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Wastewater reuse in Vietnam: potential, challenges, and strategic solutions

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ABSTRACT

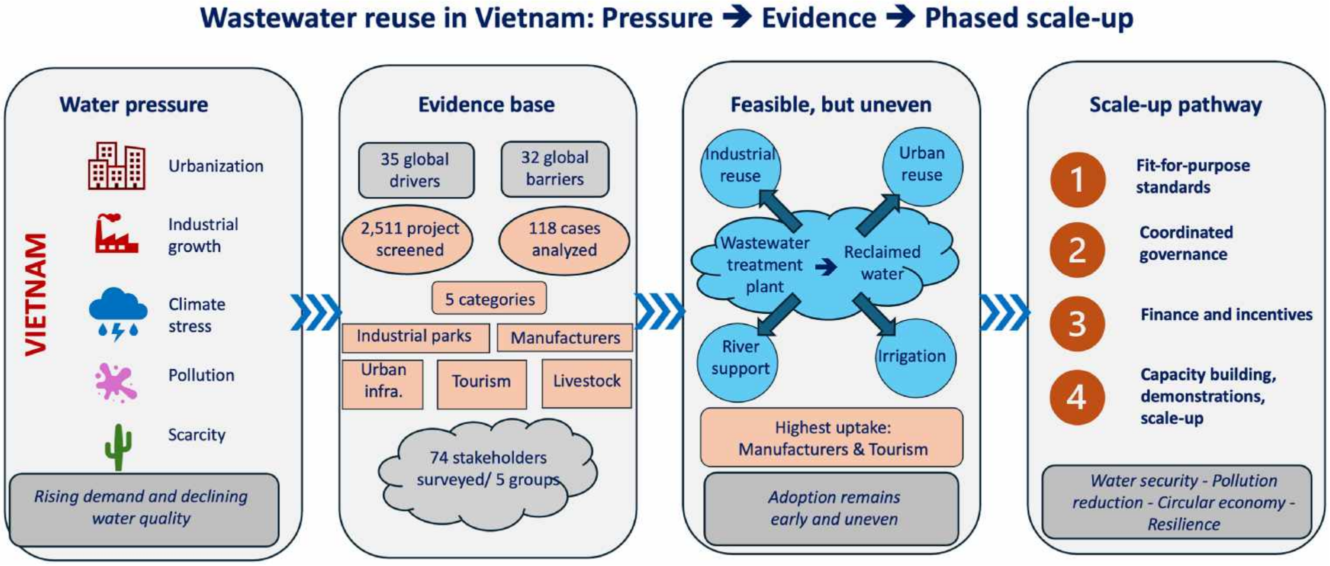
Vietnam faces growing pressure on water resources due to rapid urbanization, industrial expansion, climate change, and declining water quality. Wastewater reuse offers a promising pathway to enhance water security, reduce pollution, and advance circular-economy objectives. This study assessed wastewater reuse potential in Vietnam through a mixed qualitative approach: a systematic review of international experience, targeted review of Vietnamese policies and sectoral evidence, screening of 2,511 wastewater-generating projects reported on the national environmental consultation portal, detailed analysis of 118 selected projects, and validation through stakeholder consultation and questionnaire survey. Results show that wastewater reuse in Vietnam is driven mainly by rising water demand, environmental pressure, and regulatory interest in resource circulation, and emerging market incentives linked to green production and supply chains. However, implementation remains limited and uneven across sectors. Manufacturing and tourism projects show the strongest uptake, while industrial park infrastructure, urban systems, and livestock applications face greater institutional, technical, and economic constraints. Main barriers are the absence of fit-for-purpose reclaimed-water standards, fragmented institutional responsibilities, high treatment and monitoring costs, limited financial incentives, and low implementation confidence. Scale-up will require clearer regulation, stronger inter-agency coordination, targeted incentives, improved technical capacity, and explicit integration into long-term water and urban development strategies.

Key words: drivers and constraints, institutional barriers, regulatory framework, urban water management, wastewater reuse, water security

HIGHLIGHTS

- Analyzes drivers and barriers to wastewater reuse in Vietnam.
- Identifies critical gaps in standards, coordination, and funding.
- Demonstrates technical feasibility of reuse for industry and urban settings.
- Highlights need for urban-overlap and integrated water management.
- Proposes actionable strategies with regard to policy/governance/investment for water security.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is essential for socioeconomic development, serving agriculture, industry, and service sectors. As Vietnam rapidly transitions from an agricultural economy to urbanized and industrialized systems (Tran *et al.* 2021; Tong *et al.* 2022; Hoang *et al.* 2023), water security has become a critical prerequisite for sustainable development. However, rising demand, coupled with inadequate supply and drainage infrastructure, threatens the country's water availability. Climate change further exacerbates droughts, saltwater intrusion, and extreme rainfall, while overexploitation and pollution of surface and groundwater intensify scarcity (Nhi *et al.* 2022; Pham *et al.* 2023; Phuong *et al.* 2024).

Wastewater reuse has emerged as a sustainable solution to reduce pressure on natural water sources, optimize resource usage, and advance the circular economy, especially in water-scarce regions. It involves capturing and treating wastewater, including municipal wastewater or stormwater, for nonpotable or potable applications (US EPA 2019). Globally, developed countries such as Singapore and Israel have successfully applied reuse models in agriculture, industry, and urban sectors through effective pricing policies and greenhouse gas (GHG) reduction incentives, achieving both treatment efficiency and environmental benefits (Helmecke *et al.* 2020; Jeffrey *et al.* 2022; Santos *et al.* 2023; Szalkowska & Zubrowska-Sudol 2023). In developing Asia-Pacific nations, particularly in China and India, both planned and de-facto water reuse are primarily motivated by acute water scarcity and growing water pollution (Nguyen *et al.* 2018; Liao *et al.* 2021; Breitenmoser *et al.* 2022; Wang *et al.* 2023). Expanded wastewater reuse implementation can reduce dependency on groundwater, ease stress on surface water bodies, decrease pollutant loads, and improve the operational efficiency of supply and drainage systems, with estimate potential savings of up to 44% of natural water supply and 42% reduction in urban wastewater discharge (Van Khanh *et al.* 2023; Trang *et al.* 2025).

In Vietnam, research on wastewater reuse remains limited, particularly in relation to existing legal framework, technical infrastructure, and policy instruments. This study assesses the current status and potential of wastewater reuse in Vietnam by drawing on international experiences, identifying key drivers and barriers shaping adoption, and evaluate case studies of wastewater reuse in Vietnam. The findings aim to inform strategies for strengthening water security and supporting sustainable urban development.

2. MATERIALS AND METHODS

This study employed a mixed qualitative approach combining systematic literature review, case study analysis, and stakeholder consultation to assess the potential, drivers, and barriers of wastewater reuse in Vietnam. The study framework is illustrated in Figure 1, progressing through: (I) review of international wastewater reuse, (II) identification of key drivers and barriers, (III) assessment of wastewater reuse practices in Vietnam, (IV) presentation of findings, used for selection

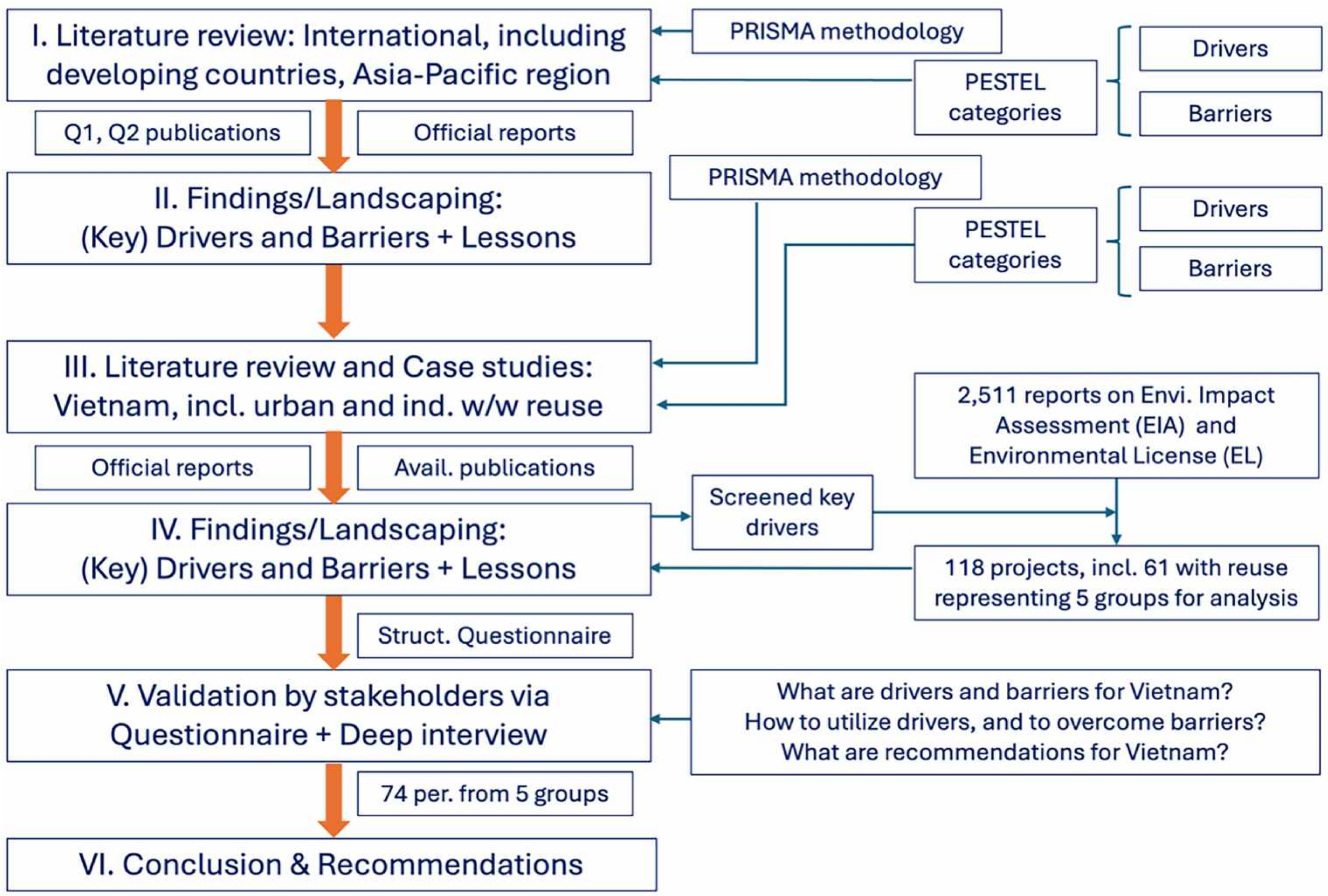


Figure 1 | Logical framework of the study.

of case studies, followed by analysis of cases, (V) validation and supplementation through survey questionnaires and in-depth interviews, and (VI) development of recommendations. Detailed research methodologies for each step are provided below.

2.1. Literature review of global wastewater reuse implementations

A systematic literature review was conducted following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines (Page *et al.* 2021) to identify drivers and barriers of wastewater reuse implementation. Databases included Scopus, Web of Science, PubMed, and Google Scholar. Inclusion criteria encompassed publications from 2015 to 2025 in English, peer-reviewed Q1 or Q2 journals, and reports from international organizations (e.g., World Bank, United Nations Children's Fund (UNICEF), Food and Agriculture Organization of the United Nations (FAO), and the Asian Development Bank (ADB)). Studies had to address global or regional drivers or barriers using PESTEL analysis, which primarily concerns six factors: political, economic, social, technological, environmental, and legal. The PESTEL framework is a multifaceted approach used to analyze macroenvironmental factors impacting an organization, company, or industry (Johnson *et al.* 2017; Lee & Jepson 2020). Search strings combined (i) reuse terms; (ii) implementation/scale-up terms; (iii) driver/enabler or barrier/challenge terms, (iv) nonpotable reuse applications; and (v) additional policy/finance/institution keywords, applied to Title–Abstract–Keywords where available. The systematic literature review focused exclusively on nonpotable reuse applications, as these represent the most technically feasible and practically applicable solutions for water security in the socioeconomic context of lower-middle-income countries like Vietnam. Detailed methods of the literature review process, including search strings development, inclusion criteria, exclusion criteria, screening and selection process, and data extraction and synthesis, are provided in the Supplementary Information 1. Search terms used for the systematic literature review are provided in Supplementary Information 2 (Table S1).

For the review of drivers, an initial title and abstract screening ($n = 450$) was followed by full-text assessment ($n = 120$), yielding a final set of 35 publications. Similarly for the review of barriers, an initial title and abstract screening ($n = 420$) and subsequent full-text assessment ($n = 110$) resulted in 32 publications. Keywords representing the main drivers and barriers were extracted for each PESTEL dimension to highlight lessons learned from international wastewater reuse practices. International examples were selected for relevance to successful implementation, considering strong policies, advanced treatment technologies, supportive financial mechanisms, and socioenvironmental comparability. Cases from both developed and developing countries, particularly in the Asia-Pacific region, were included to capture diverse approaches and lessons transferable to Vietnam.

2.2. Assessment of wastewater reuse in Vietnam

2.2.1. Initial assessment of drivers and barriers from global wastewater reuse practices

From the systematic literature review of international wastewater reuse implementations, an assessment of drivers and barriers for wastewater reuse practices in Vietnam was conducted through a targeted qualitative review. The secondary data review synthesized existing research, technical reports, and official statistics to establish a baseline on wastewater generation, treatment capacity, reuse practices, and relevant policy frameworks. Because the number of available data was limited, as wastewater reuse practices in Vietnam are yet to be widespread and well-established, this review stage was not designed as a formal systematic review. Instead, relevant sources were identified purposively based on their direct relevance to wastewater reuse governance, implementation conditions, and sector practice in Vietnam. Collected data were synthesized to identify patterns of drivers and barriers specific to Vietnam. Stakeholder-institution mapping was conducted to identify key interactions involved in wastewater reuse, including regulatory frameworks, infrastructure conditions, and implementation constraints. This mapping method clarified gaps and overlaps in regulatory and operational responsibilities and highlighted potential areas for coordination. Combined with international case comparisons, this approach provided a structured basis for assessing Vietnam's reuse potential and informing policy recommendations.

2.2.2. Evaluation of current wastewater reuse implementations in Vietnam

A total of $n = 2{,}511$ projects generating wastewater in Vietnam between 2023 and 2025 were reviewed using the public consultation portal of the Ministry of Agriculture and Environment (MAE, formerly Ministry of Natural Resources and Environment ((MONRE) 2023), a mandatory component of the Environmental Impact Assessment (EIA) and Environmental Licensing (EL) process. This timeframe was selected because the centralized digital database was only established following the implementation of the 2020 Law on Environmental Protection and Decree No. 08/2022/ND-CP (Government of Vietnam 2020, 2022). From this dataset, $n = 118$ project reports were selected based on water consumption (Pham *et al.* 2017; World Wide Fund for Nature (WWF) 2018; Water Environment Partnership in Asia 2024), pollution potential (Government of Vietnam 2022), location in water-scarce or economically dynamic regions (World Bank Group 2019; Ministry of Planning and Investment 2025), and involvement of reputable foreign, high-technology, or 'green'-certified enterprises. EIA reports and applications for EL were screened using the keywords 'wastewater reuse' or 'recycled wastewater' before the detailed contents of the reports were examined (all in Vietnamese language). The only reported wastewater reuse activities occurring during the operational phase of the projects were considered, while reuse during the construction phase was excluded from the analysis.

2.3. Validation of findings with stakeholders

From the assessment of wastewater reuse in Vietnam, key drivers and barriers for the Vietnamese contexts were identified, and findings were validated and supplemented through a stakeholder consultation workshops and structured questionnaires. To confirm literature-based findings and identify perceived opportunities and constraints, the workshop engaged stakeholder representatives from five groups: (1) industrial park (IP) operators, (2) industrial factories, (3) government officers, (4) experts and academics, and (5) wastewater contractors. The structured questionnaire collected detailed information on PESTEL dimensions of reuse, as well as recommendations for actions to enhance wastewater reuse in Vietnam. Detailed contents of the questionnaire are included in Supplementary Information 3.

3. RESULTS AND DISCUSSION

3.1. Global wastewater reuse implementation:

3.1.1. Major driving factors

The major drivers identified from international practices are summarized in Table 1.

International experience from both developed and developing countries shows that successful wastewater reuse implementation is shaped by interacting factors across the PESTEL dimensions (political, economic, social, technological, environmental, and legal). In general, reuse tends to scale where environmental pressures (such as water scarcity or pollution) create demand, while political commitment, legal clarity, technological reliability, social acceptance, and economic feasibility enable implementation.

In water-scarce advanced economies, strong institutional framework and advanced treatement technologies have supported large-scale applications. For example, Singapore's NEWater program reuses nearly 40% of its wastewater for domestic and industrial applications (Jeffrey *et al.* 2022), while Israel reuses more than 80% for agriculture, enabled by advanced treatment technologies, strong financial incentives, and supportive policies (Helmecke *et al.* 2020; Shoushtarian & Negahban-Azar 2020; Santos *et al.* 2023). In arid or water-stressed cities, reuse has also been adopted as a long-term strategy for water security. For example, in Windhoek, Namibia, potable reuse has been practiced since 1968, driven by the integration of long-standing commitment to water security and continuous investment in technology (Lahnsteiner *et al.* 2017; Murray *et al.* 2018; Mapani *et al.* 2023). In emerging middle-income regions, reuse initiatives often focus on agriculture and industrial applications. For example, Chile has promoted wastewater reuse in agriculture through public–private partnerships, leading to improved crop productivity and reduced freshwater withdrawals (Villamar *et al.* 2018; Livia *et al.* 2020; Vera-Puerto *et al.* 2022). Across the rapidly urbanizing Asia–Pacific region, wastewater reuse is increasingly driven by urban growth, industrial expansion, and worsening water pollution. China has progressively developed a comprehensive governance framework that integrates reuse into broader water resource planning. This includes legal provisions in water and environmental legislation, national technical guidelines for reclaimed water quality classification, and coordinated reuse policies introduced since 2021 that define monitoring requirements and promote integration into regional water management strategies (Chen *et al.* 2024; Pan *et al.* 2025). Similar drivers are observed in other emerging economies such as India, where water scarcity and pollution pressures increasingly motivate reuse adoption (Breitenmoser *et al.* 2022).

Overall, international evidence suggests that wastewater reuse is most successful where environmental pressures generate demand and are supported by coherent policy frameworks, reliable treatment technologies, economic incentives, and public acceptance. In practice, these drivers operate collectively: scarcity and pollution create demand signals, while regulatory clarity, institutional capacity, and viable financing mechanisms convert that demand into scalable reuse systems. Detailed mechanisms and representative examples of these driving factors are presented in Supplementary Information 4 (Table S2).

Table 1 | Major driving factors for global wastewater reuse implementation

Category	Core driving factors and source of information
Political	Strategic prioritization in water-security and drought planning; clear cross-sector and authority coordination; policy commitment and programmatic momentum (Chang *et al.* 2013; Breitenmoser *et al.* 2022; Wang *et al.* 2023)
Economic	Cost recovery; fit-for-purpose tariffs; investment incentives; bankable financing models; public–private partnerships and stable offtake arrangements (Breitenmoser *et al.* 2022; Fagundes & Marques 2023; World Bank Group 2025a)
Social	Trust in water quality; perceived safety; demonstrated reliability; transparency; public/user acceptance (Verhoest *et al.* 2022)
Technological	Fit-for-purpose treatment capability; monitoring and QA/QC; operational capacity; performance verification (Breitenmoser *et al.* 2022; Finnerty *et al.* 2024)
Environmental	Water scarcity; drought and climate pressure; pollution reduction; freshwater protection; circular-economy rationale (UNESCO 2020; Liao *et al.* 2021; Wang *et al.* 2023; World Bank Group 2025a, b)
Legal	Explicit reuse standards; fit-for-purpose quality requirements; predictable permitting; monitoring and enforcement; institutional role clarity (European Union 2020; Riazi *et al.* 2023; Chen *et al.* 2024; Pan *et al.* 2025)

3.1.2. Major challenging factors

The major barriers identified from international practices are summarized in Table 2.

Similar to driving factors, barriers for international wastewater reuse were identified across the literature spanning all six PESTEL domains but repeatedly converge around three implementation bottlenecks: (i) policy and regulatory instrument design, (ii) institutional capacity and coordination, and (iii) financing and tariff structures. First, *instrument gap* (Legal/Political → Economic) occurs when standards or permits exist but without streamlined approval processes, risk-proportionate monitoring requirements, liability clarity, or feasible compliance pathways (Rodrigues *et al.* 2024). Second, *institutional capacity and coordination constraints* (Political/Legal/Technological) arise from fragmented institutional arrangements and limited enforcement capacity, which increase transaction costs and constrain scale-up, particularly where reuse requires coordination across multiple agencies or depends on decentralized and onsite systems (Riazi *et al.* 2023). Third, *financing and tariff design constraints* (Economic) limit adoption where reclaimed water often struggles to compete with underpriced freshwater and many projects lack cost-recovery mechanisms or blended finance models that reflect system-wide benefits and long-term operation and management needs (Fagundes & Marques 2023). These constraints appear across diverse contexts despite cross-country variation in governance systems and infrastructure conditions (Lee & Jepson 2020). Detailed mechanisms and representative examples of these driving factors are presented in Supplementary Information 5 (Table S3).

3.2. Vietnam's wastewater reuse: initial assessment of drivers and barriers

3.2.1. Initial assessment of drivers

Wastewater reuse in Vietnam is influenced by a combination of persistent and emerging drivers and barriers. Consistent with international experience, six key driver groups corresponding to the PESTEL framework collectively influence the direction and feasibility of reuse initiatives.

Economic and environmental motivations are particularly important in the Vietnamese context, reflecting rising water demand, localized water scarcity, and declining surface and groundwater quality. Policy and legal frameworks also signal growing national interest in resource circulation and water sustainability, including the Law on Environmental Protection (2020), the Law on Water Resources (2023), and Vietnam's National Action Plan for Circular Economy Action Plan. Supporting regulations such as Decree No. 08/2022/ND-CP (2022) introduce incentive mechanisms for waste collection, treatment, recycling, and reuse. These provisions extend beyond initial investment support, offering preferential loans, interest-rate subsidies, and credit guarantees for environmental protection projects, including wastewater treatment and reuse, through mechanisms such as the Vietnam Environment Protection Fund (Prime Minister of Vietnam 2008; Vietnam Environment Protection Fund n.d.). Such incentives help reduce compliance costs while enabling enterprises to lower freshwater procurement and discharge fees through internal water recycling. Beyond regulatory incentives, participation in international supply chains has become a strong driver for Vietnamese enterprises to adopt wastewater reuse

Table 2 | Major barriers for global wastewater reuse implementation

Category	Core barrier factors and source of information
Political	Fragmented mandates; unclear leadership and accountability; weak interagency coordination; short political and planning horizons (Breitenmoser *et al.* 2022; Wang *et al.* 2023; Rodrigues *et al.* 2024)
Economic	High CAPEX (Capital Expenditure)/OPEX (Operating Expense); underpriced freshwater; tariff misalignment; weak cost recovery; uncertain demand; limited project bankability (Fagundes & Marques 2023; World Bank Group 2025a, b)
Social	Low public acceptance; perceived health risks; 'yuck factor'; limited trust and transparency; weak public education (Mu'azu *et al.* 2020; Pathiranage *et al.* 2024)
Technological	Limited operational reliability; weak operator and regulator capacity; limited local oversight; fit-for-purpose treatment challenges (Rupiper & Loge 2019)
Environmental	Concerns over micropollutants, salinity, and nutrient loads; site-specific environmental risks; stricter monitoring and compliance burdens (UN-Water 2021)
Legal	Ambiguous standards; inconsistent permitting; liability uncertainty; weak enforcement; policy–institution–regulation misalignment (Breitenmoser *et al.* 2022; Rodrigues *et al.* 2024)

practices. Export-oriented manufacturers increasingly face environmental compliance requirements from global buyers, particularly in sectors such as textiles and garments. Meeting these standards allows companies to maintain market access and obtain internationally recognized environmental certifications, often framed as 'green' credentials. Technological readiness is also gradually improving as industrial zones and utilities adopt more advanced treatment systems and as research develops lower-cost materials suitable for local conditions. Social acceptance and community awareness, while still uneven across regions, are increasing in areas experiencing water scarcity or high operational costs. Meanwhile, climate-related motivations are beginning to emerge as an additional driver, linked to Vietnam's Net-Zero 2050 commitments and growing interest in carbon market mechanisms. Although GHG mitigation is not yet a major practical driver of wastewater reuse in Vietnam, it is emerging as a secondary strategic consideration within the broader environmental rationale for reuse.

In the near term, most enterprises continue to prioritize water security, treatment cost, regulatory compliance, and operational reliability over carbon reduction. However, wastewater reuse may increasingly support climate objectives by reducing dependence on energy-intensive long-distance freshwater abstraction and conveyance, lowering the energy and chemical burden associated with supplying and treating conventional water sources, improving water circulation efficiency in industrial water systems, and, where relevant, creating synergies with sludge-to-energy or biogas recovery pathways within broader circular-economy strategies. This climate-related rationale is currently more visible in large and export-oriented firms, but it is likely to grow as Vietnam advances its Net-Zero 2050 agenda (Nguyen & Gilleski 2022) and as green finance, carbon reporting, and supply-chain decarbonization requirements become more influential.

3.2.2. Initial assessment of barriers

Despite the emerging motivations listed above, Vietnam continues to face significant barriers that constrain large-scale wastewater reuse implementation. Consistent with the PESTEL framework applied in the international analysis, these barriers arise from environmental pressures, infrastructural limitations, and institutional constraints.

Pressure on water resources is increasing as total annual water demand reaches 117.03 billion m^3, driven primarily by agriculture (73.1%), aquaculture (15.3%), and industrial activities (8.3%) (Pham *et al.* 2023). Rapid industrialization and urban expansion have intensified water consumption in major cities and thus place additional pressure on water sources and urban water infrastructure (World Bank Group 2019; Water Environment Partnership in Asia 2024). However, treatment capacity remains limited: as of 2025, only about 18% of domestic wastewater is treated before discharge (Government of Vietnam 2025). Consequently, large volumes of untreated wastewater are discharged into urban canals and rivers, contributing to severe pollution, flooding, and public health risks (Strady *et al.* 2017; Nguyen *et al.* 2019; Tong *et al.* 2024). Rapid urbanization has also created spatial 'overlap' between industrial, residential, and peri-urban areas without coordinated water planning, complicating integration of wastewater reuse within existing urban water systems.

Institutional and regulatory constraints also limit reuse adoptions. Although wastewater reuse is acknowledged in national policy frameworks – including the Law on Environmental Protection (2020), the amended Law on Water Resources Law (2023), the National Strategy for Rural Clean Water Supply and Sanitation to 2030 (Prime Minister of Vietnam 2021), and the National Action Plan for Circular Economy (Decision 687/QĐ-TTg) (Prime Minister of Vietnam 2022) –existing regulations, such as the National Technical Regulation on Surface water quality (QCVN 08 2023), the National Technical Regulation on Domestic and Municipal Wastewater (QCVN 14 2025c), and the National Technical Regulation on Industrial Effluent (QCVN 40 2025b), primarily address discharge standards rather than defining reclaimed water quality for specific reuse purposes or establishing licensing, monitoring, and risk management procedures (Van Khanh *et al.* 2023; Beil *et al.* 2025; Tran 2025). In practice, industrial zones seeking to reuse treated wastewater often must meet standards equivalent to surface or potable water, making reclaimed water economically uncompetitive. As a result, some zones instead reuse water from polishing ponds of centralized wastewater treatment plants (CWTPs) or harvest stormwater from regulation reservoirs for irrigation, sanitation, and fire protection within industrial boundaries.

Governance fragmentation adds further limitations. Responsibilities for wastewater treatment, reuse, and water resource planning are distributed across multiple agencies, including the MONRE, the Ministry of Construction (MOC), the Ministry of Agriculture and Rural Development (MARD), Ministry of Industry and Trade (MOIT), and the Ministry of Health (MOH), leading to overlapping mandates and weak coordination. Recent administrative reforms, particularly the merger of MONRE and MARD into the MAE, may help reduce this fragmentation and improve policy alignment.

3.3. Vietnam's wastewater reuse: evaluation of current wastewater reuse implementations

The screening of 2,511 projects in Vietnam with wastewater generation data between 2023 and 2025 collected from the public consultation portal of the MAE (2026) resulted in 118 projects classified as 'highest pollution risk', 'highest water consumption', 'located in the most economically dynamic development zones', 'located in the most water-scarce regions', or 'employing the newest and greenest production technologies'. These projects were grouped into five categories: (1) IP Infrastructure; (2) heavy industry, manufacturing, processing, and assembly; (3) urban infrastructure, water supply and drainage, solid waste, and transportation; (4) tourism and hospitality facilities; and (5) livestock and animal agriculture. Detailed screening information of 118 projects with wastewater generation data in Vietnam is presented in Supplementary Information 6 (Table S4) and Supplementary Spreadsheet 1 – List of projects and categories.

A breakdown of the project counts and their respective percentages within each industrial group are displayed in Figure 2. The internal distribution and statistical variability of water reuse percentages within each category, including the mean, median, and sector-specific ranges, is presented in Figure 3.

3.3.1. Group 1: industrial park infrastructure

IP Infrastructures (Group 1) exhibit a low overall adoption rate of water reuse, despite the wide range of reuse percentages across individual projects (Figures 2 and 3). This significant variability suggests a high technical potential for reclamation that remains largely untapped and inconsistently deployed across the sector.

Within IPs (Group 1), CWTPs facilitate the reuse of treated water for irrigation of green spaces, road cleaning, landscaping, and fire protection, thereby reducing freshwater consumption. However, these activities are often informal and not officially reported. Very few industrial zones explicitly include wastewater reuse activities in their EIA documentation or environmental permit applications. To date, DEEP C IP in Hai Phong City is the only identified case implementing a pilot treatment system technically capable of producing reuse-quality effluent for industrial processes (Ministry of Agriculture and Environment (MAE) 2025). Despite this technological progress, economic and legislative barriers remain dominant. High capital costs for advanced treatment technologies, combined with low tariffs for freshwater extraction and the absence of regulatory or financial incentives, result in very low actual reuse rates across Group 1.

Another challenge for wastewater reuse in IPs is the unclear allocation and coordination of responsibilities between IP Management and state regulatory agencies. Formal oversight is mainly assigned to the MAE, but the respective roles of IP Management Boards and other involved authorities remain insufficiently defined. While relevant standards and laws exist,

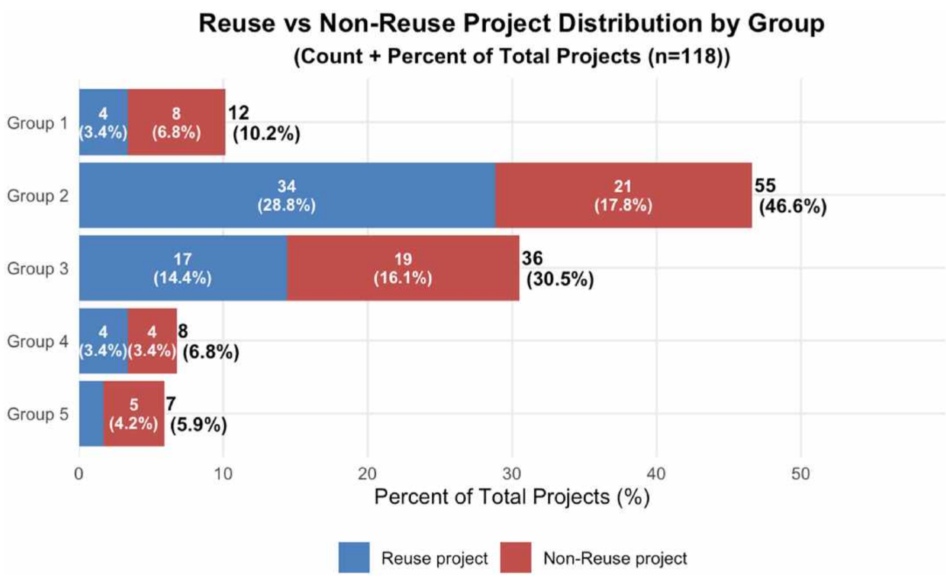


Figure 2 | Reuse vs. nonreuse project distribution in Vietnam ($n = 118$) across five categories: (1) IP infrastructure; (2) manufacturing and industrial processing; (3) urban infrastructure, utilities, and transportation; (4) tourism and hospitality facilities; and (5) livestock and animal agriculture. Data sourced from MAE public consultation portal (2023–2025).

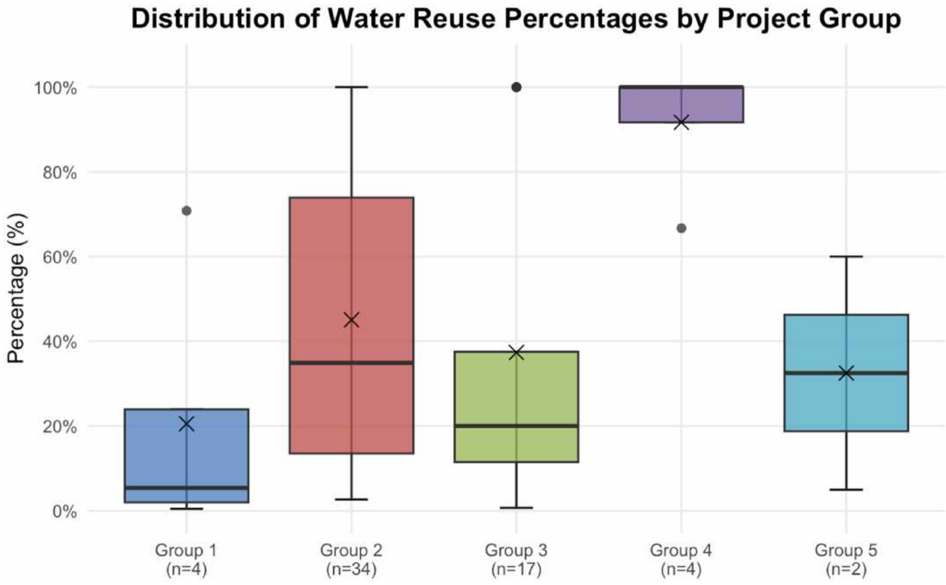


Figure 3 | Distribution of wastewater reuse percentages across five project categories ($n = 118$). The boxes represent the interquartile range (IQR), the internal horizontal line denotes the median, and the 'x' marker indicates the mean reuse rate. Whiskers extend to the minimum and maximum values (excluding outliers).

including the National Technical Regulation on Domestic Water Quality (QCVN 01-1:2024/BYT 2024), the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT 2023), the Law on Environmental Protection (2020), the Law on Water Resources (2023), and Decree No. 08/2022/ND-CP elaborating the Law on Environmental Protection 2020 (2022), the overall regulatory framework lacks coherence, creating challenges for enterprises seeking compliance.

Although encouraged by provisions in the Law on Water Resources (2023) and the Law on Environmental Protection (2020), the transfer of reclaimed wastewater to external entities beyond the boundaries of the generating facility has rarely been implemented in practice. Regulatory authorities remain cautious about such arrangements due to concerns that reuse water transferred to external users may be difficult to monitor and control, particularly given the limited current capacity for supervision and the absence of comprehensive regulations on risk management, pollution control, and public health protection. For example, if the supplying party is unable to provide a sufficient volume of reclaimed water, the receiving party may face disruptions to its water supply. Conversely, if the water demand of the receiving party suddenly declines – for instance, due to reduced production demand or operational incidents – the supplying facility must identify alternative storage options or ensure that the treated wastewater meets all regulatory requirements before it can be discharged into the environment, even though the system may have originally been designed primarily for reuse. This situation represents a major challenge for IP infrastructure development projects, particularly for developers operating CWTPs, who seek to supply (or sell) reclaimed wastewater from these facilities to industrial or service enterprises. These enterprises typically operate as secondary investors (tenants) leasing land within the IP and using shared infrastructure services such as water supply, drainage, energy, and telecommunications. In this context, the development of clear legal and technical guidelines is essential to enable the practical implementation of such wastewater reuse arrangements.

At locations where reuse is implemented, it is primarily motivated by operational cost savings and the practical advantages of securing a stable internal water supply for cooling, washing, or process recirculation. These applications are technically feasible, and emerging research on lower-cost treatment materials (e.g., modified rice husk for heavy metal removal or low-pressure membrane for turbidity, flocs and ions removal) illustrates potential pathways for more affordable industrial reuse. However, lack of detailed reuse-related regulations and weak enforcement continue to prevent widespread adoption.

3.3.2. Group 2: manufacturing and industrial processing

The highest number of wastewater reuse and internal recycling practices was identified at the level of individual production and manufacturing facilities (Group 2), characterized by a robust median reuse rate (Figures 2 and 3). This trend is driven by strong economic incentives, as the high water demand of industrial processing necessitates operational cost reductions through internal water recycling.

The analysis for Group 2 focused on facilities representing three water-intensive and high-pollution sectors: brewing, textile dyeing, and food processing (Decree No. 08/2022/ND-CP 2022). In the brewing sector, Heineken Vietnam Brewery (Ba Ria – Vung Tau province) applies advanced treatment and water-efficiency measures and has integrated circular economy practices consistent with international sustainability standards. In the textile sector, the reuse system at the Billion Union Textile Factory (Thanh Hoa province) demonstrates that multistage treatment can produce high-quality reclaimed water. The project reuses 4,835 m^3/day out of a total treatment capacity of 10,500 m^3/day (≈45%). This reuse module was required because the receiving water body, the Lach Bang River, has limited remaining assimilative capacity due to pollution from domestic, industrial, and aquaculture sources. Installing the recycling module enabled the project to obtain EIA approval from the Ministry of Natural Resources and Environment (Billion Union Company and Institute of Environmental Science and Engineering (IESE) 2024). A third notable case in Group 2 is the JAPFA Food Processing and Animal Feed Plant (Binh Phuoc province), which installed an ultrafiltration system to recycle 1,000 m^3/day of wastewater from a total 4,850 m^3/day, helping address local freshwater scarcity. Additional recycling units are planned to increase the reuse rate (Koastal Eco Industries and Institute of Environmental Science and Engineering (IESE) 2024). Despite these examples, industrial wastewater reuse remains limited and case-specific. Wider adoption will require clearer reclaimed-water standards, stronger economic incentives, and more coherent regulatory frameworks.

Industrial wastewater reuse is encouraged under the Law on Water Resources (2023), the Law on Environmental Protection (2020), and Decree No. 08/2022/ND-CP (2022). However, specific standards, regulations, and technical guidelines for wastewater reuse have not yet been established. The former standard governing agricultural reclaimed water use, the National Technical Regulation on Water Quality for Irrigated Agriculture (QCVN 39:2011/BTNMT 2011), is no longer in effect. As a result, the required treatment level for wastewater reuse must currently be inferred from other applicable standards. For agricultural irrigation, treated wastewater must meet the requirements of Class B on the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT 2023) due to the absence of a dedicated irrigation reuse standard. For urban and domestic water supply, reclaimed water would need to meet at least the requirements of the National Technical Regulation on Domestic Water Quality (QCVN 01-1:2024/BYT 2024). For industrial water supply, the required quality may range from Class C on the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT 2023) up to the National Technical Regulation on Domestic Water Quality (QCVN 01-1:2024/BYT 2024), or higher depending on the intended use. These requirements create financial challenges and reduce the economic competitiveness of wastewater reuse compared with conventional freshwater supply. Additional technical challenges arise from the management of concentrated brine streams produced by reverse osmosis (RO) systems. Under the National Technical Regulation on Industrial Effluent (QCVN 40:2025/BTNMT 2025b), chloride concentrations must remain below 500 mg/L when discharged to Class A receiving waters and below 1,000 mg/L for Class B receiving waters (these limits do not apply to discharges into marine or saline waters), making treatment of RO concentrate streams particularly costly. Furthermore, effective implementation of wastewater and sludge reuse requires robust systems for monitoring, risk management, and pollution control, which remain limited.

3.3.3. Group 3: urban infrastructure, utilities, and transportation

While urban infrastructure projects demonstrate moderate average reuse rates, the sector is marked by extreme volatility, with some projects achieving near-total reuse while others implement none (Figures 2 and 3). Such disparity indicates that the integration of reclaimed water in urban settings is heavily contingent upon specific local planning mandates and regional policy frameworks.

Urban wastewater reuse in Vietnam is shaped largely by public-good and environmental drivers linked to citywide water security, climate adaptation, and sustainable urban development. Urban reuse initiatives are typically embedded within integrated planning for water supply, drainage, and urban greenery. Centralized treatment plants can serve multiple purposes such as irrigation, street cleaning, industrial cooling, and groundwater recharge, offering scalability and reduced pressure on freshwater sources. However, realizing these benefits requires substantial capital investment, effective inter-agency coordination, and strong public acceptance.

In practice, urban wastewater reuse remains limited, with only a few small-scale initiatives demonstrating its potential. The wastewater treatment plant of Thu Dau Mot city (Binh Duong province) has explored reuse for landscaping and industrial applications in response to groundwater depletion and increasing climate and pollution. In Buon Ma Thuot city (Dak Lak province), treated wastewater is reused for coffee irrigation during the dry season, reflecting both economic and environmental drivers. While technically feasible and helpful in reducing groundwater extraction, the model faces challenges such as high operation and maintenance costs, variable influent quality, and the need for continuous monitoring to prevent long-term pollutant accumulation. In Da Lat (Lam Dong province), treated municipal wastewater is reused to irrigate urban green areas and high-value floriculture. This model shows that reuse can reduce pressure on freshwater supplies and take advantage of nutrient content in treated effluent.

However, borader expansion of urban reuse is constrained by concerns about reuse water quality, soil salinity risks, and the absence of clear national standards for reclaimed water (World Bank Group 2014). Large-scale implementation has not materialized due to fragmented institutional responsibilities, weak integration between drainage and water supply systems, and limited monitoring capacity (Trang *et al.* 2022). Low water tariffs remain a further disincentive for promoting wastewater reuse. Institutional fragmentation among the construction, environment, and agriculture sectors has constrained the deliberate and planned integration of urban wastewater reuse into peri-urban agricultural irrigation, resulting in significant losses of water and nutrient resources and necessitating costly investment in nitrogen and phosphorus removal during treatment. Meanwhile, downstream farmers informally use this water for vegetable cultivation and aquaculture in the absence of alternative water sources, generating considerable food safety risks (Qadir *et al.* 2010).

In a recent and notable case in Hanoi, the Yen Xa Wastewater Treatment Plant, which has been commissioned in 2025 with a design capacity of 270,000 m^3/day, was designed to treat effluent to Class B of the National Technical Regulation on Industrial Effluent (QCVN 40:2025/BTNMT) (2025b). Treated effluent is currently used to replenish the To Lich River, maintaining environmental flow in what was formerly an open wastewater drainage canal. This watercourse faces the risk of drying up following the completion of an interceptor sewer system designed to collect 100% of wastewater generated within the catchment and convey it to the treatment plant, rather than discharging directly into the canal as was previously the case. A critical limitation, however, lies in the fact that the plant was designed to meet Class B of the National Technical Regulation on Industrial Effluent (QCVN 40:2025/BTNMT) (2025b), which is a discharge standard whose pollutant concentration limits are substantially less stringent than the surface water quality standard applicable to the To Lich River (National Technical Regulation on Surface Water Quality, QCVN 08:2023/BTNMT, Class B) (2023). Experts are currently exploring the development and promulgation of a dedicated water quality standard for urban river replenishment, alongside opportunities to upgrade the Yen Xa plant to meet such a standard in the future, as a more pragmatic alternative to the costly option of diverting water from the Red River for environmental flow augmentation. It is further necessary to revise the effluent quality targets for other wastewater treatment plants within the urban core, so that their treated effluent may qualify for replenishment of other inner-city rivers.

Together, these cases show that urban reuse in Vietnam remains at a small scale and faces significant regulatory and operational barriers, despite clear environmental and public-good motivations. Across reviewed cases, the relative importance of drivers varies by context: environmental compliance pressures dominate in degraded water environments, economic savings motivate production facilities, and public-good objectives (water security, climate adaptation, and urban environmental quality) drive most urban initiatives. Finally, the absence of regulatory requirements to integrate large-scale reuse planning into integrated water resources management and regional water balance assessments constitutes an additional and significant structural barrier to planned and systematic wastewater reuse.

3.3.4. Group 4: tourism and hospitality facilities

Four out of eight projects reviewed in Group 4 reported wastewater reuse. This group exhibits the most stable and highest percentage of water reuse across all studied sectors, with a median rate that nears total saturation (Figures 2 and 3). The consistency in this sector reflects the clear logistical alignment between wastewater treatment and the high, ongoing demand for landscaping and irrigation within hospitality facilities. The relatively higher reuse rates observed are largely associated with the desire to obtain 'green' or 'eco' labels for the projects through wastewater reuse practices and other sustainability measures.

3.3.5. Group 5: livestock and animal agriculture

Livestock farming shows limited adoption and moderate reuse levels, with project variability remaining relatively constrained (Figures 2 and 3). Among the livestock projects reviewed, only two were found to have implemented wastewater reuse in practice. In this sector, reclaimed water is primarily diverted toward facility sanitation and localized irrigation, though its implementation is strictly governed by the scale of the operation and the specific treatment technologies employed. These findings suggest the need for further discussion on how to improve reuse opportunities, for example through better integration between livestock farms, agricultural production areas, and crop cultivation for animal feed. However, implementing such circular economy models remains challenging under current regulatory, technical, and economic conditions.

Currently, wastewater treatment in livestock farming remains technically difficult and costly, while many livestock projects operate with relatively low profit margins and are often located in rural areas. Livestock wastewater typically contains very high concentrations of total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and biochemical oxygen demand (BOD), which can lead to environmental pollution, public complaints, and incidents such as fish kills if not adequately treated. Under the National Technical Regulation on the Effluent of Livestock (QCVN 62:2016/BTNMT) (2016), higher allowable limits for parameters such as TN and TP are permitted compared with other industrial sectors. However, under the recently updated National Technical Regulation on the Effluent of Livestock (QCVN 62:2025/BTNMT) (2025a), the values of allowable limits have significantly reduced, for example, TN values have been tightened: 20 and 60 mg/L instead of 50 and 150 mg/L for Class A and B, respectively.

As a compromise solution, the application of the National Technical Regulation on Livestock Wastewater Used for Crops (QC 1-195:2022/BNNPTNT) (2022) has been proposed, whereby treated livestock wastewater meeting the required criteria may be used for **root irrigation** for tree types of crops. In practice, however, this approach faces operational constraints: irrigation demand depends on weather conditions (for example, irrigation may not be needed during rainy periods), requiring storage capacity for treated wastewater, as in most cases this flow cannot meet the discharge standards in terms of key parameters such as BOD, COD, TSS, TN, TP (Ministry of Agriculture and Rural Development (MARD) 2022; Ministry of Natural Resources and Environment (MONRE) 2025a). When wastewater supply exceeds irrigation demand, additional storage or alternative management solutions are required, while shortages raise questions about how water demand should be met. Without relevant regulations and detailed technical guidance, root irrigation within livestock farms may be feasible, but transferring treated wastewater for reuse outside the farm boundary remains difficult to implement.

3.4. Stakeholder perception – validation of findings

A list of stakeholders who participated in consultation workshop is provided in Supplementary information 7 (Table S5) and Supplementary Spreadsheet 2 – Consultation Workshop. Detailed questionnaire responses for wastewater reuse drivers and barriers selected by consultation workshop participant are listed in Supplementary information 8 and 9 (Tables S6 and S7), respectively, and in Supplementary Spreadsheet 2 – Consultation Workshop. Summary diagrams of stakeholder responses of all driving and barrier factors, categorized by PESTEL dimensions, are provided in Supplementary information 10 and 11 (Figures S1 and S2). Summary diagrams of stakeholder responses on KEY driving and barrier factors (chosen by 70% or more of consultation workshop participants), categorized by PESTEL dimensions, are provided in Supplementary information 12 and 13 (Figures S3 and S4).

Stakeholders identified several key driving factors to wastewater reuse adoption in Vietnam (Table 3). The highest-rated factors were concentrated in the economic and environmental domains, particularly long-term economic benefits (95.95%), cost savings from reduced freshwater consumption (95.70%), and the location of projects in water-scarce regions encouraging alternative water sources (96.13%). Strong policy and legal factors were also viewed as important, including government policies promoting water reuse (94.13%) and environmental protection regulations (94.70%). In addition, stakeholders highlighted the role of industrial and market-related conditions, such as water-intensive industries (economic, 94.13%), high-pollution loads requiring improved wastewater management (environmental, 93.70%), and the adoption of green and high-tech industrial development models (technology, 94.70%). Social factors, especially public awareness and environmental pressure (94.13%), were also recognized as supportive conditions, although trust, perceived safety, and user acceptance received slightly lower scores. Overall, the results suggest that wastewater reuse in Vietnam is driven primarily by a combination of water stress, economic benefits, environmental management pressures, and enabling policy conditions.

Key barriers to wider wastewater reuse adoption were also pinpointed by stakeholders (Table 4). The most highly rated political constraint was weak enforcement mechanisms (95.95%), while long payback periods (94.70%), uncertain return on investment (93.75%), and high CAPEX/OPEX requirements (92.27%) were rated highest for economic challenges. Social barriers were also prominent, especially limited demand for reclaimed water (95.95%), low customer or stakeholder

Table 3 | Summary of key driving factors (chosen by 70% or more of consultation workshop participants) on the questionnaire with mean percentage from five stakeholder groups, categorized by PESTEL dimensions

PESTEL domain	Key driving factors (mean percentage from five stakeholder groups, %)
Political (P)	• Government policies promoting water reuse (94.13%) • Clear coordinating authority (85.40%) • Cross-sector coordination (85.40%) • Strategic prioritization in water-security and drought planning (84.40%) • Policy commitment and programmatic momentum (82.30%)
Economic (E)	• Long-term economic benefits (95.95%) • Cost savings from reduced freshwater consumption (95.70%) • Financial incentives or subsidies and bankable financing mechanisms (94.70%) • Water-intensive industries with high water demand (94.13%) • Fit-for-purpose tariffs (81.92%)
Social (S)	• Public awareness and environmental pressure (94.13%) • ESG/sustainability reporting requirements (92.70%) • Transparency (86.17%) • Demonstrated reliability (83.35%) • Public/user acceptance (82.92%) • Trust in water quality (81.87%) • Perceived safety (81.35%)
Technology (T)	• Adoption of green and high-tech industrial development models (94.70%) • Availability of advanced treatment technologies (93.75%) • Fit-for-purpose treatment capability (84.78%) • Innovation and research and development (83.69%) • Operational capacity of treatment facilities (83.30%) • Performance verification mechanisms (78.10%)
Environmental (E)	• Location in water-scarce regions encouraging alternative water sources (96.13%) • Location in economically dynamic regions with strong industrial development (93.70%) • Industries with high pollution loads require improved wastewater management (93.70%) • Drought and climate pressure (87.22%) • Water scarcity (85.40%) • Pollution reduction and improved wastewater management (84.35%) • Climate change adaptation and resilience (84.35%)
Legal (L)	• Environmental protection regulations (94.70%) • Predictable permitting procedures (84.40%) • Institutional role clarity in reuse governance (83.35%) • Explicit wastewater reuse standards (82.35%) • Monitoring and enforcement mechanisms (82.30%) • Fit-for-purpose reclaimed water quality requirements (78.53%)

acceptance (94.52%), and ‘yuck factor’ or psychological aversion (94.13%). Legal and administrative constraints remained significant, with respondents highlighting high environmental or technological standards (91.65%), inconsistent permitting (84.40%), liability uncertainty (82.30%), and ambiguous standards (78.53%). Technical and institutional weaknesses, including lack of clear inspection guidelines (86.60%), limited local oversight (84.40%), and limited operational reliability (82.35%), were also widely recognized. In general, the findings indicate that the main barriers to wastewater reuse in Vietnam lie not only in treatment cost and technology performance, but also in weak enforcement, uncertain project economics, limited market acceptance, and unclear regulatory conditions.

In summary, the survey questionnaire results reveal tension between the high environmental urgency and the systemic structural bottlenecks. While the Environmental domain provides the strongest impetus for water reuse – driven specifically by extreme water scarcity in specific regions (96.13%) – the Political domain presents an almost equal and opposite force through weak enforcement mechanisms (95.95%). This suggests that while the demand for reclaimed water is undisputed, the governance remains functionally under-resourced, hindering effective enforcement. Furthermore, an economic paradox is evident: stakeholders recognize the long-term economic benefits (95.95%) and cost savings (95.70%) of reuse, yet they are

Table 4 | | Summary of key barrier factors (chosen by 70% or more of consultation workshop participants) on the questionnaire with mean percentage from five stakeholder groups, categorized by PESTEL dimensions

PESTEL domain	Highest-rated barrier factors (mean percentage from five stakeholder groups, %)
Political (P)	• Weak enforcement mechanisms (95.95%) • Weak interagency coordination (87.22%) • Unclear leadership and accountability (85.40%) • Short political and planning horizons (84.40%) • Fragmented mandates (84.35%)
Economic (E)	• Long payback period (94.70%) • Uncertain return on investment (93.75%) • High CAPEX/OPEX (92.27%) • Underpriced freshwater (84.35%) • Uncertain demand (84.35%) • Limited project bankability (82.35%) • Tariff misalignment (82.35%) • Weak cost recovery (82.35%)
Social (S)	• Limited demand for reclaimed water (95.95%) • Low acceptance by customers or stakeholders (94.52%) • 'Yuck factor' (psychological aversion) (94.13%) • Perceived health risks (87.22%) • Low public acceptance (85.40%) • Limited trust and transparency (85.40%) • Weak public education and awareness (85.40%)
Technology (T)	• Lack of clear inspection guidelines (86.60%) • Limited local oversight (84.40%) • Limited operational reliability (82.35%) • Fit-for-purpose treatment challenges (82.30%) • Weak operator and regulator capacity (78.53%)
Environmental (E)	• Stricter monitoring and compliance burdens (81.92%) • Site-specific environmental risks (81.30%) • Salinity and nutrient loads (80.92%) • Concerns over micropollutants (77.00%)
Legal (L)	• High environmental or technological standards (91.65%) • Inconsistent permitting (84.40%) • Weak enforcement (83.35%) • Liability uncertainty (82.30%) • Policy–institution–regulation misalignment (81.30%) • Ambiguous standards (78.53%)

simultaneously deterred by the reality of long payback periods (94.70%) and high initial CAPEX (92.27%). Socially, high 'Yuck factor' (94.52%) and limited demand for reuse (95.95%) further prevent the realization of the identified economic potential of wastewater reuse.

3.5. Recommended actions for Vietnam

Based on the above analysis and findings, we propose the following recommendations to leverage drivers and overcome barriers, thereby motivating wastewater reuse implementations in Vietnam.

3.5.1. Strengthen the policy and regulatory framework

Current regulations primarily address discharge standards and lack dedicated reclaimed-water quality standards tailored to different reuse purposes. Priority actions include:

- Updating relevant legal documents to explicitly address wastewater reuse, including incentive mechanisms (e.g., updating Decree No. 53/2024/ND-CP (2024) detailing the 2023 Law on Water Resources) and procedures for preparing, reviewing, and approving EIAs and environmental permits for projects involving wastewater reuse (e.g., updating Decree No. 08/

2022/ND-CP (2022) implementing the 2020 Law on Environmental Protection). These updates would operationalize policies encouraging wastewater reuse.
- Developing purpose-specific National Technical Regulations (QCVN) for irrigation, cooling, industrial processes, and non-contact domestic uses.
- Establishing risk-based classification and treatment requirements aligned with international guidelines (e.g., World Health Organization 2013; ISO 16075 2020) and issuing technical guidance for designing wastewater reuse projects in urban, industrial, and industrial-zone contexts, for different water-use purposes.
- Incorporating clear monitoring, reporting, and compliance mechanisms to ensure the safety and transparency of reuse water. Utilizing digital tools to improve efficiency of applications.

3.5.2. Improve institutional coordination and governance

Wastewater reuse is currently governed by multiple ministries without clear leadership or coordinated mandates. To enhance governance:

- Designate a lead agency (potentially Ministry of Agriculture and Environment (MAE, following the merger of MONRE and MARD) to coordinate policies and oversee implementation.
- Establish an interministerial coordination mechanism or national task force on wastewater reuse (supported by a directive from the Prime Minister).
- Integrate wastewater reuse objectives into national water resources planning, sectoral development plans, and local urban planning processes, including incorporation into the Water Resources Law and national planning legislation.

3.5.3. Expand incentive economic mechanisms

High upfront and operational costs deter enterprises from investing in reuse systems. Recommended interventions include:

- Developing public–private partnership models to mobilize private-sector investment in wastewater treatment and reuse infrastructure.
- Offering tax incentives, reduced environmental fees, or operational subsidies for facilities implementing reuse.
- Establishing cost-reflective pricing frameworks for reclaimed water to ensure it remains competitive with potable water tariffs.
- Classifying wastewater reuse systems as ‘green investments’ to improve access to preferential loans, green credit, and environmental funds.

3.5.4. Build technical capacity and improve social acceptance

Limited technical knowledge and low public awareness remain major constraints. Needed actions include:

- Providing training programs for utilities, industrial operators, and government staff on advanced treatment technologies, decentralized reuse systems, and water quality monitoring.
- Communicating transparently with communities and businesses on the benefits, safety, and regulatory safeguards associated with reuse.
- Implementing well-documented demonstration projects to build confidence, showcase effectiveness, and facilitate replication.

3.5.5. Validation of proposed recommendations with stakeholder questionnaire

The above recommendations were incorporated into the same stakeholder questionnaire used to identify the main drivers and barriers (see Section 2.3 – Validation of findings with stakeholders) as a validation step to gather stakeholder feedback. In addition to the recommendations proposed by the research team, the questionnaire also provided space for participants to suggest additional recommendations based on their own perspectives. While the preceding analysis utilized the PESTEL framework to categorize the current landscape of drivers and barriers, the recommendations were structured into four categories: (1) Policy and Regulatory Framework, (2) Institutional Coordination and Governance, (3) Incentive Economic Mechanisms, and (4) Capacity Building. This reconstruction of categories for recommendations is justified by the shift from analytical observation to strategic implementation-oriented actions. Many barriers overlap across domains, and effective responses often require integrated measures spanning institutional, economic, technical, and social dimensions.

Specifically, environmental objectives are now embedded within recommendations instead of serving as a standalone factor group like in the analysis, while the newly added Capacity Building category incorporates social and technical demonstrations.

Detailed questionnaire responses of the stakeholders to validate recommendations on wastewater reuse are listed in Supplementary information 14 (Table S8). The summary diagram of all recommendations chosen by consultation workshop participants on the questionnaire is provided in Supplementary information 15 (Figure S5). The summary diagram of KEY recommendations (chosen by 70% or more of consultation workshop participants) is provided in Supplementary information 16 (Figure S6).

Overall, suggested recommendations were agreed by stakeholders, with 14 key recommendations surpassing the 70% stakeholder approval threshold (Table 5). Capacity building emerged as the area of highest consensus, particularly regarding the need for improved transparency and public communication (94.08%) and the implementation of demonstration projects (91.27%). Stakeholders also strongly prioritized the policy and regulatory framework, specifically calling for clear reclaimed-water regulations (91.60%) to resolve existing legal ambiguities. This indicates a strong level of consensus across the five stakeholder groups on the main actions needed to advance wastewater reuse in Vietnam, particularly in relation to regulatory reform, institutional coordination, financial incentives, capacity building, and demonstration-oriented implementation.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusion

This study examined the emerging landscape of wastewater reuse in Vietnam through a combined assessment of international experience, national policy and institutional conditions, project-level evidence, and stakeholder perspectives. The findings show that wastewater reuse is an increasingly relevant component of water security, pollution control, and circular resource management. Across the detailed review of 118 wastewater-generating projects and stakeholder consultation, wastewater reuse is technically viable in several Vietnamese settings, particularly where water demand is high, freshwater alternatives are constrained, or environmental compliance pressures are strong. Reuse is most visible in manufacturing and hospitality facilities, while adoption remains limited and fragmented in industrial park infrastructure, urban systems, and livestock production. However, implementation remains at an early and uneven stage, with clear differences across sectors and reuse contexts. The main constraints are not primarily technological feasibility, but institutional and economic conditions for scale-up, as well as the absence of fit-for-purpose reclaimed-water standards, fragmented regulatory responsibilities, high treatment and monitoring costs, weak economic incentives, and limited confidence in compliance and quality assurance.

Table 5 | Summary of key recommendations (chosen by 70% or more of consultation workshop participants) with mean percentage from five stakeholder groups

Category	Recommendation (mean percentage from five stakeholder groups, %)
Policy and regulatory framework	• Establish clear reclaimed-water regulations (91.60%) • Update legal documents (89.17%) • Establish risk-based classification (70.57%) • Strengthen coordination among government agencies (70.75%)
Institutional coordination and governance	• Designating a lead agency to coordinate policies (84.72%) • Encourage collaboration among industries and stakeholders (72.57%) • Establish an interministerial coordination mechanism (75.62%)
Incentive economic mechanisms	• Provide financial incentives (87.17%) • Establish cost reflective or competitive pricing schemes (84.11%) • Develop public–private partnership models (70.52%)
Capacity building	• Improve transparency and public communication (94.08%) • Implement pilot and demonstration projects (91.27%) • Increase public awareness and communication (89.17%) • Promote research, innovation, and technology transfer (75.62%)

Overall, the findings suggest that wastewater reuse in Vietnam should be approached as a strategic water-management option rather than only an add-on to wastewater treatment. Its near-term expansion is most likely in controlled nonpotable applications with clear demand, manageable risk, and identifiable users, especially in industrial and selected urban contexts. Broader mainstreaming, however, will depend on whether Vietnam can move from general policy recognition to an operational framework that aligns water quality requirements, permitting, monitoring, institutional coordination, and financial viability. Under these conditions, wastewater reuse could become an important pillar of more resilient and resource-efficient water management in Vietnam.

4.2. Recommendations

Based on the findings of this study, wastewater reuse in Vietnam should be promoted through a phased, fit-for-purpose strategy rather than by applying uniform expectations across all sectors and reuse applications. In the near term, priority should be given to nonpotable uses with clear demand, manageable health and environmental risks, and relatively strong implementation readiness. The evidence from reviewed projects suggests that these conditions are most evident in selected manufacturing facilities, tourism and hospitality complexes, and some controlled urban applications. By contrast, more complex reuse schemes, including interfacility transfers or large-scale public reuse systems, should be pursued more cautiously until stronger monitoring, storage, operational control, and legal safeguards are in place.

A first priority is to establish a clearer regulatory framework for reclaimed water. Current Vietnamese regulations still focus mainly on wastewater discharge and do not yet provide sufficiently specific, end-use-based requirements for reuse. As a result, many technically feasible reuse options remain in a legal and operational grey zone. A more workable framework should define reclaimed-water quality in relation to intended uses, together with associated monitoring, permitting, and risk-management requirements. Such an approach would reduce uncertainty for both regulators and investors and provide a more practical basis for expanding reuse beyond isolated pilot or internal recycling applications.

A second priority is to improve institutional coordination and implementation capacity. Rather than lack of treatment technology, wastewater reuse in Vietnam is more constrained by fragmented responsibilities, limited enforcement capacity, and weak confidence in long-term compliance. Accordingly, reuse implementation will progress with clearer allocation of responsibilities across relevant authorities and stronger technical guidance for utilities, industrial operators, and project developers. Demonstration projects remain important, but their role should be to generate operational evidence, test governance arrangements, and support regulatory learning under Vietnamese conditions rather than simply to showcase treatment technologies.

A third priority is to address the weak economic case for reuse under current conditions. High treatment and monitoring costs, together with low freshwater tariffs and limited financial incentives, continue to undermine wider adoption. Reuse promotion should therefore be linked to broader water-security, circular-economy, and green-investment strategies, especially in areas facing growing resource pressure or environmental stress.

Finally, a fourth priority should be placed on greater attention to capacity building and awareness raising. Many stakeholders, including local authorities, utilities, industries, and the public, still have limited familiarity with the technical, regulatory, and safety aspects of wastewater reuse. For professionals, professional capacity and reuse implementation quality can be strengthen with training programs, technical guidance documents, and knowledge-sharing platforms. To build public confidence in safe reuse practices, broader communication efforts are needed to reduce perception barriers that may otherwise limit the wider adoption of reclaimed water in Vietnam.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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