



METHANE MITIGATION IN CHINA'S WASTE SECTOR THROUGH CO-BENEFICIAL AND LOCALIZED STRATEGIES

June 2026

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Suggested Citation

X. Cheng, M. Zhu*, J. Behrendt, J. Zhang, S. Vaddeboina, G. Hu, Y. Li, S. Sahu, S.J. Smith, R. Cui, N. Hultman "Methane Mitigation in China's Waste Sector Through Co-beneficial and Localized Strategies." Center for Global Sustainability, University of Maryland. 40 pp.

Acknowledgements

The authors gratefully acknowledge Nazar Kholod, Chengcheng Mei, Lingyan Chen, and Sha Fu for their review and helpful input on the report.

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1. OVERVIEW

Methane (CH₄) is a potent greenhouse gas, with its atmospheric concentration having more than doubled since pre-industrial times (IPCC, 2023). Over a 20-year period, methane has a Global Warming Potential (GWP) approximately 80 times higher than carbon dioxide (CO₂) (IPCC, 2023), making the reduction of CH₄ emissions from anthropogenic sources one of the essential strategies to mitigate global warming and meet the goals of the Paris Agreement. Globally, the waste sector contributes an estimated 20% of methane emissions, making it the third largest source after agriculture (40%) and fossil fuels (35%) (CCAC, 2021). Despite this, the waste sector remains understudied in global methane mitigation research, particularly in the context of rapidly urbanizing economies such as China. As one of the world's largest generators of municipal solid waste (MSW) and municipal wastewater, China offers both a significant challenge and a critical opportunity for methane mitigation in the waste sector (Duan et al., 2020; Lu et al., 2019). Understanding China's waste sector methane emissions is therefore essential for both national carbon neutrality goals and global climate efforts.

China, as the largest methane emitter in the world, has been placing increasing policy focus on methane mitigation in the waste sector (GMI, 2024, Yu et al., 2022). Since the early 2000s, methane mitigation in the waste sector has been integrated into China's broader climate strategies (Zhu et al., 2025b). This commitment was further underscored in 2023 with the release of China's first national methane action plan, which emphasizes the co-benefits of waste sector methane management for reducing waste pollution, indicating China's growing attention and ambition in reducing methane emissions in the waste sector (MEE, 2023a). Despite these

policy efforts, there are still many questions about applying more comprehensive policy instruments, offering stronger and more stringent policy incentives, implementing existing policies, and guiding appropriate mitigation strategies in different contexts which need further analysis and study.

In recent years, China has also accelerated technological innovation to support waste sector methane mitigation and strengthen the implementation of its emerging policy framework. A series of national technical demonstrations and guidelines have been launched to incentivize the development and deployment of waste sector methane control technologies (MIIT, 2012; MOHURD, 2022). However, significant technical and operational barriers persist. Many mitigation technologies still face challenges related to economic feasibility, regional adaptability, and other long-standing operational priorities in waste treatment. These constraints underscore the need for a clear and well-organized technical inventory that fully accounts for regional differences, outcomes with co-benefits, and long-term sustainability. Identifying such co-beneficial and region-based strategies will be essential for enabling China to reduce methane emissions while delivering broader environmental and social benefits.

This brief explores the potential challenges and opportunities in China to mitigate methane emissions from the waste sector. Special attention is given to three key aspects: (1) available technologies for methane mitigation and their application in solid waste and wastewater systems; (2) synergistic effects between methane mitigation and co-benefits such as air pollution control, energy recovery, and resource utilization; and (3) regional disparities in emission level and technology application across different areas.

2. WASTE METHANE EMISSIONS IN CHINA

2.1 Methane emissions estimates

Methane emissions from both solid waste and wastewater have been increasing in China, as treatment in both sectors expands (Figure 1). Methane emissions largely occur in the waste sector from: 1) organic carbon decomposition in landfills and 2) wastewater treatment. Waste methane emissions are a significant source of methane emissions in China, with the mean across collected estimates being 14% of total anthropogenic emissions (Behrendt et al., 2025). According to global estimates, China is the largest global emitter for both landfills and the wastewater sector (European Commission, 2023; Hoesly & Smith, 2024; U.S. Environmental Protection Agency, 2024b). There is a wide range of estimates in the literature for waste methane emissions in China (5-11.7 TgCH₄), but most estimates suggest waste methane emissions in China have been increasing from 2005 to the latest available data (Behrendt et al., 2025). Estimates collected from literature for solid waste emissions in China range from 1.6-5.4 Tg CH₄, and wastewater ranges from 1.6-6.8 Tg CH₄ (Behrendt et al., 2025). However the higher estimates for both subsectors tend to be from global analyses, which may use default IPCC emission factors and not take into account regional conditions. Additionally, some estimates are developed using different methodology such as satellite observations, which can help to improve estimates using emission factors and activity data. This analysis is focusing on municipal solid waste and wastewater methane emissions only, as the data is more readily available in China. Data collected for this study suggests that municipal

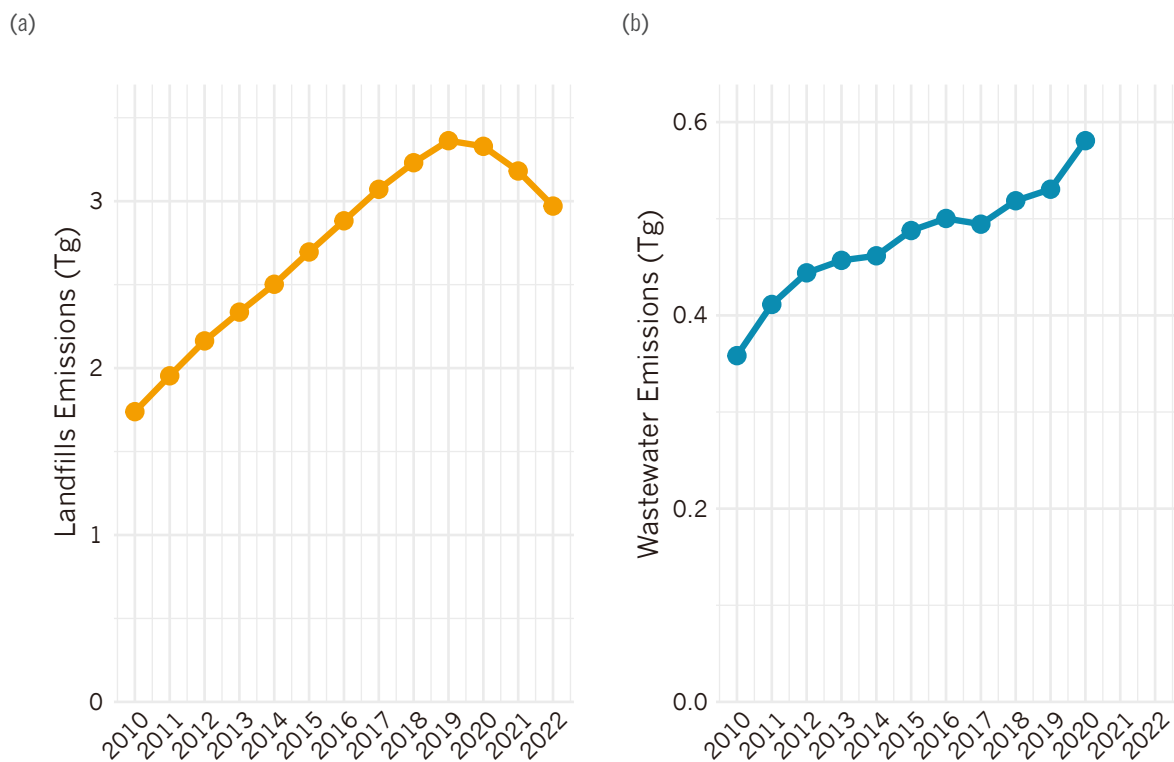
landfill methane emissions have increased steadily through 2019 and have since started to decline, while municipal wastewater emissions have exhibited an upward trend (Figure 1). Other literature estimates for municipal wastewater are higher than the data used in this study (Behrendt et al., 2025). Solid waste emissions may be declining potentially due to increasing incineration (Liu et al., 2026). In contrast, wastewater emissions have likely been increasing due to the rapid expansion of treated wastewater in China (Zhao et al., 2019).

Methane emissions are highly dependent on local conditions and a number of environmental factors, leading to uncertainty in methane emissions estimates. Methane emissions from landfills are challenging to measure, as emissions can change rapidly based on conditions and waste content (Kumar et al., 2024). Wastewater methane emissions are also affected by management and environmental conditions, such as substrate, management practices, weather and diurnal changes (Song et al., 2023). This variation in local conditions makes using global emission factors for estimating emissions difficult. To improve emission estimates, it is essential to strengthen MRV systems, refine localized emission factors, and better integrate satellite and ground-based measurements into estimates.

Despite the uncertainty, the overall increasing trend in methane emissions aligns with the rapid expansion of waste generation and treatment activities nationwide, which has substantially reshaped China's waste sector over the past decades. Better understanding the magnitude and trends in solid waste and wastewater treatment, as well as management practices, can help to understand methane emissions and mitigation opportunities.

FIGURE 1. METHANE EMISSIONS FROM THE WASTE SECTOR.

(a) Methane emissions from landfills (2010–2022). (b) Methane emissions from municipal wastewater (2010–2020). Unit: Tg CH₄. Source: Using the same data as Du et al., 2023 for municipal wastewater and Ma et al., 2024 for landfills. Wastewater data only available through 2020.



2.2 Waste management in China

Over the past 30 years, as China's economy and population have expanded and urbanization has increased, the waste sector has grown and changed significantly (Mian et al., 2017; Xu et al., 2020). The development of waste treatment has improved public health, advanced environmental protection, and promoted resource conservation, while the expansion of treatment facilities has also resulted in increased greenhouse gas (GHG) emissions (Hariyani et al., 2025). Municipal solid waste treatment increased almost 2.5 times, from 75 million tons in 2003 to 254 million tons in 2023, with sanitary treatment rates increasing from 50% to around 100% (NBS, 2004; 2024). As for wastewater, in 2003, 25 billion tons of municipal wastewater were treated (NBS, 2004), almost quadrupling to 94 billion tons in 2023 (MEE, 2024a). As of 2023, China also possessed the world's largest municipal wastewater treatment capacity (Tong et al., 2024). In addition

to municipal systems, industrial wastewater treatment has also expanded significantly. In 2023, a total of 33.91 billion tons of industrial wastewater were treated (MEE, 2024a).

To navigate this complex problem of rapidly increasing waste, China has implemented a number of strategies and policies for waste management. Currently, China is gradually shifting from landfills to incineration for solid waste disposal, along with composting and 3R strategies (reduce, reuse and recycle) of organic MSW, due to limited land availability, public concerns about landfill pollution, and resource recovery (Cui et al., 2023; Liu et al., 2017; NBS, 2004; NBS, 2024; Wei et al., 2024). Even though the amount of waste being disposed of in landfills is declining, the total volume of accumulated waste in the legacy and existing landfills remains large, and the associated methane emissions are still significant (Wei et al., 2024). At the same time, China has

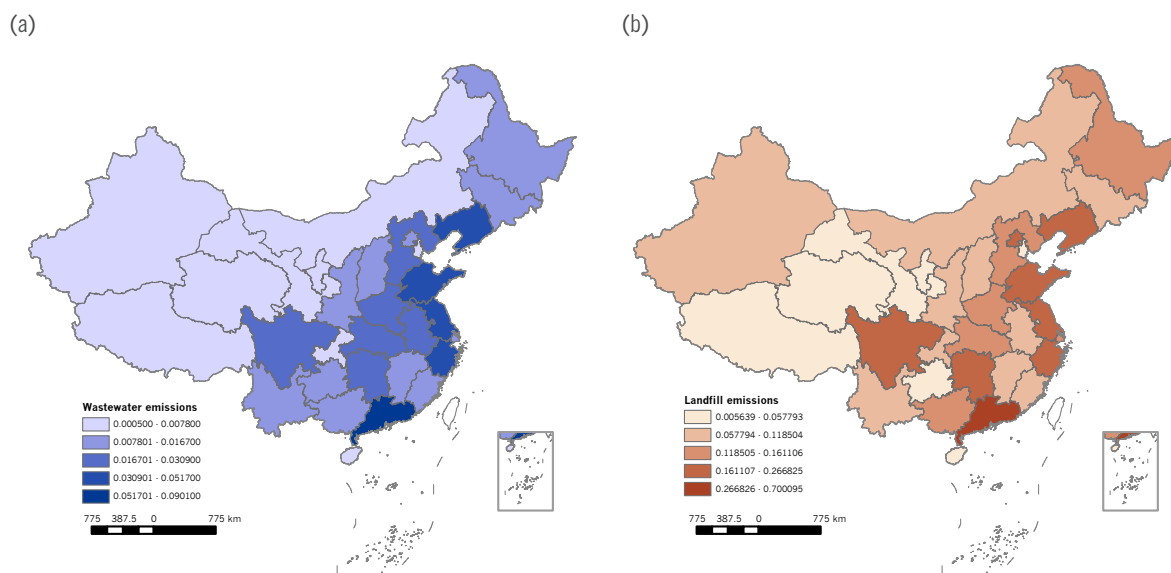
made substantial efforts to expand its municipal wastewater treatment sector through both policy and technological advancement. Investment in expanding wastewater treatment facilities continues to increase, with projections rising from RMB 166 billion in 2024 to RMB 225 billion in 2028 (Zhao, 2024). Despite these achievements, methane emissions from wastewater remain a significant issue that has not been sufficiently addressed. Moreover, the major drivers of waste methane emissions do not manifest uniformly across the country. Differences in socioeconomic development, waste composition, technology adoption, and local management practices create significant spatial variations.

2.3 Regional differences in waste methane emissions

Waste methane emissions exhibit spatial variation across China, given that waste production, composition, and treatment approaches vary across provinces. Identifying high-emission provinces and super-emitting facilities can help reveal near-term opportunities for targeted methane mitigation. As shown in Figure 2, provinces such as Shandong and Guangdong exhibit high methane emissions from both municipal wastewater treatment and landfills. In particular, Shandong, Jiangsu, Zhejiang, and Guangdong show relatively high CH₄ emissions from wastewater systems, while Shandong, Liaoning, and Guangdong are among the top emitters from landfills.

FIGURE 2. REGIONAL DISTRIBUTION OF METHANE EMISSIONS IN 2020.

(a) Municipal wastewater. (b) Landfills. Unit: Tg CH₄. Source: Using the same data as Du et al., 2023 for municipal wastewater and Ma et al., 2024 for landfills.



These spatial differences in emissions are primarily driven by variation in waste treatment volume, which typically reflect underlying socioeconomic factors such as population size, economic growth, and urbanization rate (Han et al., 2024; Liu et al., 2025). Multiple studies have demonstrated that solid waste and waste output are significantly higher in economically developed

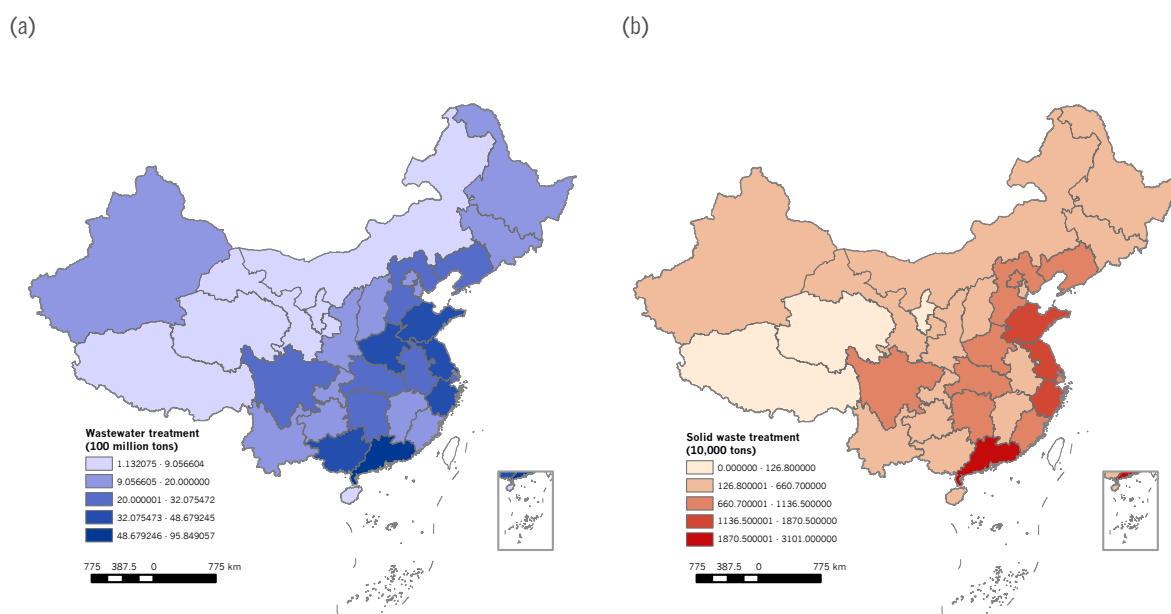
and densely populated eastern provinces, such as Guangdong, Jiangsu, Zhejiang, and Shandong, where emissions from wastewater treatment and landfill are also correspondingly higher (Cai et al., 2014; Liu et al., 2025; Lou et al., 2017). In contrast, western and less urbanized regions including Tibet, Qinghai, and Ningxia report minimal emissions due to lower waste

generation and correspondingly limited landfill and wastewater treatment infrastructure (Lou et al., 2017; Wang et al., 2023). This supports that

increased waste generation and treatment activity are key drivers of methane emissions.

FIGURE 3. REGIONAL DISTRIBUTION OF WASTE TREATMENT VOLUME IN 2020.

(a) Municipal wastewater treatment. (b) Municipal solid waste treatment. The wastewater treatment volume is from MEE, 2022 and the solid waste treatment volume is from NBS, 2021.



However, differences in treatment volume do not fully explain all spatial emission patterns (Figure 3). Despite the dominant role of waste treatment volume in determining total methane emissions, other factors, such as waste composition, treatment practices, and the deployment of methane recovery technologies, also significantly influence emission levels, particularly in terms of emission efficiency and intensity (Liu et al., 2025; Zhang et al., 2019). For instance, provinces in northeastern China (e.g., Liaoning province) exhibit a higher proportion of food waste in landfills (approximately 60%), which contributes to higher emission intensities, while northwestern provinces report lower kitchen waste content (around 39%), suggesting a lower methane generation potential (Cai et al., 2014). Treatment infrastructure can also influence emission levels, such as well-equipped gas collection systems. Cities such as Beijing and Shanghai achieve

relatively lower methane emissions due to their widespread implementation of landfill gas recovery systems (Lou et al., 2017). In addition, landfill operating time is another critical factor. Older landfills often contain large volumes of aged waste that continue to decompose and emit methane for years after initial disposal. Some inland cities with long-operating landfills and limited gas recovery infrastructure tend to exhibit higher emission intensities (Liu et al., 2025). Climate conditions further contribute to regional disparities. In cold and arid regions such as Xinjiang, microbial activity is suppressed and waste degradation is slow, resulting in lower methane emissions. In contrast, warmer and more humid southeastern regions experience faster microbial degradation, leading to greater methane generation from the same volume of waste (Lou et al., 2017).

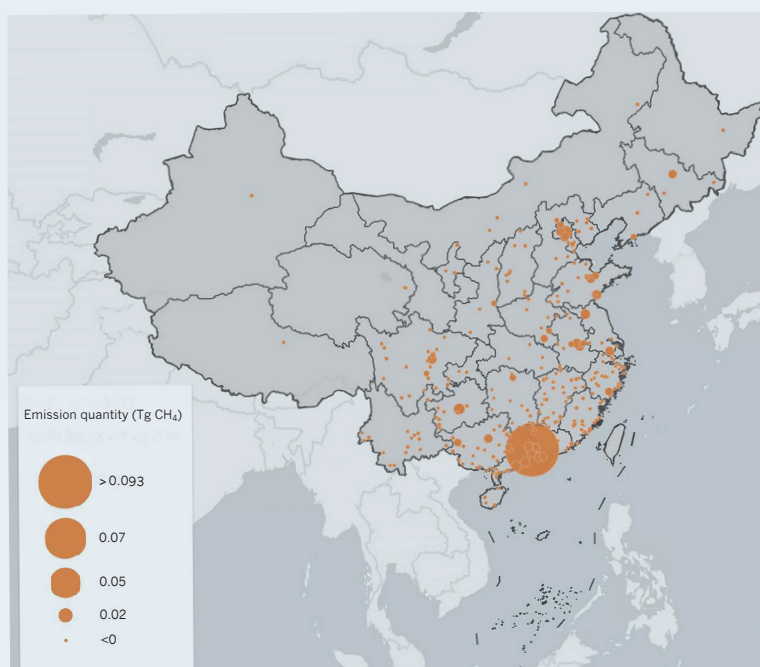
SUPER EMITTING LANDFILLS IN CHINA

Emissions from landfills have high spatial and temporal variability, making the identification of large point source emissions critical. Recent research defines “super-emitters” as sources that release disproportionately large amounts of methane, contributing significantly to total emissions. These emissions are typically concentrated at specific locations

such as well sites, production facilities, or large municipal waste management sites like landfills (Casey et al., 2021; U.S. Environmental Protection Agency, 2024a). Therefore, evaluating super-emitters can help identify key sources of emissions and support the development of targeted mitigation strategies.

FIGURE 4. DISTRIBUTION OF METHANE EMISSIONS FROM SOLID WASTE DISPOSAL SITES IN 2024.

Source: (Climate TRACE, 2024). Note: solid waste disposal sites may include some industrial solid waste facilities.



One of the largest landfills in China is the Xingfeng Municipal Solid Waste Sanitary Landfill in Guangzhou (Figure 4). Xingfeng began operations in 2002 and is one of the largest sanitary landfills in China and Asia in terms of daily processing capacity (Huanwei, 2022). By 2020, the landfill handled an average of 7,000 tons of municipal waste per day, covering approximately 90% of Guangzhou’s waste disposal needs (Sanitation Technology Network, 2023). In 2024, its CH₄ emission level reached 93.23 kt CH₄, accounting for about 1.55% of China’s total landfill methane emissions that year (Climate TRACE, 2024).

Super-emitter sites present a unique policy opportunity for mitigating emissions by enabling targeted, high-impact

interventions. Policymakers should allocate resources more efficiently and achieve significant reductions in methane emissions with relatively focused actions including site-specific emissions monitoring, legacy waste remediation, special funds, pilot program, and specific technology deployment. The Xingfeng landfill has implemented integrated waste management and gas collection systems. It is now developing an excavation program for its legacy waste (Guangzhou Municipal Ecological Environment Bureau, 2009; 2024) which is helping to significantly reduce its high emission levels, setting a replicable example for managing similar sites nationwide.

Waste methane emissions in China are substantial and driven by a range of region-specific factors. Addressing these challenges requires not only recognizing the emissions level, but also understanding which technological options are available and the contexts in which they can be most appropriately applied with the maximum synergetic effect.

3. MITIGATION STRATEGIES

3.1 Technology mapping

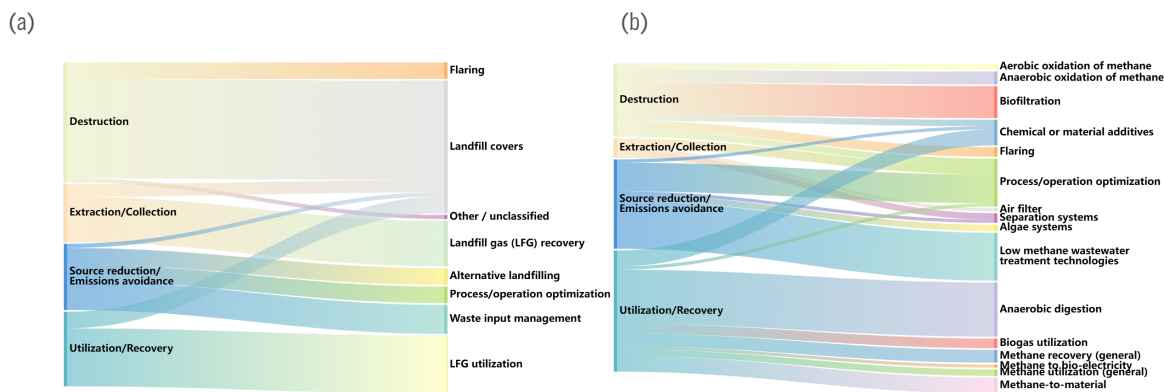
To address the significant methane emissions from the waste sector, numerous studies have explored potential mitigation measures. According to our recently released database, Global Methane Abatement Solutions Tracker (GMAST), which reflects a global compilation of methane mitigation technologies (Zhu et al., 2025a), effective strategies fall into four main categories: 1) destruction, 2) extraction /collection, 3) source reduction/emissions avoidance, and 4) utilization/recovery. This section presents technology mapping that connects these four strategic categories with their specific applications across the landfill and wastewater systems (Figure 5).

- ▶ **Destruction** strategies include systems like biological oxidation and thermal oxidation, which are extensively used in landfills to break down methane before it escapes into the atmosphere.
- ▶ **Extraction/collection** systems serve as enabling infrastructure for both recovery and destruction. These systems are primarily found in landfill operations, where gas collection and extraction systems are used to collect methane from below the site for further treatment.
- ▶ **Source reduction/emissions avoidance** focuses on preventing methane formation at early stages of treatment by avoiding anaerobic conditions, improving organic load management, or reducing waste generation. This is particularly notable in wastewater treatment where techniques like aerobic treatment of wastewater, chemical or material additives, and constructed wetlands systems are used in the process.
- ▶ **Utilization/recovery** strategies, such as anaerobic digestion and methane-to-energy systems, are applied across both sectors to capture methane for productive use.

This mapping provides a comprehensive overview of the sectoral relevance of various technologies and serves as a foundation for deeper analysis.

FIGURE 5. MAJOR TECHNOLOGY TYPES AND CATEGORIES.

(a) Technology distribution in the landfills sector. (b) Technology distribution in the wastewater sector. The left categories in each panel represent the four main technology categories including: destructions, extraction/collection, source reduction/emissions avoidance, and utilization/recovery. The right categories represent specific technology types. The width of each flow represents the number of technologies collected. The definitions of the technology types and key examples can be found in the appendix. Source: (Zhu et al., 2025a).



Landfills

Methane in landfills is produced as buried organic waste decomposes under anaerobic conditions. It is emitted as it diffuses across the landfill surface, as well as from specific hotspots such as cracks in the landfill cover, malfunctioning gas collection systems, leachate infrastructure, and inefficient flaring systems (RMI, 2023). A range of technologies can be employed to control methane emissions from landfills, including advanced monitoring systems to detect and reduce fugitive emissions, engineered covers to limit surface emissions by oxidising methane, robust well and pipe systems to ensure effective methane capture, end-of-pipe solutions to manage emissions from leachate systems, and technologies for the beneficial use of collected landfill gas (RMI, 2023).

Specifically, among the wide array of methane mitigation technologies deployed in landfill systems, some have gained increasing attention through comprehensive studies and broader promotion. Landfill covers, including traditional soil and clay covers and bio-based covers, are fundamental measures for managing landfills. Current studies include extensive research on biocovers, biofilters, and bio-windows – all designed to promote microbial oxidation of methane in soil or engineered cover layers (Duan

et al., 2022; Pratt & Tate, 2018). It also covers a number of innovations in materials (e.g., geomembrane covers, geosynthetic clay liners, vegetated covers), which are designed to limit methane escape and facilitate gas collection, recovery, and utilization (Sadasivam & Reddy, 2014; Spokas et al., 2006; Sun et al., 2015). Another major technology type available in the field falls under LFG (Landfill Gas) recovery and utilization, which includes LFG collection systems, enhanced LFG recovery systems, and LFG-to-energy systems (Qu et al., 2019). It is a crucial component for the methane mitigation system for landfills. These technologies focus on capturing methane, combusting it and converting it into usable energy.

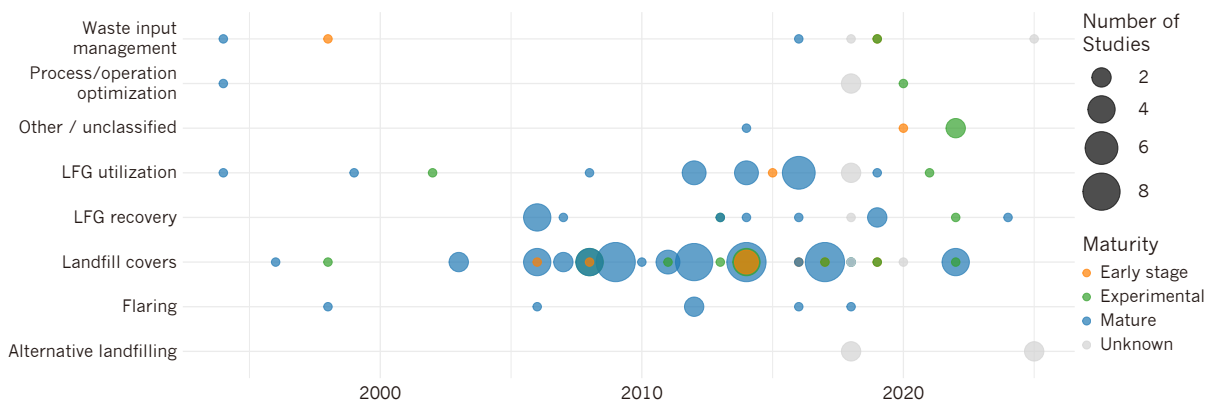
Waste input management and alternative landfilling strategies represent source-level interventions. These include mechanical biological treatment (MBT), organic waste diversion, and aerobic landfill management, aiming to reduce or delay methane generation at its origin by promoting aerobic conditions or decreasing organic compounds (Cai et al., 2018; Chai et al., 2016; Ma et al., 2025). These strategies are also potentially synergistic with other policy goals. For example, expanding composting and organic waste diversion can reduce landfill methane emissions and simultaneously decrease demand

for synthetic fertilizers through the production of nutrient-rich compost while improving soil health. Diverting high-moisture organic waste from the waste stream can also increase the efficiency of

incineration and energy recovery, accompanied by effective measures to control pollutants, such as dioxins, from incineration processes.

FIGURE 6. LANDFILL TECHNOLOGY DEVELOPMENT BY TYPE AND MATURITY.

The x-axis refers to the publication year of research on the technology as a proxy for the timeline of technology availability. While publication dates do not precisely indicate when technologies were developed or implemented, the distribution of studies reflects evolving research priorities and the progression of technological maturity. Each bubble represents one or multiple studies in that year, with size indicating the number of studies and color denoting the maturity level (early stage, experimental, mature, or unknown). Source: GMAST (Zhu et al., 2025a). For more information on methodology and how maturity level was determined, please see Zhu et al., 2025a.



The development trend of landfill methane mitigation technologies reflects a combination of early foundational innovation and ongoing technical diversification (Figure 6). The initial efforts began in the 1990s, primarily focusing on LFG collection systems, flaring, and basic cover systems, which now represent some of the most mature and widely implemented technologies in the field. For instance, LFG recovery approaches such as vertical well systems and energy conversion have been extensively applied in practice. After two decades of development, a number of mitigation measures were developed and reached technical maturity over time such as some landfill cover systems with biological oxidation units. Meanwhile, a substantial proportion of novel and specialized enhancement technologies, such as photocatalytic oxidation, supervisory control and data acquisition-based gas management, and membrane-enhanced methane recovery systems, remain in the early or experimental stages. These approaches offer promising enhancements in performance but have

yet to reach commercial-scale deployment. The large number of mature technologies indicates substantial progress already in this sector, with the ongoing emergence of new techniques suggesting that landfill methane mitigation remains in a growth phase.

Wastewater

In the wastewater sector, methane is produced during anaerobic decomposition of the organic matter in wastewater treatment. The primary sources of methane emissions in wastewater treatment plants include primary sedimentation tanks, biological treatment units, secondary clarifiers, sludge thickeners, and sludge treatment processes (Maktabifard et al., 2023; Yang et al., 2023). Better optimizing wastewater treatment processes, collecting fugitive biogas, and utilizing recovered methane would contribute considerably to reducing CH₄ emissions from wastewater treatment (GMI, 2013).

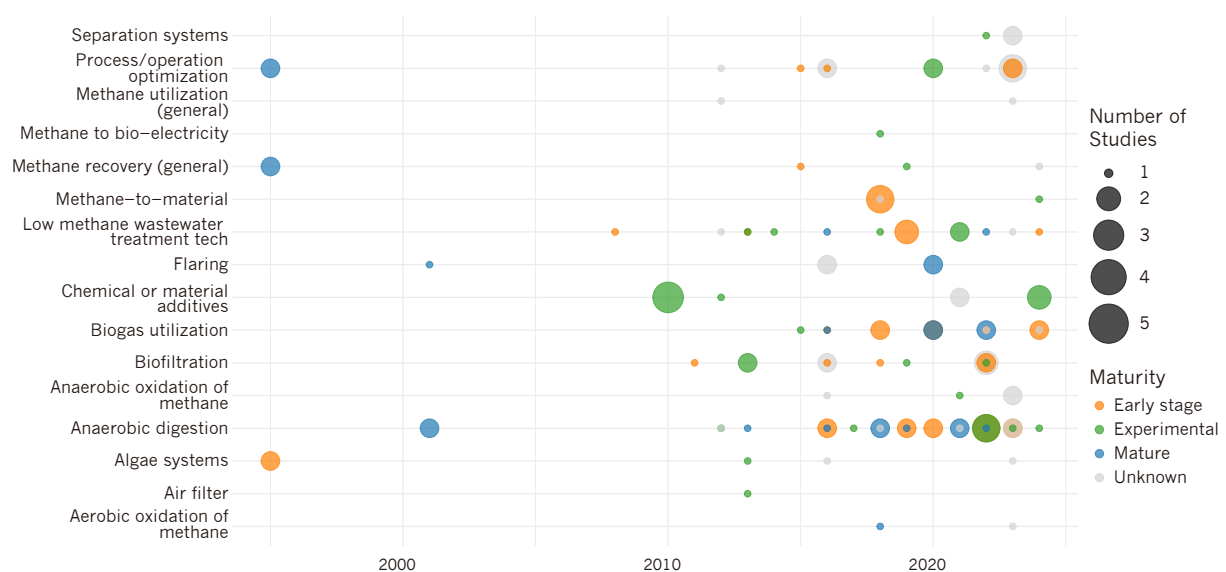
Specifically, a variety of mitigation strategies are

available for wastewater treatment. Anaerobic digestion (AD) systems represent the most widely researched and implemented group, with numerous detailed techniques such as conventional digesters, anaerobic membrane bioreactors (AnMBRs), co-digestion systems, and enhanced digestion processes, to stabilize organic sludge, reduce methane leakage, and improve methane recovery and utilization (Admasu et al., 2022; Du et al., 2023; Malyan et al., 2021). Methane oxidation (*Anaerobic & Aerobic*) strategies, such as methane oxidizing bacteria (MOB), improved aeration during sludge storage, bioscrubbers, and biofilters, can destroy methane and prevent its release into the atmosphere (He et al., 2023; Khabiri et al., 2022; Yusuf et al., 2012). Meanwhile, low methane wastewater treatment technologies, such as constructed wetlands with microbial fuel cells (CW-MFC), aerobic sludge treatment, and reverse anaerobic-anoxic-oxic (r-A/A/O) processes, aim to reduce methane formation by generating aerobic conditions or lowering the organic share in effluent (Ren et al., 2013; Yusuf et al., 2012; Zhang et al., 2021).

Process/operational optimization, such as shortening sludge retention times, improving aeration, and enhancing sedimentation-digestion linkages, can also play a critical role in reducing fugitive methane from treatment plants (Du et al., 2023; Harclerode et al., 2020). Additionally, chemical or material additives such as activated carbon, biochar, iron ochre, and gypsum are used to alter the chemical environment in wastewater or sludge, either suppressing methanogenesis or enhancing oxidation and gas separation (Lauzurique et al., 2024; Malyan et al., 2021). At the downstream end, methane recovery and methane utilization technologies in the wastewater sector form a critical part of integrated strategies. These include systems for biogas capture, combined heat and power (CHP), and methane-to-material conversions such as methanol or bioplastics, turning methane emissions into usable resources (He et al., 2023; Mundra & Lockley., 2024).

FIGURE 7. WASTEWATER TECHNOLOGY DEVELOPMENT BY TYPE AND MATURITY

The x-axis refers to the publication year of research on the technology as a proxy for the timeline of technology availability. While publication dates do not precisely indicate when technologies were developed or implemented, the distribution of studies reflects evolving research priorities and the progression of technological maturity. Each bubble represents one or multiple studies in that year, with size indicating the number of studies and color denoting the maturity level (early stage, experimental, mature, or unknown). Source: GMAST (Zhu et al., 2025a). For more information on methodology and how maturity level was determined, please see Zhu et al., 2025a.



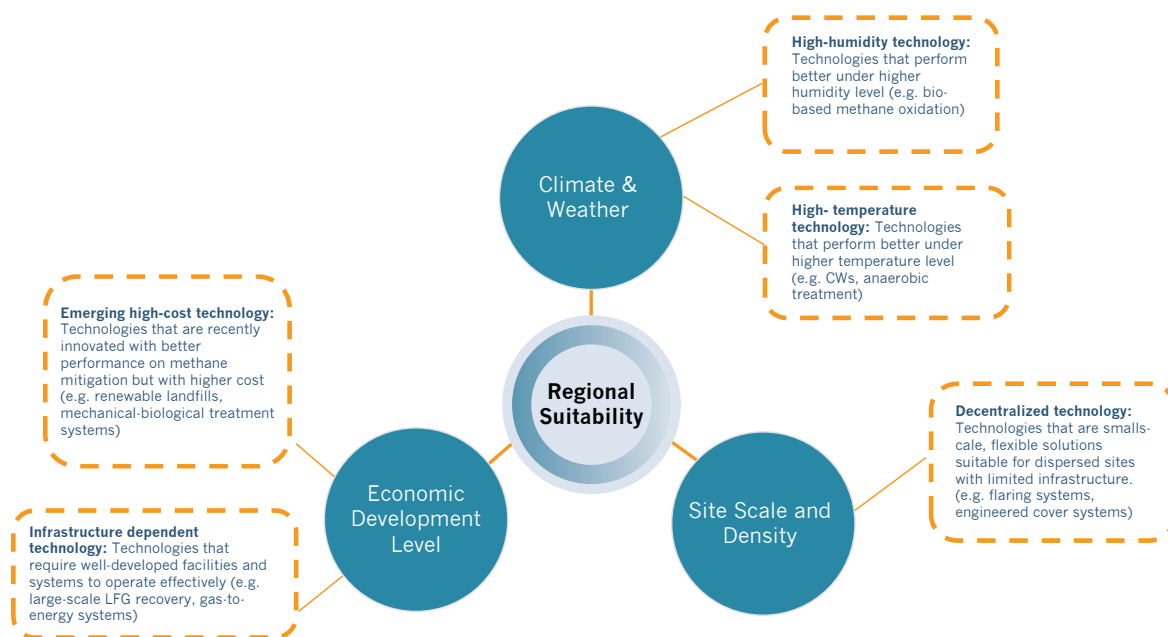
Research on wastewater methane mitigation technologies started in the last century, but more than half of the studies have been published within the past 10 years. According to the maturity level mentioned in the studies collected, most technologies remain in early development or experimental stages. This indicates that the wastewater sector mitigation technology is still undergoing rapid evolution (Figure 7). More foundational technologies such as anaerobic digestion (AD), flaring, and algae-based stabilization ponds with biogas collection emerged earlier and are now considered mature and commercially viable, especially for conventional AD setups, biogas collection units, and flaring devices. In contrast, a significant number of technologies remain at the early or experimental stage, particularly in areas such as membrane-based methane capture (e.g., Granular Anaerobic Membrane Bioreactors, Electrochemical Anaerobic Membrane Bioreactors), electrochemical systems, and chemical or material additives (e.g., biochar-assisted systems, iron dosing). These approaches show promising performance in lab and pilot-scale trials but not for widespread adoption in wastewater treatment facilities. Certain categories, such as microbial fuel cells, denitrifying anaerobic methane oxidation (DAMO)-based biological oxidation, and methane-to-material conversion technologies, represent emerging frontiers in the field. Their application reflects a growing interest in achieving both methane mitigation and resource

recovery goals, but they still require technical validation under operational conditions.

3.2 Regional variation of mitigation measures

China exhibits substantial regional differences in weather and climate, economic development, and the scale and operating conditions. These variations significantly influence the suitability and effectiveness of available methane mitigation strategies in the waste sector. We summarize the suitability of several types of technologies across climate, economic, and management conditions that vary throughout China (Figure 8). High-temperature technology and high-humidity technology are impacted by local climate and weather, making them more suitable for deployment in southern China. The application of infrastructure-dependent technology and emerging high-cost new tech is constrained by local economic development levels, meaning that the more developed eastern areas are in a better position for adoption. Decentralized technology is linked to the density and scale of treatment sites, and is thus more suitable in western regions where sites tend to be smaller and more scattered. The following sections provide a more detailed discussion of how these contextual factors influence the regional suitability of methane mitigation technologies.

FIGURE 8. ANALYTICAL FRAMEWORK FOR ASSESSING REGIONAL SUITABILITY OF WASTE METHANE MITIGATION TECHNOLOGIES.



Climate and weather conditions. Regional climatic conditions critically affect the performance of methane mitigation technologies. In southern and eastern China, the warm and humid climate enhances microbial activity and accelerates methane generation which leads to higher biogas production, making these regions more suitable for LFG collection and energy recovery systems (Cai et al., 2018). For example, the Laogang Landfill in Shanghai can process over 60 million cubic meters of biogas annually. With the application of LFG recovery systems, it generates more than 100 million kWh of electricity and reduces approximately 600,000 tons of CO₂ emissions each year (iGDP, 2021a). Additionally, the higher methane oxidation rates observed in South China also support the deployment of biological treatment measures such as biocover, biofilter, and bios-window for landfill management (Schirmer et al., 2022). For wastewater treatment, temperature-sensitive technologies, such as constructed wetlands, anaerobic treatment, and anaerobic membrane bioreactor, also perform more effectively in these warmer regions (Contreras et al., 2022; Harclerode et al., 2020). In southern China including Guangdong, Jiangxi, and Shanghai, constructed wetlands are widely

used for wastewater treatment and improving the environment (MEE, 2023b). Conversely, the colder winter temperatures in northeast China suppress microbial processes, leading to slower methane production and reduced biological treatment efficacy (Cui et al., 2022). In such contexts, more decentralized and temperature insensitive mitigation approaches, such as gas collection and flaring systems, are more suitable. Also, some technologies are broadly applicable across all regions regardless of climate, including partial nitrification/anaerobic ammonia oxidation (PN/A), high-rate activated sludge (HRAS), and high-solids anaerobic digestion (HSAD), which are less sensitive to temperature and humidity variations (Du et al., 2023).

Economic development level. The level of economic development plays a critical role in shaping the feasibility and selection of methane mitigation technologies. Economically developed regions, such as eastern China, typically possess greater financial and technical capacity and better developed infrastructure, allowing them to implement more advanced and high-cost strategies, including mineral landfills, renewable landfills, mechanical-biological

treatment systems, and enhanced anaerobic treatment for wastewater (Mekonnen et al., 2017). Furthermore, in more economically developed regions, the presence of advanced infrastructure enables the implementation of infrastructure-dependent mitigation strategies, such as large-scale LFG recovery and gas-to-energy systems. In major cities such as Guangzhou, Shanghai, and Shenzhen, landfill gas projects have demonstrated significant potential for energy recovery while simultaneously contributing to methane emission mitigation (iGDP, 2021a). These regions can be early actors for waste methane mitigation, helping to drive innovation in technology development and expand commercial availability. In contrast, less economically developed regions, such as northwest China, with limited fiscal resources, limited supporting facilities, and relatively lower waste generation rates, require more cost-effective and easy to integrate solutions such as implementing soil cover and gas flaring best practices due to the lack of efficient LFG collection and utilization network and infrastructure (Cui et al., 2022). Additionally, some technologies are low-cost, easy-to-operate such as constructed wetland systems, which is well-suited for wastewater treatment in underdeveloped rural areas. For example, the Jiuxi Constructed Wetland Project in Yunnan successfully treated wastewater while enhancing the local environment, demonstrating the viability of this approach in small-town settings (Zhang, 2018).

Treatment site scale and density. The size and spatial distribution of landfills are also key determinants of technological suitability. Regions such as east and northeast China contain a larger number of large-scale landfills (exceeding 5 million cubic meters), which offer significant

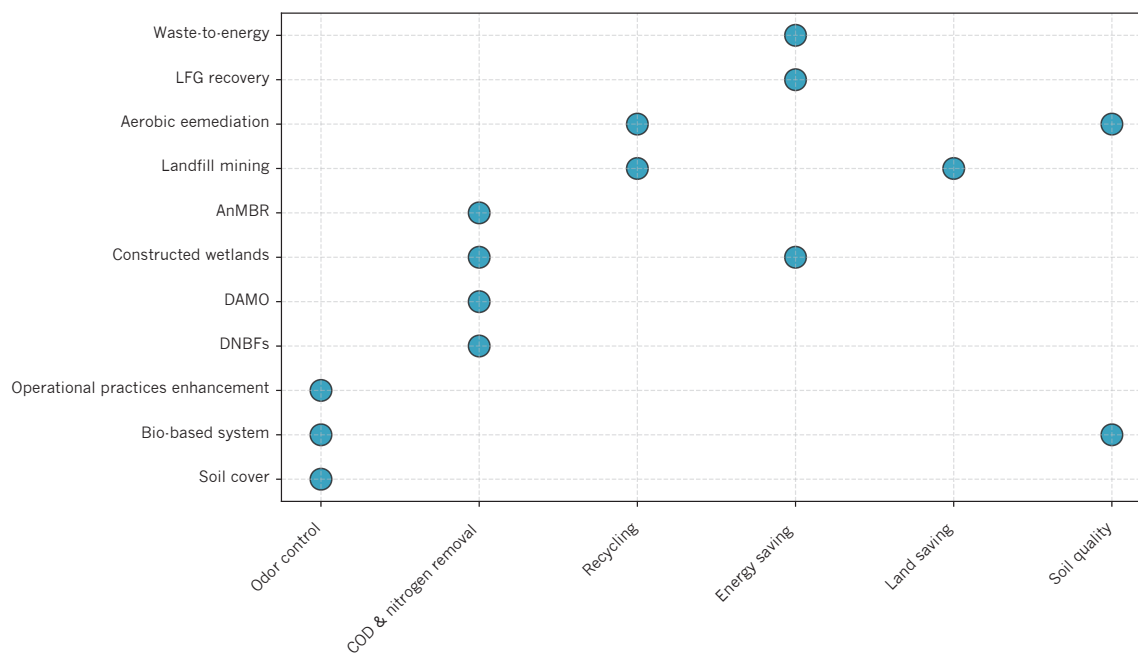
opportunities for reducing methane emissions at the site level (Cui et al., 2022). These landfills are well-suited for centralized and technically intensive mitigation systems, including large-scale LFG recovery and downstream utilization technologies (Noyola et al., 2018). For example, the Xingfeng Landfill Gas-to-Energy Project in Guangzhou, one of China's largest cities, collects over 60 million m³ of landfill gas annually (iGDP, 2021a). In contrast, landfills in northwest and southwest China tend to be smaller and more dispersed, making centralized approaches less viable. In these areas, low-cost and easily implementable technologies are more effective, offering flexibility and economic viability for decentralized waste management systems, such as gas flaring systems and engineered cover systems.

3.3 Methane reduction and synergetic effects

Many measures and technologies generate substantial synergetic effects between waste methane mitigation and other environmental, economic or operational objectives. These technologies play a significant role in emissions control while simultaneously advancing goals such as odor control and air quality improvement, chemical oxygen demand (COD) and nitrogen removal, resource recycling, energy saving, land saving, and soil quality enhancement (Figure 9). Recognizing and prioritizing such co-beneficial solutions can amplify the overall economic and environmental effectiveness of mitigation strategies. The following sections highlight key examples of these technologies and their synergetic contributions along with methane reduction.

FIGURE 9. MAPPING OF METHANE MITIGATION TECHNOLOGIES AND THEIR CO-BENEFITS.

The chart links each technology (listed on the vertical axis) with potential co-benefits (horizontal axis). Each bubble indicates the presence of a co-benefit associated with the respective technology.



Odor control. Odorous fugitive emissions negatively impact surrounding communities and often trigger public complaints, increasing resistance to landfilling operations and wastewater treatment. While the primary aim of odor control is to improve local air quality in the neighborhood and enhance the living environment, it can also contribute to methane mitigation. For instance, functional soil covers such as fine concrete, commonly used to absorb hydrogen sulfide (H₂S) and suppress odors, can simultaneously limit fugitive methane emissions (Cui et al., 2022). When paired with bio-based systems like bio-covers, bio-filters, and bio-windows, these covers create favorable conditions for microbial activity that helps oxidize methane (Sun et al., 2021). Additionally, enhanced operational practices such as the dumping, spreading, and compacting of municipal solid waste are conducive to reducing odor and have synergistic effects on methane emission control in the meantime (Garland &

Frankiewicz, 2023). For example, the Beijing Gao'antun Landfill has adopted a comprehensive odor control strategy that integrates daily fine soil coverage and standardized compaction operations. The daily application of fine soil helps suppress fugitive odor emissions and provides a barrier to methane escape. Its consistent dumping, spreading, and compacting routines also contribute to reduced anaerobic zones and improved overall emission control performance (Beijing Chaoyang Gao'antun Sanitary Landfill, 2022).

COD & nitrogen removal. The removal of organic compounds from wastewater is primarily intended to reduce water pollution and meet effluent discharge standards, however, it also plays an important role in reducing methane generation during downstream sludge treatment processes. Technologies such as denitrification biofilters (DNBFs) are typically deployed to increase the

nitrogen removal efficiency and help reduce COD in effluent (Du et al., 2023). In the meantime, it also leads to a lower amount of biodegradable organic matter, thereby indirectly limiting methane production (Du et al., 2023). Another example is denitrifying anaerobic methane oxidation (DAMO), a microbial process that simultaneously consumes methane and nitrogenous compounds such as nitrate or nitrite under anaerobic conditions. This technology not only improves nitrogen removal efficiency but also directly reduces methane emissions from wastewater systems (He et al., 2023).

Recycling. The enhancement of resource recycling is intended to maximize the recovery of valuable materials. However, it also significantly reduces methane emissions by limiting the availability of organic carbon for anaerobic decomposition. One of the key technological pathways is renewable landfills (RLs). RLs transform traditional landfills into circular systems that allow for staged degradation, excavation, and reuse of stabilized waste. By integrating the waste-to-material and waste-to-energy pathways, RLs enable simultaneous resource recovery and significant methane reduction through enhanced landfill gas control (Cui et al., 2022).

Energy saving. Energy recovery has long been a primary driver and goal of many landfill and wastewater treatment strategies, including LFG as well as biogas collection and utilization. As a complementary approach to upstream treatment technologies such as anaerobic digestion, energy recovery plays a crucial role in methane mitigation by capturing methane before it escapes into the atmosphere. In China, these technologies have been increasingly adopted, generating dual benefits in terms of both renewable energy production and climate mitigation. For instance, by 2023, 200 landfills across China had installed LFG recovery systems with end-use applications ranging from power generation to fuel supply (China Solid Waste Network, 2025). Waste-to-energy (WTE) is another key technology in this regard given the fast decrease of operating landfills. WTE systems combust waste at high temperatures to generate heat for electricity

production, reduce dependence on fossil fuels, and promote energy savings. At the same time, they significantly reduce the volume of waste sent to landfills, thereby effectively lowering methane emissions generated from landfilling (Okuh et al., 2023). For example, the Xingfeng Landfill has initiated a legacy waste excavation project starting in 2024. The city plans to excavate approximately 3.5 million cubic meters of aged waste which will be sent to the local WTE incinerators to generate more energy (Guangzhou Municipal Ecological Environment Bureau, 2024). However, it is important to acknowledge that WTE units, while useful for energy recovery, can also emit toxins (such as dioxins) and heavy metals leading to air pollution concerns if not equipped with stringent emission controls.

Land saving. With the rapid increase of solid waste, land resources for landfills are becoming increasingly scarce. To alleviate this pressure, technologies such as landfill mining and ecological restoration have been developed and applied, creating opportunities for redevelopment into recreational areas, industrial parks, or other valuable land uses. This process not only addresses the shortage of land resources but also plays a crucial role in reducing methane emissions (Zhi et al., 2023). For example, since 2009, Beijing has carried out the remediation of 1,011 informal landfills, treating approximately 8.0×10^7 tons of aged waste and saving about 1,333 hectares of land resources, which are turned to country parks after redevelopment. Shanghai also launched the “Laogang Solid Waste Comprehensive Utilization Base” ecological restoration project, which became China’s largest and most challenging landfill remediation demonstration. The project established 512 hectares of public forest and achieved a total greening area of 10 km², transforming the former landfill into a suburban themed park (Zhan et al., 2022).

Soil quality. The biocover system, as one of the key methane mitigation strategies, is also an effective technology for improving soil quality in landfill environments. They typically consist of a layer of organic oxidizing material, densely populated with methanotrophic bacteria, placed

over a coarse gas distribution layer (Stern et al., 2007). To further enhance their performance, biochar can be incorporated into the biocover matrix. As a porous and carbon-rich amendment, biochar improves moisture retention, increases gas residence time, and creates a favorable environment for microbial activity. This not only enhances methane oxidation efficiency, but also contributes to long-term soil regeneration and ecological restoration (Bordoloi et al., 2021). In addition, aerobic remediation serves as another soil-improving strategy by injecting oxygen into the landfill body to stimulate aerobic microbial processes. These microbes convert organic matter into stabilized compounds and CO₂, instead of methane (Ma et al., 2025). In China, the technique was first piloted at the Heishitou Landfill in Beijing, and has since been applied at sites such as the Jinkou Landfill in Wuhan, where a 200-million-RMB project combined aerobic systems with site capping. After 12 months of full operation, the landfill met national reuse standards and was transformed into a forested public park as part of the Wuhan Garden Expo. The approach has since gained traction and is gradually being scaled up across the country (Liu et al., 2023; Sanitation Technology Network, 2016).

Beyond the technological co-benefits above, these synergies also highlight a broader policy opportunity: waste methane mitigation can simultaneously advance climate goals, improve local environmental quality, and enhance waste system performance. These co-benefits strengthen the rationale for regulating methane and underscore the need to integrate mitigation measures into existing policy frameworks. Embedding methane control into odor and air-

quality standards, linking LFG management with pollution and safety regulations, and aligning methane mitigation with energy recovery and resource-recycling programs can significantly amplify overall policy effectiveness. Despite the need of further emphasis on the co-beneficial effects of mitigation measures, China has already begun incorporating such integrated approaches by promoting LFG utilization, strengthening pollution-methane coordinated control, and tightening operational standards in landfill and wastewater systems.

4. POLICY TRENDS

China has a long history of regulating the waste sector through a cross-administration governance structure (Table 1). Solid waste management involves multiple ministries including the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Ecology and Environment (MEE), and the National Development and Reform Commission (NDRC) to regulate solid waste from the perspectives of source reduction and reuse, recycling and composting, energy and resource recovery, and waste segregation, treatment, and disposal (IGDP, 2021a). Wastewater governance follows a similar multi-agency model. The State Council releases multiple action plans, while other administrations such as MOHURD, MEE, and NDRC are responsible for managing wastewater systems, setting environmental standards and pollutant control requirements, and guiding investment and infrastructure development in implementation.



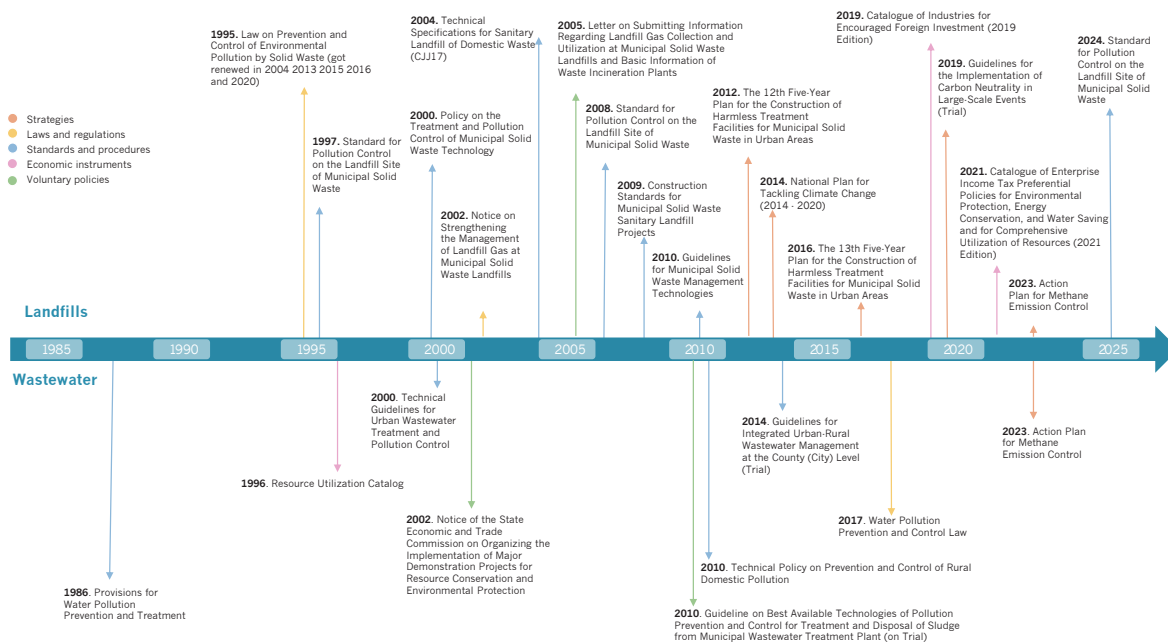
TABLE 1. KEY MINISTRIES AND RESPONSIBILITIES FOR WASTE MANAGEMENT IN CHINA.

Ministry	Solid Waste	Wastewater
Ministry of Ecology and Environment (MEE)	<ul style="list-style-type: none"> ▶ Pollution control standards; ▶ Environmental risk management; ▶ Technical guidance on waste treatment; ▶ Resource utilization; ▶ Regulation and supervision for incineration. 	<ul style="list-style-type: none"> ▶ Rural area wastewater management; ▶ Wastewater treatment facilities regulation; ▶ Environmental risk management; ▶ Discharge standards and permission; ▶ Wastewater monitoring and technical standards.
Ministry of Housing and Urban Rural Development (MOHURD)	<ul style="list-style-type: none"> ▶ Integrated management of MSW; ▶ Construction and operational supervision of treatment plants; ▶ Control of MSW incineration, fly ash and flue gas; ▶ Standards for waste collection, transport and transfer stations; ▶ Waste sorting; ▶ Rural area solid waste management. 	<ul style="list-style-type: none"> ▶ Planning and supervision of construction and operation of wastewater treatment facilities; ▶ Sewer network and urban drainage management; ▶ Technical standards for wastewater treatment plants; ▶ Sludge treatment; ▶ Rural and county-level wastewater management; ▶ Investment, financing and participation of private/social capital.
National Development and Reform Commission (NDRC)	<ul style="list-style-type: none"> ▶ Circular economy and resource recovery; ▶ Rural area solid waste management; ▶ Regional planning for waste treatment; ▶ MSW reduction and source separation; ▶ Waste disposal fees; ▶ Investment and financing. 	<ul style="list-style-type: none"> ▶ Green and low-carbon transition of wastewater treatment; ▶ Wastewater infrastructure; ▶ Wastewater resource recovery; ▶ Synergetic control on pollution reduction and carbon mitigation; ▶ Regional planning for wastewater treatment.
Ministry of Finance (MOF)	<ul style="list-style-type: none"> ▶ Management of waste treatment fees and tax; ▶ Subsidies and fiscal incentives; ▶ Private/social capital participation. 	<ul style="list-style-type: none"> ▶ Wastewater treatment fees; ▶ Fiscal incentives; ▶ Investment, financing and participation of private/social capital.
Ministry of Agriculture and Rural Affairs (MARA)	<ul style="list-style-type: none"> ▶ Rural solid waste management. 	<ul style="list-style-type: none"> ▶ Rural wastewater treatment and facility construction/operation management.

China's regulation on methane from the waste sector started from a safety protection, energy saving, and pollution control perspective in the 1980s and gradually put more emphasis on waste sector methane emissions' contribution to climate change beginning in the 21st century (Figure 10) (Yu et al., 2022). Currently, China has developed a relatively well-rounded policy toolkit, including strategies (e.g., action plans), laws and regulations, standards and procedures, economic instruments (e.g., subsidies), and voluntary programs (e.g., pilot projects and programs) to control methane emissions from the waste sector. By leveraging these policy instruments, China has been taking a series of key measures to mitigate methane emissions from solid waste disposal and wastewater treatment, including implementing waste classification, promoting circular economy, encouraging technology updates, and so forth.

FIGURE 10. KEY POLICIES IN MITIGATING METHANE EMISSIONS FROM THE WASTE SECTOR IN CHINA.

Source: (Zhu et al., 2025b).



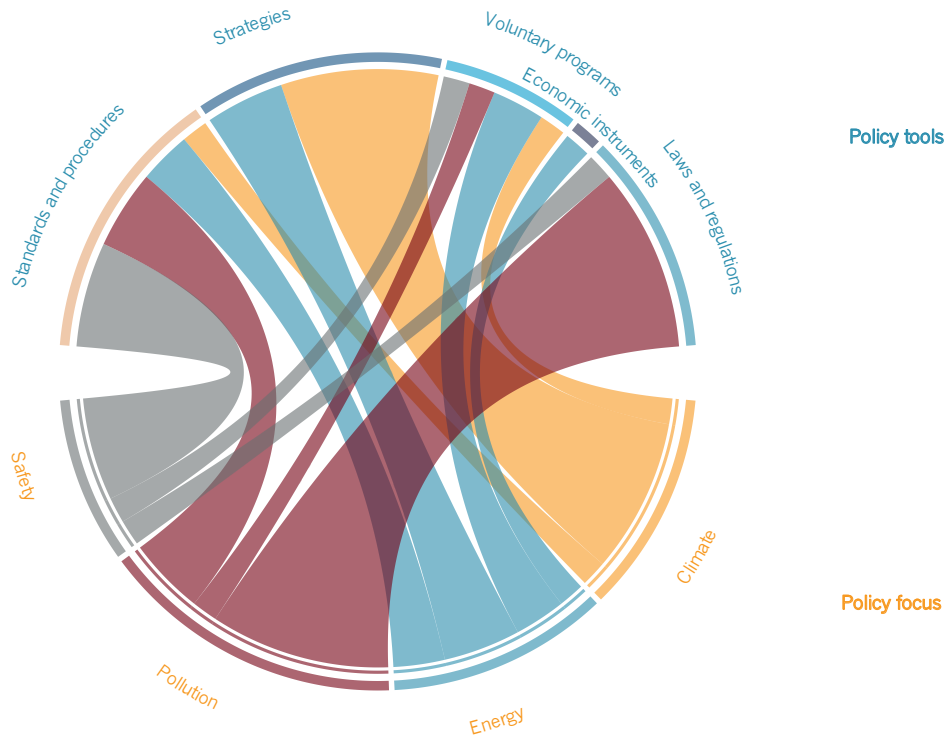
4.1 Landfills

The development of landfill methane regulation in China has evolved through several stages, each with different major focuses. In the late 20th century, regulatory attention on landfill methane was primarily driven by safety concerns. The first comprehensive landfill regulation, the *Standard for Pollution Control on the Landfill Site of Municipal Solid Waste* (issued by the Environmental Protection Agency in 1997), required the installation of gas distribution, collection, and flaring systems to prevent explosions and fires (MEE, 2008). This safety-oriented approach remained dominant into the early 2000s. During this period, pollution control also emerged as a key concern. In technical guidelines such as the *Guidelines for Municipal Solid Waste Management Technologies*, methane was classified alongside other pollutants, including wastewater and odor, as a target for control (MEE, 2010b). A shift of focus occurred in 2005 when the Ministry of Housing and Urban-Rural Development issued a

policy requiring local governments to report on the implementation of landfill gas collection and utilization systems, as well as MSW incineration facilities (MOHURD, 2005). This marked the beginning of methane being recognized not only as a pollutant and safety hazard but also as a potent greenhouse gas contributing to climate change. Since then, a series of landfill-related policies have underscored the importance of regulating methane emissions as part of China's broader climate commitments under the Kyoto Protocol, covering areas such as gas monitoring & reporting, information disclosure, as well as methane utilization and mitigation technologies (MEE, 2023a; 2024b; NDRC, 2014; 2016). Also, landfill gas has long been viewed as a recoverable energy source, suitable for direct use or power generation. While earlier policy efforts focused mainly on capturing methane for mere energy saving, recent policies emphasize its dual role in climate mitigation given that utilization has been regarded as a major mitigation strategy.

FIGURE 11. POLICY INSTRUMENT DISTRIBUTION ACROSS FOCUS AREAS IN THE LANDFILLS SECTOR.

The diagram illustrates how different policy tools (shown in blue text at the top) – including strategies, standards and procedures, laws and regulations, and economic instruments and voluntary programs – are allocated among key policy focus areas (shown in orange text at the bottom), namely safety, pollution, energy, and climate. The width of each flow represents the number of policy documents utilizing a specific instrument within a given area.



Over the past three decades, China has developed a comprehensive policy instrument toolkit for controlling methane emissions from landfills across multiple focus areas (Figure 11). Among the various policy instruments employed, strategies stand out as a preferred tool, reflecting the government's strong focus on climate and energy concerns, such as China's Methane Action Plans launched in 2023 (MEE, 2023a). Standards and procedures also play a significant role, primarily addressing methane emissions from the perspectives of safety and pollution control. For example, in the *Standard for Pollution Control on the Landfill Site of Municipal Solid Waste* (1997), the volumetric concentration of methane within two meters above the landfill working surface is forbidden to exceed 0.1% so as to prevent explosion (MEE, 1997). This standard is updated in 2024 mentioning that methane concentration above the landfill should be kept below 5%, and

methane concentration inside landfill buildings or structures should be kept below 1.25% (MEE, 2024b). Laws and regulations are also frequently used and applied to govern pollution-related issues, such as the *Law on Prevention and Control of Environmental Pollution by Solid Waste* (MEE, 2020). In contrast, voluntary programs and economic instruments are used less frequently in the waste sector, suggesting a need to strengthen their role in supporting methane mitigation efforts.

The government has introduced several key measures through current policies. These include encouraging waste classification, promoting food waste prevention, advancing the circular economy, expanding composting efforts, guiding landfill gas collection and utilization, supporting technological innovation for methane mitigation, and recommending the capping and closure of uncontrolled landfills. However, certain policy

areas still require greater attention. In particular, China has not implemented direct policies targeting methane emissions from rural landfills (Zhu et al., 2025b). Unlike large urban centers, rural areas often lack the infrastructure, financial resources, and technical capacity needed for standardized waste collection, sorting, and treatment. Waste management in rural areas remains a significant challenge, both in terms of pollution control and methane mitigation. Additionally, many existing policies addressing the climate impact of landfill methane are still at the strategic planning stage, lacking specific standards and mandatory requirements.

4.2 Wastewater

Regulation of methane emissions from municipal wastewater in China dates back to the last century. In 1986, the State Council issued the *Provisions for Water Pollution Prevention and Treatment*, which encouraged the recovery and utilization of biogas from sludge for resource conservation (State Council, 1986). This marked the first time methane was explicitly addressed in the waste sector. Then, after 2000, China's municipal wastewater treatment industry entered a phase of rapid expansion (Zhang et al., 2023), prompting a corresponding increase in regulations targeting methane emissions, particularly from sludge treatment. In 2000, the Ministry of Ecology and Environment issued the *Technical Guidelines for Urban Wastewater Treatment and Pollution Control*, which further emphasized biogas collection and utilization during sludge treatment (MEE, 2000). Subsequent guidelines, such as the *Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant (on Trial)*, provided detailed technical instructions

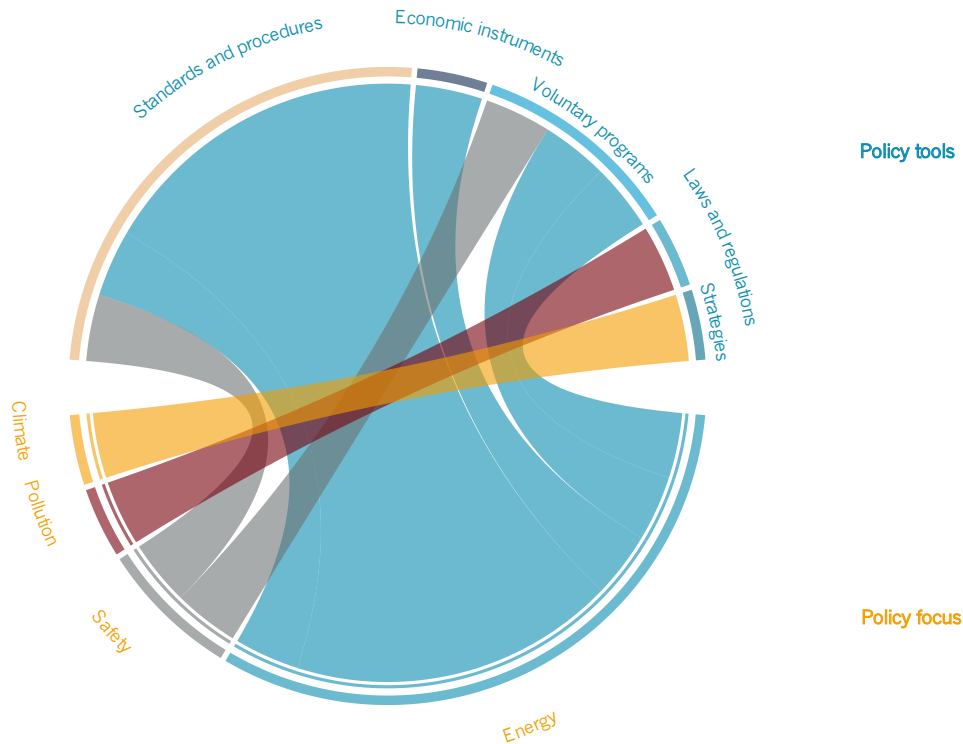
for the control, collection, and utilization of methane from sludge (MEE, 2010a). These policies highlighted not only the energy potential of methane but also the safety risks associated with its management. In recent years, methane emissions from wastewater treatment have gained increased attention from the government for their contribution to climate change. In 2023, methane from this sector was explicitly identified as a key emission source to be regulated under China's national methane action plan (MEE, 2023a).

In the wastewater sector, standards and procedures are the most commonly employed policy instruments, with a primary focus on the energy usage of methane (Figure 12). For instance, the *Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant (on Trial)* issued in 2010, mandated the installation of metering devices to monitor biogas production to promote the utilization of biogas energy (MEE, 2010a). Voluntary programs represent another frequently adopted instrument, also centered on biogas energy use during wastewater treatment. These initiatives typically include technical guidance for gas utilization and the implementation of pilot projects to serve as references for industry stakeholders in methane mitigation efforts. Strategic planning instruments are rarely utilized, with the notable exception of the Methane Action Plan introduced in 2023, which explicitly frames methane mitigation from a climate change perspective (MEE, 2023a). Economic incentives are similarly infrequent, exemplified by the 1996 release of the *Resource Utilization Catalog*, which identified resource recovery projects eligible for tax credits and exemptions (State Economic and Trade Commission, 1996).



FIGURE 12. DISTRIBUTION OF POLICY INSTRUMENTS IN THE WASTEWATER SECTOR.

The diagram illustrates how different policy tools (shown in blue text at the top) – including strategies, standards and procedures, laws and regulations, and economic instruments and voluntary programs – are allocated among key policy focus areas (shown in orange text at the bottom), namely safety, pollution, energy, and climate. The width of each flow represents the number of policy documents utilizing a specific instrument within a given area.



Current wastewater policies in China include several key measures, such as guiding sludge treatment processes, promoting technological innovation, recovering biogas from sludge, monitoring methane emissions from major sources, and encouraging the recycling of sludge byproducts. However, significant challenges remain, which contribute substantially to methane mitigation in this sector. Most policies focus primarily on biogas recovery from sludge treatment, while largely overlooking methane emissions from the broader treatment process itself, which is also a major emission source. Moreover, even though sludge treatment is recognized as the main focus for methane mitigation in the wastewater sector by policymakers, sludge management still tends to be neglected compared to wastewater treatment in the context of regulating wastewater overall (Zhang et al., 2023). As a result, existing

standards for sludge treatment are often vague and loosely defined. There is a need for more detailed, specific, and enforceable regulations that can provide clear, practical guidance for effective sludge disposal.

5. CHALLENGES AND BEST PRACTICES IN CHINA

Despite increasing policy attention and the adoption of various technical measures, significant challenges remain in China’s waste sector. Several critical issues including leachate management, legacy landfills, waste sorting, and overall wastewater GHG emissions have yet to be

adequately addressed. To close these gaps, it is essential to implement more targeted measures and apply appropriate technologies across different stages of waste treatment. A number of best practices have already emerged within China that offer valuable lessons and replicable models, and can serve as demonstrations for broader adoption.

5.1 Key issues and challenges in China's waste sector

Landfills

China's landfill sector faces a range of challenges across the entire waste management lifecycle, from pre-treatment to post-closure, which stays as barriers for methane mitigation in the landfills.

- ▶ **Before landfilling.** A major upstream challenge lies in the inadequate sorting of waste before landfilling. Despite waste classification policies in major cities, implementation remains incomplete locally and uneven across regions, particularly in smaller cities and rural areas (Beijing MCPNR, 2020; Liu, 2022; Shanghai Urban Management and Law Enforcement Bureau, 2019). As a result, there is a significant proportion of biodegradable waste, such as food waste among the solid waste that still enters landfills (rather than being incinerated). These organic components are the major drivers of methane generation under anaerobic conditions. Without effective source separation and special treatment for separated waste before landfilling such as composting, incineration or anaerobic digestion combined with LFG collection to recover the residual energy in biodegradable materials, methane emissions from landfills cannot be mitigated from the source (iGDP, 2019).
- ▶ **During operation.** Methane emissions from landfills do not solely originate from waste degradation within the landfill body. A significant portion can also be attributed to the leachate treatment systems. Additionally, poorly managed leachate systems can

cause serious secondary pollution, affecting surrounding soil, surface water, and groundwater, especially in ecologically vulnerable areas like northwest China (Xu & Wang, 2020). Leachate systems currently have received insufficient policy and technological attention in China.

- ▶ **After closure.** Post-closure management of legacy landfills represents one of the most urgent yet under-addressed challenges. China has been promoting the concept of zero-waste city since 2018 (State Council, 2018). In 2024, China has announced its national goal to achieve zero-waste cities across the country by 2035, which further expedites the shift toward waste incineration and material recycling (State Council, 2024). As the new policy framework phases out new landfilling projects, a large number of existing landfills still pose long-term environmental and methane leakage risks. The scientific and orderly closure of these sites, along with effective post-closure management, is critical to fully realizing the climate benefits of the zero waste transition. The Ministry of Housing and Urban-Rural Development issued a public consultation notice on the Construction Standards for Remediation Projects of Existing Landfill Facilities (Draft for Comments) in 2023 (MOHURD, 2023), further emphasizing the need for addressing the issue of legacy landfills .

Wastewater

The wastewater sector in China also confronts several critical and under-recognized challenges that hinder effective methane mitigation and broader environmental management goals.

- ▶ **Limited policy and regulatory focus on methane emissions.** Methane emissions from wastewater treatment processes have received little policy and regulatory attention compared to their pollution issue. Most national and local-level wastewater guidelines prioritize water quality indicators – such as chemical oxygen demand (COD), ammonia nitrogen, and pathogen control – while overlooking



greenhouse gas emissions associated with biological treatment processes (MEE, 2009; NDRC, 2023). As a result, methane produced during anaerobic digestion in sewer networks, treatment plants, or sludge handling facilities often goes unmonitored and unmitigated. The lack of comprehensive accounting frameworks, monitoring systems, and mitigation measures in the wastewater sector poses a significant barrier to targeted action.

- ▶ **Evaluating technology trade-offs.** Selecting appropriate wastewater treatment technologies presents a complex dilemma when balancing water quality improvement, greenhouse gas mitigation, and economic feasibility. Some advanced technologies offer excellent pollutant removal performance but may lead to higher GHG emissions. For instance, certain anaerobic treatment processes are effective at reducing organic loads but release large amounts of methane if gas capture and utilization systems are not in place. On the other hand, aerobic or membrane-based technologies may produce fewer direct emissions but are highly energy-intensive, resulting in significant indirect carbon emissions over their life cycle. This creates a trade-off between treatment effectiveness and climate impact, making it difficult to identify solutions that are both environmentally and economically optimal. This illustrates the inherent challenge in designing integrated wastewater strategies that simultaneously address pollution control, GHG reduction, and cost efficiency.
- ▶ **Sludge management.** Sludge, the semi-solid byproduct in primary and secondary sedimentation tanks and associated equipment of wastewater treatment, is another overlooked component (Yu et al., 2023). Untreated or poorly managed sludge can become a substantial source of methane emissions, especially when stored or disposed of under anaerobic conditions in landfills, open lagoons, or uncovered piles (Piippo et al., 2018). Although some urban centers have piloted co-treatment or energy recovery from

sludge, the majority of smaller cities and rural wastewater facilities still lack dedicated sludge treatment infrastructure. Also, the lack of well-defined standards and comprehensive guidance for sludge disposal has led to inconsistent handling practices and limited investment in treatment technologies (iGDP, 2019). Usually, sludge is simply dewatered and buried without stabilization or energy recovery, missing the opportunity to reduce methane emissions and harness its energy potential.

5.2 Technical recommendations and best practices

Landfills

A comprehensive suite of technologies is needed to address methane emissions and other environmental challenges throughout the landfill lifecycle:

- ▶ **Upstream (Pre-landfill):** Strengthening municipal solid waste sorting systems to divert biodegradable waste from landfills. Enhancing composting and anaerobic digestion combined with LFG collection capacity can reduce organic load and methane potential at the source. In Shanghai, the enactment of the *2019 Municipal Solid Waste Management Regulation* mandated household-level waste sorting. This policy now enables the city to divert around 8,000 tons of kitchen waste from landfills each day, which is instead treated through anaerobic digestion. By reducing the organic load entering landfills, this intervention has significantly cut methane generation, lowered the operational stress on LFG systems, and helped decrease greenhouse gas emissions from landfill operations (iGDP, 2021b).
- ▶ **Midstream (Operational stage):** Improving leachate treatment is essential. A range of technologies can be applied to improve leachate treatment and simultaneously reduce methane emissions, including biological treatment, physicochemical methods,

membrane separation, and advanced oxidation processes (Cherni et al., 2021). For example, the Beijing Shougang Biomass Energy Leachate Treatment Project applies a multi-stage membrane separation process consisting of a membrane bioreactor (MBR), nanofiltration (NF), and reverse osmosis (RO) to achieve deep purification of landfill leachate. The treated effluent maintains a COD level below 30 mg/L, enabling the efficient removal of organic pollutants and ammonia nitrogen, and significantly reducing the biodegradable load entering the landfill, and thereby lowering the potential for methane generation at the source (China Water Network, 2015). Another example is the leachate treatment project at the transfer station in Rudong County, Nantong City, Jiangsu Province. The facility combines multiple treatment processes, including pretreatment, air flotation, hydrolytic acidification, and a membrane bioreactor (MBR) integrated with nitrification-denitrification and ultrafiltration. It treats approximately 100 tons of complex leachate per day and achieves a COD removal rate of over 98% and an ammonia nitrogen removal rate of over 97%. This high treatment efficiency significantly reduces the biodegradable organic load, thereby lowering the potential for methane generation (China Solid Waste Network, 2024).

- ▶ **Downstream (Post-closure):** A suite of technologies and strategies is needed to address the challenge of legacy landfills including landfill ecological restoration, landfill remediation, and landfill mining (Ma et al., 2025). In general, there are two major approaches for remediating existing landfill sites in China: (1) in-situ closure and stabilization, and (2) off-site relocation and resource recovery, which typically involves excavation, sorting, and transferring the waste to waste-to-energy facilities (Minsheng Security, 2024). In-situ closure often demands long-term monitoring and maintenance and closed landfills can still pose environmental and safety risks due to gas leakage and land instability. In economically developed and

land-scarce regions, especially in eastern and coastal China, revitalizing closed landfill sites and exploring high-value land reuse options offer long-term environmental and economic benefits. A notable example comes from Guangzhou: in April 2023, the Guangzhou government issued a draft decision on its Municipal Aged Landfill Remediation Project for public consultation (Guangzhou Government, 2023). The plan proposed pilot projects at three previously closed landfills, Chenjiashan, Datian Mountain, and Huoshaogang. The selected approach involves a phased process of stabilization, excavation, sorting, and resource recovery, aiming to develop a replicable model for aged landfill remediation in Guangzhou and beyond. One of the local waste-to-energy operators had successfully co-incinerated approximately 646,000 tons of excavated aged waste by the end of 2023 (Minsheng Security, 2024).

Wastewater

Effective methane mitigation in the wastewater sector requires a thoughtful selection of treatment technologies based on overall emissions, operational feasibility and economic viability.

- ▶ **Prioritize technologies with co-benefits.** Select treatment processes that not only improve effluent quality but also reduce methane and other GHG emissions. Constructed wetlands (CWs) is a representative example of such technologies. As a low-carbon and energy-efficient approach, CWs rely on natural ecological processes and require minimal external energy or chemical inputs. In addition, plant biomass from CWs can be harvested for biogas or liquid fuel production, further enhancing resource recovery potential. For example, a large-scale constructed wetland was established in the Yunnan Caohai Artificial Wetland in Dianchi Lake. By slowing water flow, extending retention time, and promoting aerobic conditions through dense vegetation and substrate layers, the wetland buffers sewage inflow, improves water quality, reduces organic and nutrient loads, and suppresses methane emissions (Guangming Daily, 2024).



- ▶ **Capture and control process emissions.** For technologies that may generate methane (e.g., anaerobic treatment), incorporating gas collection and oxidation units to mitigate emissions during the treatment process is critical. Recent studies have developed integrated approaches for recovering and controlling dissolved methane, combining methods such as mechanical degassing, membrane contactors, and vacuum degassing to extract methane from anaerobic effluent. These techniques are often coupled with gas collection systems to enable centralized treatment and resource utilization (Zhang et al., 2022). For example, the Gao'antun Sludge Treatment Center in Beijing applies a full-chain process integrating thermal hydrolysis, anaerobic digestion, and combined heat and power (CHP), enabling effective capture and utilization of methane generated during sludge treatment. With an annual power generation of over 32 million kWh and a self-sufficiency rate of 66%, it demonstrates how large-scale municipal facilities can implement integrated methane recovery and emission control strategies (China Water Network, 2023).
- ▶ **Evaluate strategies on a multi-gas basis.** When selecting wastewater treatment technologies, it is important to assess not only how much methane can be reduced, but also whether other greenhouse gases, such as nitrous oxide (N₂O), may increase as a result. N₂O has a global warming potential nearly 300 times that of CO₂, so mitigation schemes must minimize both CH₄ and N₂O simultaneously. Some technologies, such as activated sludge process (ASP) may reduce methane emissions considering its maintenance of the aerobic environment, but could lead to higher N₂O generation if oxygen supply or carbon sources are not properly controlled (Law et al., 2012).
- ▶ **Avoid high energy-consuming technologies.** Some advanced purification technologies, while effective in pollutant removal, are extremely energy-intensive and could result in high indirect carbon emissions and high mitigation cost. In selecting such technologies, careful consideration should be given to their level of economic feasibility and total carbon emissions in the life cycle. For example, although electrochemical oxidation has shown promise in wastewater treatment and environmental remediation, it remains challenged by high power consumption and limited long-term electrode stability (Chen et al., 2024). Future research should focus on developing efficient, low-cost electrode materials, optimizing operational parameters, and integrating with other treatment technologies to support its large-scale industrial application (Delanmeyer Separation Technology, 2025).

6. CONCLUSION AND POLICY IMPLICATIONS

China has made substantial progress in addressing methane emissions from its waste sector, but there are still further steps that can be taken to better meet its climate commitments and align with the global methane pledge. The following policy implications are drawn from the analysis.

Implement region and site-specific policies targeting super-emitter sources. Given the uneven spatial distribution of methane emissions across China's provinces and the contributions of a few large super emitters, it is critical to design and enforce region and site-specific mitigation policies. The governments can initiate mitigation actions first in regions such as eastern China and south China with higher emission levels, set specific mitigation targets for major super emitters such as Xingfeng landfill, launch specific developing plans for gradually phasing out landfills, and give actual incentives like tax credit to these sites to motivate mitigation practices (Cai et al., 2018; Shanghai government, 2022).

Encourage synergetic strategies that integrate methane mitigation with broader waste management priorities. Many waste sector interventions designed for pollution control, energy conservation, or resource recovery offer co-benefits for methane mitigation. Governments should adopt a synergetic framing, embedding methane considerations into mainstream waste policies, emphasizing the methane mitigation effect of certain measures, and guiding companies to pick up strategies that have co-benefits of mitigating methane rather than releasing more GHG, so as to generate synergetic effects across air quality, public health, and energy supply.

Develop regionally tailored technical guidelines. Because the suitability and performance of mitigation technologies vary significantly with climate, infrastructure, economic capacity, and landfill scale, the local governments should formulate region-specific technical guidelines that reflect local contexts. They should also be supported with regionally disaggregated data on waste characteristics, emissions profiles, and treatment capacity.

Increase policy emphasis on methane's climate impact. In the current regulation system, with more policies concerning methane in the waste sector treating methane as a pollutant or energy resource, the climate angle is under-recognized in regulatory practice. The government should add more climate concerns to the policy-making process when it comes to methane in waste management.

Introduce more binding regulatory measures. Many of the existing policies in China remain in the form of strategies, guidelines, or voluntary programs – especially in the wastewater sector. To ensure consistent and enforceable action, stronger regulatory instruments are needed, such as binding emissions standards, mandatory reporting requirements, and permitting conditions linked to methane control. For specific areas that are easy to be neglected like sludge treatment and legacy landfill management, more strengthened technical specifications and targeted regulations should be applied to prevent a possible policy vacuum.

Expand the use of market-based instruments. The use of market-based tools such as subsidies, tax incentives, and emissions trading remains limited in the waste methane domain. Expanding the use of market-based instruments can help mobilize private investment and encourage innovation (Cai et al., 2018). Potential policy options include subsidies, carbon credits, tax exemptions, green bonds, and public-private partnerships to encourage new practices and technology implementation in the waste sector's methane emissions.

Enhance support for rural waste management. Rural landfills and small-scale treatment sites remain under-regulated and poorly managed (Yu et al., 2022). Policymakers should increase support for rural areas through tailored policies, fiscal transfers, technology sharing, and workforce training (Zhou et al., 2022). Pilot projects demonstrating low-cost, decentralized solutions such as composting, bio-covers, and basic LFG collection systems can help scale up practical mitigation approaches in these regions.

Strengthen control of methane emissions from sludge treatment. Current sludge treatment policies in China focus mainly on biogas recovery, often neglecting methane emissions from it. To close this gap, more binding and specific regulations are needed, including enforceable standards, mandatory monitoring, and clear technical requirements (iGDP, 2022). Sludge treatment should be regulated as a major emissions source rather than just a water pollution issue to prevent policy blind spots.

Initiate diverse knowledge-building activities. Methane mitigation in the waste sector suffers from data gaps and limited technical awareness, especially at local government and facility operator levels. The government should invest in waste methane measurement, reporting and verification (MRV), technology innovation, and open-access databases to fill the information gap. Also, the government should convene more knowledge-building activities to help change lifestyles and behaviors toward lower waste production and reduce methane emissions from the source.



APPENDIX

Definitions of the Technology Types

A wide range of technologies are available to reduce methane emissions in the waste sector. To provide a clearer and more consistent framework for analysis, this study classifies these technologies into standardized categories

and types (Figure 5). Tables A-1 and A-2 present detailed definitions of each technology type included in Figure 5, along with representative examples to support interpretation.

TABLE A-1 TECHNOLOGY TYPE IN THE LANDFILL SECTOR.

Technology type	Description	Examples
Alternative landfilling	Alternative landfilling refers to a set of engineered landfill designs and operational practices that is different from conventional landfill disposal methods. It can minimize methane generation at the source. These approaches aim to reduce or avoid the formation of anaerobic conditions that drive methane production, often through enhanced aeration, material substitution, or modified waste layering strategies.	Ectopic remediation, in situ aerobic treatment, mineral landfills (ML), renewable landfills (RL).
Flaring	Flaring is a widely applied methane destruction technology in landfill operations, involving the controlled combustion of collected landfill gas (LFG) to convert methane (CH ₄) into carbon dioxide (CO ₂) and water vapor.	Flaring
Landfill covers	Landfill covers refer to engineered surface layers applied over landfill waste bodies, designed not only to isolate waste from the environment but also to serve as a functional medium for mitigating methane emissions. Landfill covers include both conventional cover systems and bio-based covers that can enhance methane oxidation and control fugitive gas.	Biocovers and biofilters, functional soil covers (FSC), geosynthetic clay liners (GCL).
Landfill Gas (LFG) recovery	Landfill Gas (LFG) recovery refers to the extraction and collection of landfill gas generated from the anaerobic decomposition of organic waste. The primary objective of LFG recovery is to capture methane before it escapes into the atmosphere, typically consisting of a network of gas wells, trenches, piping, and vacuum pumps that extract gas from the waste body.	Horizontal LFG recovery, LFG collection system, vertical gas wells.
Landfill Gas (LFG) utilization	Landfill Gas (LFG) utilization refers to the process of capturing and converting methane-rich landfill gas into useful forms of energy, such as electricity, heat, or fuel. Depending on gas quality and project design, the captured gas can undergo purification, compression, or upgrading before being routed to various end uses.	Combined heat and power (CHP), power generation, vehicle fuel production.
Process/operation optimization	Process/operation optimization refers to a set of strategies aimed at improving the operational parameters and treatment conditions within landfills to reduce methane generation at the source. These approaches focus on modifying existing landfill processes.	Aerobic landfill management, refinement process for MSW landfilling (RPL).
Waste input management	Waste input management aims to prevent or reduce the deposition of methane-generating waste, particularly biodegradable organic material, into landfills. By controlling the quantity, composition, and treatment of waste prior to landfilling, this approach minimizes the biochemical potential for methane formation during anaerobic decomposition processes.	Mechanical biological treatment (MBT), source-separated waste collection.

TABLE A-2 TECHNOLOGY TYPE IN THE WASTEWATER SECTOR.

Technology type	Description	Examples
Aerobic oxidation of methane	Aerobic oxidation of methane refers to a biological methane destruction pathway in which methane is oxidized into carbon dioxide by aerobic microorganisms in the presence of oxygen. The process is primarily mediated by aerobic methane-oxidizing bacteria (MOB), which utilize methane as a carbon and energy source under oxic conditions.	Aerobic methane oxidizing bacteria (MOB), downflow hanging sponge (DHS) reactor.
Air filter	Air filter refers to gas-phase treatment units designed to capture and remove volatile organic compounds (VOCs), methane, and other trace gases from exhaust air streams. It is used in wastewater treatment to adsorb volatile compounds, including trace levels of methane, from gas streams.	Activated carbon filters.
Algae systems	Algae systems refer to a class of nature-based and biotechnological wastewater treatment approaches that leverage microalgae in combination with bacteria, to enhance organic matter removal, oxygen production, and indirect methane mitigation. These systems contribute to source reduction/emissions avoidance by altering treatment conditions to suppress anaerobic decomposition that would otherwise generate methane.	High rate algal ponds (HRPs), photobioreactors (PBRs), waste stabilization ponds.
Anaerobic digestion (AD)	Anaerobic digestion (AD) is a widely adopted biological process in wastewater management that decomposes organic matter in the absence of oxygen, producing biogas primarily composed of methane and carbon dioxide. AD enables both stabilization of organic waste and energy recovery through the capture and use of biogenic methane.	Anaerobic membrane bioreactor (AnMBR), biochar-enhanced anaerobic digestion.
Anaerobic oxidation of methane (AOM)	Anaerobic oxidation of methane (AOM) refers to a group of microbial processes in which methane is oxidized in the absence of oxygen using alternative electron acceptors. AOM represents an emerging destruction-based methane mitigation strategy that targets dissolved or fugitive methane in anaerobic treatment effluents.	Denitrifying anaerobic methane oxidation (DAMO), Mn-dependent anaerobic oxidation of methane (Mn-AOM).
Biofiltration	Biofiltration is a biological gas treatment technology that removes methane from wastewater treatment systems by passing the gas stream through a biologically-active filter medium. This destruction-based methane mitigation strategy relies on the metabolic activity of methane-oxidizing microorganisms (such as methanotrophs).	Bioscrubber, biotrickling filters (BTFs)
Biogas utilization	Biogas utilization refers to the recovery, upgrading, and productive use of biogas generated from anaerobic treatment processes in wastewater management systems. This approach is categorized under utilization and recovery strategies for methane mitigation, aiming to reduce emissions by capturing and utilizing biogas.	Biogas upgrading and utilization
Chemical or material additives	Chemical or material additives refer to the intentional incorporation of chemical substances into wastewater treatment systems to enhance methane mitigation through emission avoidance, methane destruction, or resource recovery.	Biochar-based biogas enrichment, addition of iron ochre in constructed wetlands.
Flaring	Flaring is a methane destruction technology that involves the controlled combustion of methane emitted from anaerobic treatment units, sludge handling systems, or covered lagoons in wastewater management.	Flaring
Low methane wastewater treatment technologies	These technologies refer to certain wastewater treatment measures that, although not explicitly designed for methane mitigation, inherently result in low methane emissions throughout their operational processes.	AN and A (Anaerobic–Aerobic) system with biogas utilization



Technology type	Description	Examples
Methane recovery (general)	This type refers to a broad category of technologies designed to capture methane produced during wastewater treatment processes.	Power-to-Methane (PtM) system
Methane utilization (general)	This type refers to the broad category of strategies that capture and use methane generated during wastewater treatment processes for productive purposes.	Combined Heat and Power (CHP)
Methane to bio-electricity	Methane to bio-electricity refers to an emerging class of biotechnological approaches that utilize methane as an electron donor to directly generate electrical energy via engineered microbial systems, particularly within microbial fuel cells (MFCs).	Engineered methanotrophic microbial fuel cell
Methane to material	Methane-to-material refers to a class of technologies that convert methane into chemical materials such as biodegradable plastics, methanol, bio-based chemicals, or other functional products.	Methane-to-methanol conversion, production of biodegradable polymers
Process/Operation Optimization	Process/Operation Optimization refers to the strategic refinement and control of operational conditions, system configurations, and treatment sequences to reduce methane generation, enhance methane capture, or improve energy/resource recovery.	CANDO (Coupled Aerobic-anoxic Nitrous Decomposition Operation) process
Separation systems	Separation systems refers to technologies and strategies designed to physically or chemically isolate methane from wastewater streams, before it is generated or after it has been produced (effluent or gas-phase separation).	Effluent methane management

Available key technologies and application cases

A wide range of methane mitigation technologies are available in the waste sector. To maximize environmental, operational, and economic benefits, different regions can adopt context-appropriate technologies that also offer valuable

co-benefits. Table A-3 summarizes a selection of key mitigation technologies currently in use, along with their functional characteristics, regional suitability, and representative application cases. This overview is intended to provide practical guidance for companies and policymakers in selecting appropriate technologies for landfill and wastewater treatment applications.

TABLE A-3 KEY AVAILABLE TECHNOLOGIES.

	Technology option	Brief description	Co-benefits	Regional preference	Application examples
Prevention	Landfills mining	The process of excavating, processing and reusing previously landfilled waste.	Land saving; Resource recycling	Urbanized/ eastern regions	Xingfeng Landfill (Guangzhou), Baotian Landfill (Lei et al., 2023)
	Soil cover	The layer of soil used to cover the surface of waste in landfills, one of the basic landfill management measures.	Odor control; Waste exposure prevention	Small scattered sites/ western inland regions	Beijing Gao'antun Landfill (Beijing Chaoyang Gao'antun Sanitary Landfill, 2022).
	Incineration power generation (Waste-To-Energy (WTE) Industry)	The process of burning solid waste to convert its chemical energy into electricity.	Energy recovery	Large waste output regions/ east and south regions	Widely used-Qianzishan Waste-To-Energy Plant (Wuhan) (Hubei Daily News, 2025)
	Aerobic remediation	An environmental cleanup method that uses oxygen-dependent microorganisms to degrade organic pollutants in soil.	Soil quality	Warm and humid regions/ southern and eastern regions	Heishitou Waste Disposal Site (Beijing), Jinkou Landfill (Wuhan) (Sanitation Technology Network, 2016)
	Denitrification biofilters (DNBF)	Filtration systems that use denitrifying bacteria under anoxic (oxygen-free) conditions to convert nitrate (NO ₃) into nitrogen gas (N ₂), thereby removing nitrogen from wastewater or contaminated water sources.	COD removal	Warm/southern regions	Qingtongxia No.1 Wastewater Treatment Plant (China Water Network,2024)
	Denitrifying Anaerobic Methane Oxidation (DAMO)	A biological process in which methane is oxidized anaerobically using nitrate or nitrite as the electron acceptor, resulting in simultaneous methane removal and denitrification under oxygen-free conditions.	COD removal	Developed regions/ eastern regions	
	Constructed wetlands	A system designed to mimic the functions of natural wetlands for the treatment of wastewater using vegetation, substrate, and associated microbial communities.	COD removal; Effluent purification; Landscaping	Warm/southern regions/ rural areas	Caohai Artificial Wetland in Dianchi Lake (Yunnan) (Guangming Daily, 2024)

	Technology option	Brief description	Co-benefits	Regional preference	Application examples
Utilization	LFG recovery	Practices of capturing methane from decomposing landfills and converting it into useful energy.	Energy recovery	Developed regions/eastern and southern regions	Tianziling Landfill (Hangzhou) (CAUES, 2025) Laogang (Shanghai) (NEA,2012)
	Anaerobic Membrane Bioreactor (AnMBR)	Combining anaerobic treatment with membrane filtration to capture and recover methane-rich biogas.	COD removal; Energy recovery; Sludge reduction	Warm/southern regions	
	Anaerobic digestion	Technological systems that treat organic waste under oxygen-free conditions, breaking down organic matter to produce methane-rich biogas and generating digestate.	COD removal; Energy recovery	All regions	Beijing CanFit Environmental Technology Co., Ltd (iGDP, 2021b)
Destruction	Biofilter	A passive treatment system that uses a porous, biologically active medium to oxidize methane into carbon dioxide and water through methanotrophic bacteria.	Odor control; Soil quality	Warm/southern regions	Baotou Municipal Solid Waste Landfill (Biogascn, 2011)
	Biocover	An engineered landfill cover to biologically oxidize methane through methanotrophic bacteria.	Odor control; Soil quality	Warm/southern regions	
	Thermal or catalytic oxidation	The high-temperature processes that destroy methane by converting it into carbon dioxide and water, either through direct combustion (thermal) or with the aid of a catalyst (catalytic).	Energy recovery	All regions	

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