alternative interventions: small-scale composting, large-scale composting, and anaerobic digestion, with all alternatives assuming active landfill gas extraction and the upgrading or closure of open dumpsites. The findings indicate that combining landfill improvements (gas extraction and dumpsite upgrading) with large-scale composting offers the highest mitigation potential, with a regional technical mitigation potential exceeding 33.5 million metric tons of CO_2 equivalent by 2050, representing a decrease of more than 35 % compared with baseline projections. Small scale composting and anaerobic digestion also provide significant climate benefits, each capable of avoiding nearly 16.8 million metric tons of CO_2 equivalent regionally. The study concludes that transitioning to organic waste treatment technologies is highly effective for achieving national climate goals and aligning with European Union environmental standards. Nevertheless, implementing these sustainable systems requires overcoming major structural barriers, most notably establishing source-separated biowaste collection networks, securing substantial financial investments, and enhancing the institutional capacities of local governments.

1. Introduction

Municipal solid waste (MSW) management has become a critical environmental challenge worldwide due to its growing contribution to environmental degradation and greenhouse gas (GHG) emissions. Rapid urbanization, economic development, and changing consumption patterns have resulted in significant increases in waste generation across many regions, including Southeast Europe. According to World Bank estimates, total annual solid waste generation worldwide was approximately 2.56 billion tonnes in 2022 and is projected to reach 3.86 billion tonnes by 2050, representing an increase of nearly 50 % (World Bank,

Corresponding author: dejanubavin@uns.ac.rs

2025). This trend is particularly pronounced in low- and middle-income countries, where it is estimated that more than 90 % of waste is improperly disposed of. Inadequate waste management systems, such as those in Western Balkans countries where landfill disposal rates range between 80 % and 90 % of total municipal waste generated without proper environmental controls are particularly concerning.

The widespread reliance on unsanitary, uncontrolled dumpsites poses a critical challenge, as the absence of gas capture, leachate treatment, and systematic monitoring drives unmitigated methane emissions and severe environmental degradation (SEPA, 2022). Unsanitary and uncontrolled landfills are major anthropogenic sources of fugitive methane (CH_4) emissions, generated primarily through the anaerobic digestion of organic matter in the absence of gas capture systems (Kaza et al., 2018). Because methane has a Global Warming Potential (GWP) roughly 28 to 36 times higher than that of carbon dioxide (CO_2) over a 100-year timescale, and upwards of 80 times higher over a 20-year horizon, it significantly accelerates atmospheric warming in the near term (IPCC, 2021; UNEP and CCAC, 2021). Consequently, transitioning from open dumping to controlled sanitary landfills equipped with gas-to-energy recovery, alongside diverting biodegradable waste through composting and anaerobic digestion, represents one of the most cost-effective and rapid mitigation opportunities within national climate strategies and Nationally Determined Contributions (UNEP, 2024; World Bank, 2025).

Globally, the waste sector contributes approximately 3–5 % of total anthropogenic GHG emissions, with methane emissions from landfills representing the dominant share (IPCC, 2021; Bogner et al., 2008; World Bank, 2025). These emissions result primarily from the anaerobic decomposition of biodegradable organic waste disposed of in landfills. In regions where waste management systems are underdeveloped and recycling, composting, and energy recovery remain limited, the climate impact of the sector becomes particularly significant. In addition to climate implications, poorly managed waste systems contribute to soil and water contamination, air pollution, public health risks, and biodiversity loss (Kaza et al., 2018).

Countries in Southeast Europe, including Serbia, Montenegro, North Macedonia, and Bosnia and Herzegovina, face substantial challenges in developing sustainable waste management systems aligned with European Union environmental standards (REC, 2021). Although progress has been made in recent years through legislative reforms and regional waste management initiatives, landfilling remains the dominant waste treatment method across the region. Many disposal sites operate as uncontrolled or insufficiently engineered landfills that often lack landfill gas collection systems, leachate treatment, and adequate environmental monitoring. As a result, the waste sector remains a notable contributor to national GHG emissions in these countries (UNFCCC, 2022, 2023).

Serbia's municipal solid waste sector continues to be characterized by high landfill dependency (exceeding 80 %), low rates of household-level sorting, and a sharp disparity compared to EU recycling targets (European Commission, 2023a; SEPA, 2024). A dominant share of municipal waste is directed to active sanitary facilities and numerous non-compliant dumpsites that operate without landfill gas capture, generating substantial methane releases that elevate the sector's national carbon footprint (Stanisavljević et al., 2012; SEPA, 2024).

Although research has consistently highlighted the climate benefits of capturing landfill gas, diverting organic waste, and adopting thermal and biological treatments (Stanisavljević et al., 2012), widespread modernization has historically been impeded by financial, institutional, and technical constraints (Vujić et al., 2017). Recent structural interventions, including strategic regional landfill development and the commissioning of waste-to-energy infrastructure, represent initial steps toward addressing these systemic bottlenecks (SEPA, 2024; World Bank, 2025).

Similar systemic challenges are evident throughout the Western Balkans, where municipal waste management frameworks diverge significantly from EU circular economy benchmarks. Montenegro continues to struggle with high landfill dependency and limited source-separation infrastructure, resulting in low recycling yields (European Commission, 2023b, 2023c). In North Macedonia, uneven collection networks, particularly in peripheral and rural municipalities, alongside the prevalence of substandard dumpsites, sustain high fugitive methane emissions and localized soil and water contamination (UNEP, 2024). In Bosnia and Herzegovina, administrative decentralization and complex jurisdictional overlaps between entities and cantons pose acute institutional barriers, delaying the rollout of regional sanitary landfills, integrated waste strategies, and target-driven climate initiatives (World Bank, 2025). The transition toward sustainable waste management systems in these countries therefore represents an important opportunity for reducing GHG emissions while simultaneously addressing broader environmental and socioeconomic challenges. Measures such as increasing recycling rates, implementing separate collection systems for biodegradable waste, expanding composting and anaerobic digestion, improving landfill management, and introducing landfill gas recovery technologies could significantly reduce emissions from the sector. Moreover, these measures align with the principles of the circular economy, which emphasize resource efficiency, waste prevention, and the recovery of materials and energy (European Parliament and Council of the European Union, 2008).

Given the growing importance of climate mitigation policies and the ongoing alignment of Southeast

European countries with European environmental frameworks, identifying effective strategies for reducing GHG emissions in the waste sector is particularly relevant. This paper therefore examines the potential for emission reduction within municipal waste management systems in Serbia, Montenegro, North Macedonia, and Bosnia and Herzegovina, with a focus on technological, organizational, and policy measures that can contribute to achieving climate and environmental objectives in the region.

The main contribution of this study is the harmonized assessment of greenhouse gas emission reduction potentials across selected Western Balkan countries using a consistent set of waste management improvement scenarios over the period 2026–2050. By applying a common assessment framework, the study enables comparative analysis of country-specific mitigation potentials and aggregation of the results at the regional level, while accounting for the combined effects of organic waste diversion, landfill gas extraction, and dumpsite upgrading. This approach provides a consistent basis for identifying national and regional opportunities for climate change mitigation through improved waste management

2. Methods

2.1. Study design and analytical framework

Several methodological approaches can be used to estimate greenhouse gas (GHG) emissions from municipal solid waste management, including Life Cycle Assessment (LCA), the IPCC Guidelines for National Greenhouse Gas Inventories, and the Solid Waste Emissions Estimation Tool (SWEET).

LCA is widely used to assess the environmental impacts of municipal solid waste management across the entire life cycle, including upstream and downstream processes, which makes it useful for comparing alternative management scenarios and identifying environmental trade-offs (Laurent et al., 2014a, 2014b; Yadav and Samadder, 2018; Khandelwal et al., 2019; Liem et al., 2023). However, its results can be highly sensitive to system boundaries, inventory data quality, allocation choices, and other methodological assumptions (Christensen et al., 2009; Vergara et al., 2011; Menikpura et al., 2013; Laurent et al., 2014a, 2014b). In contrast, the Intergovernmental Panel on Climate Change (IPCC) Guidelines provide standardized methodological guidance for national greenhouse gas inventory reporting and are therefore valuable for ensuring consistency and comparability across countries, but they are less suited to detailed local scenario analysis and may not fully capture the specific conditions of individual waste management systems (IPCC, 2019). SWEET is a tool developed under the Global Methane Initiative (GMI). It is based on IPCC methodologies and is designed for practical use at the project, source, and municipality level. It allows users to establish a baseline, compare alternative waste management scenarios, and estimate potential emission reductions from improved waste management strategies, including dumpsite closure, landfill gas management, waste diversion, composting and anaerobic digestion (CCAC, 2020; CCAC, 2021; Milovanović et al., 2021; Stege et al., 2022; GMI, 2025). Its main limitation is that, compared with a full LCA, it provides a more focused emissions estimate and does not cover the broader range of environmental impacts associated with waste management (Zhao et al., 2009; GMI, 2025).

While all three approaches aim to quantify emissions associated with waste management activities, they serve different purposes and operate at different analytical scales. LCA provides a comprehensive framework for evaluating environmental impacts across the entire life cycle of waste management systems, including upstream and downstream processes. In contrast, the IPCC Guidelines are mainly intended for standardized inventory reporting, focusing on direct emissions from waste treatment and disposal. SWEET is particularly suitable for local governments and practitioners because it supports scenario-based assessment of emission reduction potential under alternative municipal solid waste management strategies.

This study employs a quantitative scenario-based analytical approach to assess potential greenhouse gas (GHG) emission reductions achievable through improvements in municipal solid waste (MSW) management across four non-EU Southeast European (SEE) countries: Serbia, Bosnia and Herzegovina, North Macedonia, and Montenegro. The analysis covers the period from 2026 to 2050, with 2025 serving as the baseline reference year. Emissions are modeled under a Business-As-Usual (BAU) scenario and compared with three alternative intervention scenarios, enabling a systematic quantification of the environmental benefits associated with transitioning from predominantly landfill-based disposal to organic waste treatment technologies.

The study is structured around two main components: (1) a contextual overview of the current waste management situation in each country, drawing on national legislative frameworks, statistical reports, and planning documents; and (2) an environmental modeling component that quantifies GHG emission reductions under the defined scenarios. Country-level data on demographics, waste generation, waste composition, and existing waste treatment infrastructure were compiled

from national statistics agencies, environmental protection agencies, and strategic planning documents for each country.

2.2. Emissions Modeling Tool: SWEET

Greenhouse gas emissions were estimated using the Solid Waste Emissions Estimation Tool (GMI, 2024), developed by the United States Environmental Protection Agency (US EPA) on behalf of the Global Methane Initiative (GMI). SWEET is an Excel-based, first-order modeling tool designed to quantify emissions of methane (CH_4), black carbon, carbon dioxide (CO_2), nitrous oxide (N_2O), particulate matter (PM_{10}/$PM_{2.5}$), nitrogen oxides (NO_x), and sulfur oxides (SO_x) from municipal solid waste sector sources at the city or country level. Emissions are expressed as metric tons of carbon dioxide equivalent (CO_2e).

SWEET estimates annual emissions from the following MSW sector sources:

- waste collection and transportation;
- open burning of waste and landfill fires at dumpsites;
- landfills and dumpsites (including sanitary landfills, controlled landfills, and open dumpsites;
- waste handling equipment (e.g., bulldozers, forklifts);
- organic waste management facilities (e.g., composting plants, anaerobic digestion facilities); and
- waste combustion and waste-to-energy installation.

The tool is designed to support municipal solid waste management decision-making by allowing users to establish a baseline emissions scenario and compare it with up to four alternative intervention scenarios. It also enables tracking of progress over time and estimating contributions to broader city or national emission reduction targets. To ensure transparency and reproducibility, the key SWEET model parameters and assumptions used in the emission calculations are summarized in Table 1, including landfill methane generation, methane collection efficiency and oxidation and global warming potential (GWP) factors. Emission factors for composting and anaerobic digestion were applied as SWEET default values, which are derived from the US EPA Waste Reduction Model (WARM) (GMI, 2024).

2.3. Country-level data inputs

Country-level input data were compiled for each of the four study countries and entered into the SWEET model. Data categories included demographic parameters (population covered by waste collection services), climatic conditions (mean annual temperature and annual precipitation), waste generation rates (kilograms per capita per day and projected annual growth), waste composition (proportions of organic waste, recyclables, and other fractions), and quantities of waste currently treated and disposed of (landfilling by landfill type, composting, recycling, waste-to-energy). Three types of waste disposal facilities were characterized in the model: sanitary landfills, controlled (unsanitary) landfills, and open dumpsites.

Table 1
Key SWEET model parameters and assumptions used in the emission calculations

Parameter/ Assumption	**Value used in SWEET**	**Unit**
SWEET version	Version: 4.0.5	March 2024
Global warming potential of methane (GWP_{100})	28	kg CO_2e/kg CH_4
Global warming potential of nitrous oxide (GWP_{100})	298	kg CO_2e/kg N_2O
Global warming potential of black carbon (GWP_{100})	900	kg CO_2e/kg BC
Climate zone classification	4 – Moderately Dry	Category
Methane correction factor (MCF) – sanitary landfills	1.0	Dimensionless
Methane correction factor (MCF) – controlled dumpsites	0.8	Dimensionless
Methane generation potential (L_0) – food waste	70	m^3 CH_4/tonne
Methane generation potential (L_0) – green waste	93	m^3 CH_4/tonne
Methane generation potential (L_0) – paper and cardboard	186	m^3 CH_4/tonne
Methane destruction efficiency of combustion devices	98	%
Methane collection efficiency – baseline / alternative scenarios (sanitary landfills)	0 / 48	%
Methane oxidation factor – sanitary landfills without gas collection	10	%

The quantities of waste deposited at sanitary and controlled landfills were obtained from national statistics databases. Waste disposed of at open dumpsites was estimated based on the proportion of the population not covered by organized waste collection services and national per capita waste generation rates. The number and type of waste collection vehicles and landfill machinery were estimated from data for representative municipalities in each country. A summary of the key input parameters used in the SWEET model for each country is provided in Table 2.

2.4. Scenario definition

Three alternative waste management scenarios were defined and modeled for each country, in addition to the Business-As-Usual (BAU) scenario. The scenarios were developed to reflect varying levels of organic waste diversion from landfills, achieved through the implementation of small-scale composting, large-scale composting, or anaerobic digestion (AD) technology. All three alternative scenarios additionally assumed (1) the installation of active landfill gas extraction systems at sanitary landfills beginning in 2026 and (2) the closure or upgrading of open dumpsites to controlled landfill standards by 2026.

Assuming simultaneous, full-scale implementation starting in 2026 across all four countries is a deliberate methodological choice intended to establish a standardized comparative baseline.

Given the severe institutional weaknesses, financial constraints, and administrative complexities characterizing the Western Balkans, forecasting exact national rollout schedules or phased ramp-up rates would be highly speculative. Therefore, the modeled scenarios are intended to quantify and compare the maximum technical mitigation potential of different waste management pathways relative to BAU, rather than serve as realistic temporal implementation forecasts. The three intervention scenarios are defined as follows:

Scenario 1 - Small-Scale Composting (Composting-SS): This scenario reflects a minimum diversion rate of 20 % of the biowaste fraction. It is representative of collection schemes that focus primarily on large waste producers and provide only limited household participation, such as bring-scheme drop-off points. The composting infrastructure modeled is smaller and decentralized and is assumed to become operational in 2026.

Scenario 2 - Large-Scale Composting (Composting-LS): This scenario assumes a maximum diversion rate of 70 % of the biowaste fraction. It requires intensive, large-scale source-separation schemes covering both commercial and household sectors. A central large-scale composting facility is assumed to commence operations in 2026.

Scenario 3 - Anaerobic Digestion (AD): This scenario also assumes a maximum diversion rate of 70 % of the biowaste fraction, equivalent in diversion scale to Scenario 2. However, rather than aerobic composting, the diverted organic waste is treated through anaerobic digestion, which produces biogas as an energy co-product (De Baere and Mattheeuws, 2012). An AD plant with the corresponding capacity is assumed to become operational in 2026.

The specific treatment capacities modeled under each scenario for each country are summarized in Table 3.

Model outputs are reported as annual emission reductions relative to the BAU scenario, expressed in metric tons of CO_2 equivalent (CO_2e). In addition to CO_2e, methane (CH_4) emission reductions are reported separately in metric tons of CO_2e, as methane is the dominant

Table 2
Summary of key SWEET model input parameters by country

Parameter	Serbia	Bosnia and Herzegovina	North Macedonia	Montenegro
Population covered by waste collection	5,869,304	2,504,580	1,277,460	529,912
Mean annual temperature (°C)	11.0	11.0	11.5	11.7
Annual precipitation (mm/year)	896	1,028	619	1,250
Waste generation (kg/capita/day)	1.26	1.05	1.35	1.45
Annual growth rate (%)	1 %	1 %	1%	1 %
Organic waste fraction (%)	43.0 %	42.1 %	43.0 %	43.2 %
Recyclables fraction (%)	39.6 %	44.5 %	39.4 %	42.0 %
Other fractions (%)	17.4 %	13.4 %	17.6 %	14.8 %

Table 3
Organic waste treatment capacities modeled under each scenario, by country

Country	Scenario 1 – SS Composting (t/year)	Scenario 2 – LS Composting (t/year)	Scenario 3 – Anaerobic Digestion (t/year)
Serbia	230,000	800,000	800,000
Bosnia and Herzegovina	75,000	250,000	250,000
North Macedonia	55,000	185,000	185,000
Montenegro	20,000	80,000	80,000

contributor to GHG emissions from landfilling organic waste. Particulate matter reductions, reported as $PM_{2.5}$ and PM_{10}, are also presented, as these pollutants result from eliminating open waste burning at upgraded dumpsites. Cumulative totals for the analysis period (2026–2050) are provided for each emission category and scenario, both at the individual country level and at the regional (SEE) level.

3. Results and discussion

This chapter presents the results of SWEET model analyses for each of the four study countries and for the Southeast European (SEE) region as a whole. Results are organized by country and include projected emission reductions in CO_2e, CH_4, and particulate matter ($PM_{2.5}$ and PM_{10}) under each of the three defined alternative scenarios compared to the Business-As-Usual (BAU) scenario, for the period 2026 to 2050. When interpreting the tabulated results, it should be noted that all total emission reductions reported relative to the BAU scenario reflect the combined effect of the common landfill improvement measures (landfill gas extraction and dumpsite upgrading) and the respective organic waste diversion technology, whereas differences among Scenarios 1, 2, and 3 isolate the specific impact of organic waste treatment scale and technology.

3.1. Serbia

Under the BAU scenario, total GHG emissions from Serbia's municipal solid waste sector are projected to increase continuously through 2050, driven by rising waste generation rates and the continued predominance of landfill disposal.

Scenario 1 (Composting-SS), which combines baseline landfill improvements with the diversion of 230,000 t/year of organic waste to small-scale composting beginning in 2026, results in a modest reduction in total emissions relative to BAU. Total emissions under this scenario are projected to decline by approximately 5 % between 2026 and 2050. However, when compared to the BAU scenario, total emissions in 2050 would be approximately 22 % lower. Over the full analysis period, cumulative CO_2e emission reductions amount to 9,682,629 metric tons (Table 4).

Scenario 2 (Composting-LS), which diverts 800,000 t/year of organic waste to large-scale composting, yields the most substantial reductions among the three scenarios. Total emissions are projected to decrease by approximately 35.8 % between 2026 and 2050, and by approximately 47.4 % compared to the BAU scenario. Cumulative CO_2e reductions over the analysis period total 19,626,958 metric tons (Table 4). Cumulative CH_4 reductions amount to 18,825,290 metric tons of CO_2e (Table 5).

Scenario 3 (Anaerobic Digestion), which processes the same quantity of organic waste as Scenario 2 (800,000 t/year) using AD technology, yields substantially lower emission reductions than large-scale composting, broadly comparable to those of Scenario 1. Total emissions under Scenario 3 are projected to decline by approximately 5 % between 2026 and 2050, and by approximately 21.9 % relative to BAU. Cumulative CO_2e reductions amount to 10,584,695 metric tons (Table 4). Notably, Scenario 3 achieves the largest particulate matter reductions due to the elimination of open dumpsite burning, with cumulative $PM_{2.5}$ and PM_{10} reductions of 11,713 and 11,731 metric tons, respectively.

3.2. Bosnia and Herzegovina

Under the BAU scenario, total GHG emissions from Bosnia and Herzegovina's MSW sector are projected to increase continuously through 2050.

Scenario 1 (Composting-SS), diverting 75,000 t/year to small-scale composting, results in an approximate 13.4 % increase in total emissions between 2026 and 2050, though this represents a 19.6 % reduction relative to BAU in 2050. Cumulative CO_2e reductions over the full analysis period total 3,549,711 metric tons (Table 6).

Scenario 2 (Composting-LS), diverting 250,000 t/year to large-scale composting, yields the strongest results. Total emissions are projected to decrease by approximately 14.5 % between 2026 and 2050, and by

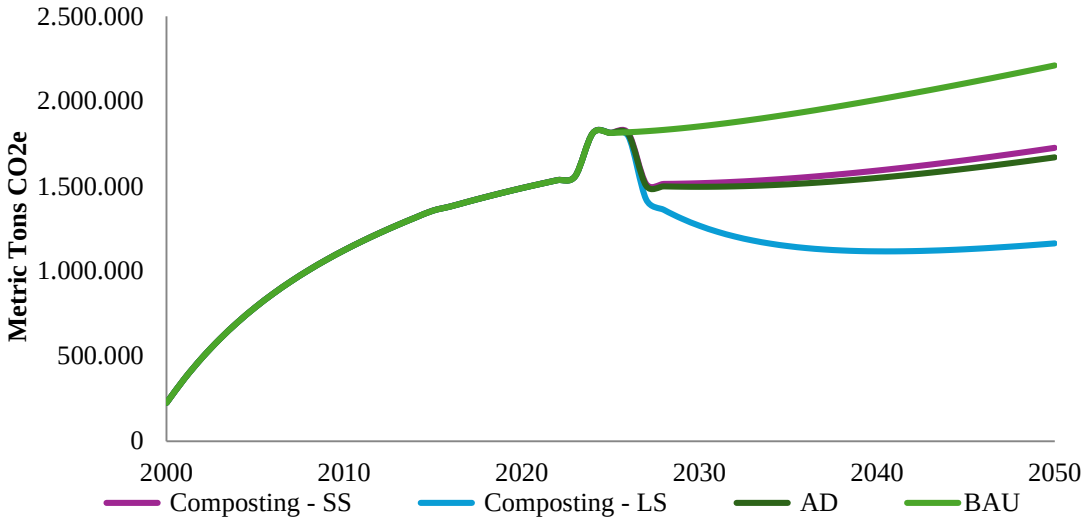


Figure 1. Overview of total emissions for three scenarios in comparison to BAU - Serbia

Table 4
Serbia - Total CO_2e emission reductions by scenario (metric tons)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	-6,593	-24,088	-12,426
2027	-311,293	-401,544	-321,153
2030	-335,336	-585,054	-355,572
2035	-378,200	-775,326	-411,381
2040	-418,114	-892,764	-460,585
2045	-453,736	-977,483	-503,217
2050	-485,988	-1,047,590	-541,081
Total avoided	**-9,682,629**	**-19,626,958**	**-10,584,695**

Table 5
Serbia – CH_4 emission reductions by scenario (metric tons of CO_2e)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	1,254	4,275	2,275
2027	-303,368	-372,892	-306,305
2030	-327,174	-555,524	-340,276
2035	-369,621	-744,282	-395,305
2040	-409,098	-860,132	-443,688
2045	-444,261	-943,185	-485,458
2050	-476,029	-1,011,541	-522,416
Total avoided	**-9,461,098**	**-18,825,290**	**-10,169,528**

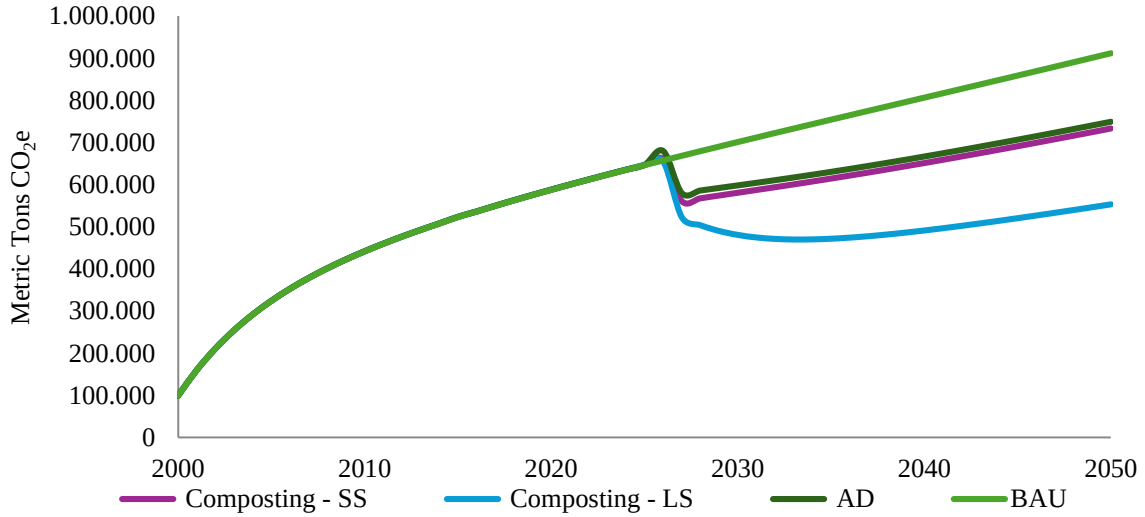


Figure 2. Overview of total emissions for three scenarios in comparison to BAU - Bosnia and Herzegovina

Table 6
Bosnia and Herzegovina - Total CO_2e emission reductions by scenario (metric tons)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	2,354	-3,164	21,785
2027	-107,829	-146,415	-89,152
2030	-120,440	-220,924	-103,467
2035	-139,863	-283,005	-124,416
2040	-155,313	-315,740	-140,390
2045	-167,768	-338,966	-152,804
2050	-178,559	-359,120	-163,227
Total avoided	**-3,549,711**	**-6,983,525**	**-3,153,619**

Table 7
Bosnia and Herzegovina – CH_4 emission reductions by scenario (metric tons of CO_2e)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	404	1,314	615
2027	-109,800	-141,891	-110,533
2030	-122,472	-216,261	-125,498
2035	-142,000	-278,103	-147,571
2040	-157,559	-310,588	-164,727
2045	-170,131	-333,552	-178,384
2050	-181,043	-353,431	-190,113
Total avoided	**-3,604,903**	**-6,856,963**	**-3,751,598**

approximately 39.4 % relative to BAU in 2050. Cumulative CO_2e reductions amount to 6,983,525 metric tons (Table 6). Cumulative CH_4 reductions total 6,856,963 metric tons of CO_2e (Table 7).

Scenario 3 (Anaerobic Digestion), treating 250,000 t/year through AD, results in a 17.9 % reduction relative to BAU in 2050, with cumulative CO_2e reductions of 3,153,619 metric tons (Table 6) and cumulative CH_4 reductions of 3,751,598 metric tons of CO_2e (Table 7).

3.3. North Macedonia

Under the BAU scenario, total GHG emissions from North Macedonia's MSW sector are projected to increase through 2050.

Scenario 1 (Composting-SS), diverting 55,000 t/year, results in a continued increase in total emissions of approximately 22.2 % between 2026 and 2050, though this is 14.8 % lower than BAU emissions in 2050. Cumulative CO_2e reductions total 1,931,525 metric tons over the analysis period (Table 8).

Scenario 2 (Composting-LS), diverting 185,000 t/year, results in a projected decrease of approximately 8.8% between 2026 and 2050, and a 36.4 % reduction relative to BAU. Cumulative CO_2e reductions total 4,308,899 metric tons (Table 8), and cumulative CH_4 reductions total 4,145,076 metric tons of CO_2e (Table 9).

Scenario 3 (Anaerobic Digestion), processing 185,000 t/year, results in a 13.1 % reduction relative to BAU. Cumulative CO_2e reductions amount to 1,641,530 metric tons (Table 8).

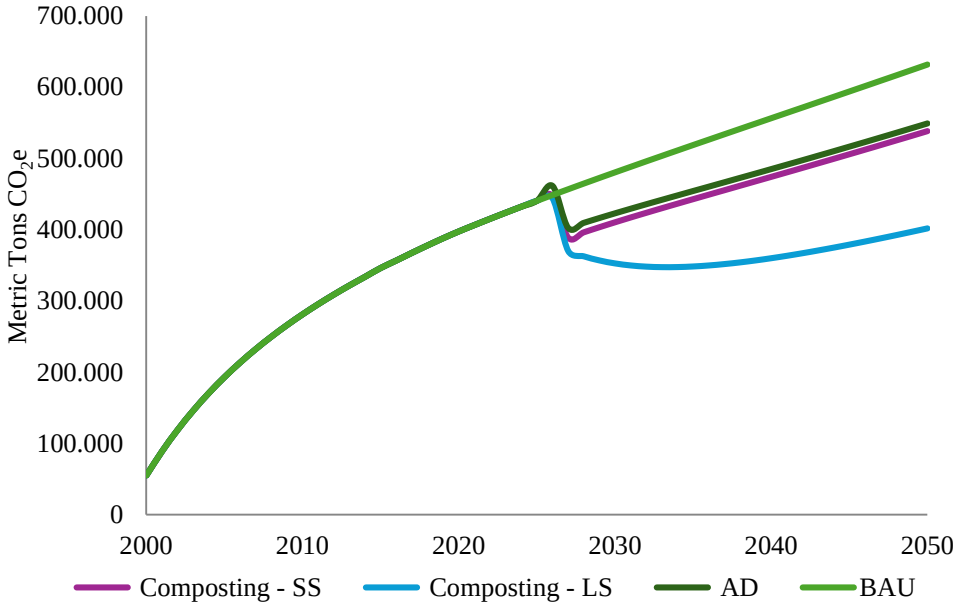


Figure 3. Overview of total emissions for three scenarios in comparison to BAU – North

Table 8
North Macedonia - Total CO_2e emission reductions by scenario (metric tons, selected years shown)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	-1,419	-4,720	12,691
2027	-67,985	-86,551	-54,251
2030	-70,143	-127,813	-57,505
2035	-76,071	-170,475	-64,576
2040	-82,388	-196,502	-71,446
2045	-88,221	-214,949	-77,448
2050	-93,536	-229,960	-82,676
Total avoided	**-1,931,525**	**-4,308,899**	**-1,641,530**

Table 9
North Macedonia – CH_4 emission reductions by scenario (metric tons of CO_2e, selected years shown)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	327	1,080	454
2027	-66,221	-80,693	-66,611
2030	-68,327	-121,777	-70,240
2035	-74,164	-164,131	-77,963
2040	-80,385	-189,835	-85,517
2045	-86,117	-207,941	-92,237
2050	-91,325	-222,595	-98,220
Total avoided	**-1,882,297**	**-4,145,076**	**-1,987,235**

3.4. Montenegro

Under the BAU scenario, total GHG emissions from Montenegro's MSW sector are projected to increase through 2050.

Scenario 1 (Composting-SS), diverting 20,000 t/year, results in a slight decrease in total emissions of approximately 3.2 % between 2026 and 2050 and a 26.9 % reduction compared to BAU in 2050. Cumulative CO_2e reductions total 1,623,464 metric tons (Table 10).

Scenario 2 (Composting-LS), diverting 80,000 t/year to large-scale composting, yields the greatest reductions. Total emissions decrease by approximately 28.7% between 2026 and 2050, and by 46.2 % relative to BAU. Cumulative CO_2e reductions total 2,657,537 metric tons (Table 10), and cumulative CH_4 reductions total 2,590,254 metric tons of CO_2e (Table 11).

Scenario 3 (Anaerobic Digestion), also treating 80,000 t/year, results in a modest increase of approximately 3 % in total emissions between 2026 and 2050, but a 22.1 % reduction relative to BAU. Cumulative CO_2e reductions total 1,363,959 metric tons (Table 10).

3.5. Southeast Europe - Regional Aggregated Results

Aggregating results across all four countries provides an estimate of the total emission reduction potential achievable through coordinated waste management improvements at the regional level.

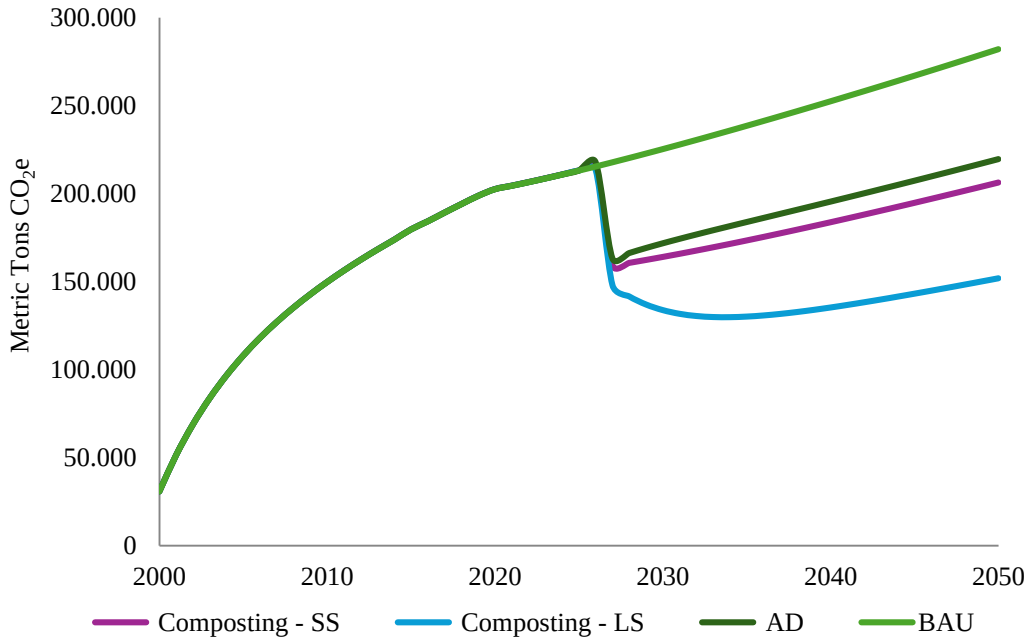


Figure 4. Overview of total emissions for three scenarios in comparison to BAU - Montenegro

Table 10
Montenegro - Total CO_2e emission reductions by scenario (metric tons, selected years shown)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	-94	-1,988	2,391
2027	-58,863	-69,875	-54,694
2030	-61,365	-91,541	-53,545
2035	-65,249	-108,467	-54,695
2040	-68,851	-117,242	-57,030
2045	-72,354	-123,931	-59,682
2050	-75,901	-130,255	-62,488
Total avoided	**-1,623,464**	**-2,657,537**	**-1,363,959**

Table 11
Montenegro – CH4 emission reductions by scenario (metric tons of CO2e, selected years shown)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	100	393	66
2027	-58,666	-67,469	-57,043
2030	-61,165	-89,062	-55,967
2035	-65,039	-105,861	-57,242
2040	-68,631	-114,503	-59,708
2045	-72,123	-121,053	-62,497
2050	-75,660	-127,231	-65,447
Total avoided	**-1,618,052**	**-2,590,254**	**-1,429,736**

The combined modeled population covered by waste collection across the four countries is approximately 10.2 million people.

Under Scenario 1 (Composting-SS), cumulative CO_2e reductions at the regional level total 16,787,329 metric tons over the 2026–2050 period (Table 12). Cumulative CH_4 reductions amount to 16,566,350 metric tons of CO_2e (Table 13).

Under Scenario 2 (Composting-LS), cumulative CO_2e reductions total 33,576,919 metric tons, driven by both landfill improvements and organic waste diversion. This is approximately double the reduction under Scenario 1, with the additional ~16.8 million metric tons directly reflecting the substantially greater diversion of organic waste.

Cumulative CH_4 reductions total 32,417,583 metric tons of CO_2e (Table 14). This scenario represents more than a 35 % reduction in cumulative CO_2e emissions compared to the BAU scenario at the regional level.

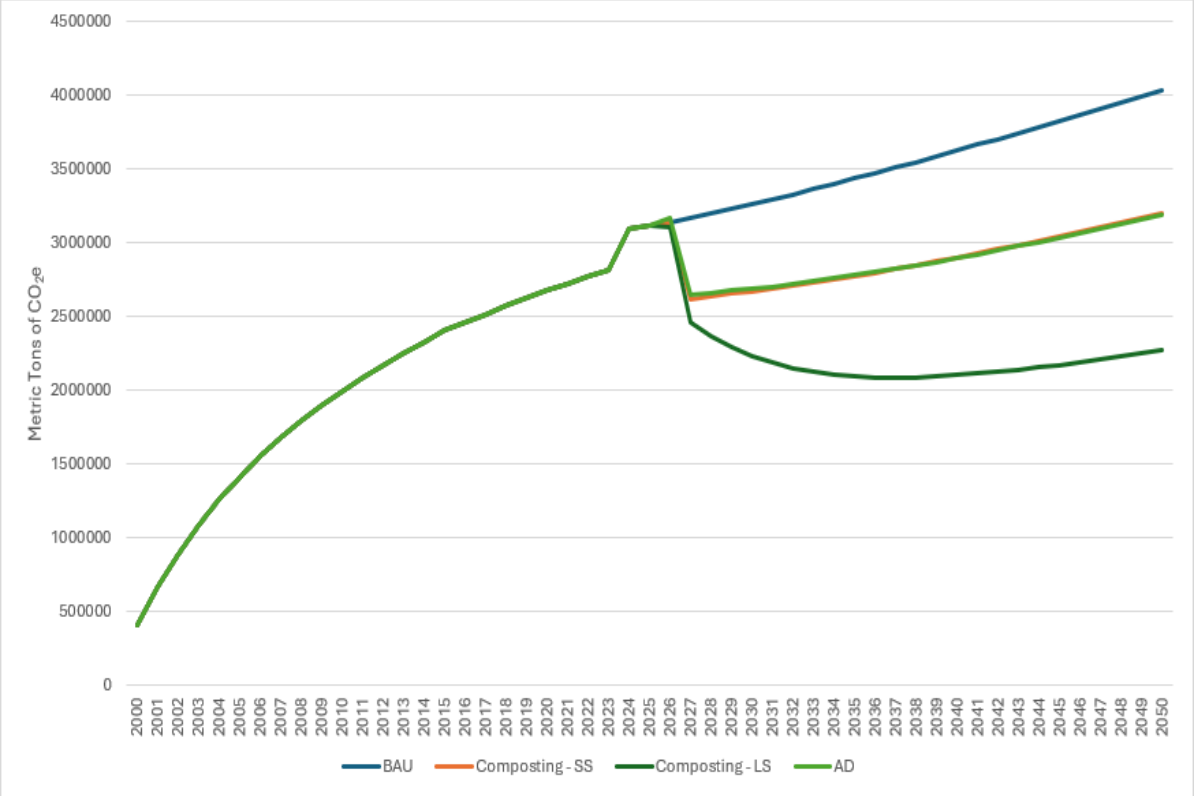


Figure 5. Overview of total emissions for three scenarios in comparison to BAU - Region of Southeast Europe

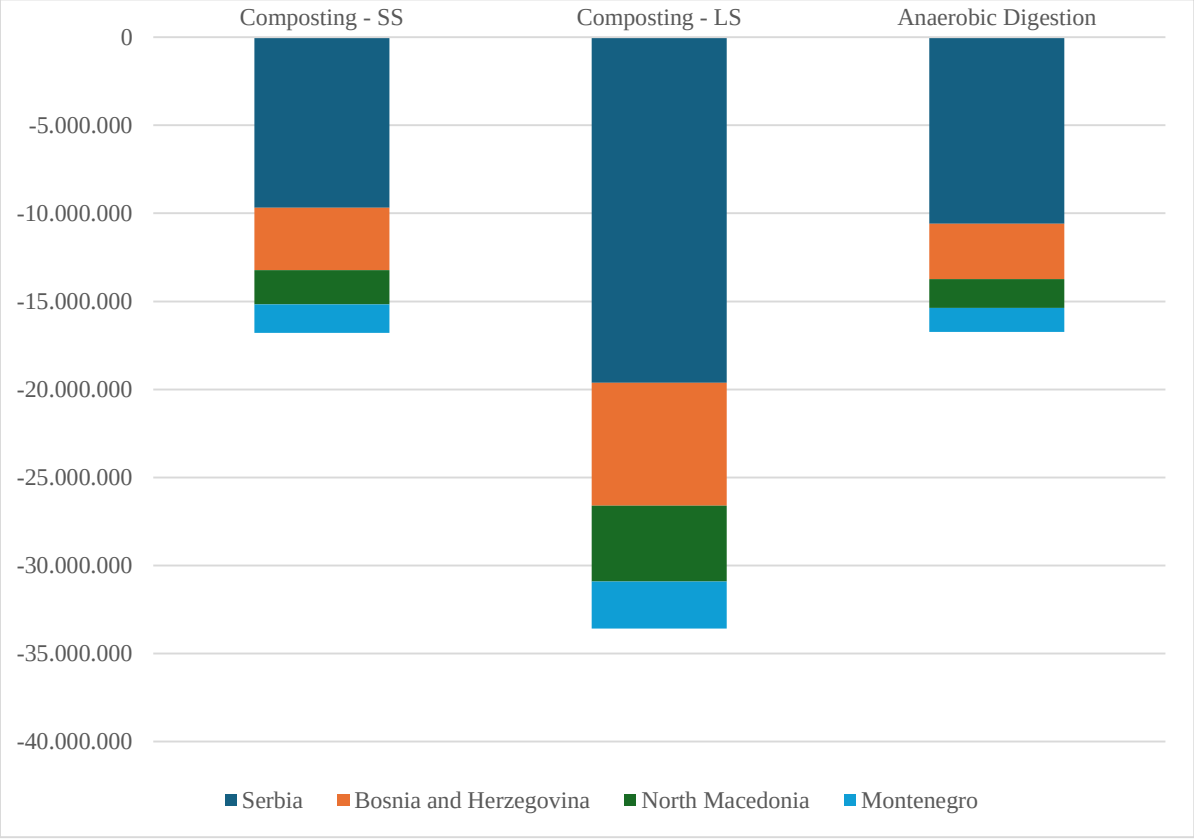


Figure 6. Total emission reduction by countries and scenarios (CO_2eq)

Table 12
Southeast Europe (Regional) - Total CO_2e emission reductions by scenario (metric tons)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	-5,752	-33,960	24,441
2027	-545,970	-704,385	-519,250
2030	-587,284	-1,025,332	-570,089
2035	-659,383	-1,337,273	-655,068
2040	-724,666	-1,522,248	-729,451
2045	-782,079	-1,655,329	-793,151
2050	-833,984	-1,766,925	-849,472
Total avoided	**-16,787,329**	**-33,576,919**	**-16,743,803**

Table 13
Southeast Europe (Regional) – CH_4 emission reductions by scenario (metric tons of CO_2e)

Year	Scenario 1 Composting-SS (t)	Scenario 2 Composting-LS (t)	Scenario 3 Anaerobic Digestion (t)
2026	2,085	7,062	3,410
2027	-538,055	-662,945	-540,492
2030	-579,138	-982,624	-591,981
2035	-650,824	-1,292,377	-678,081
2040	-715,673	-1,475,058	-753,640
2045	-772,632	-1,605,731	-818,576
2050	-824,057	-1,714,798	-876,196
Total avoided	**-16,566,350**	**-32,417,583**	**-17,338,097**

3.6. Summary of Cumulative Emission Reductions Across Countries and Scenarios

Table 14
Summary of cumulative CO_2e and CH_4 emission reductions (2026–2050) by country and scenario (metric tons of CO_2e)

Country	Sc.1 CO_2e	Sc.2 CO_2e	Sc.3 CO_2e	Sc.1 CH_4	Sc.2 CH_4	Sc.3 CH_4
Serbia	-9,682,629	-19,626,958	-10,584,695	-9,461,098	-18,825,290	-10,169,528
Bosnia and Herzegovina	-3,549,711	-6,983,525	-3,153,619	-3,604,903	-6,856,963	-3,751,598
North Macedonia	-1,931,525	-4,308,899	-1,641,530	-1,882,297	-4,145,076	-1,987,235
Montenegro	-1,623,464	-2,657,537	-1,363,959	-1,618,052	-2,590,254	-1,429,736
SEE Region Total	**-16,787,329**	**-33,576,919**	**-16,743,803**	**-16,566,350**	**-32,417,583**	**-17,338,097**

Table 15
Cumulative Emissions (metric tons of CO_2e) by country and waste management scenario (2026–2050)

Country	BAU	Scenario 1	Scenario 2	Scenario 3
Serbia	49,680,227	39,997,597	30,053,270	39,095,530
Bosnia and Herzegovina	19,643,712	16,094,002	12,660,188	16,490,093
North Macedonia	13,525,000	11,593,475	9,216,103	11,883,471
Montenegro	6,189,954	4,566,490	3,532,414	4,825,997
SEE Region Total	89,038,893	72,251,563	55,461,975	72,295,091

Absolute cumulative emissions under BAU and all scenarios are presented in Table 15. Under Scenario 3 (Anaerobic Digestion), cumulative CO_2e reductions total 16,743,803 metric tons (Table 12), broadly comparable to Scenario 1. Cumulative CH_4 reductions total 17,338,097 metric tons of CO_2e (Table 13), which is slightly higher than under Scenario 1.
Values represent cumulative GHG emissions over the period 2026–2050, expressed in tonnes of CO_2 equivalent (t CO_2e).

4. Discussion

The results of this study demonstrate that transitioning from predominantly landfill-based municipal solid waste management to systems incorporating organic waste treatment technologies holds considerable potential for greenhouse gas emission reductions across the Southeast European (SEE) region. Under the most ambitious scenario modeled (Scenario 2 - Large-Scale Composting), cumulative CO_2e emission reductions across the four study countries could exceed 33.5 million metric tons over the period 2026–2050, representing a reduction of more than 35 % compared to the Business-As-Usual trajectory. Even the minimum intervention scenario (Scenario 1 - Small-Scale Composting) could yield cumulative reductions of nearly 16.8 million metric tons CO_2e at the regional level.

Direct comparison with prior literature is limited because no previous studies have applied this modeling approach at a multi-country, regional level in Southeast Europe. Still, our core findings align with earlier single-country SWEET and landfill studies (Stanisavljević et al., 2012; Vujić et al., 2017; Milovanović et al., 2021; Stege et al., 2022), confirming that combining organic waste diversion with landfill gas capture yields the highest GHG reductions. Notably, the per-capita emission reductions estimated in our study are higher than those typically reported in Central or Western Europe. This is due to the specific baseline conditions in the Western Balkans, where over 80 % of waste still goes to unmanaged dumpsites or basic landfills and the organic fraction is high (~42–43 %), leaving much greater room for improvement. Finally, our direct methane reduction estimates are consistent with previous LCA studies (Vergara et al., 2011; Menikpura et al., 2013; Yadav and Samadder, 2018), even though the SWEET model focuses on direct operational emissions rather than full upstream and downstream life-cycle stages.

These findings are of particular policy relevance given the current composition of municipal solid waste in the region. Across all four countries, biodegradable organic waste (food waste and green waste) constitutes approximately 40–43 % of total MSW by mass. Under current BAU conditions, most of this fraction is disposed of in landfills, both sanitary and unsanitary, where it undergoes anaerobic decomposition and generates methane, a potent short-lived climate pollutant approximately 28 times more powerful than CO_2 over a 100-year time horizon. Diverting even a fraction of this material to aerobic composting or anaerobic digestion systems dramatically reduces methane generation at disposal sites.

A key finding of this analysis is that Scenario 2 consistently yields greater CO_2e emission reductions than Scenario 1 across all four countries. It is important to clarify that this enhanced mitigation performance is driven primarily by the substantially higher organic waste diversion rate (70 % in Scenario 2 versus 20 % in Scenario 1) rather than differences in the biological composting process itself. As noted in the scenario definitions, Scenario 2 processes approximately 3.5 times more organic waste than Scenario 1 in Serbia, for example. Notably, while the diverted organic waste volume increases by a factor of 3.5, the total cumulative CO_2e reduction approximately doubles (from 9.68 to 19.63 million metric tons), because both scenarios share a substantial baseline reduction resulting from common landfill gas extraction and dumpsite upgrading measures. In contrast, when diversion volumes are held constant, as is the case between Scenarios 2 and 3, large-scale composting yields roughly twice the reductions of anaerobic digestion (33.6 vs. 16.7 million metric tons at the regional level), and Scenario 3 delivers CO_2e reductions broadly comparable to those of Scenario 1.

There are, however, important differences between composting and anaerobic digestion that are not fully captured by CO_2e metrics alone. Anaerobic digestion generates biogas, which, when collected and used for energy production, provides a significant added benefit by contributing to renewable energy and reducing reliance on fossil fuels. In contrast, composting converts organic matter aerobically, generating CO_2 rather than CH_4 as the primary gaseous emission, and producing a compost product that can be applied to agricultural land,

landscaping, and other non-food applications, thereby returning nutrients and organic carbon to soils.

Both technologies are consistent with the principles of a circular economy and can contribute to EU alignment targets; the choice between them should ultimately be guided by country-specific conditions, including infrastructure readiness, financing capacity, and the maturity of separate biowaste collection systems.

Serbia presents the largest absolute emission reduction potential among the four countries, reflecting its substantially larger population and waste generation volume. The modeling results indicate that the combined implementation of landfill gas recovery, dumpsite upgrading, and large-scale composting (Scenario 2) in Serbia alone could cumulatively avoid nearly 19.6 million metric tons of CO_2e by 2050 compared to BAU. Furthermore, comparing Scenario 2 directly to Scenario 1 demonstrates that scaling up organic waste diversion from 230,000 t/year to 800,000 t/year independently contributes nearly 9.9 million metric tons of additional CO_2e reductions. Serbia already has some existing composting and waste-to-energy infrastructure, providing a foundation for scale-up. The Waste Management Program for Serbia (2022–2031) envisions the construction of municipal composting plants and targets biowaste recycling rates of 20 % by 2025 and 40 % by 2029, which aligns with the scale of intervention represented by Scenario 1 and partially Scenario 2 in this study (Government of Serbia, 2021).

While the modeling results demonstrate clear environmental benefits from transitioning to advanced organic waste treatment, realizing these benefits in practice faces a set of common structural barriers across the SEE region that must be addressed through targeted policy action.

The most fundamental prerequisite for large-scale organic waste treatment, whether composting or anaerobic digestion, is an effective separate biowaste collection system. Currently, separate collection of biowaste is either nonexistent or operates at minimal scale across all four countries. Without reliable, high-quality source-separated biowaste streams, the economic and technical performance of downstream treatment facilities is significantly compromised. Expanding separate collection requires investment in waste collection infrastructure, as well as sustained public awareness and behavioral change campaigns.

Financial constraints represent a second major barrier. The cost of constructing and operating regional composting or anaerobic digestion facilities significantly exceeds the capacity of local governments, which bear primary responsibility for waste management but frequently operate with limited budgets and low waste service fee revenues. Additional investments of tens of millions of euros are estimated to be required in Serbia alone for biowaste collection and composting infrastructure.

Institutional and technical capacity deficits are a third constraint. Local governments in the region frequently lack the administrative, technical, and operational expertise required to plan, procure, operate, and regulate modern waste treatment infrastructure. Strengthening institutional capacity through training programs, technical assistance, and public-private partnership frameworks is therefore an essential complement to physical infrastructure investment.

Data gaps represent a fourth structural challenge. These gaps limit the ability of national and local authorities to design evidence-based waste management strategies and to track progress toward national and EU targets. Establishing standardized, mandatory waste data collection and reporting systems aligned with Eurostat methodologies (Eurostat, 2023) is an urgent priority.

Several limitations should be considered when interpreting the findings of this study. The SWEET model is designed to provide first-order, city- and country-level estimates of MSW sector emissions and is not intended as a substitute for detailed site-specific technical analyses or investment feasibility studies. Emissions estimates are sensitive to input assumptions regarding waste composition, landfill depth, waste decay rates, and methane generation and oxidation factors, all of which carry inherent uncertainty in the SEE context given the limited availability of empirical data. Country-level input data on waste generation and composition were derived from national statistics databases and planning documents, which in some cases rely on estimates and projections rather than systematic measurement. Projections to 2050 assume a constant 1% annual waste growth rate across all four countries, which aligns with official national waste management strategies and planning documents in the region (e.g., in Serbia). Regarding model sensitivity, the scenario design already tests the main policy variables: comparing Scenarios 1 and 2 shows the impact of the organic waste diversion rate (20% vs. 70%), while comparing Scenarios 2 and 3 isolates the effect of treatment technology choice (composting vs. anaerobic digestion). For the remaining parameters, because organic treatment capacities are modeled as fixed tonnages (Table 3) and landfill gas (LFG) capture is applied uniformly across Scenarios 1–3, moderate variations in the waste growth rate, organic fraction, or LFG collection efficiency simply scale the baseline (BAU) trajectory or shift the common landfill mitigation component equally across all three scenarios. While this slightly changes the **overall** percentage reduction relative to BAU, it does not affect the absolute reductions per ton of treated waste or the relative ranking among Scenarios 1, 2, and 3. Furthermore, the scenarios assume that landfill improvements and treatment facilities achieve their full design capacities immediately in 2026, without modeling a phased implementation or ramp-up period. In practice, simultaneous deployment across the SEE region is unrealistic given the structural,

institutional, and financial barriers discussed above, which make actual implementation trajectories highly unpredictable. Consequently, the reported emission reductions- particularly in the near term - should be interpreted as an idealized technical mitigation potential (an upper-bound benchmark for comparing policy alternatives against BAU) rather than realistic projections of future emissions. Finally, this study does not quantify the full range of environmental co-benefits associated with the modeled scenarios, including avoided air pollution from dumpsite fires (beyond PM2.5 and PM10), groundwater and soil contamination prevention from dumpsite remediation, or the economic value of compost products and recovered materials. Incorporating these co-benefits into a comprehensive cost-benefit analysis would further strengthen the economic case for transitioning to advanced waste management systems in the SEE region.

5. Conclusions

The findings of this study have direct implications for national climate policy and EU accession trajectories across the SEE region. While the EU Landfill Directive (1999/31/EC) mandates Member States to progressively reduce biodegradable municipal waste landfilled to 75 %, 50 %, and ultimately 35 % relative to a 1995 baseline (Council of the European Union, 1999), the four analyzed Western Balkan countries - as EU candidate and potential candidate countries - incorporate these percentage benchmarks into their national waste management strategies using adjusted national baseline years and deferred transition timelines (REC, 2021; European Commission, 2023a, 2023b, 2023c). However, formal policy alignment rarely guarantees timely implementation on the ground. In Serbia, for instance, national targets for reducing biodegradable waste disposal have already been postponed across successive planning cycles due to slow infrastructure rollout, with the current national program shifting the compliance horizon toward the late 2020s and 2030s (Government of Serbia, 2021; SEPA, 2024). Across all four countries, persistent institutional weaknesses, governance challenges, financial deficits, and slow operational transformation mean that officially stated target dates remain highly uncertain. Nevertheless, our modeling results demonstrate the technical magnitude of the prize: achieving these EU alignment benchmarks through an integrated approach - combining dumpsite upgrading and landfill gas capture with composting or anaerobic digestion - would not only fulfill eventual EU accession requirements under Chapter 27, but also deliver substantial GHG emission reductions contributing to each country's Nationally Determined Contributions (NDCs) under the Paris Agreement.

At the regional level, the cumulative emission reductions achievable under Scenario 2, exceeding 33.5 million metric tons CO_2e over 25 years, represent a significant contribution to broader European and global climate goals. When coupled with foundational landfill improvements, the comparability of results between Scenario 1 and Scenario 3, despite the former relying on small-scale composting and the latter on large-scale anaerobic digestion, suggests that both technological pathways can deliver climate benefits of similar magnitude, and that the choice between them should be driven primarily by local feasibility, co-product value, and available financing rather than by GHG considerations alone.

Acknowledgement

The study was funded by Environment and Climate Change Canada (ECCC) through the International Climate Finance program, under the project “Methane emission reductions in Southeastern European waste sector through application of GMI resources” (Project No. GCXE24E004),

This work was also supported by the project of the Department of Environmental Engineering and Occupational Safety and Health at the Faculty of Technical Sciences Novi Sad (Istraživanje, razvoj i primena inovativnih inženjerskih pristupa za unapređenje stanja životne i radne sredine).

References

Bogner J., Pipatti R., Hashimoto S., Diaz C., Mareckova K., Diaz L., Kjeldsen P., Monni S., Faaij A., Gao Q., Zhang T., Ahmed M. A., Sutamihardja R. T. M. Gregory R. Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, Waste Management & Research, 2008, 26 (1), 11–32. https://doi.org/10.1177/0734242X07088433,

CCAC, 2020, Estimating Waste Sector GHG Emissions in Tyre Caza, Lebanon. Paris: Climate and Clean Air Coalition / ISWA,

CCAC, 2021, Solid Waste Emissions Estimation Tool (SWEET), User Manual. Paris: Climate and Clean Air Coalition,

Christensen T. H., Gentil E., Boldrin A., Larsen A. W., Weidema B. P. Hauschild M. C balance, carbon dioxide emissions and global warming potentials in LCA-modelling of waste management systems, Waste Management & Research, 2009, 27 (8), 707–715, https://doi.org/10.1177/0734242X08096304,

Council of the European Union (1999), Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, Official Journal of the European Union, L 182, 1–19,

De Baere L., Mattheeuws B. (2012) Anaerobic digestion of the organic fraction of municipal solid waste in Europe', in Solid Waste Technology & Management.

Chichester: Wiley-Blackwell, 517–526,
European Commission (2023a) Serbia 2023 Report: Communication on EU Enlargement Policy. Brussels: European Commission,
European Commission (2023b) Montenegro 2023 Report. SWD (2023) 694 final. Brussels: European Commission,
European Commission (2023c) Commission Staff Working Document: Reports on Enlargement (Western Balkans). Brussels: European Commission,
European Parliament and Council of the European Union (2008) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste, as amended by Directive 2018/851/EU, Official Journal of the European Union, L 150, 109–140,
Eurostat (2023) Municipal Waste Statistics. Luxembourg: Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics (Accessed: 24 August 2026),
GMI (2024) Solid Waste Emissions Estimation Tool (SWEET), Version 4.0.5 [Excel-based model]. Washington, DC: Global Methane Initiative / U.S. EPA,
GMI (2025) SWEET User Manual, v5.0. Washington, DC: Global Methane Initiative / U.S. EPA,
Government of Serbia (2021) Waste Management Programme for the Republic of Serbia for the period 2022–2031. Belgrade: Government of Serbia,
IPCC (2019) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Edited by Calvo Buendia E., Tanabe K., Kranjc A., Baasansuren J., Fukuda M., Ngarize S., Osako A., Pyrozhenko Y., Shermanau P. Federici, S. Hayama: Institute for Global Environmental Strategies (IGES) / IPCC,
IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press,
Kaza S., Yao L., Bhada-Tata P. Van Woerden F. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. 2018, Washington, DC: World Bank,
Khandelwal H., Dhar H., Thalla A. K. Kumar S. Application of life cycle assessment in municipal solid waste management: A worldwide critical review, Journal of Cleaner Production, 2019, 209, 630–654. https://doi.org/10.1016/j.jclepro.2018.10.233,
Laurent A., Bakas I., Clavreul J., Bernstad A., Niero M., Gentil E., Hauschild M. Z. Christensen T. H. Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives, Waste Management, 2014a, 34 (3), 573–588. https://doi.org/10.1016/j.wasman.2013.10.045,
Laurent A., Clavreul J., Bernstad A., Bakas I., Niero M., Gentil E., Christensen T. H. Hauschild M. Z. Review of LCA studies of solid waste management systems – Part II: Methodological guidance for a better practice, Waste Management, 2014b, 34 (3), 589–606. https://doi.org/10.1016/j.wasman.2013.12.004,
Liem Y. F., Farahdiba A. U., Warmadewanthi I. Hermana J. Municipal Solid Waste Management in the Top 25 Most Populated Countries: A Review on the Application of LCA to Select Appropriate System in Reducing Greenhouse Gas Emissions, Future Cities and Environment, 2023, 9 (1), Article 9. https://doi.org/10.5334/fce.179,
Menikpura S. N. M., Gheewala S. H., Bonnet S. Chiemchaisri C. Evaluation of the effect of recycling on sustainability of municipal solid waste management in Thailand, Waste and Biomass Valorization, 2013, 4 (2), 237–257. https://doi.org/10.1007/s12649-012-9119-5,
Milovanović D., Živančev M., Ubavin D., Bežanović V. Petrović M. D. Quantification of climate change mitigation potential at Novi Sad landfill, IOP Conference Series: Materials Science and Engineering, 2021, 1163 (1), 012029.https://doi.org/10.1088/1757-899X/1163/1/012029,
REC (Regional Environmental Centre for Central and Eastern Europe) (2021) Waste Management in the Western Balkans: Current State and Prospects for EU Alignment. Szentendre, Hungary.
SEPA (Serbian Environmental Protection Agency) (2022) Report on the State of the Environment in the Republic of Serbia for 2021. Belgrade: SEPA.
SEPA (Serbian Environmental Protection Agency) (2024) Report on Waste Management in the Republic of Serbia. Belgrade: SEPA.
Stanisavljević N., Ubavin D., Batinić B., Fellner J. Vujić GMethane emissions from landfills in Serbia and potential mitigation strategies: a case study, Waste Management & Research, 2012, 30 (10), 1095-1103. https://doi.org/10.1177/0734242X12451867,
Stege G. A., Law H. J., Ramola A. Mazo-Nix S. Mini-review of waste sector greenhouse gas and short-lived climate pollutant emissions in Tyre Caza, Lebanon, using the Solid Waste Emissions Estimation Tool (SWEET), Waste Management & Research, 2022, 40 (8), 1129–1142. https://doi.org/10.1177/0734242X221076295,
UNEP (2024) Global Waste Management Outlook 2024: Beyond an Age of Waste: Turning Rubbish into a Resource. Nairobi: United Nations Environment Programme.
UNEP and CCAC (2021) Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme and Climate and Clean Air Coalition.

UNFCCC (2022) National Inventory Report of Serbia. Bonn: United Nations Framework Convention on Climate Change.

UNFCCC (2023) National Greenhouse Gas Inventories – Western Balkans submissions. Bonn: UNFCCC.

Vergara S. E., Damgaard A., Horvat A. Boundaries matter: Greenhouse gas emission reductions from alternative waste treatment strategies for California's municipal solid waste, Resources, Conservation and Recycling, 2011, 57, 87–97. https://doi.org/10.1016/j.resconrec.2011.09.011,

Vujić G., Stanisavljević N., Batinić B., Jurakić Ž. Ubavin D. Barriers for implementation of "waste to energy" in developing and transition countries: a case study of Serbia, Journal of Material Cycles and Waste Management, 2017, 19 (1), 55–69, https://doi.org/10.1007/s10163-015-0377-8,

World Bank (2025) What a Waste 3.0: A Global Snapshot of Solid Waste Management to 2050. Washington, DC: World Bank. Available at: https://openknowledge.worldbank.org/ (Accessed: 24 August 2026).

Yadav P., Samadder S. R. A critical review of the life cycle assessment studies on solid waste management in Asian countries, Journal of Cleaner Production, 2018, 185, 492–515. https://doi.org/10.1016/j.jclepro.2018.02.298,

Zhao W., van der Voet E., Zhang Y. Huppes G., Life cycle assessment of municipal solid waste management with regard to greenhouse gas emissions: Case study of Tianjin, China, Science of The Total Environment, 2009, 407(5), 1517–1526. https://doi.org/10.1016/j.scitotenv.2008.11.007,

Prelazak na održivo upravljanje otpadom u odabranim zemljama Zapadnog Balkana: koristi za klimu od primene mera integrisanog upravljanja otpadom

Dejan Ubavin #, Dušan Milovanović, Miodrag Živančev, Goran Vujić

Univerzitet u Novom Sadu, Fakultet Tehničkih nauka, Novi Sad, Srbija

INFORMACIJE O RADU

Primljen 31 avgust 2026
Prihvaćen 02 novembar 2026

Naučni rad

Ključne reči:
Upravljanje otpadom
Emisije gasova sa efektom staklene bašte
Kompostiranje
Anaerobna digestija

Citiranje: Ubavin D., Milovanović D., Živančev M., Vujić G., Transitioning to Sustainable Waste Management in Selected Western Balkan Countries: Climate Benefits of Integrated Waste Management Interventions, Recycling and Sustainable Development, 19 (2), 2026, 49-67.

https://doi.org/10.30544/RSD120

I Z V O D

Upravljanje komunalnim čvrstim otpadom u jugoistočnoj Evropi u velikoj meri se oslanja na odlaganje otpada na nesanitarne deponije i smetlišta, što dovodi do značajnih emisija gasova sa efektom staklene bašte, naročito metana. U cilju rešavanja ovog značajnog problema u oblasti zaštite životne sredine, u radu je procenjen potencijal za smanjenje emisija gasova sa efektom staklene bašte u sistemima upravljanja komunalnim čvrstim otpadom u Srbiji, Bosni i Hercegovini, Severnoj Makedoniji i Crnoj Gori. Primenom kvantitativnog pristupa zasnovanog na scenarijima, uz korišćenje alata za procenu emisija iz čvrstog otpada (Solid Waste Emissions Estimation Tool – SWEET), modelovane su emisije za period od 2026. do 2050. godine. U analizi je upoređen referentni scenario nastavka dosadašnje prakse (business as usual – BAU) sa tri alternativne mere: kompostiranjem manjeg obima, kompostiranjem velikog obima i anaerobnom digestijom. Svi alternativni scenariji podrazumevaju aktivno sakupljanje deponijskog gasa, kao i sanaciju i unapređenje postojećih neuređenih odlagališta otpada ili njihovo zatvaranje. Rezultati pokazuju da kombinacija unapređenja deponija, koje obuhvata sakupljanje deponijskog gasa i sanaciju neuređenih odlagališta, sa kompostiranjem velikog obima pruža najveći potencijal za smanjenje emisija gasova sa efektom staklene bašte. Procenjeni tehnički potencijal za smanjenje emisija na regionalnom nivou premašuje 33,5 miliona tona ekvivalenta ugljen-dioksida (CO_2 ekv.) do 2050. godine, što predstavlja smanjenje veće od 35% u odnosu na projekcije referentnog scenarija. Kompostiranje manjeg obima i anaerobna digestija takođe donose značajne koristi za klimu, pri čemu svaka od ovih mera omogućava izbegavanje emisija od gotovo 16,8 miliona tona CO_2 ekv. na regionalnom nivou. U radu se zaključuje da prelazak na tehnologije tretmana organskog otpada predstavlja veoma efikasan način za ostvarivanje nacionalnih klimatskih ciljeva i usklađivanje sa standardima Evropske unije u oblasti zaštite životne sredine. Međutim, primena ovih održivih sistema zahteva prevazilaženje značajnih strukturnih prepreka, pre svega uspostavljanje sistema odvojenog sakupljanja biootpada na mestu nastanka, obezbeđivanje značajnih finansijskih ulaganja i jačanje institucionalnih kapaciteta lokalnih samouprava.