STUDY

Methane emissions from Europe's landfills

Scenarios and Data Challenges

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Executive Summary

Background

Methane emissions from landfills represent a significant and often underestimated climate challenge. Methane is the second most important greenhouse gas after carbon dioxide and has a higher Global Warming Potential: Its greenhouse effect is 27 times that of CO_2 over 100 years and 79.7 times over 20 years. Given methane's short atmospheric lifetime and powerful near-term warming effect, rapid mitigation can deliver substantial climate benefits. Landfills accounted for around 11% of global anthropogenic methane emissions[1], making improved monitoring, modelling, and reduction strategies essential. Within the European Union, around 18% of methane emissions in 2021 originated from solid waste disposal[2]. Satellite-based studies suggest actual emissions may be significantly higher than reported[3].

The European Union (EU) has established a comprehensive policy framework to reduce landfilling, promote recycling, and strengthen the circular economy. These initiatives – anchored in the Waste Framework Directive (WFD)[4], Landfill Directive[5], Circular Economy Action Plan[6], and the EU Methane Regulation (2024/1787)[7] – support the broader climate targets set under the European Green Deal[8] and Fit-for-55 package[9]: a 55% reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050. The waste sector is increasingly in focus, as evidenced by ongoing discussions on a ban on landfilling untreated municipal waste, revisions to the Landfill Directive, and debates over the inclusion of waste-to-energy in the EU Emissions Trading System (EU ETS)[10].

Against this backdrop, the present study provides a robust, scenario-based quantitative assessment of future methane emissions from municipal solid waste (MSW) deposited in landfills across the EU-27+UK between 2022 and 2050. The study also evaluates data quality, methodological consistency, and uncertainties using country-specific analyses, including detailed reviews of National Inventory Documents (NIDs) submitted to the UNFCCC[11]. The objective is to improve the understanding of methane emissions from landfilling, highlight data gaps, and support evidence-based policymaking to accelerate methane-reduction efforts.

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[1] Global Methane Emissions Initiative, 2010.
[2] UNFCCC 2025a.
[3] Dogniaux et al, 2025.
[4] EC 2018b.
[5] EC 2018a.
[6] EC 2020.
[7] EC 2024.
[8] EC 2019.
[9] EC 2021.
[10] EC 2023a, EP 2022.
[11] UNFCC 2024, UNFCC 2025.

Key Findings

1. Methane emissions from landfills remain substantial even as landfill waste declines

Modelling shows that landfill emissions persist for decades after disposal ends due to ongoing anaerobic decomposition. Under the Status Quo scenario, in which annual MSW landfilling remains at 2022 levels until 2050 for the EU-27+UK:

- 1902 million tonnes of MSW would be deposited.
- This would generate 1,515 million tonnes CO_2e (GWP 100) of methane by 2130, excluding emissions from historical MSW deposits pre-2022.
- 37% of these emissions would occur after 2050, long after waste disposal stops.

In contrast, full implementation of the Waste Framework Directive – reducing landfilling of MSW to 10% by 2035/2040 in accordance with the Landfill Directive – would:

- Cut MSW landfilled to 870 million tonnes,
- Reduce methane emissions to 701 million tonnes CO_2e,
- Achieve a 54% reduction compared with the Status Quo.

A complete landfill ban for MSW starting in 2023, although hypothetical, illustrates the mitigation potential: emissions would fall to 52 million tonnes CO_2e, i.e. are reduced to 1/29th of the Status Quo (≈96.6% lower). The modelling excludes emissions from historical MSW deposits prior to 2022.

2. Methane's near-term climate impact highlights the importance of rapid action

Using GWP 20, methane emissions become nearly three times higher than under GWP 100:

- Status Quo: 4473 million tonnes CO_2e (GWP 20) vs 1515 million tonnes (GWP 100)
- WFD: 2071 million tonnes CO_2e (GWP 20) vs 701 million tonnes (GWP 100)

This underscores methane's critical importance for near-term climate mitigation, especially before 2050. Methane has a very high short-term warming impact (as reflected in GWP 20), so reducing methane emissions can slow the rate of near-term warming and "buy time", as the world is currently on course to miss established climate-protection targets and exceed the 2 °C threshold.

3. Significant differences exist between countries

Among the eight selected countries (UK, Spain, France, Italy, Greece, Portugal, Romania, Czech Republic):

- The largest landfill volumes occur in the UK, Spain, France, and Italy, reflecting country size.
- However, methane emissions do not scale linearly with waste amounts.
- Emissions are strongly influenced by:
  - Degradable organic carbon (DOC) in waste, and
  - Methane recovery (capture) rates (R).

- For instance:
  - The Czech Republic shows the highest methane emissions per tonne mainly due to a high reported DOC value (0.23).
  - The UK shows the lowest emissions per tonne, mainly supported by a high reported capture rate (56%).

Current trends indicate that France and Italy may outperform EU WFD targets, while Greece, Portugal, Romania, Spain, and the Czech Republic are not on track under current trajectories.

4. Data gaps and methodological inconsistencies remain a major challenge

The review of NIDs[12] and national statistics highlights:

- Waste types (MSW vs industrial/commercial waste) are not consistently disaggregated.
- Information on landfill gas collection systems is often missing or incomplete.
- Parameter values used in national methane models (DOC, DOCf, methane recovery, oxidation) are often global default values or not always transparent.
- Historical waste data are incomplete, requiring strong assumptions for back-casting.
- Satellite-based studies suggest actual emissions may be significantly higher than reported.

These inconsistencies complicate cross-country comparisons and result in uncertainty in national and EU-level methane estimates.

5. Methane emissions are highly sensitive to key modelling parameters

Two parameters strongly influence emission estimates:

- Degradable organic carbon (DOC)
- Methane recovery (R)

For the EU-27+UK:

- Increasing DOC from 0.15 (derived IPCC default) to 0.20 raises emissions in the Status Quo scenario from 1515 to 2021 million tonnes CO_2e (a 33% increase). The 0.20 DOC-value for the EU-27+UKis likely more realistic than the derived IPCC default value of 0.15, as the estimated emissions for the 8 focus countries are already close to those for the EU-27+UK with the derived IPCC default DOC value.
- Increasing methane recovery from 34% to 60% reduces emissions by 39%.

These sensitivities highlight the importance of both transparent parameter selection and needed improvements to the current landfill gas capture. Even when landfill facilities significantly improve gas-capture performance, methane emissions remain significant.

[12] UNFCC 2024, UNFCC 2025.

Conclusions and Takeaways

- Landfill methane emissions are significant, persistent over long periods, and highly sensitive to waste volumes and methane capture performance.
- Immediate action – reducing or banning organic waste from landfilling, accelerating circular-economy adoption, and expanding capture systems – can significantly reduce emissions before 2050.
- Data and methodological gaps remain a barrier to accurate tracking and effective policy design. Better datasets, improved parameter transparency, and enhanced monitoring (including satellite data) are essential.
- Even when MSW landfilling declines, historical deposits continue emitting methane for decades, underscoring the need for long-term mitigation strategies.
- Implementing the Waste Framework Directive, and specifically the Landfill Directive, alone can halve methane emissions, while a full ban or near-ban of municipal solid waste offers much larger benefits.
- Methane reduction is a critical near-term lever to support the EU climate targets and achieve rapid climate benefits.

Overall, this study underscores the importance of strengthening data foundations and adopting consistent modelling approaches to support effective climate action in the waste sector.

1 Background and Objectives

1.1 Background and Objectives

A better understanding of climate impacts is essential for developing effective, integrated greenhouse gas reduction strategies and avoiding misguided incentives.

Methane is the second most important greenhouse gas contributor to climate change, after carbon dioxide. Methane (CH_4) has a higher Global Warming Potential: Its greenhouse effect is 27 times that of CO_2 over 100 years and 79.7 times over 20 years. A study by the German Environment Agency (2025), based on the IPCC[13], highlights that methane in the atmosphere from human activity contributes approximately 0.5 degrees Celsius to net temperature increases. Within the European Union, around 18% of methane emissions in 2021 originated from solid waste disposal[14]. Landfills contribute substantially to global methane emissions, accounting for around 11% of global anthropogenic methane emissions[15]. Satellite-based studies suggest actual emissions may be significantly higher than reported[16].

Landfills are a significant source of methane emissions from organic waste, such as food waste, yard waste, and biomass. Landfills exist to dispose of waste by compacting and sealing off air to reduce space and volume. Organic waste fractions decompose in landfills under anaerobic conditions (in the absence of oxygen), producing methane. Methane is an unavoidable by-product of the microbial decomposition process. This process, known as anaerobic degradation, is the result of the breakdown of organic materials by microorganisms in environments with limited oxygen availability. Biogenic waste in landfills is the source of methane emissions, hindering progress towards EU climate targets and the realisation of the waste hierarchy for these wastes. Waste management, thus, plays an important role in both climate protection and resource efficiency[17].

The EU has established a comprehensive regulatory framework to reduce landfilling, promote recycling, advance circular-economy objectives, and reduce greenhouse gas emissions. Key regulatory frameworks include the Waste Framework Directive, the Landfill Directive, directives on WEEE, packaging, and single-use plastics, and the Circular Economy Action Plan, which define recycling and landfill targets, pre-treatment requirements, and energy recovery standards, amongst others. The EU Methane Strategy (2020) and the Methane Regulation (EU) 2024/1787 are key instruments that introduce mandatory measures for monitoring, reporting, and reducing methane emissions.

As part of the European Green Deal and the Fit-for-55 package, the EU has set out to reduce greenhouse gas emissions by at least 55% compared to 1990 levels by 2030 and to become

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[13] IPCC 2021a.
[14] UNFCCC 2025a.
[15] Global Methane Emissions Initiative, 2010.
[16] Dogniaux et al, 2025.
[17] For example, see: Prognos 2022.

climate-neutral by 2050. One of the many instruments to support the realisation of the climate targets is the market-based European Union Emissions Trading Scheme (EU ETS). The waste sector is also increasingly coming into focus for reducing greenhouse gas emissions, for example, through the planned revision of the Landfill Directive, discussions on an EU-wide ban on landfilling unpretreated municipal waste, and the inclusion of, e.g. municipal waste incineration in the EU ETS.

A better **understanding of landfill emissions, the underlying data and the calculation methodologies supports** discussions on sustainable policies. Against this background, this study analyses the data foundations for assessing methane emissions from landfilling and provides a quantitative orientation of the size of the impact different scenarios have on future landfill emissions.

The objective of this study is to raise awareness of the sizable contribution of methane emissions from municipal solid waste deposited in landfills and the associated data challenges in measuring methane emissions. The main report, therefore, focuses on the results, and is complemented by an Annex that elaborates on the methodology and related aspects for more technical readers.

Towards these aims, the study:

- Identifies the primary data sources and assesses these for selected countries.
- **Indicates differences** in measuring and reporting of methane emissions and uncertainties (i.e., NIDs).
- **Provides a quantitative orientation** on the overall size of methane emissions generated from MSW deposited on landfills between 2022 and 2050 in the EU-27+UK based on a robust and consistent methodology for different scenarios.

In this way, this study aims to advance the debate on reducing landfill emissions and to increase public understanding and visibility of landfill emissions data, thereby enhancing community engagement and support for emission-reduction initiatives.

1.2 Focus and Scope of the Study

The focus and scope of the study were determined based on a preparatory analysis. The objective of the preliminary analysis was to determine available data and an appropriate modelling methodology for the study to achieve robust, consistent estimation, and, in the process, identify and highlight data and methodological challenges. The preparatory research analysed available waste statistics and National Inventory Documents (NID) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) for selected countries.

The scope of the study focuses on the potential future methane emissions from current and future MSW landfilling in the EU-27+UK, plus selected relevant EU member states. The scope of waste considered includes municipal solid waste and commercial waste similar to household waste (MSW) deposited in landfills in operation, as MSW's biodegradable content is the primary source of methane emissions. Hazardous waste and mineral waste are excluded from the scope. While other waste, other than MSW, is out of scope, in some cases, it was not possible to distinguish MSW from total and/or industrial waste.

Historical depositions on landfills and emissions from these are excluded. While current methane emissions are described, they cannot be extrapolated. Current reported methane emissions result from historical waste deposits since 1950, and estimates cannot be feasibly reproduced due to insufficient data.

The study focuses on the EU-27+UK and a selection of countries (the United Kingdom, France, Greece, Italy, Portugal, Romania, Spain, and the Czech Republic). The number of countries was limited to ensure effective use of available resources for this study. The country selection is based on the size, share, and development of landfill waste deposits, as well as their share in total methane emissions in Europe.

This scope allows for improving understanding of methane generation from MSW landfilling and for highlighting how methane emissions from current disposals will occur over the next 100 years, i.e., how decisions made today will impact future emissions. By using scenarios, the results of different developments are shown, including under legal requirements (WFD), without mitigation measures (Status quo, current scenario), and with an MSW landfill ban. The implications of MSW diversion away from landfills are outside the scope of the study (e.g., the potential for biological treatment, energy use, etc.). However, the disposal of residues from mechanical-biological treatment is illustrated using France as an example (see Annex 4.3).

The principal databases for the study are the National Inventory Documents (NID) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), the IPCC guidelines for national greenhouse gas inventories, Volume 5 Waste[18], and statistical data for waste generation and treatment from Eurostat. Further details of the methodology and data can be found in the Annex.

1.3 Modelling Assumptions

Waste volumes deposited in landfills only consider municipal and commercial wastes similar to household wastes, as these wastes comprise the highest share of biogenic waste deposited in landfills.

The waste volume modelling is based on the latest available data year, 2022, from the consistent Eurostat waste statistics database and national statistics for the United Kingdom. Eurostat provides the most consistent waste data statistics at the European level. The year 2022 was selected because it is the most recent year for which Eurostat has available waste data. Eurostat provides the most suitable database for waste data. Even if it is not the best due to aggregation and the need for adjustments based on available national data, it is consistent and coherent across EU Member States.

Comparing the NID-reported waste landfilled with Eurostat waste statistics proved not to be directly possible. At the same time, Eurostat's WASTRT statistics were not suitable, as the waste with biodegradable content cannot be clearly demarcated. As the analysis showed, the primary sources of biodegradable waste are municipal waste, industrial waste similar to household waste,

[18] IPCC 2019.

and sorting and treatment residues. The most applicable waste statistic is then the WASMUN statistics from Eurostat, which apply a broader definition of municipal waste, i.e., municipal waste, waste similar to household waste, and sorting and treatment residues from MBTs (mechanical biological treatment). WASMUN also differentiates by treatment route.

A comparative orientation could be achieved by comparing the waste volumes landfilled reported in the NIDs with the WASMUN statistics for landfills, and by drawing upon key emission modelling parameters from the NIDs. This approach allowed accounting for differences between NID and WASMUN statistics, utilising the key methane-emission modelling parameters from the NIDs, while building a consistent and comparable database based on 2022 to model four scenarios for the EU-27+UK and the selected countries. In the resulting model, uncertainties are addressed through a series of explicit assumptions.

The modelling **excluded the historically deposited amounts** of municipal solid waste and emissions generated from these, due to data uncertainties, especially regarding historical waste deposits and their waste compositions, as well as the significant efforts needed to replicate their methodologies, if at all possible. Instead, the study focuses on future landfill deposits (i.e., between 2022 and 2050) to highlight the implications of different scenarios for methane emissions.

To estimate **long-term methane emissions (2022-2130)**, the municipal solid waste deposited between 2022 and 2050 was compared in four scenarios. In the scenarios, only the amount of MSW deposited in **landfills was changed**. No socio-economic or cultural dynamics, nor changes in waste composition, were considered.

The waste amounts as of 2022 were held constant for a methodological comparison to better illustrate the impacts of reducing landfilling for the EU-27+UK and the selected countries: the Czech Republic (CZ), Spain (ES), France (FR), Greece (EL), Italy (IT), Portugal (PT), Romania (RO), and the United Kingdom (UK). The focus countries allow for the presentation of different country situations that significantly influence the size or dynamics of European landfill methane emissions. Also, it was assumed that the waste composition remains unchanged, i.e., MSW still contains biogenic waste.

The four scenarios illustrate the effect of different changes in the volume of waste landfilled until 2050 on methane emissions generated over 80 years from the point of the last waste deposited. For this, IPCC's FOD (First Order Decay) method (ifeu simplified model based on IPCC waste model) and the IPCC consistent Global Warming Potential 100 (GWP 100) were applied.

The following four scenarios **provide the quantitative orientation of the effects on waste amounts deposited between 2022 and 2050 and the respective methane emissions generated between 2022 and 2130.** The **waste composition is assumed to be constant**.

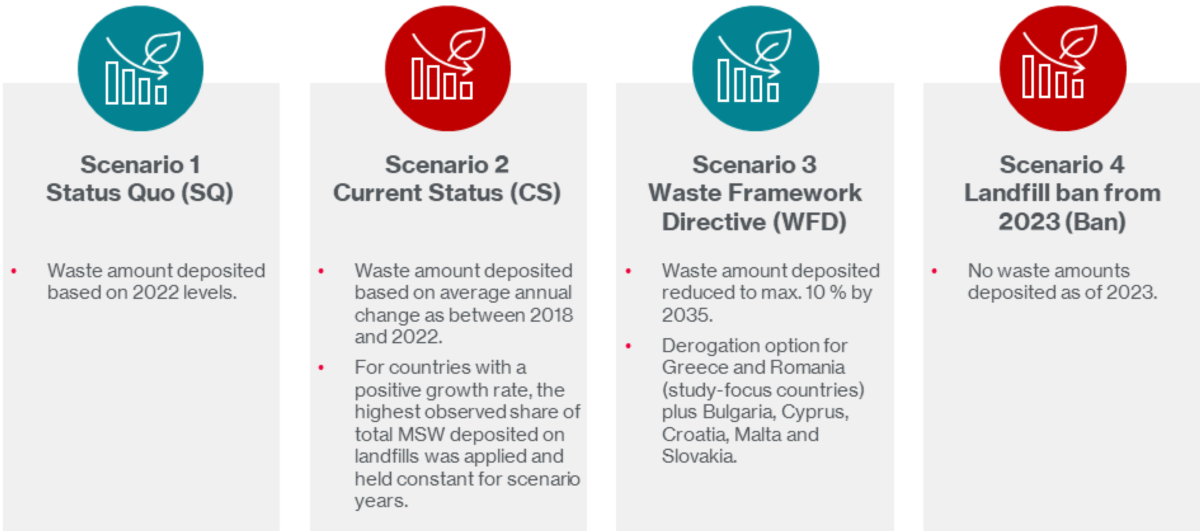
Scenario 1 Status Quo (SQ): The amount of waste annually deposited is held constant at 2022 levels, i.e., no change in the annual deposited landfill amount is modelled. This scenario shows an upper range of possible future methane emissions.

Scenario 2 Current Status (CS): The amount of waste annually deposited is based on the average annual change between 2018 and 2022. For countries with a positive growth rate, the highest observed share of total MSW deposited on landfills was applied and held constant. The rate was held constant for those Member States with a landfilling rate below 10%.

Scenario 3 Waste Framework Directive (WFD): The amount of annual waste deposited was reduced to a maximum of 10% by 2035 in accordance with the Landfill Directive (LFD). The derogation option was applied for Greece, Romania, Bulgaria, Cyprus, Croatia, Malta and Slovakia. i.e. countries with derogation option were modelled to reach the 10% target by 2040. For countries that had already achieved a rate below 10%, the landfill rate was held constant. The annual landfilled amount is held constant in the modelling from 2035 or 2040 until 2050, depending upon whether a country falls under the derogation option. This scenario was titled WFD, as the implementation of LFD will require the adoption of WFD, reflecting the waste hierarchy[19].

Scenario 4 Landfill ban from 2023 (Ban): In this scenario, no waste amounts are deposited as of 2023, i.e. this scenario assumes a landfill ban for mixed MSW and household similar waste as of 2023 to show that even if no MSW and household similar waste is deposited in landfills, these landfill sites will still generate emissions over a long time. The modelled emissions reflect one year (2022) of MSW deposited in landfills.

Figure 1: Four scenarios of MSW annual deposition between 2022 and 2050



Source: Prognos and ifeu, 2025.

For the landfill methane emissions modelling (CH_4), the IPCC First Order Decay method for 2022-2030 (80 years from 2050, as the last year of municipal waste disposal considered) was applied using the ifeu-simplified model based on the IPCC waste model. The simplified ifeu model allows modelling different amounts of waste sent to landfill over a defined time frame. All landfill parameters (IPCC guidelines): the degradable carbon content (DOC), its fraction degraded (DOCf), the methane correction factor (MCF), the oxidation rate (OX), the methane content in landfill gas

[19] The scenarios are referred to as “WFD scenarios” because their design is based on measures along the waste hierarchy in accordance with the Waste Framework Directive (2008/98/EC). The assumed landfilling level of a maximum of 10% of municipal waste corresponds to the binding target set out in Article 5(5) of the Landfill Directive (EU) 1999/31/EC. The 10% landfilling target is indirectly supported by the Waste Framework Directive (WFD), but it is not laid down as a separate numerical target. Formally, it remains a target of the Landfill Directive, while the WFD provides the systematic framework and the overarching obligations that lead to the same outcome.

(FCH_4), methane recovery (R) and the k-value (defining the methane generation rate over time) are kept constant in the emissions modelling for all scenarios. The parameters used are primarily IPCC default values (also used by most countries), along with country-specific data for DOC and methane recovery, where available. Sensitivities were calculated to highlight the influence of the parameter value choices. The impact on climate change is calculated using the most recent IPCC data.[20] Global Warming Potential 100 (GWP 100) = 27 kg CO_2e/kg CH_4. The GWP 100 is the internationally agreed default.

Municipal waste and emissions from landfill deposition are calculated for the eight focus countries. The EU-27+UK results are based on EU-27-level data plus UK-level data. Greater detail on the methodology is provided in the Annex.

[20] IPCC 2021.

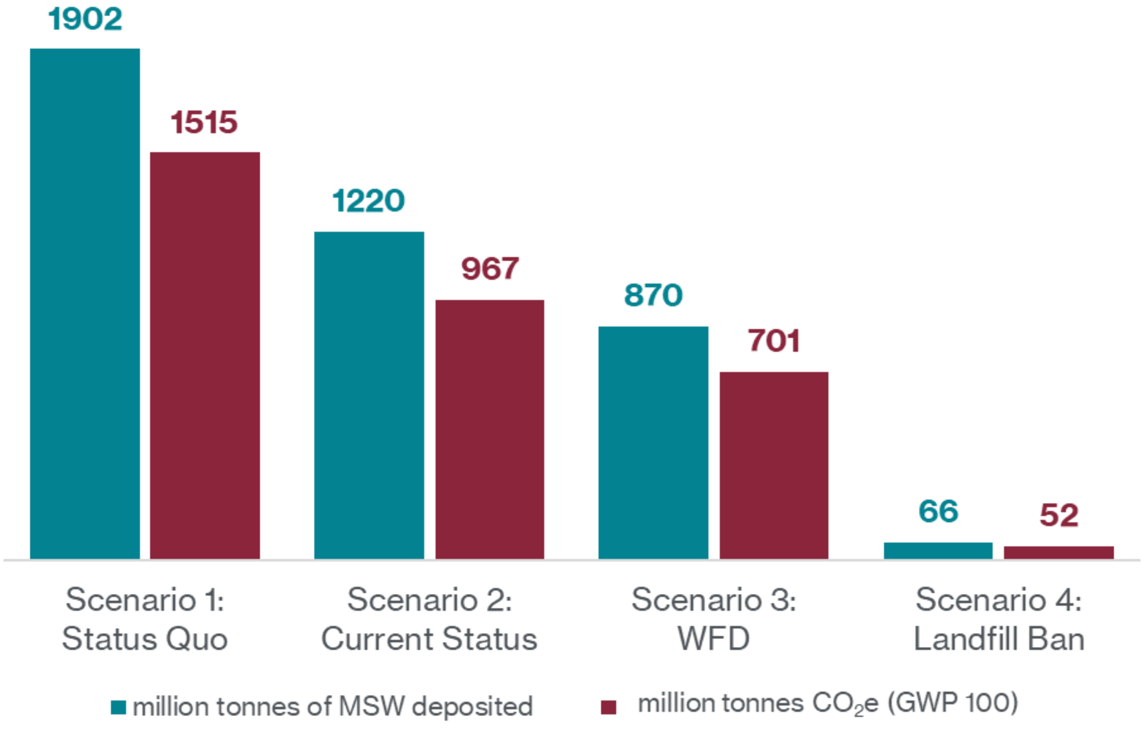
2 Main Results

2.1 EU-27+UK: MSW Deposited on Landfills and Methane Emissions from MSW Deposited on Landfills

In the Status Quo scenario, 1515 million tonnes CO_2e (GWP 100) methane will be produced by 2130 from the 1902 million tonnes of MSW deposited between 2022 and 2050. This is **2 times as much CO_2e** as the Waste Framework Directive (WFD) scenario, in which **701 million tonnes CO_2e** (GWP 100) methane will be produced with the realisation of the WFD from the 870 million tonnes of MSW deposited.

A complete ban on MSW landfill ban, as of 2023 (or full ban on MSW biogenic waste) would result in only **52 million tonnes CO_2e** (GWP 100) methane, which would be **reduced to 1/29th of the CO2e** of the Status Quo scenario (96.6% lower), **and 1/13th of** the WFD scenario (92.3% lower).

Figure 2: Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100) for EU-27+UK by Scenario



Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

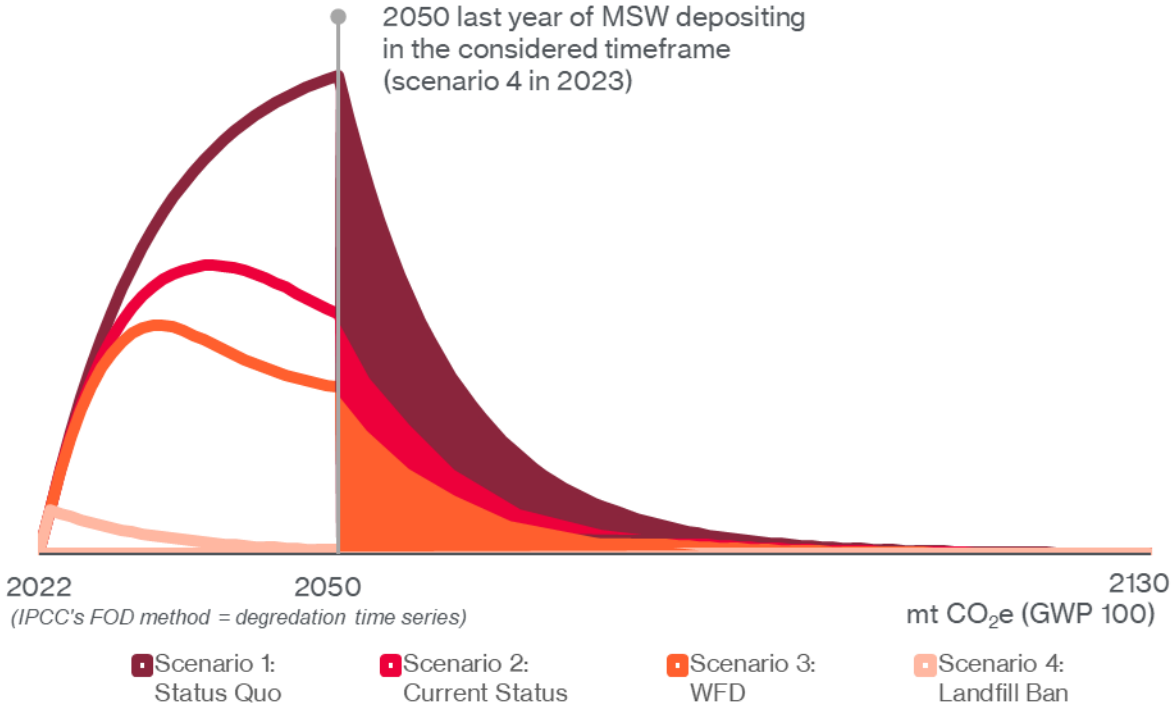
Figure 3 depicts the annual emissions between 2022 and 2130 from the MSW deposited on landfills between 2022 and 2050. The figure illustrates the gradual increase in emissions with each additional year of MSW deposited. The annual emissions grow until 2050 and subsequently decline as no more waste is deposited (2023 for the landfill ban scenario), and the rate of anaerobic decomposition decreases over time. Still, the area under each line, starting from the year 2050, highlights how methane emissions are produced for many years after the last tonne of MSW is deposited in landfills.

For the Status Quo scenario, 37% of the total methane emissions generated after 2050, i.e. in the period 2050 to 2130, **562** million tonnes **of the total 1515** million tonnes **CO_2e** (GWP 100) are released from MSW deposited on landfills between 2022 and 2050.

In the WFD scenario, 27% of the total methane emissions produced will be released after 2050, i.e. in the period 2050 to 2130, **189 of 701** million tonnes **CO_2e** (GWP 100) are released.

Methane emissions persist for many years after depositing MSW in landfills.

Figure 3: Annual methane emissions between 2022 and 2130 for the annual MSW deposited on landfills between 2022 and 2050 by scenario.



Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

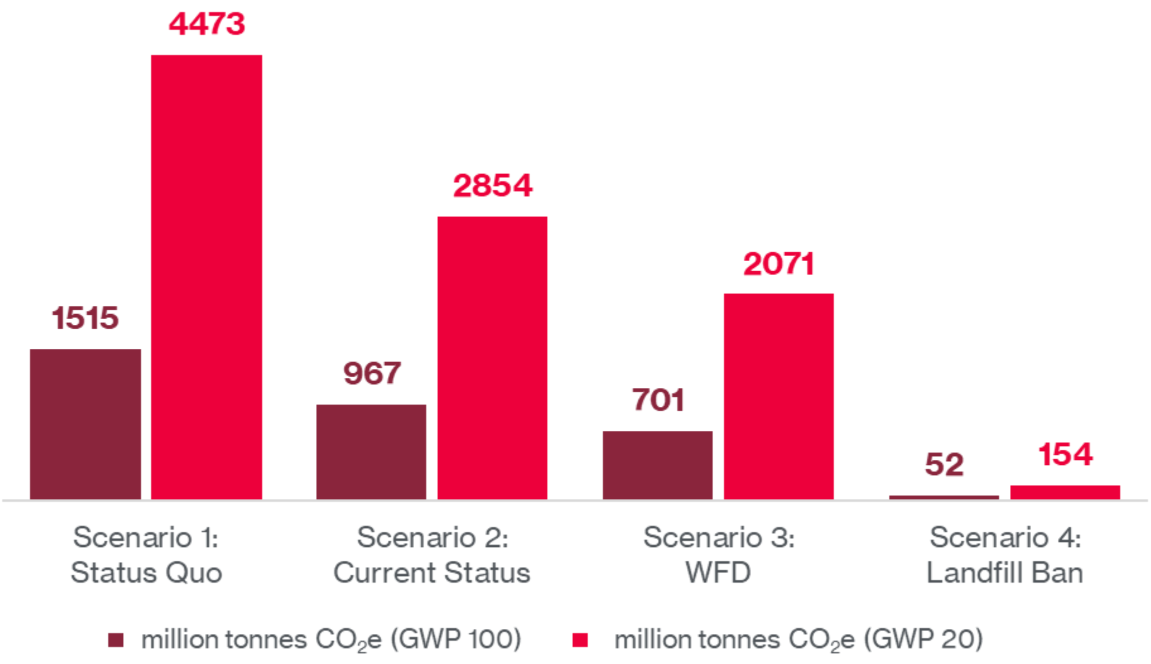
2.2 100-year versus 20-year Global Warming Potential

Global Warming Potential (GWP) quantifies a greenhouse gas's climate impact relative to CO_2 over a given time period. The standard is GWP 100, reflecting effects over 100 years; methane has a GWP 100 of 27, meaning 1 kg of methane has the potential to warm the climate as much as 27 kg of CO_2. As a short-lived climate pollutant with an atmospheric lifetime of ~12 years, the impact of methane in the atmosphere is limited to these 12 years, which is captured by GWP 20. Here, methane's value is 79.7, nearly three times its GWP 100.

Figure 4 highlights that the GWP 20 for non-fossil methane is **three times higher** than for GWP 100 across the four scenarios. In the Status Quo scenario, this is 4473 million tonnes **CO_2e (GWP 20)** versus 1515 million tonnes **CO_2e (GWP 100)**. In the WFD scenario, it is respectively 2854 million tonnes **CO_2e (GWP 20)** versus 967 million tonnes **CO_2e (GWP 100).**

Methane has a very high short-term warming impact (as reflected in GWP 20), so reducing methane emissions can slow the rate of near-term warming and "buy time", as the world is currently on course to miss established climate-protection targets and exceed the 2 °C threshold. While near-term methane mitigation can delay this trajectory, it must be implemented in tandem with robust CO_2 reduction measures.

Figure 4: 100-year versus 20-year Global Warming Potential (GWP)



Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

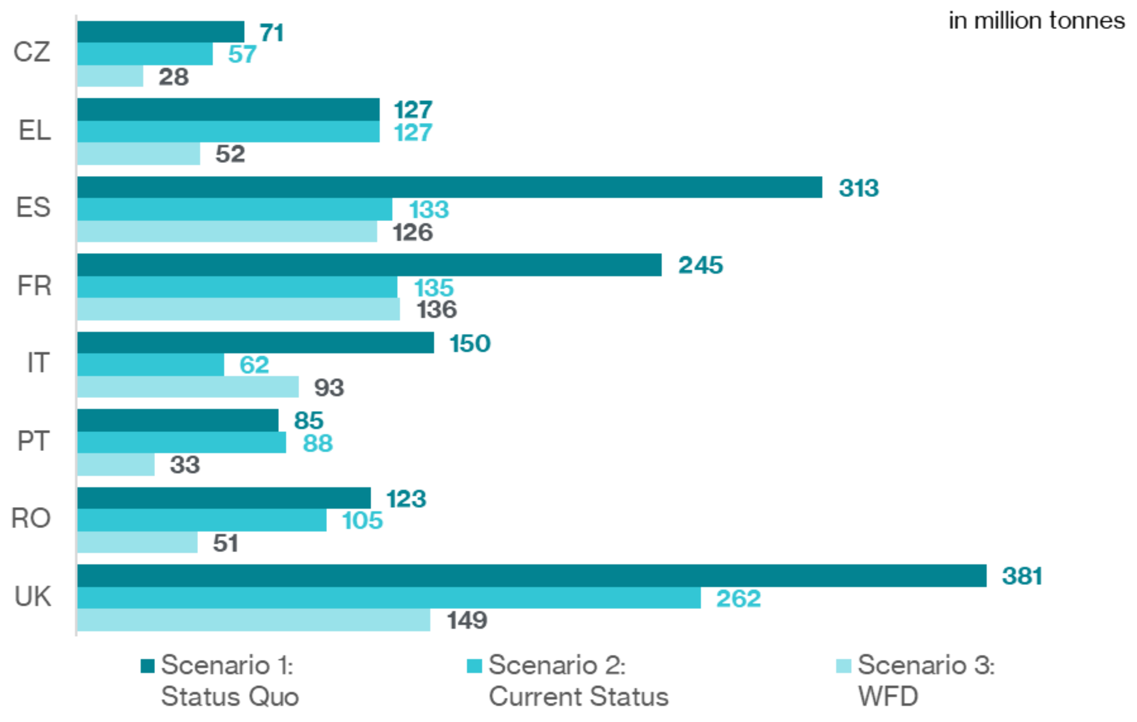
2.3 Country Focus: MSW Deposited on Landfills and Methane emissions for EU-27+UK from MSW Deposited on Landfills

Comparing the eight selected focus countries, the United Kingdom (UK), Spain (ES), France (FR), and Italy (IT) have the highest total amounts of MSW deposited in landfills. The country's waste amounts reflect the size, share and development of landfill waste deposits of these countries (see 4.1.2 for the country selection criteria).

The comparison between the Current Status and WFD scenarios suggests that some countries are advancing more rapidly in reducing MSW deposition in landfills. The modelling suggests that in France (FR) and Italy (IT), with the recent trends (Scenario 2), their Current Status will be lower than required by WFD (Scenario 3): FR: 135<136 million tonnes MSW deposited on landfills and IT: 62<93 million tonnes MSW deposited on landfills.

The modelling of the Current Status also suggests that some of the selected countries are not advancing sufficiently. In Greece (EL) and Portugal (PT), the current trend modelling of the Current Status (Scenario 2) will lead to the same or higher levels of MSW deposited on landfills than in the Status Quo scenario (Scenario 1) (EL: 127=127 million tonnes; PT: 88>85 million tonnes) and are not on track of reaching the WFD scenario. In the other selected countries, the current trend of Current Status modelling (Scenario 2) is insufficient to achieve the WFD scenario (Scenario 3): CZ: 71 → 57 → 28, RO: 123 → 105 → 52, UK: 381 → 262 → 149 million tonnes of MSW deposited on landfills.

Figure 5: Total MSW deposited by Country and Scenario between 2022 and 2025 in million tonnes



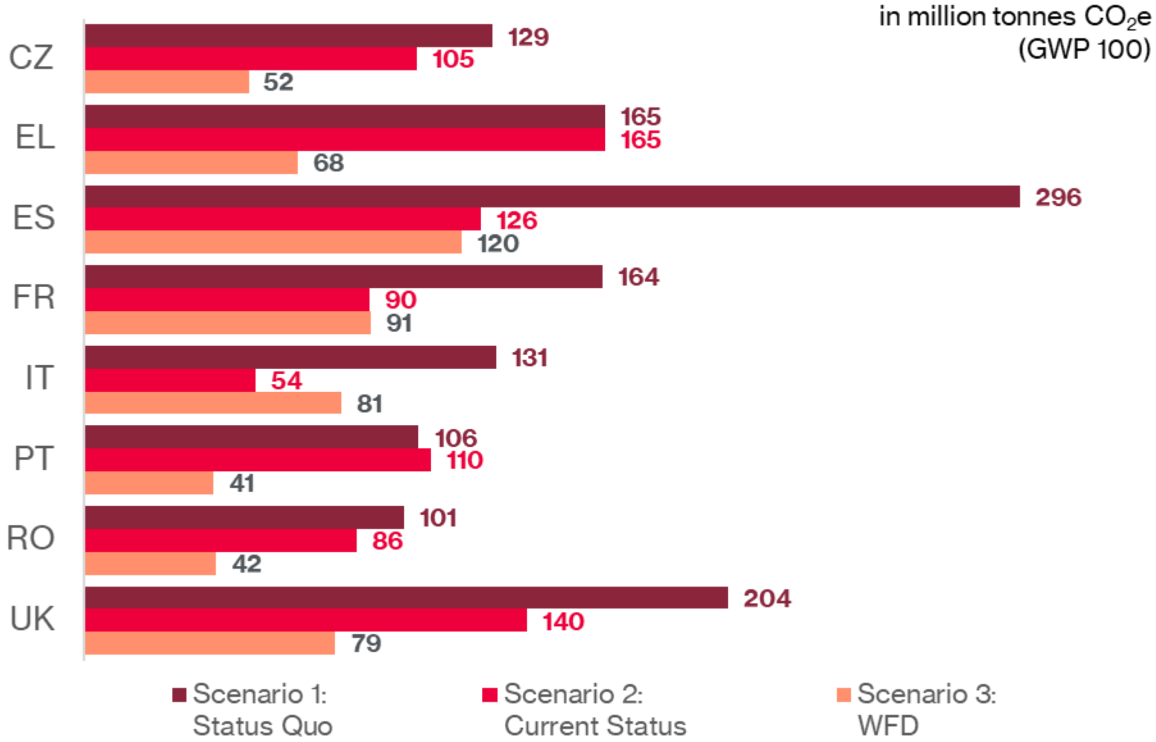
Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

The resulting methane emissions show a similar relative size by country as MSW deposited on landfills, but with varying orders of magnitude, as methane emissions do not scale linearly with waste amounts. In the Status Quo scenarios, Spain stands out with 296 million tonnes CO_2e. Spain is followed by the United Kingdom with 204 million tonnes of CO_2e, Greece with 165 million tonnes of CO_2e, and France with 164 million tonnes of CO_2e.

The effects of the MSW waste deposition scenarios are reflected in methane emissions. For example, Italy's methane emissions are lower in the Current Status scenario than in the WFD scenario.

Countries' overall size of methane emissions from MSW deposited on landfills varies because of the amount of MSW deposited, as well as key parameters affecting the generation of methane emissions.

Figure 6: Methane emissions by Country and Scenario 2022-2130 in million tonnes CO_2e (GWP 100)



Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050. Note for EL and CZ: The modelling is based on methane recovery rates for 2023 from the EU's official inventory submission 2025 (EEA 2025a, page 479, April 2025). See methodological note on the next page.

Two significant methane emission modelling parameters are:

- Degradable organic carbon (DOC), which expresses the share of carbon that is biodegradable (not to be confused with biogenic or organic waste), and
- Methane recovery (R), also known as Capture Rate.

Figure 7 makes the effect of these parameters explicit. Expressing methane emissions from MSW deposited in landfills per tonne of MSW landfilled allows for comparisons across countries. Methane emissions per tonne of MSW deposited in landfills (kg CH_4/t MSW landfilled) are like the "footprint" to compare country results. It is informed by the waste composition, as expressed by the DOC parameter, and the methane recovery rate (R) (0 if none are installed or low). The methane footprint per tonne of MSW deposited in landfills is highest in the Czech Republic at 68 kg CH_4 per tonne MSW landfilled, and lowest in the United Kingdom at 20 kg CH_4 per tonne MSW landfilled.

High methane emissions result from higher DOC values and low methane recovery (R). For the DOC parameter, estimates are often based on the IPCC default value. In this study, the DOC parameters were used as in the National Inventory Documents (NIDs). Spain and France apply the IPCC DOC default values. The model's derived IPCC DOC default value of 0.15 is the result of a rounded average for Europe (Eastern 0.14; Northern 0.13; Southern and Western 0.16 as in IPCC, 2006). The default value is not explicitly stated, but the overall average, and thus the value for Europe, is obtained using this averaging approach. For the EU-27 aggregate model and for the United Kingdom[21], this derived IPCC default DOC value was also used.

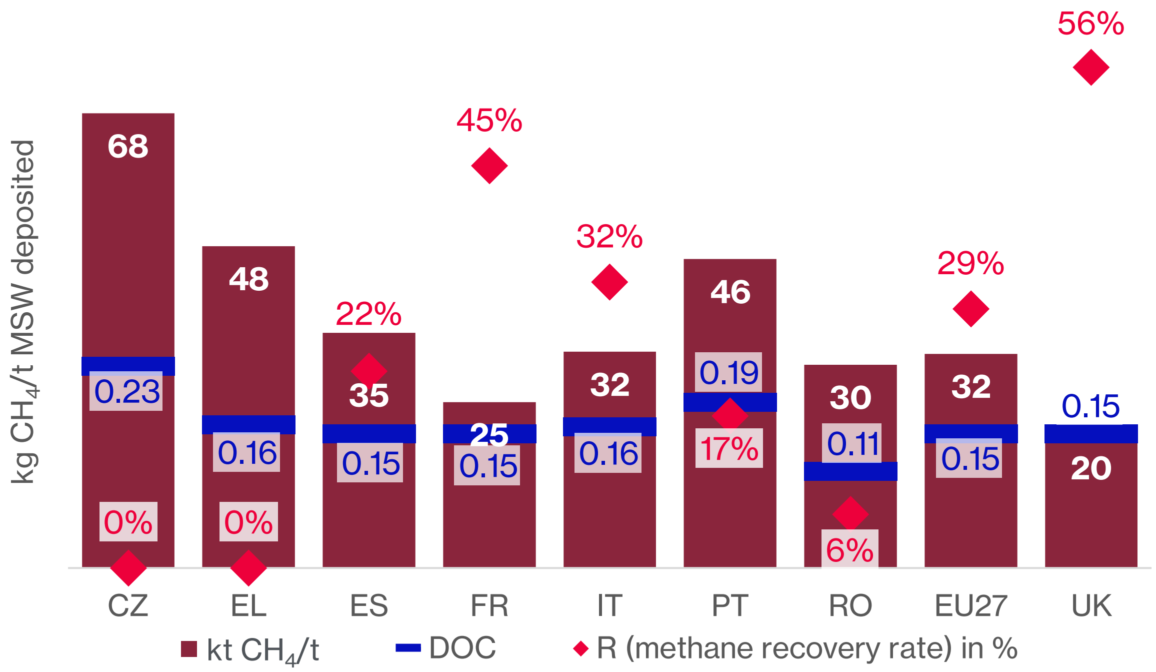
The figure shows that the applied DOC values vary across countries, ranging from 0.23 in the Czech Republic to 0.11 in Romania.

The methane recovery rate (R) or methane capture rate ranges in the modelling from 0% for the Czech Republic to 56% for the United Kingdom. The methane recovery rates for 2023 are based on the EU's official inventory submission 2025 (EEA 2025a, page 479, April 2025) as a consistent data source for the emission modelling. The methane recovery rates are not explicitly stated in the respective NIDs and CRTs. These rates can, however, be derived e. g. from the Common Reporting Tables (CRT) for 2023 (submitted on or after April 2025). The deviation between the EEA submission and the rates derived from the CRTs is noteworthy for CZ and EL. CZ: 0% (EEA, 2025a) versus 10% (CZ CRT 2025), and EL: 0% (EEA, 2025a) versus 27% (EL CRT 2025).

Applying the derived national methane recovery rates for 2023 in the modelling for Greece and Czechia (27% and 10%), the results of the ranking of countries would not change for the Czech Republic; the specific methane emission footprint would be 61 kg CH_4 per tonne. For Greece, the specific methane emission footprint would be 35 kg CH_4 per tonne MSW landfilled, and thus in the range of Spain. Per scenario the results for CZ are: 116 $mtCO_2e$ (Scenario 1), 95 $mtCO_2e$ (Scenario 2), and 47 $mtCO_2e$ (Scenario 3), for EL: 121 $mtCO_2e$ (Scenario 1 and 2), 50 $mtCO_2e$ (Scenario 3). The modelling results may differ, as shown in Figure 6, but remain robust for the Czech Republic; for Greece the ranking would be better.

[21] UK does not report the DOC in its NID but only background data, based on which a rough estimate was done (see Chapter 4.3).

Figure 7: Comparison of emissions footprint, DOC and R values



Source: Prognos and ifeu, 2025. Note for EL and CZ: The modelling is based on methane recovery Rates for 2023 from the EU's official inventory submission 2025 (EEA 2025a, page 479, April 2025). See methodological note on the previous page.

2.4 Sensitivities of Methane Emissions to DOC and R-Value for EU-27+UK

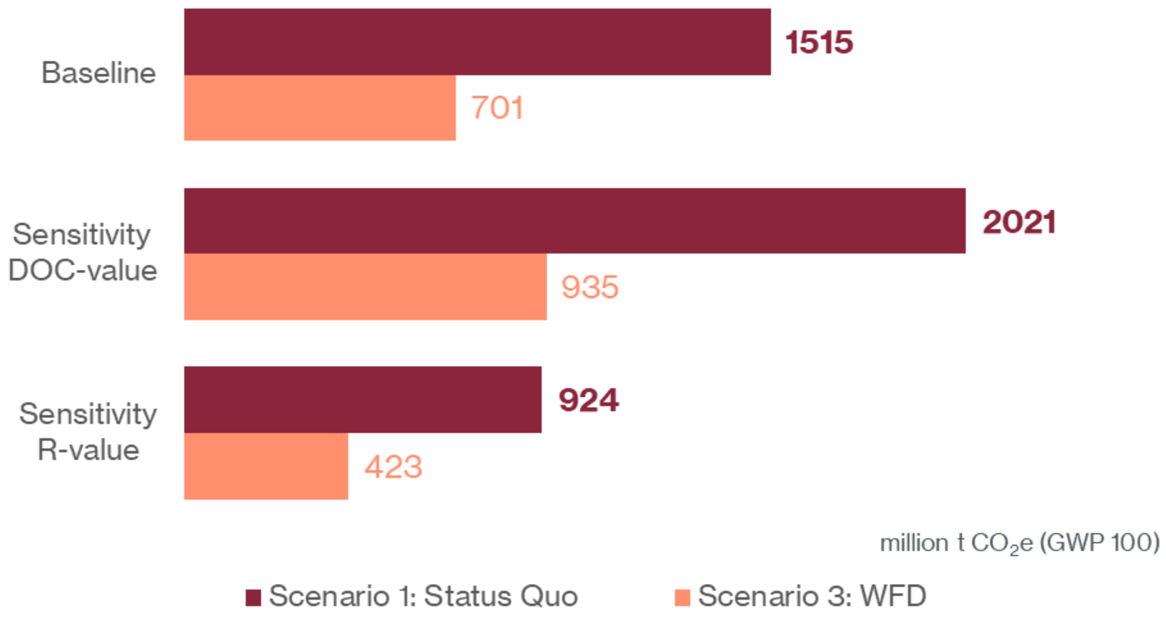
The effect of the chosen values for the DOC and R parameters is significant, as illustrated in Figure 8 for the EU-27+UK.

Changing the DOC value from 0.15 (derived IPCC default) to 0.20 results in **2021** million tonnes **CO_2e** (for scenario 1) compared to the baseline of 1515 million tonnes **CO_2e of** methane emissions from MSW deposited on landfills between 2022 and 2050. That is **1.3 times higher** than in the baseline derived in this study for the Status Quo scenario. Respectively, the WFD scenario would be 935 million tonnes CO_2e, rather than 701 million tonnes CO_2e.

The **0.20 DOC-value** for the EU-27+UK seems **more realistic** than the derived IPCC default value of 0.15, as the estimated emissions for the 8 focus countries are already close to those for the EU-27+UK with the derived IPCC default DOC value. The total methane emissions of the seven selected EU-27 countries are already at about 80% of the EU-27 result estimated with the derived IPCC default. Hereby, it is essential to recall that the EU-27 is based on EU-27 values, not an aggregation of country data. This study only investigated the eight selected focus countries.

In contrast, increasing methane recovery from an average of 34% (2023) to 60% would reduce methane emissions by 39% relative to the baseline.

Figure 8: Sensitivities of Methane Emissions for EU-27+UK to DOC and R-Value



Source: Prognos and ifeu, 2025.
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

3 Key Observations and Takeaways

Actions taken today affect future landfill emissions.

If we do not act, the MSW deposited between 2022 and 2050 will amount to 1902 million tonnes, resulting in **1515 million tonnes of methane emissions** in the EU-27+UK, excluding historical deposits. The implementation of the WFD, and specifically the LFD, would **reduce** methane emissions **by 54 %** compared to the Status Quo scenario.

Methane has a very high short-term warming impact (as reflected in GWP 20), so reducing methane emissions can slow the rate of near-term warming and “buy time”, as the world is currently on course to miss established climate-protection targets and exceed the 2 °C threshold. While near-term methane mitigation can delay this trajectory, it must be implemented in tandem with robust CO_2 reduction measures.

Even after 2050 (end of time frame considered for MSW disposal) methane emissions persist for many years

Assuming no change in waste composition and recovery rate, the emissions after deposition stops account for **37%** of the total methane emissions generated (562 million tonnes from 1515 million tonnes CO_2e) in the Status Quo scenario. In the WFD scenario, it is **27%.**

Methane emissions per tonne of MSW deposited allow for comparison across countries.

Results depend on the key parameters, methane recovery (R) and degradable organic carbon (DOC). The DOC, in turn, depends on the waste composition, i.e., the biodegradable content of the waste deposited in landfills. Even if MSW deposited in a country is comparatively low, methane emissions can be significant if DOC is high and the R-value is low.

Data challenges exist for accurately modelling methane emissions from MSW deposited.

In particular, historical data on and waste composition of deposits are limited or not publicly available; therefore, the study focuses on MSW deposits between 2022 and 2050.

Uncertainties on actual emissions exist. Especially regarding current emissions from historical depositions, some studies suggest emissions are significantly higher than reported (e.g., studies based on satellite data).

The above considerations should be critically reflected upon when discussing, selecting, and applying CO_2e emission factors. Although these factors could be derived from the data presented in this study, they are only valid for the respective scenarios and underlying assumptions.

4 Annex: Methodology and Data Basis

4.1 Overall Modelling Approach: Data Context and Approach

Given that a key aim is to show and raise awareness of the temporal relationship between landfill waste deposited and methane emissions generated, scenarios are a key element of this study. Modelling scenarios for emissions is an essential process for understanding future greenhouse gas emissions, their impacts on climate change, and the effectiveness of different strategies to reduce emissions.

For modelling different pathway scenarios that can be influenced by policies, excluding historical depositions from the emissions model is an effective way to estimate future impacts and compare scenarios. Modelling allows to quantify differences and provide quantitative orientation under different assumptions, while ensuring consistency and comparability. This, in turn, supports public debate and awareness.

The modelling work thus sought a consistent landfill waste volume modelling approach to represent different waste amounts under defined scenarios, including clear definitions of key methane emission modelling parameters, value ranges, and IPCC default values.

A preparatory analysis was therefore conducted to determine an appropriate modelling methodology for the study to achieve robust, consistent estimation and, in the process, identify and highlight data and methodological challenges. The preliminary analysis focused on the Czech Republic and Slovakia, with the main study focusing on the Czech Republic, Spain, France, Greece, Italy, Portugal, Romania, and the United Kingdom.

The analysis examined the National Inventory Documents submitted to the United Nations Framework Convention on Climate Change (UNFCCC), the IPCC guidelines for national greenhouse gas inventories, Volume 5 Waste[22], and statistical data for waste generation and treatment from Eurostat.

The data and NID analysis highlighted that the availability of background data on landfill methane emissions varies across regions and countries. European Union member states and the United Kingdom, as Annex I parties to the Kyoto Protocol, have committed to reporting greenhouse gas emissions according to the Common Reporting Format (CRF). Accordingly, methane emissions are determined and reported using a standardised approach. However, the availability and collection of background data on landfill methane emissions pose several challenges.

The analysis of the NIDs also showed that different methodologies were used to determine the amounts of waste landfilled. Waste is not consistently differentiated by type (e.g., municipal solid waste (MSW), industrial waste (IW), garden waste, etc.). The level of detail for the origin of the biodegradable waste fractions landfilled differs between the selected countries. At the Solid Waste

[22] IPCC 2019.

Disposal Site (SWDS), industrial waste is often included, although not always in the same way or at all. Technical information on the type of site, like gas collection, is not a reporting obligation for the NIDs, but for statistics; here, the data is missing. For some countries information on gas collection is not available, is only very limitedly available, or is very time-intensive to obtain (e.g., analysis of satellite images). In the NIDs, parameter values applied in the emission calculations are not always explained.

The share of biodegradable content and the parameters used to estimate landfill emissions are often IPCC default values.[23] A recent study[24], for example, has highlighted the uncertainty and range in methane emissions levels. Data on methane recovery is reported in the NID of the EU-27 for all EU member states[25]. However, information on how the values were determined is not provided.

Additional analysis highlighted that municipal solid waste and commercial waste similar to household waste, are the principal sources of biodegradable waste. Methane emissions occur at various stages in a landfill's life cycle, both in existing and closed landfills. Closed landfills emit methane at a reduced rate, as no new waste is added, and the rate of anaerobic decomposition decreases over time. For existing landfills, methane emissions are often partly captured to control and minimise them. By installing gas collection systems, landfill gas (mainly methane and carbon dioxide) can be partly recovered and either used to generate energy or flared to prevent its release into the atmosphere.

Key challenges include differences in data availability, data quality, and reporting practices for landfill waste volumes and landfill infrastructure, as well as calculation data across countries, as shown in NIDs, despite clear emission modelling methodologies provided by the IPCC. In addition, uncertainties in landfill methane emission modelling arise from the application of IPCC default values and the sensitivities of key parameters. In summary, the following observations were made:

- **Incomplete data:** Not all landfills have the infrastructure to measure and monitor methane emissions effectively.
- **Lack of or limits of standardisation:** Different data collection and assessment methods can be a source of inconsistencies and uncertainties in reported data. Countries may produce national inventories of methane emissions from landfills, derived from modelling that utilises assumptions and data from various sources. Some of these differences may result from variations in technologies, waste compositions, waste collection systems, and climate, among other factors, within and between countries. Recent studies using satellite-based measurement approaches have contributed to the discussion of uncertainty in reported or modelled emission estimates[26].

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[23] IPCC 2019.
[24] Dogniaux et al., 2025.
[25] NID for EU from UNFCC 2025.
[26] Dogniaux et al, 2024.

- **Uncertainties increase and assumptions become stronger the further backwards the estimations of historical waste deposited in landfills go.** Historical data on landfill deposition are limited; methodologies and datasets have varied in the past. Assumptions of different strengths are made by countries to estimate historical waste deposited in landfills and resulting emissions.

For a landfill methane emission modelling approach suitable for scenario analysis, two models were combined.

- A waste model to quantify the most relevant waste volumes with biodegradable content deposited on landfills that allows estimating 4 different scenarios, and
- A methane emissions model that quantifies the future methane emissions from wastes deposited on landfills over time.

In the following sub-chapters, further explanations and details are provided on the:

- **4.2 Waste data and methods**: details the waste statistic data situation and describes the waste modelling and waste modelling scenarios.
- **4.3 Methane emissions data and methods:** details the methane emissions data situation and describes the methane emissions modelling.

4.2 Waste Data and Methods

4.2.1 Principal available waste data sources and discrepancies

The waste volume modelling is based on the latest available data year, 2022, from the consistent Eurostat waste statistics database and national statistics for the United Kingdom. Eurostat provides the most consistent waste data statistics at the European level. The year 2022 was selected because it is the most recent year for which Eurostat has available waste data. Eurostat provides the most suitable database for waste data. These are supplied in different waste statistics. The most relevant for this study are WASGEN, WASTRT, and WASMUN. Each of these provides a unique and complementary perspective. As a result, they are not fully correspondent to each other.

For example, the totals of WASGEN and WASTRT vary due to import and export effects. This difference between generation and treatment is also reflected in the WASMUN statistics. WASMUN, however, does not provide amounts per waste stream. WASMUN does not provide information on the waste composition directed to landfills and the respective biodegradable content. WASMUN also includes the stabilised output from MBT-pre-treated mixed solid waste. Even if the data are not optimal due to aggregation and the need for adjustments based on available national data, the database is consistent and coherent across EU Member States.

As the analysis showed, the primary sources of biodegradable waste are municipal waste and industrial waste similar to household waste, and sorting and treatment residues. At the same time, Eurostat's WASTRT statistics were not suitable, as the waste with biodegradable content cannot be clearly demarcated.

The most applicable waste statistic is then the WASMUN statistics from Eurostat, which apply a broader definition of municipal waste, i.e., municipal waste, waste similar to household waste, and sorting and treatment residues from MBTs (mechanical biological treatment). WASMUN also differentiates by treatment route.

NIDs also report on the amount of waste landfilled. However, the country selection analysis of the NIDs highlighted no consistent methodology for estimating the amount landfilled. For example, a country may include all wastes deposited in landfills, including industrial and construction waste, most of which do not contain biodegradable waste. Scope and data sources used may vary by country, as may transparency regarding them. In some cases, NIDs are detailed, including waste composition information; in others, they are not.

Comparing the NID-reported waste landfilled with Eurostat waste statistics proved not to be directly possible. However, a comparative orientation could be achieved by comparing the waste volumes landfilled with the WASMUN statistics for landfills, and waste volumes landfilled reported in the NIDs. For some countries, significant differences exist between WASMUN and NID-reported waste volumes deposited in landfills. This comparison allowed accounting for discrepancies between NID and WASMUN statistics, and considering implications for building a consistent and comparable database based on 2022 WASMUN waste statistics to model the four scenarios for the EU-27+UK. In the resulting model, uncertainties are addressed through a series of explicit assumptions.

The modelling **excluded the historically deposited amounts** of municipal solid waste and emissions generated from these, due to data uncertainties, especially regarding historical waste deposits and their waste compositions, as well as the significant efforts needed to replicate their methodologies, if at all possible. Instead, the study focuses on future landfill deposits (i.e., between 2022 and 2050) to highlight the implications of different scenarios for methane emissions (2022-2130).

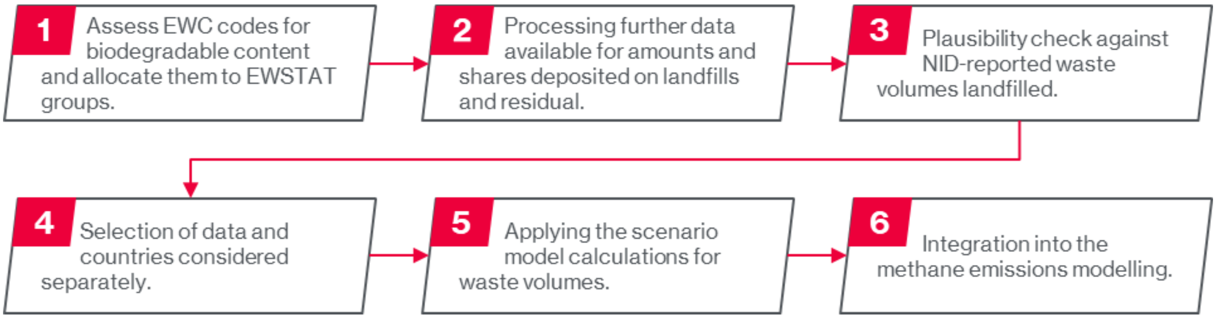
4.2.2 Methodology for landfilled organic wastes from MSW

The following key data sources were used: Eurostat's statistical databases WASTRT (NHAZ) and WASMUN, and the European Waste Classification for Statistics (EWC-Stat), for selected waste categories based on the Prognos European List of Waste (LoW) to EWC-STAT correspondence approach.

The landfill waste volume modelling was conducted bottom-up, i.e. for each EU Member State and the UK from which the aggregate (EU-27+UK) is formed. The main steps of the waste volume modelling were (see Figure 9):

- **Step 1:** Assess EWC Codes for biodegradable content and allocate them to EWSTAT groups
- **Step 2:** Processing further data available
- **Step 3:** Plausibility checks against NIDs
- **Step 4**: Selection of data and countries considered
- **Step 5:** Applying the scenario modelling
- **Step 6:** Integration with the methane modelling

Figure 9: Key waste modelling steps



Source: Prognos and ifeu, 2025.

Step 1: Assess EWC Codes for biodegradable content and allocate them to EWSTAT groups (as data on EWC basis are rarely available).

In the **first step**, the non-hazardous EWC Codes were assessed for their biodegradable content and allocated to the EWSTAT groups, which have a waste-stream (material-based) focus, using correspondence tables. Healthcare codes were excluded from the analysis, as were plastic waste fractions, since biodegradable plastics play only a very minor role.

Table 1: Allocation of biodegradable waste EWC codes to EWSTAT classes

EWSTAT_Classification		EWC_Codes		biodegradable non-hazardous
07.2	Paper and cardboard wastes Match*: 5//5	030310	fibre rejects, ... sludges	complete
		030399	wastes not otherwise specified	share
		150101	paper and cardboard packaging	complete
		191201	paper and cardboard	complete
		200101	paper and cardboard	complete
07.5	Wood wastes Match*: 7//7	030101	waste bark and cork	complete
		030105	sawdust, cuttings, wood...	complete
		030301	waste bark and wood	complete
		150103	wooden packaging	complete
		170201	wood	complete
		191207	wood other than 19 12 06	complete
		200138	wood other than 20 01 37	complete
07.6	Textile wastes Match*: 7//12 (?)	040210	organic matter from natural	complete
		040221	wastes from unprocessed textile fibres	minor share
		040222	wastes from processed textile fibres	minor share
		150109	textile packaging	minor share
		191208	textiles	minor share
		200110	clothes	minor share
		200111	textiles	minor share

EWSTAT_Classification		EWC_Codes		biodegradable non-hazardous
W091	Animal and mixed food waste Match*: 21//25	020102	animal-tissue waste	complete
		020103	plant-tissue waste	complete
		020199	wastes not otherwise specified	share
		020201	sludges from washing and cleaning	complete
		020202	animal-tissue waste	complete
		020203	materials unsuitable for consumption	complete
		020299	wastes not otherwise specified	share
		020301	sludges from washing, cleaning, peeling...	share
		020302	wastes from preserving agents	complete
		020304	materials unsuitable for consumption ...	complete
		020399	wastes not otherwise specified	share (?)
		020499	wastes not otherwise specified	share (?)
		020501	materials unsuitable for consumption ...	complete
		020599	wastes not otherwise specified	share (?)
		020601	materials unsuitable for consumption ...	complete
		020602	wastes from preserving agents	share (?)
		020701	wastes from washing...of raw materials	complete
		020702	wastes from spirits distillation	complete
		020704	materials unsuitable for consumption	complete
		190809	grease and oil mixture from oil/water separation containing only edible oil and fats	share (?)
		200108	biodegradable kitchen and canteen waste	complete
W092	Vegetal wastes Match*: 2//2	020107	wastes from forestry	complete
		200201	biodegradable waste	complete
W101	Household wastes Match*: 2//4	200301	mixed municipal waste	share
		200307	bulky waste	share
W102	Mixed and undifferentiated materials Match*: 4//22	020799	wastes not otherwise specified	minor share
		150105	composite packaging	minor share
		150106	mixed packaging	minor share
		190203	premixed wastes composed ...	minor share
W103	Sorting residues Match*: 2//11	190502	non-composted fraction	complete
		191212	other wastes (including mixtures of materials)	share
W11	Common sludges Match*: 2//18	190805	sludges from treatment of urban waste water	complete
		170506	dredging spoil ..	share
W121	Mineral waste C&D Match*: 1//12	170904	mixed construction and demolition wastes ...	minor share

* Match = number of waste codes containing biodegradable fractions compared to the number of EWC-Codes for non-hazardous waste within the EWC-Stat Group

Source: own assessment Prognos AG.

The allocation to the classification shows that waste codes containing biodegradable waste can be assigned to the different EWSTAT classes. Since EWSTAT uses a material-flow-based approach, it is not possible to provide a precise quantification.

However, the allocation allows for an initial indicative assessment of which EWSTAT classes contain noteworthy biodegradable wastes (table above), and which relevant proportions are landfilled (table below). The following table (see below) shows the landfill shares for the EWSTAT classes containing biodegradable fractions at the EU-27 level. These two tables combined indicate that the two classes, household wastes (W101) and sorting residues (W103), have a noteworthy share of biodegradable content (table above) and a significant share is landfilled (table below). For mineral waste from construction and demolition (W121), it is the opposite, has a low share of biodegradable content and a low share landfilled.

Table 2: EWSTAT classes containing biodegradable waste fractions and the share landfilled for non-hazardous waste

EWSTAT Classification	Waste fraction	Total amount of non-hazardous waste treated (in kt/2022)	Total amount of non-hazardous waste landfilled* (in kt/2022)
W072	Paper and cardboard wastes	30650	10 (0%)
W075	Wood wastes	39600	60 (0%)
W076	Textile wastes	1380	160 (12%)
W091	Animal and mixed food waste	23950	1140 (5%)
W092	Vegetal wastes	42690	550 (1%)
W101	**Household and similar wastes**	**87120**	**28160 (32%)**
W102	**Mixed/undiff. materials**	**22750**	**5170 (23%)**
W103	Sorting residues	81180	35410 (44%)
W11	Common sludges	10920	490 (4%)
W121	Mineral waste from C&D	272880	22440 (8%)

* The percentages in brackets refer to the proportion of the total non-hazardous waste treated.
Source: ENV_WASTRT (data for 2022).

Thus, the waste statistics containing W101 and W103 are the most relevant to consider when analysing landfill emissions from biodegradable waste fractions. WASMUN encompasses these two waste classes, with only a marginal amount of W103 excluded.

Step 2: Processing further data available

In the second step, further statistical data were evaluated, particularly at the national level, to determine the proportion of biodegradable waste in the EWSTAT groups more precisely. This also included analyses of imports and exports, as the WASTRT data refer to waste amounts treated in a member state, including generated quantities within the country and imports, but excluding exports to other member states. However, it became apparent that, at the level of individual Member States, data at the 6-digit EWC level are available for only a few Member States.

Step 3: Plausibility checks against NIDs

In the next step, a plausibility check against NID-reported waste volumes landfilled was carried out.

For the waste sector (Volume 5 of the IPCC Guidelines), the following data are required for the calculation of methane emissions: Annual amount landfilled, broken down by waste type (Municipal waste, industrial waste, sewage sludge).

Analysis of the NIR data for the selected Member States has shown that they do not proceed uniformly, both methodologically and in terms of the level of detail presented. While some focus primarily on deposited municipal waste, other Member States consider all waste deposited in municipal waste landfills, regardless of whether it contains significant amounts of organic waste or not. In other countries, municipal waste is primarily considered. As data are generally unavailable at the AVV 6-digit level, it was not possible to make a conclusive comparison.

Step 4: Selection of data and countries considered

In step 4, the data basis to be used for the study was selected. Based on the previous steps, the WASMUN Statistic was chosen:

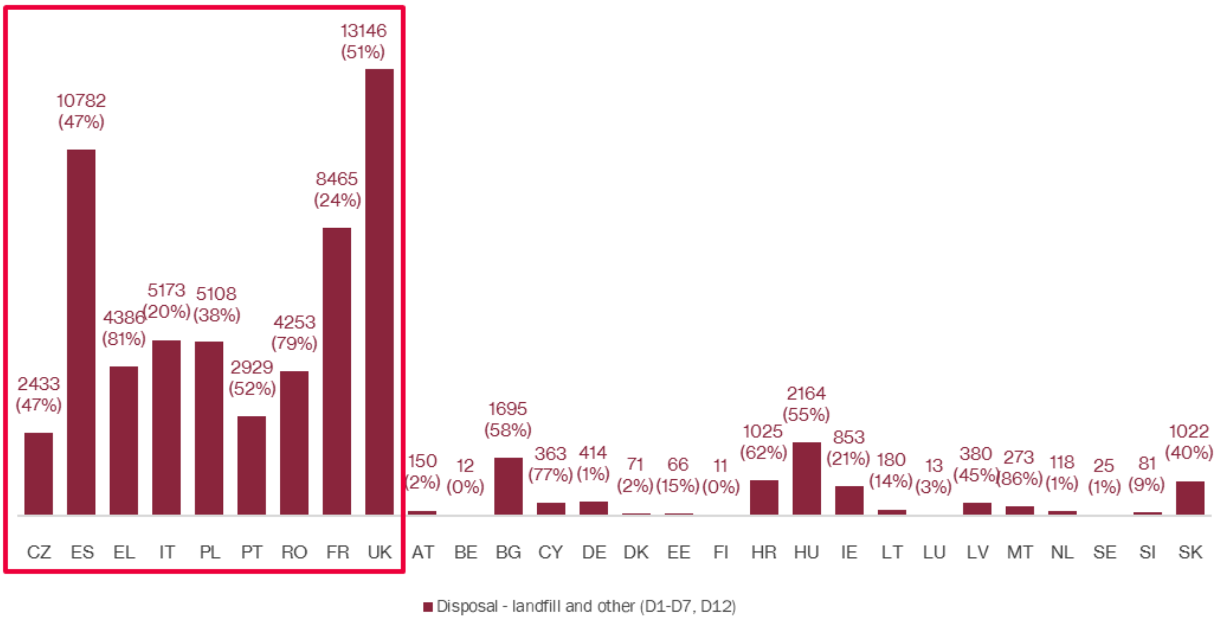
- The WASMUN statistic represents an established, regularly updated and methodologically verified data basis. WASMUN considers not only waste from households, but also commercial waste similar to household waste, thus following an expanded definition of municipal waste (containing both primary and secondary waste fractions).
- Compared to other types of waste, municipal waste has the highest proportion of biodegradable materials. This makes it highly representative of methane formation in landfills. The relevant waste codes are summarised proportionally in the WASTRT statistics under various groups, with the proportions relevant to landfill, particularly under W101 (Household and similar waste) and W103 (Sorting residues). Sorting residues contains, among others, also the output fraction from MBT pre-treatment.
- The IPCC guidelines for calculating methane emissions from landfills are based on the quantity and composition of municipal and industrial waste, as well as sewage sludge deposited. WASMUN data provide most of these parameters as presented in Table 2 and enable consistent, internationally comparable calculations.
- The WASMUN statistics serve as the basis for implementing the Waste Framework Directive, particularly the 10% landfill target. WASMUN statistics correspondingly allow for the construction of consistent scenarios for national and European reporting.

As described above, the data availability and quality were analysed, and the most consistent and robust database for EU-27+UK was selected for the country selection and emission estimation. This was municipal solid waste (MSW) and commercial waste comparable to household waste based on WASMUN statistics, as the primary sources of biodegradable waste, and as a robust MSW data basis based on an extended municipal waste definition, incl. residues from M(B)T pre-treatment.

The regional focus was selected, covering **EU-27+UK**, with **selected focus countries**: **UK, France, Greece, Italy, Portugal, Romania, Spain, and the Czech Republic**, reflecting their share in EU-27+UK MSW deposited on landfills and differing waste management situations. Following, the main steps were performed to build a consistent waste database suitable for scenario building and emissions modelling.

Countries were selected for the study whose absolute landfill volumes account for a significant share of the total within the EU-27+UK. The amount of MSW deposited in landfills in the selected member states for this study totals 56.7 million tonnes, equal to 86% of the total amount landfilled (65.6 million tonnes) within the EU-27+UK.

Figure 10: Total amount of MSW deposited in landfills in 2022 in thousand tonnes



Percentage in brackets refer to the share of MSW deposited at landfills compared to the total amount of MSW treated.
Source: ENV_WASMUN (data for 2022, data for Ireland are estimations), data for UK based on DEFRA 2024.

Step 5: Applying the scenario modelling

In step 5, the scenarios were modelled. The following four scenarios provide a quantitative orientation on the effects on waste amounts deposited between 2022 and 2050, based on methane emissions generated from these over their lifetimes between 2022 and 2130.

The waste amounts were modelled bottom-up for each of the EU-27 member states and the UK, with the waste composition assumed to be constant.

- **Scenario 1 Status Quo (SQ):** The annual amount of waste deposited until 2050 is held constant at 2022 levels, i.e., no change in the annual deposited landfill amount is modelled. This scenario shows an upper range of possible future methane emissions.

- **Scenario 2 Current Status (CS):** The annual amount of waste deposited is based on the average annual change between 2018 and 2022. For countries with a positive growth rate, the highest observed share of total MSW deposited in landfills was applied and held constant. The rate was held constant for those Member States with a landfilling rate already below 10% in 2022.

- **Scenario 3 Waste Framework Directive (WFD):** The annual amount of waste deposited was reduced to a maximum of 10% by 2035 and then kept constant in accordance with the Landfill Directive (LFD). The derogation option[27] was applied for Greece, Romania, Bulgaria from the selected member states in this study and additionally for Cyprus, Croatia, Hungary, Malta and Slovakia to derive the EU-27 scenario-based waste amounts landfilled. Countries with the derogation option were modelled to reach the target by 2040. In countries that had already achieved a rate below 10%, the landfill rate was held constant. The landfill amount is held constant in the modelling from 2035 or 2040 until 2050, depending upon whether a country falls under the derogation option. In this scenario, it is assumed that the MSW still contain biogenic wastes. This scenario was titled WFD, as the implementation of LFD will require the adoption of WFD, reflecting the waste hierarchy[28].

- **Scenario 4 Landfill ban from 2023 (Ban):** In this scenario, no waste amounts are deposited as of 2023, i.e. this scenario assumes a landfill ban for mixed MSW and household similar waste as of 2023 to show that even if no MSW and household similar waste is deposited in landfills, these landfill sites will still generate emissions over a long time.

Step 6: Integration with the methane modelling

Finally, the waste modelling data was prepared for integration into the emissions model. This involved an annual amount of waste deposited in landfills for the EU-27+UK and each of the selected countries.

[27] Member States that landfilled more than 60% of their municipal waste in 2013 may request for the derogation option.

[28] The scenarios are referred to as “WFD scenarios” because their design is based on measures along the waste hierarchy in accordance with the Waste Framework Directive (2008/98/EC). The assumed landfilling level of a maximum of 10% of municipal waste corresponds to the binding target set out in Article 5(5) of the Landfill Directive (EU) 1999/31/EC. The 10% landfilling target is indirectly supported by the Waste Framework Directive (WFD), but it is not laid down as a separate numerical target. Formally, it remains a target of the Landfill Directive, while the WFD provides the systematic framework and the overarching obligations that lead to the same outcome.

4.3 Methane Emissions Data and Methods

4.3.1 Calculation Method and scope for scenarios

Methane emissions for the scenarios are calculated following the 2019 Refinement to the 2006 **IPCC Guidelines** for National Greenhouse Gas Inventories, Volume 5 Waste, Chapter 3 Solid Waste Disposal (IPCC 2019). The **first order decay (FOD) method** described therein is mandatory for Annex I parties[29] of the Kyoto-Protocol. The equations to be used for calculating the amount of methane emissions are shown in Figure 11. The IPCC FOD method is the globally recognised method for calculating methane emissions from landfilling[30], but data uncertainties necessarily remain.

Figure 11: Equations for calculating the amount of CH_4 emissions (IPCC 2019, V5, Ch3)

1) Decomposable DOC from waste disposal data

$$DOCC_m = W * DOC * DOC_f * MCF \qquad \text{Equation 3.2}$$

2) $DDOC_m$ accumulated in the SWDS at the end of the year T

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1} * e^{-k}) \qquad \text{Equation 3.4}$$

3) $DDOC_m$ decomposed at the end of year T

$$DDOC_{m\,decompoT} = DDOC_{maT} * (1 - e^{-k}) \qquad \text{Equation 3.5}$$

4) CH_4 generated from decayed $DDOC_m$

$$L_0 = DDOC_{m\,decompoT} * F * 16/12 \qquad \text{Equation 3.3}$$

5) $$CH_4 \text{ emissions} = [\textstyle\sum_x^n CH_4 \text{ generated}_{x,T} - R_T] * (1 - OX_T) \qquad \text{Equation 3.1}$$

Legend:

$DOCC_m$ ($DOCC_{mdT}$)	= mass of decomposable DOC deposited, Gg
W	= mass of waste deposited, Gg
DOC	= degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste
DOC_f	= fraction of DOC that can decompose (fraction)
MCF	= CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)
T	= inventory year
$DDOC_{maT}$	= $DOCC_m$ accumulated in the SWDS at the end of year T, Gg
$DDOC_{maT-1}$	= $DOCC_m$ accumulated in the SWDS at the end of year (T-1), Gg
$DDOC_{mdT}$	= $DOCC_m$ deposited in the SWDS in year T, Gg
$DDOC_{m\,decompoT}$	= $DOCC_m$ decomposed in the SWDS in year T, Gg
k	= reaction constant, $k = \ln(2)/t_{1/2}$ (y^{-1})
$t_{1/2}$	= half-life time (y)
L_0	= CH_4 generation potential, Gg CH_4
F	= fraction of CH_4 by volume, in generated landfill gas (fraction)
16/12	= molecular weight ratio CH_4/C (ratio)
CH_4 generated	= Amount of CH_4 generated from decomposable material
CH_4 emissions	= CH_4 emissions emitted in year T, Gg
x	= waste category or type/material
R_T	= recovered CH_4 in year T, Gg
OX_T	= oxidation factor in year T, (fraction)

Source: own representation ifeu and Prognos, based on (IPCC 2019).

[29] EU-27 member states and UK are Annex I parties.

[30] Other methods for determining actual methane emissions are not readily available. Ground-level measurements are difficult and rare. Satellite-based methane emission measurements are still too imprecise.

The IPCC guidelines provide default values, which countries may use if they do not have country-specific data or are unable to obtain it. Country-specific data must be collected at least for the amount of waste deposited. In some cases, data sources other than those reported to Eurostat are used. Data on waste volumes landfilled is a challenge regarding historical data. Since calculating annual methane emissions requires considering waste disposal since 1950, data for the first few decades are often estimated or extrapolated. More accurate records of landfilled waste have only been available for the last 30 years or so. However, even for these data uncertainties remain (Chapter 4.2). This, in turn, leads to uncertainties about the currently reported methane emissions.

The **historical data** EU member states use to calculate their annual emissions are only partially published in the NIDs (mostly time series on waste volume and references to the parameters used). The effort required to recalculate time series to replicate the currently reported methane emissions would be immense. In this respect, currently reported methane emissions cannot be verified. This study thus focused on the emissions from MSW deposits in landfills for the period 2022-2050, excluding emissions from historical deposits in landfills.

A further challenge for countries is to determine the **waste composition** of waste landfilled, which is necessary to determine the DOC. Although waste delivered to landfills is weighed, its composition can only be determined through random sampling. Partially, sampling does not take place at the landfill itself, but directly after collection, and not all waste is landfilled. Therefore, the waste composition – if it is determined – is not necessarily representative.

Methane recovery (R) can also be based on estimates. If countries cannot measure the recovered landfill gas – which ideally should be the case – they can estimate it, for example, based on the number of landfills with gas collection systems. However, the IPCC guidelines emphasise that such estimates should be done with great care.

For **other parameters** required for the calculation, countries usually use the IPCC default values, sometimes also for the DOC.

For the purpose of this study, a simplified model was developed (‘ifeu simplified model’) based on the IPCC Waste Model[31]. The simplifications result from the scope of this study:

- Investigate MSW and similar waste to household waste (no industrial waste or sludge).
- Parameters are constant (changes over time only for waste volumes deposited).
- IPCC default values are used for DOCf, MCF, F, OX as EU countries mostly rely on these default values.

The IPCC default values used are:

- **DOCf = 0.5** (Bulk waste, used when the fractions of less, moderately and highly decomposable wastes in MSW are not known).
- **MCF = 1.0** (Managed – anaerobic; with controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires)

[31] IPCC Modell.

and includes at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste).

- **F = 0.5** (**FCH4**, fraction of methane in generated landfill gas).
- **OX = 0.1** (type of site: managed covered with CH_4 oxidising material; examples: soil, compost).

The **DOCf** default value for bulk waste is relatively robust as long as waste mixtures are collected and landfilled. The Methane Correction Factor (**MCF**) is 1 for nearly all solid waste disposal sites (SWDS) in EU-27 countries. Only Bulgaria, Croatia and Greece still dispose MSW to unmanaged SWDS, although in small amounts. The MCF=1 stands for the 100% methane generation potential under anaerobic conditions. For unmanaged or other SWDS the MCF is lower. Greece uses 0.8 for its unmanaged SWDS. This was not considered separately in this study because the quantities deposited on unmanaged SWDS are small. The standard value for the methane content in the generated landfill gas (**FCH4**) is based on a large number of landfill gas measurements. It decreases when the landfill is closed and the amount of landfill gas also declines. The default value for the Oxidation Rate **OX** is 0 for unmanaged and uncategorised solid waste disposal sites (SWDS) and for managed SWDS that are not covered with methane-affected material. For managed SWDS that are covered with methane oxidising material the IPCC default value is 0.1. In this study it was assumed that the latter accounts in general for the EU-27 member states and the UK.

Country-specific values are used for the DOC and the methane recovery (R). The latter is reported in the submission to the UNFCCC for the EU-27[32]. Information on how the values were determined is not provided. The DOC was taken from the countries NIDs as reported. Sometimes countries only report the waste composition, but not the finally derived DOC, and sometimes countries only state that they use the IPCC default values. The model's IPCC DOC default value applied is 0.15, which is the result of a rounded average for Europe (IPCC Waste Model: Eastern 0.14; Northern 0.13; Southern and Western 0.16, based on IPCC, 2006).

The **k-value** (also reflecting waste composition regarding degradation rate) is typically not reported. The k-value depends on the climate zone, which is boreal and temperate wet for the EU-27+UK. The **IPCC default value for bulk waste** for this climate zone **is 0.09**. This value was used when the IPCC DOC default regional average for Europe of 0.15 was also used. Otherwise, the k-value was calculated assuming that it correlates with the DOC. This assumption is valid, especially since the k-value has no influence on the cumulative result over 80 years. The k-value describes the degradation rate. With the 80-year horizon considered in this study, potential future methane emissions are almost completely covered, regardless of how quickly or slowly the degradation occurs.

The **time frame** for methane emissions from MSW disposal considered is over **80 years post-last disposal (2022–2130)** (last disposal year considered 2050). This corresponds to the time frame of the IPCC Waste Model and represents the minimum time horizon that should be considered. Methane emissions from today's waste disposal will be generated over a period of up to approximately 100 years. Using a shorter period than 80 years carries the risk to underestimate the methane generation potential.

[32] NID for EU-27 from UNFCCC 2025 (equivalent to EEA 2025a).

To test whether the potential future methane emissions are adequately represented by the 80-year horizon, the emissions were also calculated using the IPCC formula without taking decay kinetics into account, for the purpose of a plausibility check. The thus simplified equation is:

$$CH_4 \text{ emissions factor per unit waste} = DOC \times DOCf \times FCH_4 \times MCF \times 16/12 \times (1-OX) \times (1-R)$$

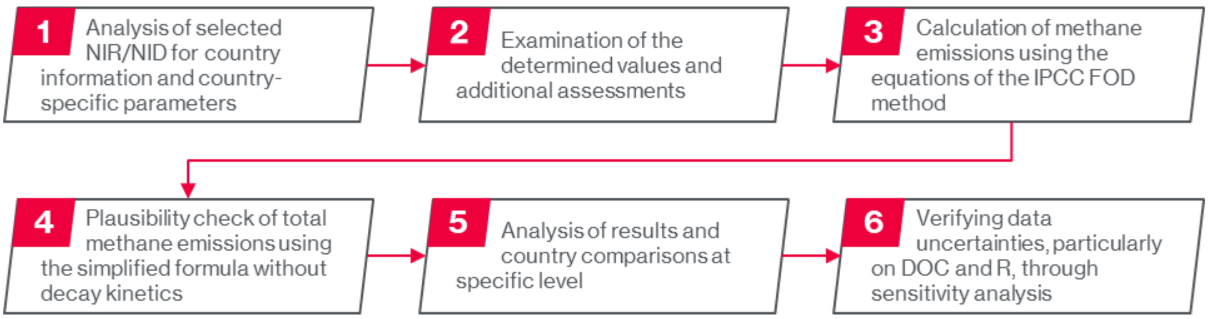
The formula without the decay kinetics calculates the 100% methane generation potential.

Data uncertainties, particularly regarding the reported parameters DOC and R, were verified through a **sensitivity analysis**.

4.3.2 Procedure and data for scenarios and sensitivities

The general approach for methane emissions modelling for the scenarios is shown in Figure 12.

Figure 12: Key methane emissions modelling steps



Source: Prognos and ifeu, 2025.

Step 1: Analysis of the country NIDs (and NIRs) for country information and country-specific parameters

In preparation for the study, National Inventory Reports (NIRs) for selected countries were analysed for the year 2021 (latest year reported available at that time). Based on experiences from previous studies (Vogt et al. 2023) and the findings from the preliminary research, it was confirmed that EU countries generally use IPCC default values, except for DOC and methane recovery (R). Based on this finding, the National Inventory Documents NIDs (previously NIRs) for the selected countries were specifically evaluated according to waste volumes and **DOC** values for the study.

Country-specific data for the **methane recovery (R)** are reported in the submission for the EU-27 to the UNFCCC for the year 2023[33]. For 2022 (base year this study) no respective data was published. The most recent data was used rather than only the available data for 2021.

[33] NID for EU from UNFCCC 2025.

Step 2: Examination of the determined values and additional assessments.

In step two, the collected data were examined, and additional assessments were conducted for cases in which countries do not report the final DOC used in their calculations, but only the waste composition and the used DOC values per waste fraction. This was the case for the UK, France and Romania. The DOC for Romania was not yet available for 2022; therefore, a value was derived from the previous NIR for 2021. The DOC was calculated based on the specified waste composition for four (DOC-relevant) waste fractions and the associated DOC default values for these waste fractions. The UK also calculates the DOC based on waste composition and DOC values for waste fractions. However, the NID for the UK[34] reports the waste composition for two types of waste (MSW and sorting residues), each as a result of a sorting analysis. In this respect, there are data uncertainties when assigning the sorting fractions to DOC-relevant waste fractions. In addition, no landfilled quantities are reported for the two types of waste. Based on the available data, the DOC was roughly estimated at approximately 0.13. However, due to the data uncertainty in this calculation, it was decided to use the derived IPCC default regional average for Europe of 0.15 for the UK. The calculated DOC for France, based on the reported waste composition and the DOC default values per waste fraction, results in approximately 0.15. For Greece, the DOC is derived by drawing upon the amounts of MSW and DOC parameters provided in a Table.

The DOC and R values used for the scenario calculation are shown in Table 3. Most of the countries report the DOC (or the waste composition and DOC values for waste fractions). Spain and France report that they use the IPCC default values. For the EU-27[35] no DOC is reported. In these cases the IPCC default regional average value was used, which was also used for the UK.

Table 3: Country-specific values for DOC and R used for calculation

Country	DOC	Source	R in 2023	Source
EU-27	0.15	Derived IPCC default value, average Europe	29%	NID for EU from UNFCCC 2025 (EEA 2025a)
Czech Republic (CZ)	0.226	CZ NID 2024 for 2022 from UNFCCC 2024	0%	
Greece (EL)	0.16	EL NID 2024 for 2022 from UNFCCC 2024	0%	
Spain (ES)	0.15	based on ES NID 2024 for 2022 from UNFCCC 2024	22%	
France (FR)	0.15	based on FR NID 2025 for 2022 from UNFCCC 2025	45%	
Italy (IT)	0.15805	IT NID 2024 for 2022 from UNFCCC 2024	32%	
Portugal (PT)	0.185	PT NID 2024 for 2022 from UNFCCC 2024	17%	
Romania (RO)	0.107814	calculated based on RO NID 2023 for 2021 from UNFCCC 2023	6%	
United Kingdom (UK)	0.15	assumption based on UK NID 2024 for 2022 from UNFCCC 2024	56%	UK NID 2024 from UNFCCC 2024

Source: as mentioned in the table.

[34] UK NID 2024 for 2022 from UNFCCC 2024.
[35] NID for EU from UNFCCC 2025 (EEA 2025a).

The methane recovery (R) reported in the NID for the EU-27[36] depicts a wide range between countries. For many countries, R is 0%[37] (no methane recovery system installed). For EU-27 member states, the highest value reported is 55% for Ireland. The 56% for the UK are derived from the UK's NID (UK NID 2024 from UNFCCC 2024). Typically, a value of 50-60% is considered technically feasible over the methane generation time frame of up to 100-years. Satellite-based studies suggest actual emissions may be significantly higher than reported[38].

Step 3: Calculation of methane emissions using the equations of the IPCC FOD method.

For the calculation, ifeu developed a simplified model (see previous Chapter). The model was already tested in the preparatory phase of this study. For this study, an interface was coordinated for efficient and harmonised data transfer and subsequently expanded to all scenarios and countries or regions to be examined. The calculation of methane emissions includes the time series of methane emissions over the time period 2022-2130 (80 years from 2050 as the last year considered for deposition (2022-2050)). The time series describes both the methane emissions and the equivalent CO_2 emissions values (CO_2e). For the impact assessment, the most recent IPCC data on Global Warming Potentials were used:

Impact assessment Global Warming Potential (GWP)

Impacts on climate change (greenhouse effect, global warming) through different climate agents are assessed using the aggregation method developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC provides characterisation factors – the Global Warming Potentials (GWPs) – for climate gases for a 20- and 100-year time horizon. The 100-year time horizon is the agreed time horizon under the Kyoto-Protocol and is therefore basically used for the study.

However, methane is a short-lived climate pollutant (SLCP). Methane's lifetime in the atmosphere is shorter than 20-years. Therefore, their GWP is higher for the 20-year time horizon, and their relative importance decreases with a longer time horizon. To show the effect of the shorter lifetime of methane, results were also calculated using the GWP 20 as a sensitivity.

As the most recent scientific basis, the characterisation factors from the 6th IPCC assessment report[39] are used. Results are reported in "CO_2-equivalents" (CO_2e). The respective GWP characterisation factors for methane from biodegradable sources (CH_4 non-fossil) are:

- GWP 100: 27 kg CO_2e/kg CH_4
- GWP 20: 79.7 kg CO_2e/kg CH_4

The calculated results are presented both as annual emissions and as a cumulative result over the 80-year time horizon (2022-2130).

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[36] NID for EU from UNFCCC 2025 (EEA 2025a).
[37] For Czechia and Greece this deviates from the data that can be derived from their national Common Reporting Tables (CRT) for 2023 (submitted 2025), see Chapter 2.3.
[38] Dogniaux et al, 2025.
[39] IPCC 2021, Table 7.15.

Step 4: Plausibility check of total methane emissions using the simplified formula without decay kinetics.

To test whether the potential future methane emissions are adequately represented by the 80-year time horizon, the emissions were also calculated using the IPCC formula without accounting for decay kinetics, as a plausibility check. The calculation was also included in the aforementioned Excel file for data exchange. Methane emissions for the deposition period 2022-2050 were determined for all countries and regions.

The formula without the decay kinetics calculates the 100% methane generation potential. The result showed that the calculation using the FOD method over the 80-year time frame is in all cases only < 0.03% lower than the results with the formula without decay kinetics. This means that methane emissions are not underestimated and, furthermore, the results are not sensitive to the k value.

Step 5: Analysis of results and country comparisons at a specific level.

In this step, the results were analysed, showing, for example, that the estimated cumulative methane emissions for the 7 selected EU countries are already at about 80% of the EU-27 estimated aggregate. This means that the IPCC default value average for Europe used for the EU-27 likely underestimates the modelled methane emissions of the EU-27.

Another important aspect of this step is the comparison of the country and the region results. Methane emissions are calculated per ton of waste to ensure a valid basis for comparison. The specific result (kg CH_4/t MSW landfilled) is like the "footprint" to compare country results. It is informed by the waste composition, as expressed by the DOC parameter, and the methane recovery rate (R) (0 if none are installed or low).

The methane footprint per tonne of MSW deposited in landfills is highest in the Czech Republic at 68 kg CH_4/t[40] MSW landfilled, and lowest in the UK at 20 kg CH_4/t MSW landfilled.

For comparison, typical "footprints" using the IPCC default values are:

- 50 kg CH_4/t waste, with R=0% and OX=0
- 45 kg CH_4/t waste, with R=0% and OX=0.1
- 40 kg CH_4/t waste, with R=20% and OX=0
- 36 kg CH_4/t waste, with R=20% and OX=0.1

The smaller "footprint" for the UK is due to its relatively high methane recovery (R=56%). The higher result for the Czech Republic, on the other hand, stems from a higher DOC (23%) and the absence of a gas collection system (R=0%).

[40] If the methane recovery Rate of 27% is used, which results from the data reported in the Common Reporting Table of Greece for 2023 (submitted 2025), the specific methane emissions for Greece are still highest with 99 kg CH_4 per tonne MSW landfilled (see also Chapter 2.3).

Step 6: Verifying data uncertainties, particularly on DOC and R, through sensitivity analysis.

The DOC values are sometimes not given as a result value in the countries NIDs and have to be estimated (Romania, UK), sometimes the IPCC default value is used, and sometimes the reported DOC values are not further explained. This means that the DOC data are subject to data uncertainty, and the sensitivity of the result to this was examined. Additionally, the sensitivity of results to a high methane recovery was tested.

Sensitivity analysis was conducted for the aggregate EU-27+UK for Scenario 1 and Scenario 3, i.e. Status Quo business-as-usual and WFD legal framework implementation assumptions.

For the **DOC, a higher value of 0.20** rather than 0.15 was tested for sensitivity. This is based on the result that the total methane emissions of the 7 selected countries of the EU-27 already add up to about 80% of the EU-27 result calculated with the IPCC default in this estimation. The 0.20 DOC-value for the EU-27+UK is likely more realistic than using the IPCC default value average for Europe of 0.15.

To test the influence on the result in case of a maximum methane recovery over the 80-year time frame, the **R-value was set to 60%** in the sensitivity.

4.3.3 Methane emissions reported for the EU-27+UK and selected countries

Methane emissions reported in the NIDs of the countries are emissions deriving from historical disposals since 1950 (starting year in the IPCC waste model) up to today. These current methane emissions were analysed to identify member countries relevant to this study.

Table 4 shows the results of the analysis for 1990 and 2022. In total, methane emissions from SWDS have been significantly reduced in the EU-27+UK between 1990 and 2022 (-57%). However, in 13 countries, methane emissions increased during that time period (positive values for “Change 1990-2022”). In 2022, France, Italy, Spain and the UK contributed 58% to the total methane emissions in the EU-27+UK (total selected countries in this study 77%). Methane emissions from unmanaged SWDS in 2022 derive mainly from disposals in the past; only Bulgaria, Cyprus, and Greece still dispose of MSW to unmanaged SWDS, although in small amounts.

Among the selected countries for this study, the UK has the highest share of MSW landfilled (20%) and the second highest share of methane emissions in 2022 (15%). Italy has the highest share of methane emissions in 2022 (18%) with a share of 7.9% MSW landfilled. Differences are likely due to varying methane recovery rates (see Figure 7).

Table 4: CH_4 emissions EU-27 and UK as reported for 2022

Member state	Total CH_4 emissions 1990		Total CH_4 emissions 2022		Change 2019-2022	MSW sent to SWDS in 2022		MSW amounts sent to SWDS in 2022 (basis: WASMUN*)	
	kt CO_2e	% of EU-27+UK	kt CO_2e	% of EU-27+UK	%	kt CO_2e	%	kt	% of EU-27+UK
Austria	4081	2%	846	1%	-79%			150	0.2%
Belgium	3323	2%	557	1%	-83%			12	0.0%
Bulgaria	2100	1%	2162	2%	3%	924	43%	1695	2.6%
Croatia	559	0%	1392	2%	149%			1025	1.6%
Cyprus	295	0%	575	1%	95%	394	69%	363	0.6%
Czech Republic	2008	1%	3725	4%	86%			2433	3.7%
Denmark	1525	1%	421	0%	-72%			71	0.1%
Estonia	239	0%	191	0%	-20%			66	0.1%
Finland	4847	2%	1384	2%	-71%			11	0.0%
France	12457	6%	11384	13%	-9%			8465	12.9%
Germany	37191	18%	2375	3%	-94%			41	0.6%
Greece	2512	1%	4514	5%	80%	1410	31%	4386	6.7%
Hungary	2977	1%	3322	4%	12%	1144	34%	2164	3.3%
Ireland	1476	1%	634	1%	-57%			853e	1.3%e
Italy	13671	7%	15565	18%	14%	1963	13%	5173	7.9%
Latvia	353	0%	405	0%	15%	111	27%	380	0.6%
Lithuania	1152	1%	573	1%	-50%	116	20%	180	0.3%
Luxembourg	103	0%	44	0%	-57%			13	0.0%
Malta	46	0%	169	0%	267%	6	4%	273	0.4%
Netherlands	15321	8%	2027	2%	-87%			118	0.2%
Poland	13313	7%	825	1%	-94%	23	3%	5108	7.8%
Portugal	2945	1%	4051	5%	38%	589	15%	2929	4.5%
Romania	1536	1%	4386	5%	186%	1728	39%	4253	6.5%
Slovakia	782	0%	1207	1%	54%			1022	1.6%
Slovenia	418	0%	176	0%	-58%			81	0.1%
Spain	6131	3%	10881	12%	77%	599	6%	10782	16.4%
Sweden	3847	2%	509	1%	-87%			25	0.0%
UK	67424	33%	13468	15%	-80%			13146	20%
EU-27+UK	**202632**		**87768**		**-57%**	**9007**		**65591**	**100.0%**

EU-27 and UK NID 2024 use GWP 100 values from the IPCC Fifth Assessment Report (28 kg CO_2e/kg CH_4).
* As data are not reported in NID for all member states, the WASMUN statistics were applied.
Grey background: member states in more detailed focus within this study.
Marked red: share >10%; marked yellow: share between 5% and 10%.
Source: UNFCCC 2024, ENV_WASMUN (data for 2022, data for Ireland are estimations), data for MSW deposited at landfills for UK based on DEFRA 2024.

4.3.4 CH_4 emissions from disposal of MBT residues – example France

In some European countries, such as Italy, France, Poland, and Germany, MSW is no longer deposited directly in landfills, either entirely or partly, but is pre-treated. The pre-treatment aims to stabilise the organic waste components, thereby significantly reducing the potential for methane generation. For example, in Germany, landfilling of untreated waste has been banned since 2005. Since then, only waste with a total carbon content ≤ 3% and mechanical-biological treated waste may be landfilled in Germany. Through biological treatment, such as composting or anaerobic digestion, stabilisation is achieved. Products from mechanical-biological treatment (MBT) are typically refuse-derived fuel (RDF) and a stabilised organic fraction (MBT waste). The MBT waste is landfilled (502 kt 2022[41]). Due to the stabilisation process, it has a different DOC than untreated MSW.

The IPCC guidelines (2019) provide no default value for MBT waste. For reporting purposes, the German Environment Agency commissioned a study to determine the DOC in MBT waste. According to this study, MBT waste contains less than 10% of the original DOC content (in per cent).[42]

To show differences in methane emissions from MBT waste compared with direct landfilling, the emission calculation was carried out using France as an example. In France, 530,000 tonnes of MBT waste were landfilled in 2022[43]. The DOC for France corresponds to the IPCC default regional average value for Europe of 0.15 (or 15%) (see Table 3). Thus, 1.5% (0.015) is the value that remains, on average, following the 90% reduction via the treatment process. With the lower DOC, the k-value was also adjusted to reflect slow degradation at 0.045 (average of the IPCC default values for paper and wood). The calculation was performed for the Status Quo scenario; all other landfill parameters were kept unchanged. The country-specific data for the calculation are:

- Disposal of 503 thousand tonnes MBT waste yearly in the time period 2022-2050
- DOC = 0.015
- Methane recovery (R) = 45% (see Table 3)

As a result, 1.0 million tonnes CO_2e (GWP 100) methane will be produced by 2130 from the 15.4 million tonnes of MBT waste deposited between 2022 and 2050. The result for the specific methane emissions (“footprint”) is 2.4 kg CH_4/t MBT waste landfilled. This footprint is 10% of the “footprint” for France for untreated MSW landfilled (25 kg CH_4/t MSW landfilled).

[41] NID Germany 2025.
[42] NID Germany 2025.
[43] FR NID 2025 for 2022 from UNFCC 2024, Figure 218.

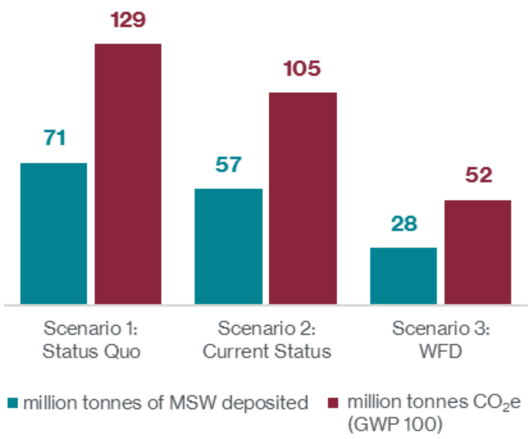
4.4 Country-Specific Data

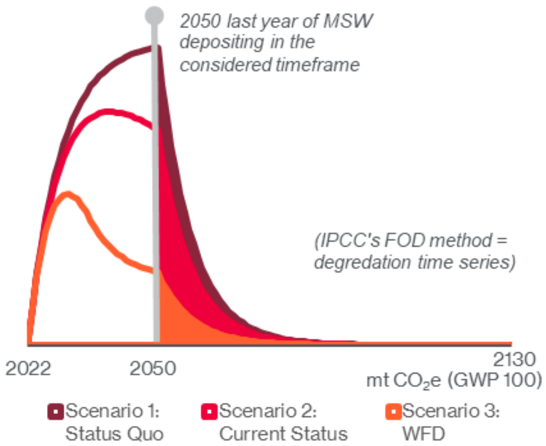
This section presents the country-specific data for the eight selected countries: the Czech Republic, Greece, France, Italy, Portugal, Romania, Spain and the United Kingdom. Equivalently to Chapter 2.1 EU-27+UK, the MSW deposited on landfills between 2022 and 2050 and methane emissions between 2022 and 2130 from those MSW deposited in landfills are presented for the three main scenarios. The country-specific data shows the different landfill trajectories and derogation options and should be read together with Chapter 2.3 Country Focus. This data does not include emissions from historical depositions in landfills before 2022.

4.4.1 Key data for the Czech Republic

CZ - Czech Republic

MSW treated (2022)	5198 kt
MSW deposited in landfills (2022)	2433 kt (46.8% of MSW treated)
Average annual change 2018 - 2022	-0.4%
Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050. The methane recovery rates for 2023 are based on the EU's official inventory submission 2025 (EEA 2025a, page 479, April 2025) as a consistent data source for the emission modelling. The methane recovery rates are not explicitly stated in the respective NIDs and CRTs for CZ. These rates can, however, be derived from the Common Reporting Tables (CRT) for 2023 (submitted April 2025 or later). CZ: 0% (EEA, 2025a) versus 10% (CZ CRT 2025). Applying the derived national methane recovery rates for 2023 in the modelling for Czechia (10%), the methane emission footprint would be 61 kg CH_4 per tonne MSW landfilled. Per scenario, the results for CZ are: 116 mt CO_2e (Scenario 1), 95 mtCO_2e (Scenario 2), and 47 mt CO_2e (Scenario 3).

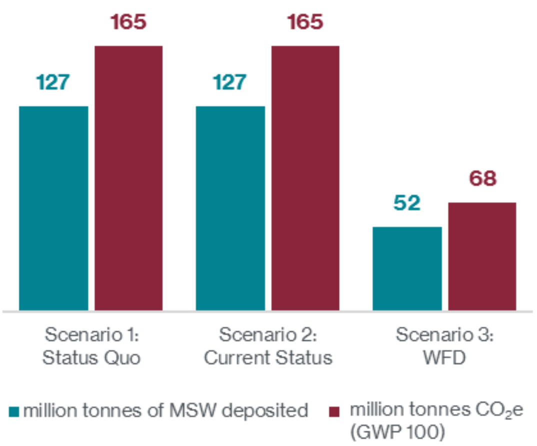
In the modelling estimation, the Czech Republic deposited 2.4 million tonnes of MSW in landfills in 2022, almost 47% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -0.4%. This trend is not sufficient to meet the WFD landfill targets.

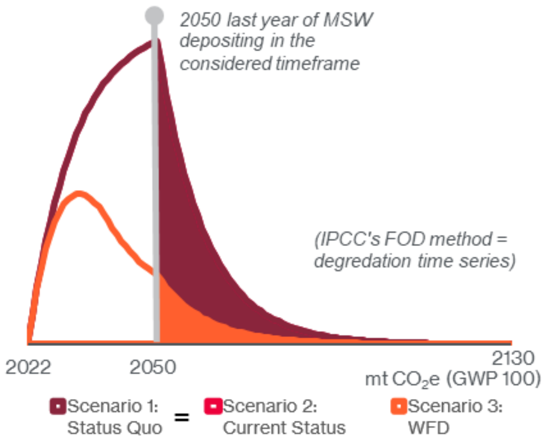
With the implementation of the WFD, the Czech Republic would reduce MSW deposited in landfills from 71 to 28 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 129 to 52 million tonnes CO_2e between 2022 and 2130, a reduction of almost 60%.

4.4.2 Key data for Greece

EL - Greece

MSW treated (2022)	5420 kt
MSW deposited at landfills (2022)	4386 kt (80.9% of MSW treated)
Average annual change 2018 - 2022	+0.5% (max. 80.9% MSW treated in this period)
Derogation option applied	yes
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050. The methane recovery rates for 2023 are based on the EU's official inventory submission 2025 (EEA 2025a, page 479, April 2025) as a consistent data source for the emission modelling. The methane recovery rates are not explicitly stated in the respective NIDs and CRTs for EL. These rates can, however, be derived from the Common Reporting Tables (CRT) for 2023 (submitted April 2025 or later). EL: 0% (EEA, 2025a) versus 27% (EL CRT 2025). Applying the derived national methane recovery rates for 2023 in the modelling for Greece (27%) results in the methane emission footprint of 35 kg CH4 per tonne MSW landfilled for Greece. Per scenario the results for EL are 121 mt CO_2e (Scenario 1 and 2), 50 mt CO_2e (Scenario 3).

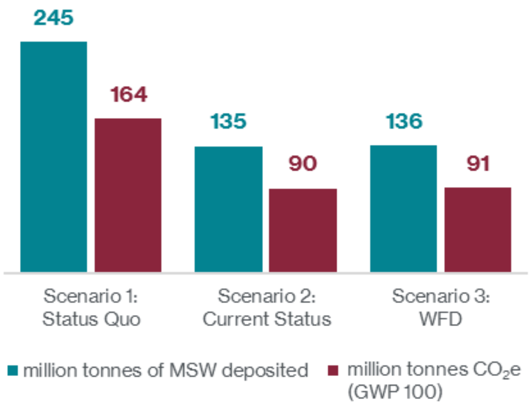
In the modelling estimation, Greece deposited 4.4 million tonnes of MSW in landfills in 2022, almost 81% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has increased at an average annual rate of 0.5%. Scenarios 1 and 2 are nearly identical, as the maximum share of MSW treated in landfills between 2018 and 2022 was applied in Scenario 2.

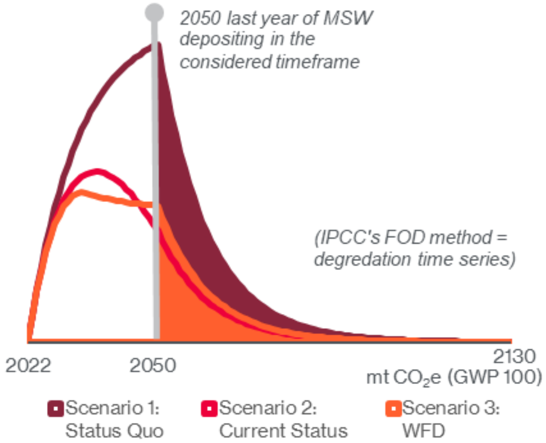
Even with the derogation option, delaying the achievement of WFD targets to 2040, the WFD would still result in significant emission reductions. Greece would reduce MSW deposited in landfills from 127 to 52 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 165 to 68 million tonnes CO_2e between 2022 and 2130, a reduction of almost 59%.

4.4.3 Key data for France

FR - France

MSW treated (2022)	34804 kt
MSW deposited at landfills (2022)	8465 kt (24.3% of MSW treated)
Average annual change 2018 - 2022	-0.6%
Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

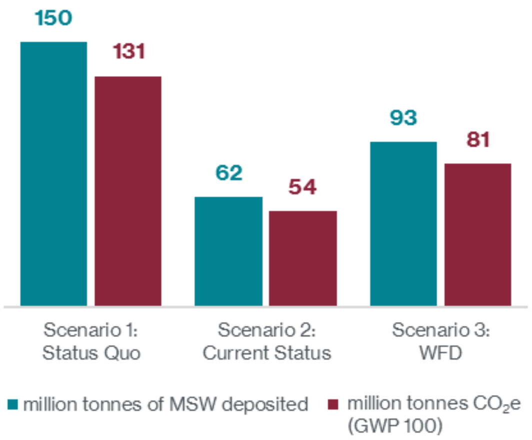
In the modelling estimation, France deposited 8.5 million tonnes of MSW in landfills in 2022, around 24% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -0.6%. This trend is on target to meet the WFD landfill targets.

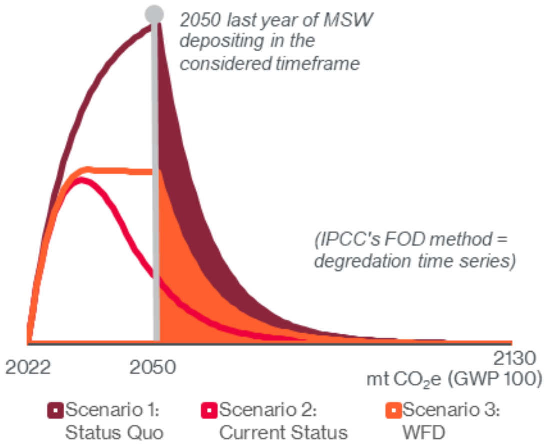
With the implementation of the WFD, France would reduce MSW deposited in landfills from 245 to 136 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 164 to 91 million tonnes CO_2e between 2022 and 2130, a reduction of almost 45%.

4.4.4 Key data for Italy

IT - Italy

MSW treated (2022)	25936 kt
MSW deposited at landfills (2022)	5173 kt (19.9% of MSW treated)
Average annual change 2018 - 2022	-0.9%
Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

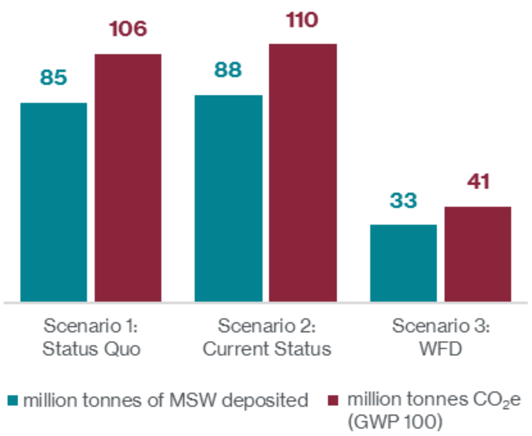
In the modelling estimation, Italy deposited 5.2 million tonnes of MSW in landfills in 2022, around 20% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -0.9%. This trend would go beyond the WFD landfill target.

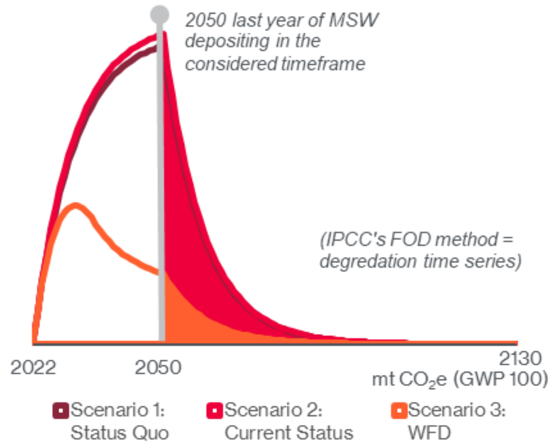
With the implementation of the WFD, Italy would reduce MSW deposited in landfills from 150 to 93 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 131 to 81 million tonnes CO_2e between 2022 and 2130, a reduction of around 38%. In the current status scenario, even by around 59%

4.4.5 Key data for Portugal

PT - Portugal

MSW treated (2022)	5614 kt
MSW deposited at landfills (2022)	2929 kt (52.2% of MSW treated)
Average annual change 2018 - 2022	+0.4% (max. 54.2% in this period)
Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

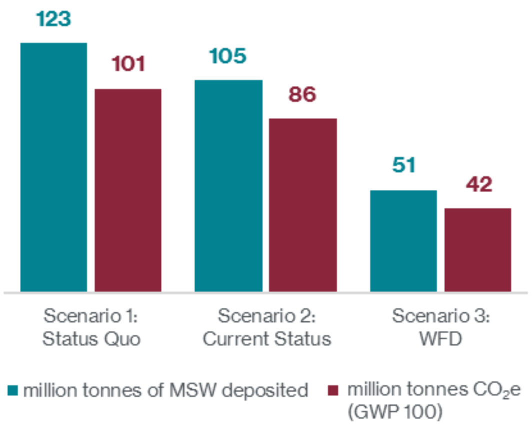
In the modelling estimation, Portugal deposited 2.9 million tonnes of MSW in landfills in 2022, almost 52% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has increased at an average annual rate of 0.4%.

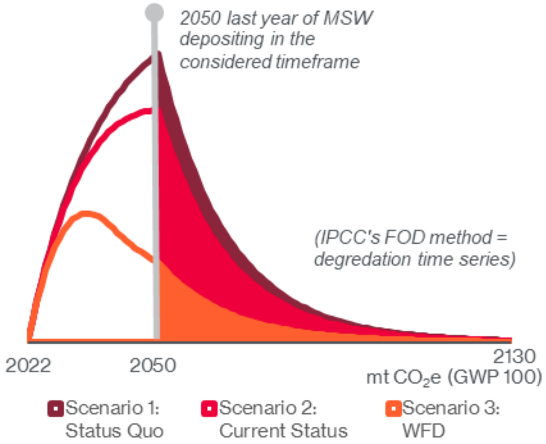
With the implementation of the WFD, Portugal would reduce MSW deposited in landfills from 85 to 33 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 106 to 41 million tonnes CO_2e between 2022 and 2130, a reduction of around 61%. In the current trend, the Current Status scenario, emissions would increase.

4.4.6 Key data for Romania

RO - Romania

MSW treated (2022)	5415 kt
MSW deposited at landfills (2022)	4253 kt (78.5% of MSW treated)
Average annual change 2018 - 2022	-1.0%
Derogation option applied	yes
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

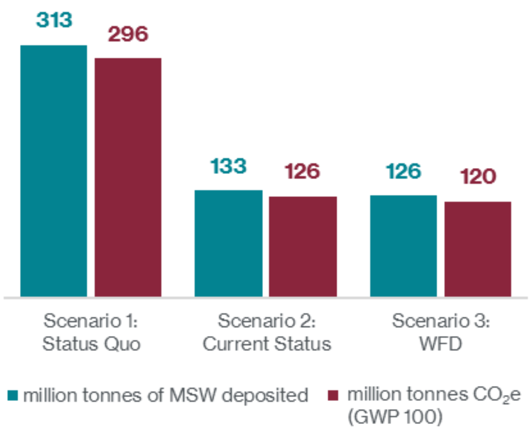
In the modelling estimation, the Czech Republic deposited 4.3 million tonnes of MSW in landfills in 2022, almost 79% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -1.0%. This trend is not sufficient rapid to meet the WFD landfill targets, due to the very high share of MSW landfilled, even when accounting for the derogation option.

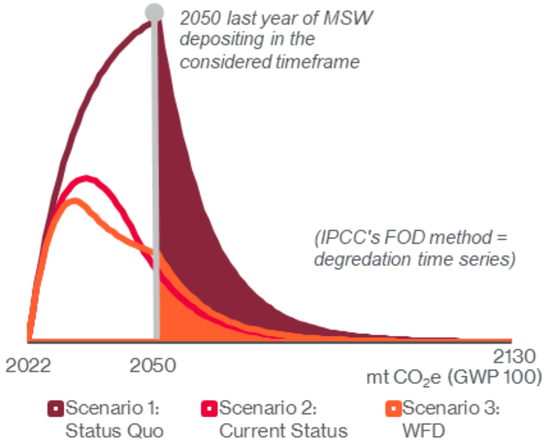
Should, Romania achieve the implementation of the WFD, MSW deposited in landfills would be reduced from 123 to 51 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 101 to 42 million tonnes CO_2e between 2022 and 2130, a reduction of around 59%. In the current trend, the Current Status scenario, emissions would only decrease by around 15%.

4.4.7 Key data for Spain

ES - Spain

MSW treated (2022)	23030 kt
MSW deposited at landfills (2022)	10782 kt (46.8% of MSW treated)
Average annual change 2018 - 2022	-1,7%
Methane Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

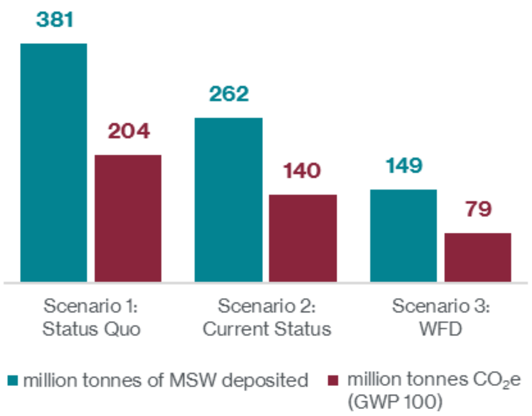
In the modelling estimation, Spain deposited 10.8 million tonnes of MSW in landfills in 2022, almost 47% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -1.7%. This trend is almost sufficient to meet the WFD landfill target.

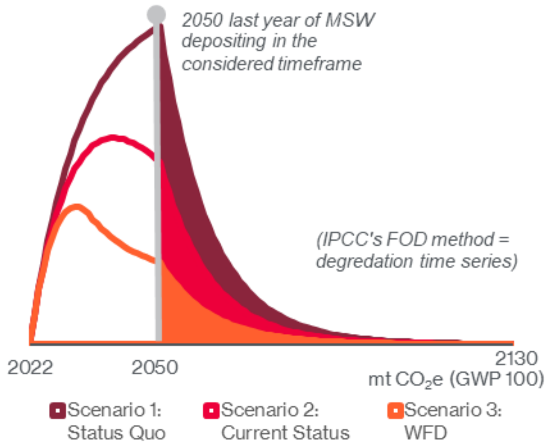
With the implementation of the WFD, Spain would reduce MSW deposited in landfills from 313 to 126 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 296 to 120 million tonnes CO_2e between 2022 and 2130, a reduction of almost 60%.

4.4.8 Key data for United Kingdom

UK - United Kingdom

MSW treated (2022)	25691 kt
MSW deposited at landfills (2022)	13146 kt (51.2% of MSW treated)
Average annual change 2018 - 2022	-1.1%
Derogation option applied	no
Total MSW deposited on landfills (2022-2050) and total methane emissions (GWP 100)	Annual methane emissions (2022-2130) for the annual MSW deposited on landfills (2022-2050) by scenario





Source: Prognos and ifeu, 2025
Notes: Emissions from historical MSW deposits pre-2022 are not included. Methane emissions are estimated for 2022-2130 from MSW deposits between 2022 and 2050.

In the modelling estimation, the United Kingdom deposited 13.1 million tonnes of MSW in landfills in 2022, around 51% of all MSW treated. Between 2018 and 2022, the amount deposited in landfills has decreased at an average annual rate of -1.1%. This trend is not sufficient to meet the WFD landfill target.

With the implementation of the WFD, the United Kingdom would reduce MSW deposited in landfills from 381 to 149 million tonnes between 2022 and 2050, resulting in a decrease in methane emissions from 204 to 79 million tonnes CO_2e between 2022 and 2130, a reduction of almost 61%. In the current trend, the Current Status scenario, emissions would only decrease by around 31%.

Glossary

80-year time horizon CH4 emissions from disposal	Time frame of CH4 emissions calculated with IPCC FOD method; to be applied on the last year of considered waste amount disposal (e.g. time frame for waste disposal is 2022-2050 à 80-year time horizon for CH4 emissions calculation is 2022-2130)
CH_4	Methane
CO_2e	CO_2-equivalents; GHG emissions transferred to CO2 equivalents using IPCC characterisation factors
CRF	Common Reporting Format
CS	Current Status
CZ, EL, ES, FR, IT, PT, RO, UK,	Country acronyms for: Czech Republic, Greece, Spain, France, Italy, Portugal, Romania, United Kingdom
DOC	Degradable organic carbon; share of carbon that is biodegradable (not to be confused with biogenic or organic waste, here only the element C)
DOCf	Fraction of degradable organic carbon which decomposes
ETS	Emissions Trading System
EU	European Union
EWC	European Waste Codes
EWSTAT	European Waste Statistics
F (CH_4)	Fraction of methane in landfill gas generated
FOD	First order decay; exponential decay kinetics; IPCC FOD method is adopted as a relatively simple model for estimating CH4 emissions from SWDS, that express overall decomposition process of a series of chain reactions of anaerobic decay of DOC
GHG	Greenhouse Gas
GWP	Global Warming Potential
GWP 100	IPCC Characterisation Factors for the 100-year time horizon (considered lifetime of emissions in the atmosphere), standard approach
GWP 20	IPCC Characterisation Factors for the 20-year time horizon (emphasises on short-lived climate pollutants, cuts short long time GHG emissions relevancy), as sensitivity
IPCC	Intergovernmental Panel on Climate Change
IW	Industrial Waste
k-value	reaction/rate constant, in units of time
kt	Thousand tonnes
LoW	List of Waste
Max.	Maximum
MBT residue	Output of MBT: stabilised organic material
MBT	Mechanical-biological treatment
MCF	Methane Correction Factor (depends on the type of site, is 1 for managed-anaerobic sites)
Mg	Megagrams (1,000 kg)
MS	Member State of the European Union
MSW	Municipal Solid Waste
Mt	Million tonnes
NID / NIR	National Inventory Documentation / National Inventory Report
Organic waste	Waste of biogenic origin (also biodegradable waste)
OX	Oxidation Factor: share of CH_4 from SWDS that is oxidised in the soil or other material covering the waste

R 1	Recovery operation - use principally as a fuel or other means to generate energy
R	Methane Recovery: share of CH_4 generated at SWDS that is recovered; Also known as Capture Rate.
SC	Scenario
SQ	Status Quo
SWDS	Solid Waste Disposal Site
t	Tonnes (metric, equal to 1,000 kg)
Thsd.	Thousand
WASGEN	Generation of waste by waste category, hazardousness and NACE Rev. 2 activity statistics published by Eurostat
WASMUN	Municipal waste by waste management operations statistics published by Eurostat
WASTRT	Treatment of waste by waste category, hazardousness and waste management operations statistics published by Eurostat
WFD	Waste Framework Directive

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