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STRUCTURAL DETERMINANTS OF WATER-USE EFFICIENCY: A RESOURCE-BASED VIEW OF THAI INDUSTRIAL FACTORIES

Nitipun NA PATTALUNG[1], Pisamai JARUJITTIPANT[1] and Kietchai VERAYANNON[1]
1 Program in Management, North Bangkok University, Thailand;
nitipun.na@gmail.com (N. N.); pisamai.ja@northbkk.ac.th (P. J.)

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Abstract
As water scarcity increasingly threatens operational continuity, evaluating how organizational resources shape sustainable conservation efforts is critical. Grounded in the Resource-Based View framework, this study investigates the impact of structural business characteristics on overall water-use efficiency among industrial factories located within Thailand's central and northeastern river basins. Employing a rigorous quantitative census-based approach, empirical data were systematically collected from 120 factories via surveys administered to senior water management executives. The analysis utilized one-way ANOVA and independent-samples t-tests to evaluate efficiency disparities across diverse firm profiles. The robust findings conclusively demonstrate that overall water-use efficiency is significantly determined by registered capital, workforce size, and industrial sector type. At the same time, operational age, ownership nationality, and location exhibit no significant effects. Furthermore, post-hoc LSD comparisons reveal a distinct resource threshold effect, indicating that small-scale factories perform significantly lower than their medium- and large-scale counterparts. Ultimately, this research confirms that firm scale and sectoral context structurally constrain environmental performance. The study offers targeted strategic guidelines and policy implications, strongly emphasizing the need for tailored financial incentives and digital inclusion to enhance the eco-efficiency of resource-constrained factories.

Keywords: Water Use Efficiency, Business Characteristics, Industrial Factories, Resource-Based View, Eco-efficiency

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Introduction

Thailand's industrial manufacturing sector is a major contributor to national output and employment. Although industry accounts for a smaller share of total national freshwater withdrawals than agriculture, a reliable water supply is critical for continuous industrial operations. Recurrent droughts, water scarcity, and episodic shortages—particularly in the central and northeastern river basins—have heightened the operational and strategic importance of factory-level water management (Office of the National Water Resources, 2021). Guided by the Resource-Based View (Barney, 1991), this study focuses on structural determinants—specifically registered capital, workforce size, years of operation, ownership nationality ratio, factory location, and industrial sector type—as critical factors that inherently shape a firm's capacity to achieve optimal water-use efficiency. While strategic water-use practices (such as the 3Rs, evaluation, and control) are undeniably important, this manuscript explicitly isolates these structural determinants. It evaluates their direct relationship to measured water-use efficiency across factories in these highly stressed river basins. Ultimately, the analysis intends to inform targeted managerial actions and differentiated policy interventions by identifying which specific structural profiles are associated with higher or lower efficiency outcomes.

The research objectives of this study are twofold: 1) to investigate the structural determinants driving differences in overall water-use efficiency among industrial factories, viewed through the lens of the Resource-Based View; and 2) to propose targeted strategic management approaches to enhance the eco-efficiency of industrial factories located in Thailand's central and northeastern river basins. Research hypothesis (H1): The overall water-use efficiency of industrial factories in Thailand's central and northeastern river basins varies significantly according to their structural determinants (specifically registered capital, workforce size, years of operation, ownership nationality ratio, factory location, and industrial sector type). The expected benefits of this study encompass both practical and policy dimensions. In practical terms, the findings provide vital empirical evidence demonstrating that specific structural determinants—such as registered capital, workforce size, and industrial sector type—are fundamentally associated with varying levels of overall water-use efficiency. These insights enable industrial factories to accurately benchmark themselves against similar firms and adopt targeted, resource-appropriate operational improvements. Furthermore, the strategic recommendations synthesized from this research provide actionable guidelines to strengthen eco-efficiency through cost-effective reuse and recycling options, as well as monitoring mechanisms. From a policy and organizational perspective, the results offer robust empirical guidance to governmental agencies and water-resource authorities for designing differentiated policy interventions. By thoroughly understanding how these structural determinants influence water-use efficiency, policymakers can formulate sector-specific support programs, refine regulatory standards, and strategically prioritize financial or technical assistance for high-risk or low-efficiency groups, thereby contributing to long-term sustainable water resource planning for Thailand's central and northeastern river basins.

Literature Reviews

Structural determinants—encompassing registered capital, workforce size, operational age, ownership structure, factory location, and industrial sector type—are widely recognized as critical factors influencing a firm's operational capabilities and environmental performance. Grounded in the Resource-Based View (RBV) (Barney, 1991), these determinants are heterogeneous, firm-level resources that fundamentally shape an organization's capacity to adopt, implement, and sustain technologies and management practices to enhance water-use efficiency. Empirical evidence strongly suggests that environmental strategy and organizational commitment significantly influence both environmental and financial

performance (Muhammad et al., 2015). Industrial factories that systematically integrate environmental objectives into their core operational strategies are markedly more likely to achieve sustained performance improvements. This perspective is robustly reinforced by empirical evidence from Asian industrial contexts; for instance, studies from China demonstrate that factories with higher capital intensity and larger labor forces achieve superior water-use efficiency due to greater access to advanced treatment technologies and total-factor water-use efficiency (Hu et al., 2006). Moreover, the selection of structural determinants—such as industrial sector type and registered capital—as independent variables is highly consistent with the findings of Duo et al. (2025), who demonstrated that industrial structure and levels of economic development are critical drivers of water consumption efficiency in industrial zones. Concurrently, selecting industrial sector type as a key structural variable is robustly supported by studies within the Thai context. Janrungautai et al. (2025) argued that the food industry's transition toward a 'green value chain' is heavily dependent on digital transformation and resource-enabled efficiency. This strongly suggests that sector-specific technological readiness creates inherent differences in environmental performance across various industrial groups. Collectively, these findings affirm that structural determinants function as vital enabling resources that dictate a factory's ability to achieve superior water-use efficiency across diverse Asian industrial contexts.

At the same time, the concept of efficiency has been conceptualized in the literature as a multidimensional construct reflecting how effectively organizations transform resources into desired outputs. Petersen & Plowman (1953) conceptualized efficiency in terms of five interrelated components: cost, quality, quantity, time, and method. These dimensions provide a practical framework for evaluating operational performance and are readily applicable to industrial water management. In this context, cost efficiency refers to minimizing water use related expenditures or achieving cost savings through technological investment; quality efficiency emphasizes maintaining or exceeding regulatory water quality standards; quantity efficiency concerns reducing total water withdrawal through conservation, reuse, and recycling practices; time efficiency reflects responsiveness and timeliness in water use management operations; and methodological efficiency captures the effectiveness of processes, techniques, and innovations employed in managing water resources. Moreover, efficiency refers to the relationship between inputs and outputs, where optimal performance is achieved when maximum output is generated from given resources (Farrell, 1957). This foundational perspective underpins modern analyses of productivity and environmental efficiency. In the context of environmental management, total-factor water efficiency extends this framework to resource-based performance, incorporating technological and structural factors into efficiency measurement (Hu et al., 2006). The central and northeastern river basins of Thailand are vital, as Thepprasit et al. (2025) emphasize that assessing water-use efficiency at the river-basin level is essential for addressing regional water stress and developing effective policy strategies for sustainable industrial growth in Thailand.

The concept of eco-efficiency, as defined by the United Nations Economic and Social Commission for Asia and the Pacific (2009), goes beyond simple resource reduction, creating a "win-win" link between environmental impact and economic value. In Thailand’s river basins, eco-efficiency serves as a strategic bridge. By adopting life cycle thinking, as suggested by Griffiths et al. (2013). Factories can evaluate water inputs across the entire production chain. This article posits that eco-efficiency is the measurable manifestation of a firm’s environmental strategy, in which synergy between capital investment and operational management reduces water-use-related costs while maintaining or increasing output quality and quantity. Furthermore, eco-efficiency is defined as an approach that enhances organizational competitiveness by using fewer resources, generating less wastewater, reducing pollution, and increasing service value through innovation. Within industrial water use management, eco-

efficiency emphasizes optimizing water use while minimizing environmental impacts, thereby aligning productivity goals with ecological sustainability. Recent sustainability research further emphasizes the importance of life cycle thinking and systemic resource optimization in industrial operations. Life cycle assessment has been widely used to evaluate environmental impacts across production systems, particularly in energy-intensive and manufacturing processes (Griffiths et al., 2013).

The resource-based view (RBV), as articulated by Barney (1991), provides a robust theoretical foundation for understanding why some factories outperform others in water-use management. Registered capital is a tangible financial resource that enables the acquisition of high-end filtration and water recycling equipment. For industrial factories, integrating digital monitoring with employee expertise creates causal ambiguity for competitors, making high WUE a sustainable competitive advantage. Financial capital and organizational capabilities are valuable, strategically deployable resources that enable firms to implement advanced technologies and structured management systems. In industrial water use management, registered capital and number of employees represent tangible and intangible assets that support the adoption of monitoring systems, recycling technologies, and continuous evaluation mechanisms. Technological standardization and coordinated development have been shown to create synergistic efficiency gains across industrial systems (Jiang et al., 2013). These systemic interactions strengthen the organizational capacity to achieve sustainable performance improvements. The empirical studies consistently demonstrate that environmental strategy and regulatory exposure influence firm-level performance outcomes. Environmental commitment has been positively associated with financial and operational performance across industrial sectors (Muhammad et al., 2015). Circular economy principles provide an operational mechanism that links strategic resources to measurable efficiency outcomes. The transition toward circular industrial systems promotes material and water recirculation through the Bio-Circular-Green (BCG) model (Panichakarn et al., 2025), wastewater reduction through recycling systems (Munaro et al., 2020), and lifecycle optimization (Ghisellini et al., 2016; Pushkar, 2019).

Thus, this study conceptualizes water-use efficiency as a multidimensional construct encompassing four measurable dimensions, which are directly influenced by the firm's structural determinants:

1) Cost Efficiency: Reflected in the substantial reduction of water-related operating and treatment costs.

2) Quality Efficiency: Indicated by the stringent maintenance or enhancement of water quality utilized throughout production processes.

3) Quantity Efficiency: Represented by the strategic optimization of water volumes through advanced reuse and recycling mechanisms.

4) Time Efficiency: Referring to the speed, agility, and overall responsiveness of water-use management operations.

This integrated multidimensional definition provides a coherent conceptual foundation for accurately assessing efficiency disparities among industrial factories and robustly supports the empirical analysis conducted herein.

Water use efficiency and industrial practice: Water use efficiency is recognized as a multidimensional construct, involving not only reductions in consumption but also improvements in cost performance, quality assurance, and operational timeliness. The framework proposed by Petersen & Plowman (1953) remains influential in interpreting how organizations balance resources and outputs. Contemporary applications extend these ideas to industrial water management, where water reuse systems, recycling technologies, and real-time monitoring tools have demonstrated measurable gains in operational efficiency. Measuring water use efficiency with multiple indicators, including quantity and time efficiency, aligns

with the operational framework proposed by Sachidananda et al. (2016), which suggests that water use efficiency in the manufacturing industry should be evaluated against operational requirements to support water reduction and strategic management goals.

Empirical studies emphasize that improvements in water performance are often contingent upon organizational resources and sector-specific constraints. For example, Gadanakis et al. (2015) found that farms adopting precision technologies and recycling systems achieved higher water use efficiency than those relying on conventional methods, illustrating how innovation capability shapes outcomes. In Thailand, Janrungautai et al. (2025) showed that the application of digital technologies, such as IoT and automation, optimizes industrial operations by enabling efficient resource allocation and enhancing operational transparency, which are critical to achieving sustainable transformation in the Thai food industry. Moreover, Karkou et al. (2024) proposed a conceptual framework for water efficiency that emphasizes the transition toward industrial circularity. Their research highlights that integrating fit-for-purpose treatment technologies with smart digital monitoring can reduce freshwater withdrawals by 50% to 90%. This reinforces the essential role of technological readiness and closed-loop systems in achieving superior water-use efficiency within resource-intensive industrial sectors. These studies demonstrate that efficiency gains arise not only from technical solutions but also from the organizational capacity needed to adopt and sustain them.

A critical research gap has been identified: existing literature within the Thai context has not definitively established whether specific structural determinants systematically shape factory-level water-use performance. Previous studies have largely been technology-driven, regionally concentrated, or limited to strategic management modeling without explicitly linking these strategies to structural firm heterogeneity. To date, no study has consistently identified which distinct structural profiles of industrial factories exhibit superior or inferior eco-efficiency. Consequently, this study contributes to the extant literature by rigorously isolating the effect of these structural determinants on water-use efficiency, utilizing a comprehensive basin-level dataset and ANOVA-based comparative analyses. The empirical results provide a clear structural map of efficiency disparities across factory types, offering strategic implications—firmly grounded in the Resource-Based View—on how various categories of enterprises can be systematically supported to strengthen national water resource resilience.

This study synthesizes core elements of strategic management with the 3Rs framework to form an integrated model of water-use efficiency that is deeply grounded in the Resource-Based View (RBV). Structural determinants—such as firm scale, operational history, and sectoral context—are incorporated as critical grouping variables for comparative analyses utilizing ANOVA and t-tests. These structural determinants serve as foundational contextual factors that inherently constrain or enable the eco-efficiency patterns identified across diverse industrial settings. The conceptual framework guiding this investigation is illustrated in Figure 1.

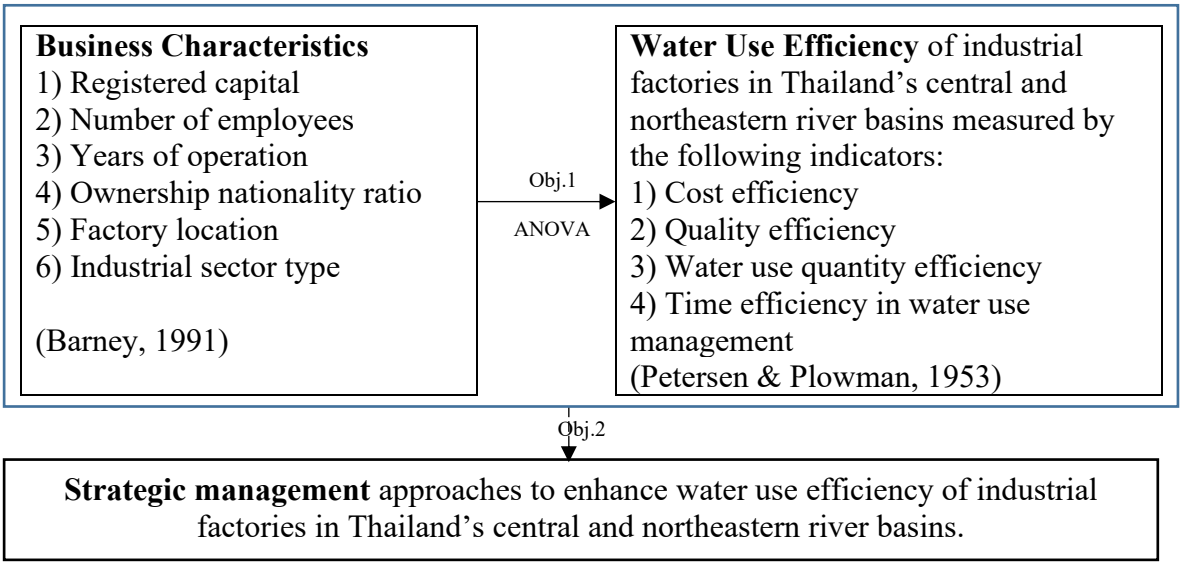

Figure 1 Conceptual Framework Linking Structural Determinants to Water-Use Efficiency

Research Methodology

This quantitative study employed a census-based survey design, targeting the entire population of 120 identifiable industrial factories across Thailand's central and northeastern river basins. While these regions house a vast number of industrial plants—all of which are legally required to maintain standard wastewater treatment systems—the number of factories that have proactively integrated the 3Rs (Reduce, Reuse, Recycle) water-use management strategy into their core operations remains significantly limited. This scarcity of specialized practitioners necessitated a census approach rather than random sampling, resulting in a focused population of 120 factories that represent the current frontier of advanced water efficiency in these regions. Consequently, the 120 factories identified constitute the entire accessible population meeting these criteria, justifying a census approach to eliminate sampling bias and ensure high representativeness of the data.

The respondents were strictly limited to senior executives, factory managers, or lead engineers with direct oversight of water-use-related strategic decisions and operational budgets, ensuring that the data reflected a high level of organizational commitment. The study analyzed six structural determinants, which were distributed with notable balance across the population: 1) Registered capital distributed among small (<50 million Baht, 30.8%), medium (50-200 million Baht, 33.3%), and large (>200 million Baht, 35.8%); 2) Workforce size categorized by employee count: <50 (30.8%), 50-200 (32.5%), and >200 (36.7%); 3) Years of operation, nearly equally split between factories operating for ≤ 10 years (49.2%) and those for >10 years (50.8%); 4) Ownership nationality distinguished by the proportion of foreign investment, with 65.8% of firms having <50% foreign shareholding and 34.2% having ≥ 50%; 5) Factory location covering the central region (35.8%), eastern region (located in the central river basin, 31.7%), and northeastern region (32.5%); and 6) Industrial sector type classified into Group 1 (37.5%), Group 2 (35.0%), and Group 3 (27.5%) based on sectoral characteristics.

Participation in this study was voluntary. All respondents were informed about the purpose of the research, and their responses were treated anonymously and confidentially. A structured questionnaire captured respondent and factory characteristics, 3Rs practices, strategic water-management items, and water-use efficiency indicators across four dimensions (cost, quality, quantity, and time). Content validity, evaluated by five experts, yielded an average IOC of 0.92. Reliability testing on a 30-item pilot yielded Cronbach's alpha ranging from 0.836 to 0.982.

A rigorous analytical approach was employed to examine significant differences in water-use efficiency across the evaluated structural determinants. For structural variables with more than two categories—specifically, registered capital, workforce size, and industrial sector type—a one-way analysis of variance (ANOVA) was systematically used. Concurrently, independent-samples t-tests were applied to dichotomous structural variables, such as years of operation and ownership-nationality ratio. Registered capital was classified into three groups: below 50 million Baht, 50-200 million Baht, and above 200 million Baht. The number of employees was categorized into small (fewer than 50 employees), medium (50-200 employees), and large enterprises (201 or more employees), consistent with Thai industrial classification standards. Industrial sector types were categorized into three primary groups: Group 1 comprises the Food & Beverage and Consumer Products industries; Group 2 encompasses industries producing intermediate and industrial goods; and Group 3 includes Resource Management, Real Estate Development, and Service industries. Where the overall ANOVA results were statistically significant, Least Significant Difference (LSD) post hoc tests were conducted to identify specific pairwise differences among group means. All statistical analyses were performed at a significance level of $\alpha = .05$.

Multiple regression analysis—previously performed by the authors (Strategic water use management affected the water use efficiency of the industrial factories located in Thailand's river basins of the (Central and Northeastern Regions; Na Pattalung et al., 2025) and relevant for interpretation—is reported in a separate MRA-focused manuscript and is incorporated into the discussion rather than presented as primary results here.

This research involving human participants was reviewed and approved by the Human Research Ethics Committee of North Bangkok University. The ethical approval certificate number is BA-6/2568, issued to the principal investigator, Mr. Nitipun Na Pattalung, affiliated with the Business Administration program at North Bangkok University. The approval was granted on 17 July 2025 and is valid until 17 July 2026. All procedures performed in this study complied with the ethical standards for research involving human participants. Participation was voluntary, and all responses were collected anonymously and used solely for academic research purposes.

Research Results

The empirical analysis systematically evaluated the impact of structural determinants on water-use efficiency. The comprehensive results of the one-way ANOVA and independent-samples t-tests, which identify significant performance disparities across diverse firm profiles, are detailed in Table 1.

Table 1 Summary of One-Way ANOVA and t-Test Results for Structural Determinants

Business characteristic	Statistic	p-value	Hypothesis result
Registered capital (F test)	5.110**	.007	Reject H_0
Number of employees (F test)	6.114**	.003	Reject H_0
Years of operation (t-test)	-1.873	.064	Do not reject H_0
Ownership nationality (t-test)	-.734	.464	Do not reject H_0
Factory location (F test)	1.762	.176	Do not reject H_0
Industrial sector type (F test)	4.365*	.015	Reject H_0

*Significant at the 0.05 level; **Significant at the 0.01 level

The statistical analyses presented in Table 1 reveal that overall water-use efficiency (WUE) differs significantly across key structural determinants, specifically registered capital ($F = 5.110$, $p = .007$), workforce size ($F = 6.114$, $p = .003$), and industrial sector type ($F = 4.365$, $p = .015$). In contrast, the independent-samples t-tests indicate no statistically significant

differences in overall WUE by years of operation (t = -1.873, p = .064) or ownership-nationality ratio (t = -0.734, p = .464). Furthermore, factory location demonstrates no significant effect on overall WUE (F = 1.762, p = .176). Consequently, the significant disparities in overall WUE are heavily concentrated at the firm scale (registered capital and workforce size) and in sectoral context. In contrast, other evaluated structural determinants are not associated with statistically significant differences in performance in this sample.

To further elucidate the significant omnibus ANOVA results, post hoc pairwise comparisons were conducted using Fisher's Least Significant Difference (LSD) test to pinpoint which structural groups differ in overall water-use efficiency, as presented in Table 2. The resulting post-hoc pattern compellingly indicates a clear resource threshold effect driven by firm scale. Specifically, small-scale factories exhibit significantly lower efficiency than their medium- and large-scale counterparts, whereas the differences between medium- and large-scale factories are not statistically significant, thereby confirming that a minimum accumulation of structural resources is inherently necessary to optimize water-use performance.

Table 2 Post-Hoc LSD Multiple Comparisons of Overall Water-Use Efficiency (WUE) by Structural Determinants

Business characteristic	**Comparison groups**	**Mean difference**	**p-value**
Registered capital	<50M฿ vs 50-200M฿	-0.41	.003**
	<50M฿ vs > 200M฿	-0.33	.014*
	50-200M฿ vs > 200M฿	0.10	.418
No. of employees	<50 vs 50-200	-0.37	.006**
	<50 vs > 200	-0.42	.001**
	50-200 vs > 200	-0.05	.673
Industrial sector type	Group 1 vs Group 2	0.09	.449
	Group 1 vs Group 3	0.38	.005**
	Group 2 vs Group 3	0.29	.034*

Remark: LSD = Fisher's Least Significant Difference; * p < .05; ** p < .01

As detailed in Table 2, the post-hoc analysis reveals specific structural disparities across the three significant determinants:

1) Registered Capital: Factories with a registered capital below 50 million THB reported significantly lower overall WUE compared to those with 50-200 million THB (mean difference = -0.41, p = .003) and those exceeding 200 million THB (mean difference = -0.33, p = .014). Notably, no significant difference in efficiency exists between the two higher-capital tiers (p = .418), reinforcing the presence of a critical financial threshold.

2) Workforce Size: Similarly, factories employing fewer than 50 individuals demonstrated significantly lower overall WUE than those with 50-200 employees (mean difference = -0.37, p = .006) and those with over 200 employees (mean difference = -0.42, p = .001). Medium and large-scale workforces did not differ significantly from one another (p = .673).

3) Industrial Sector Type: Factories in Group 1 (Food, Beverage, and Consumer Products) and Group 2 (Intermediate and Industrial Goods) exhibited significantly higher overall WUE than those in Group 3 (Resource Management, Real Estate, and Services). Pairwise comparisons confirm that Group 1 significantly outperformed Group 3 (mean difference = 0.38, p = .005), as did Group 2 (mean difference = 0.29, p = .034), while Group 1 and Group 2 remained statistically comparable (p = .449).

Overall, these post-hoc findings conclusively indicate that the significant omnibus effects are primarily driven by acute resource disparities between small-scale factories and their medium-to-large counterparts, as well as by structurally lower performance within service and resource-management-oriented sectors (Group 3). While dimension-level differences—such as specific

variations in quality and time efficiency under registered capital—follow the same trajectory, the primary strategic inferences in this manuscript are based on overall WUE to support robust, targeted managerial and policy implications.

Conclusion and Discussion

The empirical results definitively demonstrate that overall water-use efficiency (WUE) among industrial factories is systematically determined by structural factors rather than randomly distributed across the sample. The one-way ANOVA results confirm statistically significant differences in overall WUE across registered capital ($F = 5.110$, $p = .007$), workforce size ($F = 6.114$, $p = .003$), and industrial sector type ($F = 4.365$, $p = .015$). In contrast, operational age, ownership nationality, and geographic location exhibit no significant effects. These critical disparities indicate that industrial factories possessing greater financial and human resources are structurally better equipped to invest in capital-intensive technological systems, such as advanced water reuse and recycling infrastructure, which inherently enhance operational efficiency. Consequently, these findings directly fulfill the primary research objective and robustly validate the Resource-Based View (RBV) within the context of environmental performance. According to Barney (1991), firm resources that are valuable and difficult to imitate serve as a foundation for sustained competitive advantage.

Registered capital and the number of employees are critical resources that enable firms to adopt advanced technologies and structured management routines. This is consistent with Duo et al. (2025), who demonstrated that economic development and industrial structure are primary drivers of industrial water efficiency. Importantly, the non-significant ANOVA results for years of operation and ownership nationality indicate that longevity and foreign participation do not independently guarantee superior efficiency outcomes. Experience alone does not substitute for deployable financial and organizational capacity. This challenges the assumption that organizational maturity inherently leads to environmental performance advantages and underscores the primacy of resource-based capabilities.

The post hoc (LSD) comparisons reveal a "threshold effect": factories with capital below 50 million THB or fewer than 50 employees exhibit significantly lower WUE than their larger counterparts. This suggests that efficiency gains are realized once a firm surpasses a minimum resource capability. While industrial sector type of factories in Group 1 (Food, Beverage, and Consumer Products) and Group 2 (Intermediate and Industrial Goods) outperformed Group 3 (Resource Management, Real Estate, and Services). This disparity shows that water-intensive sectors often face stronger regulatory and economic pressures to optimize resource use, aligning with eco-efficiency theory. The findings revealed that Group 1 (Food, Beverage, and Consumer Products) exhibited significantly higher water use efficiency than Group 3. As Janrungautai et al. (2025) showed, the Thai food industry is increasingly adopting a 'resilient green value chain' model that prioritizes technology-enabled efficiency. The high WUE in this group reflects a successful alignment between industrial requirements and digital adoption. The structural advantage of larger, capital-intensive firms in achieving higher WUE is further reinforced by their innovation capability. The results align with Gadanakis et al. (2015), who demonstrated that adopting precision technologies enables more efficient resource allocation than conventional methods.

Strategic Approaches for Resource-Constrained Environments

To fulfill the second research objective, this study proposes targeted strategic approaches deeply grounded in structural firm heterogeneity and the Resource-Based View. Petersen and Plowman (1953) conceptualized efficiency in terms of the interconnected dimensions of cost, quality, quantity, and time, providing a robust framework for transforming structural resources into optimal outputs. In the specific context of industrial water management, this necessitates minimizing costs and extraction volumes while strictly maintaining output quality and

operational timeliness. As Sachidananda et al. (2016) emphasize, defining clear efficiency parameters is essential for identifying actionable water-reduction targets in manufacturing plants. Consequently, advanced water reuse and recycling practices are vital; however, larger firms—possessing the tangible financial resources identified by Barney (1991)—are structurally far better positioned to implement these capital-intensive systems successfully. To overcome these inherent disparities, continuous digital monitoring and evaluation systems must be deployed to detect operational inefficiencies in real time. Finally, the regional context remains paramount; as Thepprasit et al. (2025) note, assessing water-use efficiency at the river-basin level is critical for effectively mitigating regional water stress in Thailand. By explicitly linking these strategic mechanisms directly to the identified structural determinants, this research effectively bridges a significant gap in managing drought-prone industrial basins.

Integration with Strategic Water-Use Mechanisms

The strategic management approaches proposed herein draw upon compelling evidence from prior Multiple Regression Analysis (MRA) studies on strategic water-use management (e.g., Na Pattalung et al., 2025) to provide a deeper contextualization of the present findings. The empirically observed advantages of large, capital-intensive firms robustly suggest that strategic practices—such as comprehensive water reuse, advanced recycling, and systematic evaluation—are significantly more feasible when sufficient financial and human resources are readily available. Smaller firms, by stark contrast, face profound structural constraints that inherently limit the operational effectiveness of such advanced strategies, thereby underscoring the critical need for targeted, scale-appropriate support mechanisms. Ultimately, this research concludes that water-use efficiency is structurally conditioned by tangible firm resources rather than being randomly distributed across the industrial landscape. The definitive identification of a specific resource threshold provides immense practical benefits for factory managers seeking to accurately benchmark their operations, as well as crucial policy benefits for governmental authorities designing differentiated regulatory support. By explicitly integrating validated structural analysis with the theoretical frameworks of Barney (1991) and Petersen & Plowman (1953), this research contributes actionable, resource-based guidance for sustainable industrial water governance in the Asian context.

Limitations and Future Research Directions

While this study provides robust empirical insights, it is subject to several methodological limitations that must be acknowledged. First, the cross-sectional research design inherently restricts the ability to draw definitive causal inferences regarding the relationship between structural determinants and efficiency outcomes. Second, the sample is geographically confined to industrial factories within Thailand's central and northeastern river basins, which may limit the generalizability of these findings to other regions or national contexts. Third, the reliance on self-reported survey data from executives may inadvertently introduce response bias. To rigorously address these limitations, future research endeavors should employ longitudinal research designs to capture temporal dynamics, incorporate objective, metered water-use data to validate self-reported metrics, and conduct extensive cross-country comparative analyses to enhance further the external validity of the Resource-Based View framework in environmental management.

Managerial Implications

Industrial factories must strategically align their water-use management strategies with their internal resource capacities. Large, capital-intensive factories should invest aggressively in comprehensive water reuse and recycling systems that are seamlessly integrated with continuous digital monitoring. Conversely, smaller firms should prioritize low-cost efficiency measures and incremental operational improvements, with strong support from shared infrastructure or collaborative industrial estates. These strategic management approaches provide highly practical, resource-appropriate mechanisms to definitively enhance water-use

efficiency among industrial factories operating in Thailand's central and northeastern river basins.

Policy Implications

To effectively address these structural disparities, policymakers must design differentiated support instruments—including financial incentives and targeted technical assistance—specifically tailored to firm scale and sectoral water intensity. Such targeted interventions can successfully reduce structural disparities in water-use efficiency (WUE) and substantially enhance overall industrial resilience to water scarcity. Key policy interventions for small-scale factories include:

1) Promoting Digital Inclusion: To successfully bridge the technological gap and enhance WUE in small-scale industrial sectors, targeted digital inclusion programs are highly recommended.

2) Financial Incentives for Digital Adoption: Policymakers should urgently introduce targeted subsidies, low-interest loans, or tax credits specifically for small factories to implement entry-level digital water monitoring systems, such as the Internet of Things (IoT). This approach directly mitigates the high initial capital barrier, a major structural constraint.

3) Infrastructure and Connectivity Support: Government agencies must actively ensure robust, affordable digital infrastructure within industrial zones across the central and northeastern river basins. This critical support enables small-scale operators to reliably access cloud-based management tools and leverage real-time data analytics for sustained efficiency.

References

Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management, 17*(1), 99-120.

Duo, H., Wang, N., Qiao, Y., Li, Z., Yang, G., Liu, H., … & Li, F. (2025). Industrial water consumption efficiency and driving factors based on the super-efficient SBM and Tobit approach. *Scientific Reports, 15*, 12461.

Farrell, M. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General), 120*(3), 253-290.

Gadanakis, Y., Bennett, R., Park, J., & Areal, F. (2015). Improving productivity and water use efficiency: A case study of farms in England. *Agricultural Water Management, 160*, 22-32.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, 114*, 11-32.

Griffiths, O., O'Byrne, J., Torrente-Murciano, L., Jones, M., Mattia, D., & McManus, M. (2013). Identifying the largest environmental life cycle impacts during carbon nanotube synthesis via chemical vapour deposition. *Journal of Cleaner Production, 42*, 180-189.

Hu, J., Wang, S., & Yeh, F. (2006). Total-factor water efficiency of regions in China. *Resources Policy, 31*(4), 217-230.

Janrungautai, J., Jarujittipant, P., & Siriwong, P. (2025). Building Resilient Green Value Chain: A Hierarchical Model for Thai Food Industry Sustainable Transformation. *Journal of Community Development Research (Humanities and Social Sciences), 18*(3), 22-37.

Jiang, H., Zhao, S., Wang, X., & Bi, Z. (2013). Applying electromagnetic field theory to study the synergistic relationships between technology standardization and technology development. *Systems Research and Behavioral Science, 30*, 272-286.

Karkou, E., Teo, C., Savvakis, N., Poinapen, J., & Arampatzis, G. (2024). Industrial circular water use practices through the application of a conceptual water efficiency framework in the process industry. *Journal of Environmental Management, 370*, 122596.

Muhammad, N., Scrimgeour, F., Reddy, K., & Abidin, S. (2015). The relationship between environmental performance and financial performance in periods of growth and contraction: evidence from Australian publicly listed companies. *Journal of Cleaner Production, 102*, 324-332.

Munaro, M., Tavares, S., & Bragança, L. (2020). Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *Journal of Cleaner Production, 260*, 121134.

Na Pattalung, N., Jarujittipant, P., & Verayannon, K. (2025). Strategic water use management affected the water use efficiency of the industrial factories located in Thailand's river basins of the central and northeastern regions. *Procedia of Multidisciplinary Research, 3*(11), Article 28.

Office of the National Water Resources. (2021). *Annual Report 2021*. Retrieved from https://online.flipbuilder.com/bhde/xoyj/.

Panichakarn, B., Jarujittipant, P., & Siriwong, P. (2025). Operationalizing the Bio-Circular-Green Model: The "BCG 3V Strategy" for Sustainable Competitiveness in the Thai Cosmetics Industry. *Asian Interdisciplinary and Sustainability Review, 14*(2), Article 31.

Petersen, E., & Plowman, E. (1953). *Business organization and management* (3rd ed.). Illinois: R.D. Irwin.

Pushkar, S. (2019). Modeling the substitution of natural materials with industrial byproducts in green roofs using life cycle assessments. *Journal of Cleaner Production, 227*, 652-661.

Sachidananda, M., Webb, D., & Rahimifard, S. (2016). A concept of water usage efficiency to support water reduction in manufacturing industry. *Sustainability, 8*(12), 1222.

Thepprasit, C., Sukrakanchana, B., & Sa-nguanduan, N. (2025). Assessing water use efficiency and stress in Thailand's river basins: Trends, challenges, and policy strategies. *Sustainability, 17*(10), 4477.

United Nations Economic and Social Commission for Asia and the Pacific. (2009). *Eco-efficiency indicators: Measuring resource-use efficiency and the impact of economic activities on the environment*. Retrieved from https://repository.unescap.org/server/api/core/bitstreams/a20af7c1-ea24-4476-9f99-07c6a35c34ab/content.

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