

Thi Than: Regional solid waste dynamics in vietnam – [Szilárd hulladékkeletkezés és kezelés Vietnámban]
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FROM GENERATION TO TREATMENT: REGIONAL SOLID WASTE DYNAMICS IN VIETNAM (2015–2018) WITH INTERNATIONAL CONTEXT

[SZILÁRD HULLADÉKKELETKEZÉS ÉS KEZELÉS VIETNÁMBAN (2015–2018) REGIONÁLIS ÉS IDŐRENDI ÖSSZEHOSONLÍTÁS]

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Abstract. This study examines regional disparities and temporal trends in solid waste generation (SWG) and treatment (SWT) across six regions of Vietnam from 2015 to 2018, and places Vietnam in an international context. Using original data and descriptive statistics, the findings reveal notable regional inequalities in waste management performance. The Southeast (SE) and Red River Delta (RRD) maintain high and stable SWT levels (typically over 80%), supported by better infrastructure and industrial concentration, while the Mekong River Delta (MRD), Central Highlands (CH), and Northern Midlands and Mountains (NMM) lag behind due to limited resources and low public awareness. Temporal patterns show initial improvements followed by stagnation in some regions, reflecting uneven policy implementation and infrastructure challenges. Compared to other countries, Vietnam is positioned as a transitional economy where waste management systems are expanding but still rely heavily on landfilling and face structural limits in technological innovation and education. Drawing on international lessons, this study recommends region-specific strategies: decentralized composting and community collection in rural areas, and energy recovery and circular economy approaches in industrialized and coastal zones. Integrating these efforts within a circular economy framework and encouraging citizen participation can improve efficiency and equity in Vietnam's waste management system.

Keywords: Solid waste management, regional disparities, circular economy, waste treatment, Vietnam, sustainability

The Introduction

Solid waste management is a vital global sustainability issue, prompted by rapid population growth, urbanization, and industrialization. These factors increase waste and pollution, endangering ecosystems and public health, and are closely tied to achieving the United Nations Sustainable Development Goals (SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production) (Report,

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2015). Consequently, unsustainable solid waste management (SWM) practices harm public health and environmental sustainability, leading to air and water pollution, land degradation, and climate change (Abubakar *et al.*, 2022). While most developed nations handle municipal solid waste effectively, low-income and lower-middle-income countries face major hurdles due to insufficient waste infrastructure, an informal sector, and a shortage of trained personnel (Sharma *et al.*, 2019). The volume and composition of solid waste differ widely between and within regions, influenced by factors such as economic status, lifestyle, literacy, and age demographics. This variability makes it difficult to apply a one-size-fits-all approach to SWM solutions globally. Moreover, advanced technologies and skilled labor are often unsuitable for poorer countries, especially when combined with ineffective policy enforcement, limited public engagement, and infrastructure gaps, particularly in Asia and Africa (Das *et al.*, 2019; Zang *et al.*, 2024).

Vietnam was classified as a lower-middle-income country and has experienced significant economic and demographic shifts over the past twenty years, leading to a sharp rise in solid waste production (W.B, 2015). In major cities like Ho Chi Minh City, daily municipal solid waste generation was approximately 8,175 tons in 2014, which is about 1.02 kg per person per day. Waste management in Vietnam faces serious obstacles, including rapid urban growth, increased waste production, and limited resources for effective collection and treatment (Phan *et al.*, 2024). Most municipal solid waste is still disposed of in landfills (around 70–86%), with only a small portion being recycled, mainly due to incomplete legislation, weak enforcement, insufficient financial resources, and low public awareness (Verma, Borongan and Memon, 2016). Although some national reports and studies exist, few have systematically explored regional differences in waste generation and management within Vietnam, covering major cities, rural areas, and mountainous regions. Regional analysis is crucial because factors like urbanization, industrial activity, and local infrastructure greatly shape waste challenges. Most comparative research has focused on global or national trends, often overlooking Vietnam's internal diversity. Additionally, while regional data for Vietnam is available only through 2018, international datasets go up to 2022, providing an opportunity to make direct comparisons for 2015–2018 and to evaluate Vietnam's performance against more recent international trends.

This study aims to analyze regional disparities in solid waste generation and treatment in Vietnam from 2015 to 2018, and then compare Vietnam's national performance with that of several selected countries to offer an extended discussion of international studies, highlighting global trends and placing Vietnam's position within the broader context.

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Method

Data sources

Vietnamese dataset: Official national statistics on solid waste generation (SWG, tons per capita per year) and solid waste treatment (SWT, percentage treated annually) for six socio-economic regions of Vietnam, including the Red River Delta, Northern Midlands and Mountainous Area, North Central, Central Highlands, Southeast, and Mekong River Delta.

Data are only available up to 2018. Therefore, all direct comparisons with other countries were limited to the 2015–2018 period. However, some studies offer comparative assessments in the international context between Vietnam and selected countries.

Indicators

- SWG (Solid waste and wastewater generation): Measured as tons per capita per year.
- SWT (Solid waste treatment): Measured as the percentage of total generated solid waste that is treated annually.

Analytical approach

Descriptive statistics: Average values, standard deviation, minimum, and maximum.

Results

Table 1. presents the descriptive statistics (mean, standard deviation, minimum, and maximum) of solid waste generation (SWG, tons per capita) and solid waste treatment (SWT, %) across six regions in Vietnam from 2015 to 2018. There are notable differences in both SWG and SWT among the six regions. Specifically, the Southeast (SE) region has the highest average SWG and SWT, while the Mekong River Delta (MRD) has the lowest average SWT, and the Northern Midlands and Mountainous (NMM) has the lowest average SWG. This indicates that solid waste generation and treatment vary considerably across regions based on their socioeconomic characteristics.

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Table 1. Summary statistics of SWG and SWT across six regions in Vietnam from 2015 to 2018

| Regions | SWT Mean | SWT SD | SWT Min | SWT Max | SWG Mean | SWG SD | SWG Min | SWG Max |
|---------|----------|--------|---------|---------|----------|--------|---------|---------|
| VN | 81.155 | 4.249 | 75.024 | 84.350 | 0.386 | 0.036 | 0.353 | 0.427 |
| RRD | 90.425 | 4.826 | 84.287 | 94.565 | 0.482 | 0.025 | 0.449 | 0.502 |
| NMM | 56.841 | 9.623 | 45.411 | 68.962 | 0.205 | 0.010 | 0.193 | 0.216 |
| NCC | 65.820 | 7.504 | 58.740 | 75.938 | 0.301 | 0.061 | 0.248 | 0.383 |
| CH | 61.188 | 4.347 | 57.371 | 67.309 | 0.207 | 0.016 | 0.189 | 0.224 |
| SE | 95.924 | 3.362 | 92.471 | 99.427 | 0.728 | 0.066 | 0.669 | 0.801 |
| MRD | 56.247 | 10.337 | 41.642 | 66.000 | 0.225 | 0.020 | 0.208 | 0.244 |

SD: Standard Deviation

Moreover, the relationships between SWG and SWT remain consistent across all regions. The Red River Delta (RRD) has the second-highest SWG (0.482 tons per capita per year) but also a relatively high SWT (90.425%). This suggests the region has a very effective waste treatment capacity relative to the waste produced. Conversely, the MRD has the lowest SWT (56.247%) even though its SWG is not the lowest. This may indicate that the region faces significant challenges in managing solid waste. The variability measured by standard deviation (SD) varies as well. For SWT, the MRD has the highest SD (10.337), indicating notable fluctuations in waste treatment rates from 2015 to 2018. This could reflect major shifts in policies, technology, or treatment capacity within the region. For SWG, the North Central and Central Coasts (NCC) have the highest SD (0.061), suggesting that waste generation there has been more variable compared to other regions.

The results indicate that solid waste generation and treatment differ significantly across regions based on their socioeconomic factors.

Figure 1. shows the spatial and temporal distribution of SWT, with a heatmap emphasizing its performance across Vietnam's regions from 2015 to 2018. First, the SE and RRD regions consistently lead in waste treatment performance. They maintained very high and stable SWT levels throughout the period, often exceeding 80% and nearly reaching 100% (SE in 2016). This demonstrates the advanced development of waste treatment infrastructure and policies in these key economic centers. Meanwhile, the NCC and MRD regions have shown notable progress. Specifically, the NCC experienced a strong increase in performance from 58.7% (2015) to 75.9% (2018). Similarly, the MRD also saw significant growth from 41.6% (2015) to 66.0% (2018). This progress likely reflects investments and the adoption of new technologies for waste treatment in these areas.

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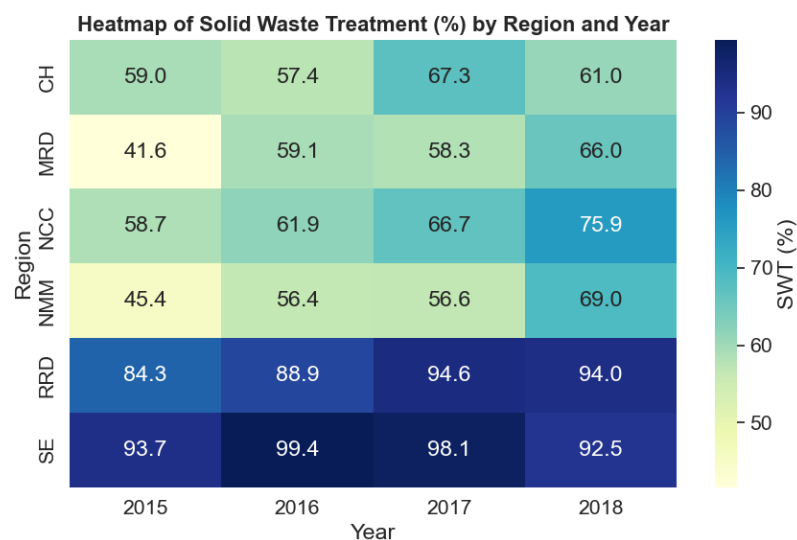


Figure 1. Heatmap of solid waste treatment (SWT, %) by regions and years (2015–2018)

The CH and NMM regions maintained consistently low and stable SWT levels. Their waste treatment effectiveness stayed below 70% throughout all four years, which is much lower than that of the other regions. This indicates that waste management in these areas still faces many challenges and did not experience significant improvements during this period.

Figure 2 illustrates the yearly trends of SWT (%) across regions. The line chart clearly shows two distinct groups of regions. One group (SE and RRD) consistently maintains high performance, while the other group (NCC, MRD, CH, and NMM) exhibits lower performance, with some members showing improvement and others stagnating.

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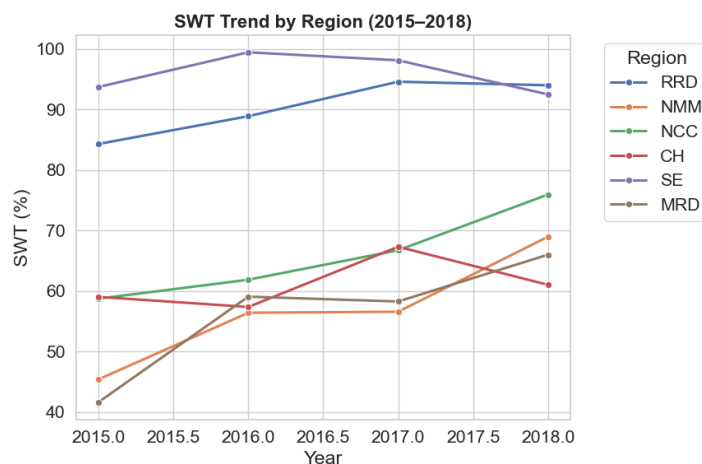


Figure 2. Trends of SWT across six regions in Vietnam from 2015 to 2018

The chart highlights the impressive growth trajectories of the NCC and MRD. The NCC's line has the steepest slope from 2017 to 2018, indicating a rapid improvement in its waste treatment performance. The MRD's line shows a steadier and consistent upward trend over the four-year period. Additionally, the SE region's line shows a slight decline in 2018 after peaking in 2016 and 2017. Similarly, the CH region's line dips slightly at the end of the period. This suggests that even high-performing regions may face challenges in maintaining peak performance.

Figure 3 illustrates the relationship between SWG and SWT for each region and year. The SE (purple) and RRD (blue) regions are grouped in the top-right corner, showing both high waste production and high treatment rates. The NMM (orange), CH (red), and MRD (brown) regions are clustered in the bottom-left, indicating low waste production and accordingly low treatment rates.

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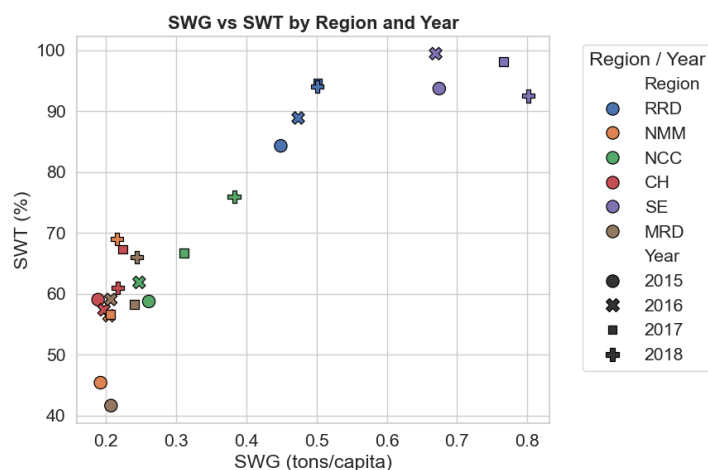


Figure 3. Distribution of SWG and SWT by region

Overall, there is a clear positive relationship between SWG and SWT. Regions that generate more waste tend to have a higher percentage of it treated. This suggests that waste treatment capacity often expands in tandem with economic growth and waste generation. Figure 4. shows the mean SWT (%) for each region from 2015 to 2018, providing the clearest summary of overall performance imbalances.

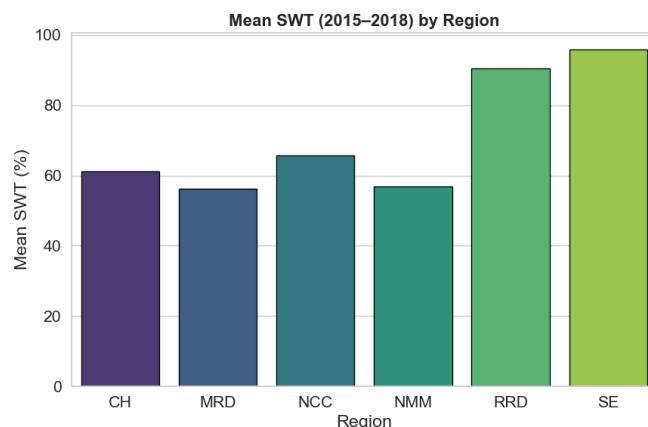


Figure 4. Mean SWT across six regions in Vietnam from 2015 to 2018

The chart clearly shows a sharp divide between regions. The SE and RRD regions stand out with consistently high average treatment rates (over 90% and nearly 90%, respectively), establishing their roles as leaders in waste management. Meanwhile, the other four regions have much lower average rates, all below 65%. This offers a static, comprehensive snapshot of each region's sustainable waste treatment capacity. It simplifies the data to highlight a key point: the persistent disparity in waste management effectiveness across Vietnam.

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Discussion

Vietnam's Regional Solid Waste Management Disparities

This study examined regional differences in solid waste generation (SWG) and solid waste treatment (SWT) across six regions of Vietnam from 2015 to 2018, showing significant disparities in waste production and treatment efficiency. A clear division exists between two regional groups, with the Southeast (SE) and Red River Delta (RRD) leading. These regions have the highest average SWG and SWT, with SWT consistently high and stable (usually >80%, with SE nearing 100%), indicating advanced waste management infrastructure and policies. These differences are primarily linked to levels of economic development and urbanization, due to the positive correlation between waste generation and population growth (Phan and Hufnagel, 2025b). The SE and RRD host the country's primary industrial centers and large cities, where waste management infrastructure, such as incineration and waste-to-energy facilities, is more developed. However, these areas still rely heavily on landfilling (70–75%) and face challenges in waste segregation and recycling (Le *et al.*, 2023).

In contrast, the remaining regions, including the North Central and Central Coast (NCC), Mekong River Delta (MRD), Central Highlands (CH), and Northern Midlands and Mountains (NMM), show significantly lower and more variable SWT, indicating structural weaknesses in waste management. These areas have much lower treatment ratios, often below 65%, with the NMM exhibiting the lowest SWG and the MRD having the lowest SWT. These differences are linked to variations in economic activity, population density, and local governance capacity. Rural and mountainous regions often face limited healthcare access, insufficient funding, and low collection coverage (Nguyen *et al.*, 2024; Thu *et al.*, 2024). Coastal and tourism-heavy cities also contend with seasonal waste surges and institutional fragmentation (Tsai *et al.*, 2021). These findings suggest that both technical and socio-economic factors drive regional inequality in waste management in Vietnam.

The results also show a positive correlation between SWG and SWT, indicating that regions with higher economic activity tend to increase their treatment capacity along with waste generation. This aligns with the law of economic development and reveals an issue of environmental equity: poorer regions have less capacity to cope. Additionally, it highlights a somewhat contradictory issue, which is the main focus of this discussion that the reliance on centralized investment and policy for current processing capacity which does not accurately reflect overall management effectiveness.

The observations in Vietnam align with findings from other countries, where economic and geographical factors strongly shape regional waste differences. In Spain, for instance, waste generation is highest in coastal and tourism-intensive regions



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(Alcay and Montañés, 2020), while Japan's urban regions outperform rural areas in waste processing efficiency (Li *et al.*, 2024). Similarly, China's Yangtze River Economic Belt has higher industrial waste treatment rates than inland provinces (Ke, Tian and Zhang, 2022). The Vietnamese situation thus fits within a larger global trend, but the disparity between regions is particularly notable. These findings highlight the importance of waste management strategies tailored to specific regions, considering local economic structures, infrastructure, and institutional capacity.

Temporal dynamics from 2015 to 2018

The temporal patterns of SWG and SWT between 2015 and 2018 show both improvements and emerging disparities across Vietnam's regions. During this four-year period, the SE and RRD consistently maintained high and stable SWT levels, usually above 80%. This highlights the success of early national policies promoting integrated waste management, especially Decision No.2149/QĐ-TTg on the National Strategy for Integrated Solid Waste Management to 2025, issued in 2009 and revised in 2018, and Decree No. 38/2015/NĐ-CP on waste and scrap management. These policy frameworks supported the development of regional waste treatment centers and investments in landfill reduction technologies, particularly in key economic zones. This continuity suggests that steady increases in waste treatment capacity have matched economic growth and industrialization in these regions.

However, both SE and CH showed a slight decline in SWT in 2018 after reaching their peaks in 2016–2017. This “plateau effect” may indicate saturation in treatment capacity or difficulties in maintaining operational efficiency once infrastructure expansion levels off. Similar periods of stagnation have been seen in other industrialized areas, where the additional benefits from further investment decrease over time and long-term sustainability depends on technological upgrades and behavioral changes (Helm *et al.*, 2022).

In contrast, the NCC and MRD showed the most significant improvements in SWT performance during the same period. The NCC experienced a sharp rise from 58.7% in 2015 to 75.9% in 2018, likely due to the completion of major infrastructure projects and the adoption of new treatment technologies supported by national investment incentives. The MRD, although starting from the lowest baseline, demonstrated steady and continuous progress (from 41.6% to 66.0%), indicating the gradual effectiveness of regional development programs. These temporal improvements may also be connected to the broader rollout of Vietnam's waste separation initiatives and donor-supported projects between 2016 and 2018. The variability in SWT (with the highest standard deviation in MRD) suggests fluctuations caused by inconsistent policy implementation or facility operations across provinces.

Such temporal differences are not unique to Vietnam. In China, local economic measures and population control policies have been shown to reduce waste generation



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by more than 30% in major cities (Zhou *et al.*, 2025), while economic growth trends directly influence solid waste volumes in Shanghai, where a 1% decrease in GDP growth results in a 3.25 Mt reduction in waste generation (Xiao *et al.*, 2020). Other countries moving toward sustainable waste management have also reported that short-term improvements are often policy-driven and can stagnate without structural change (Silva *et al.*, 2017). The Vietnamese case shows a similar pattern: rapid initial improvements in certain regions, followed by uneven progress and ongoing regional disparities.

Overall, the 2015–2018 period represents a transitional phase for Vietnam’s solid waste management system, marked by accelerated investment, localized innovation, and the first signs of regional differentiation in policy effectiveness. Continued policy enforcement and technological innovation will be critical to sustaining these gains beyond 2018 and preventing regression in treatment performance.

Vietnam in the regional and international context

The comparative international evidence highlights Vietnam’s transitional role in the global waste management landscape. The country shares many structural features with emerging economies in Southeast Asia, such as Malaysia and Thailand, including rapid industrial growth, increasing consumption, and rising solid waste production. However, despite comparable or even higher waste generation rates, Vietnam’s treatment performance (SWT) appears more stable and proportionally higher, mainly because of the broad coverage of collection and landfilling. This indicates effective institutional organization but limited technological progress in waste valorization and energy recovery (Phan and H.L., 2025a). Over the past five decades, Asia’s waste management has evolved, with more countries shifting to waste-to-energy solutions, although landfilling and open dumps still dominate disposal methods in most developing countries like Malaysia. Environmental pollution from leachate remains a challenge (Agamuthu *et al.*, 2023; Kamaruddin *et al.*, 2017).

Compared to developed nations such as the US, Australia, and Canada, Vietnam’s energy emissions and carbon footprint remain moderate. This pattern aligns with emerging economies that face moderate environmental pressures and rapidly increasing waste generation. However, as shown by Phan & H.L., the relatively small scientific workforce, limited research investment, and lower educational attainment have indirectly hampered technological innovation in waste management and environmental governance. These structural limitations partly explain why Vietnam’s SWG and SWT scores stay modest despite policy advancements (Phan and Hufnagel, 2026). Additionally, the same barriers to effective waste management exist, including socio-economic factors like awareness, education, and infrastructure, as well as cultural influences such as waste composition and habits, similar to other Asian and African countries (Zang *et al.*, 2024). The clustering results indicate that Vietnam is



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positioned between high-performing industrial economies and lower-performing developing countries (Phan and Hufnagel, 2026), suggesting a transitional phase where regulatory frameworks are improving faster than infrastructure can keep up. This middle position highlights both Vietnam's policy dedication and the ongoing need to shift from merely expanding waste treatment capacity to achieving qualitative improvements based on circular economy and resource recovery principles.

International lessons and implications for Vietnam

While Vietnam's overall waste generation and treatment rates are moderate compared to developed countries, the disparities between its regions are much more significant. These differences emphasize the need for region-specific management strategies rather than uniform national policies. By drawing on both international best practices and domestic conditions, several locally tailored approaches can be proposed to enhance solid waste management efficiency and sustainability across Vietnam.

In rural areas like the RRD or especially the MRD, where fluctuations are most significant, despite notable improvements in SWT with high population density, infrastructure and public awareness remain limited. Source separation, composting, decentralized material recovery facilities (MRFs), and curbside or door-to-door collection could provide practical solutions. These strategies cut transportation costs and encourage community-based recycling. However, ongoing community participation and active engagement from local government are essential for their success.

In contrast, mountainous and highland regions (NMM and CH) have low population density and scattered settlements, making door-to-door collection impractical. In these areas, small-scale composting and locally adapted collection points can be combined with awareness programs led by schools or local NGOs. Landfilling remains the most reliable method for disposing of biodegradable waste in such low-income contexts, although its environmental impact should be reduced through better site management and periodic monitoring (Bao *et al.*, 2023).

For coastal and tourism-focused provinces (NCC) and industrialized regions (SE, MRD, RRD), advanced solutions like source separation, energy recovery, and circular economy practices should be prioritized. Lessons from European countries indicate that landfill taxes, deposit-refund systems, and waste bans can effectively cut landfill reliance while boosting energy recovery and recycling (Malek, Mortazavi and Cialani, 2023). Additionally, end-of-waste policies and social behavior change programs can help integrate Municipal Solid Waste (MSW) into reuse and recycling chains (Adamo *et al.*, 2022).

Ultimately, integrating Vietnam's waste management strategies into a broader circular economy framework, encouraging citizen participation, supporting recycling



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initiatives, and seeking international cooperation could accelerate progress toward sustainability (Zang et al., 2024).

Conclusion

This study offers a comprehensive analysis of regional disparities and temporal dynamics in solid waste generation (SWG) and treatment (SWT) across Vietnam from 2015 to 2018, placing Vietnam within the international context and highlighting both progress and ongoing inequalities. The findings show a distinct divide between industrialized regions (SE and RRD), which consistently have high SWT performance, and less developed areas (NMM, CH, NCC, and MRD), where treatment ratios are low and unstable. These disparities are mainly caused by differences in geographic conditions, economic development, infrastructure, and governance capacity, reflecting environmental inequalities between regions.

The temporal trends indicate that Vietnam's solid waste management (SWM) system is in a transitional stage. While national policies and investments have successfully increased treatment capacity and expanded collection coverage, progress remains inconsistent, with signs of saturation in advanced regions and persistent challenges in rural and mountainous areas.

At the international level, Vietnam holds a position between high-performing industrialized nations and lower-performing developing economies. Its moderate energy emissions and carbon footprint suggest a relatively controlled environmental impact but also reveal limitations in innovation capacity, research investment, and education levels. The country's experience highlights that qualitative improvements in efficiency, technology, and community participation must support quantitative growth in waste treatment.

Policy implications suggest a regionally tailored approach. Rural and highland areas need decentralized, low-cost solutions like local composting and community-based collection, while coastal and industrial zones should focus on energy recovery, recycling, and circular economy models. Incorporating waste management with circular economy principles, boosting citizen awareness, and enhancing international cooperation will be vital for Vietnam's shift toward sustainable and fair waste governance.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author

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Absztrakt. Ez a tanulmány a szilárd hulladék keletkezésének (SWG) és kezelésének (SWT) regionális egyenlőtlenségeit és időbeli trendjeit vizsgálja Vietnám hat régiójában 2015 és 2018 között, és nemzetközi kontextusba helyezi Vietnámot ebből a szempontból. Eredeti adatok és leíró statisztikák felhasználásával az eredmények jelentős regionális egyenlőtlenségeket tárnak fel a hulladékgazdálkodásban. A délkeleti régió (SE) és a Vörös-folyó deltája (RRD) magas és stabil SWT-szintet tart fenn (jellemzően 80% felett), amit a jobb infrastruktúra és az ipari koncentráció támogat, míg a Mekong folyó deltája (MRD), a Közép-felföld (CH) és az Északi-közép- és hegyvidék (NMM) a korlátozott erőforrások és az alacsony szintű köztudat miatt lemarad. Az időbeli minták kezdeti javulást mutatnak, majd egyes régiókban stagnálást, ami az egyenetlen szakpolitikai végrehajtást és az infrastrukturális kihívásokat tükrözi. Más országokkal összehasonlítva Vietnám átmeneti gazdaságként helyezkedik el, ahol a hulladékgazdálkodási rendszerek bővülnek, de továbbra is nagymértékben támaszkodnak a hulladéklerakásra, és strukturális korlátokkal szembesülnek a technológiai innováció és az oktatás terén. A nemzetközi tanulságokra támaszkodva ez a tanulmány régióspecifikus stratégiákat javasol: decentralizált komposztálás és közösségi gyűjtés a vidéki területeken, valamint energia-visszanyerés és körforgásos gazdaság megközelítései az iparosodott és a tengerparti övezetekben. Ezen erőfeszítések körforgásos gazdaság keretrendszerbe való integrálása és a polgárok részvételének ösztönzése javíthatja Vietnám hulladékgazdálkodási rendszerének hatékonyságát és méltányosságát.

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