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A METHODOLOGY FOR INTEGRATING VIRTUAL WATER DATA INTO LIFE CYCLE COST IN THE MALAYSIA'S WATER INFRASTRUCTURE SECTOR

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ABSTRACT

Water infrastructures are crucial assets for the nation's development that are purposely designed and built to deliver essential services for supporting economic growth, public health, and environmental sustainability. However, Malaysia's water sector faces mounting challenges, including aging infrastructure, water scarcity, and inefficiencies in cost management. In response to these concerns, the Water Sector Transformation 2040 (WST 2040) roadmap was introduced to realign the water industry towards digitalization, sustainability, and resource optimization. Nevertheless, the existing practices of life cycle cost economic assessment technique remain fragmented and often overlook virtual water that refers to the indirect water consumption throughout the entire service life of water infrastructure. This paper presents a methodology proposed for the study to investigate readiness of cost data as inputs into the integration of virtual water data into the Life Cycle Cost (LCC) practice in supporting more informed and sustainable planning with specific reference to Malaysia's water infrastructure assets. The proposed methodology is designed with a qualitative research strategy, combining a comprehensive literature review with semi-structured interview approach to interview people who have established knowledge, expertise, skills, or experience in virtual water, data integration and water infrastructure planning. The study focuses on exploring the current data availability, quality, and limitations, including the identification of strategic pathways for incorporating virtual water into the LCC practices. The study findings are intended to serve as a foundational input for future data driven framework that can facilitate the stakeholders and cost estimators in Malaysia's water sector to produce more accurate cost estimation and enhance water resource governance to align the Malaysia's WST 2040 goals with the Sustainable Development Goal 6 (SDG 6) in achieving sustainable management of water and sanitation for all.

Keywords: *Virtual Water, Life Cycle Costing (LCC)*

INTRODUCTION

Water infrastructure is the backbone of Malaysia's socio-economic development, playing a pivotal role in ensuring water security, public health, and environmental sustainability. This critical sector encompasses a wide range of assets—from treatment plants, pipelines, reservoirs, and pumping stations to digital systems and institutional governance mechanisms—which collectively form a fundamental component of the nation's public infrastructure. According to IPSASB (2014), water assets are long-term tangible or intangible resources expected to deliver sustained benefits. These assets enable the abstraction, treatment, distribution, and safe discharge of water, thereby supporting national development goals (AWWA, 2012).

Despite its significance, Malaysia's water infrastructure sector faces a range of persistent and interrelated challenges. Among these are aging systems, frequent pipe bursts, high levels of non-revenue water (NRW), fragmented governance, poor integration of sustainability metrics in cost planning, and a lack of financial resilience. As of 2021, the national average NRW was 36.4%, with some states exceeding 50%, primarily due to leakages and suboptimal asset management (SPAN, 2021). These inefficiencies compromise service delivery and threaten the long-term viability of national water infrastructure.

In response to these systemic issues, the Water Sector Transformation 2040 (WST 2040) roadmap was introduced to modernize and future-proof Malaysia's water services. Central to this initiative are themes of digitalization, sustainability-driven planning, and lifecycle cost optimization (MyWASS, 2020). Within this context, one critical yet often overlooked concept is that of virtual water (VW)—the embedded or indirect water used throughout an infrastructure's lifecycle, from materials production and construction to operation, maintenance, and disposal. Virtual water becomes particularly relevant in resource-intensive infrastructure such as desalination plants, urban pipelines, and treatment facilities.

While Life Cycle Costing (LCC) is increasingly adopted to estimate long-term project costs—including capital expenditure (CapEx), operational expenditure (OpEx), maintenance, and end-of-life disposal—virtual water considerations remain largely absent from current costing practices. Traditionally, infrastructure decisions have focused on minimizing upfront costs, often ignoring future environmental and financial burdens. However, tools such as Net Present Value (NPV), Equivalent Annual Cost (EAC), and cost-per-unit analysis offer more holistic assessments of total cost over time (Woodward, 1997). Notably, Malaysia's Public Works Department (JKR) has mandated the implementation of LCC in public projects through *Surat Arahan KPKR 2023*, reflecting growing institutional awareness of long-term asset stewardship (CIDB, 2020). Nevertheless, without the integration of virtual water data, LCC frameworks remain incomplete and unable to fully support sustainable water governance.

In the Malaysian context, the application of virtual water remains underutilized—particularly in infrastructure planning and environmental management—despite rising water stress in urban regions such as Klang Valley and Penang. Embedding virtual water into LCC models offers the potential to enhance procurement transparency, improve budgeting accuracy, and strengthen infrastructure resilience. This is especially pertinent under WST 2040's emphasis on circular economic principles and data-driven governance. However, successful integration requires robust data infrastructure. High-

resolution data on water use across all life cycle stages—design, construction, operation, and end-of-life—is essential. Such data must include virtual water coefficients for materials, energy use, and operational processes (Lee & Mokhtar, 2023). Currently, however, Malaysia's data landscape is fragmented, generalized, and often disconnected from infrastructure applications (Tan & Zaini, 2019), limiting evidence-based planning and diminishing the reliability of LCC outcomes.

Despite these limitations, the integration of virtual water into LCC presents significant opportunities. First, it enables a more comprehensive evaluation of water usage across an asset's lifecycle, helping stakeholders identify high-consumption phases and adopt sustainable alternatives. For instance, selecting materials with lower virtual water footprints or installing efficient technologies may yield long-term environmental and financial gains—even when initial costs are higher (Kounina et al., 2018; Goh et al., 2019). Second, a VW-inclusive LCC aligns with Environmental, Social, and Governance (ESG) frameworks, promoting value-based procurement, green financing, and lifecycle sustainability assessments. This approach supports Malaysia's shift toward performance-based planning and resource efficiency under WST 2040. Finally, incorporating VW data into LCC can enhance inter-agency coordination and cross-sectoral decision-making. Through multi-criteria analysis, infrastructure planning can better balance economic viability with environmental responsibility.

RESEARCH AIM

This study aims to propose a methodology to explore how virtual water data can be integrated into life cycle cost analysis in Malaysia's water infrastructure sector.

RESEARCH OBJECTIVES

1. To examine the evolution and current practices of LCC in Malaysia's water infrastructure.
2. To investigate the relevance and readiness of virtual water data in cost analysis.
3. To assess data quality issues affecting integration into LCC.

METHODS

This study employs a qualitative approach combining secondary and primary data collection.

Secondary Data Collection:

A comprehensive literature review was conducted to:

- Understand current LCC practices and their evolution
- Explore virtual water concepts and integration strategies

- Identify data challenges in the water sector Sources include academic journal articles, government publications (e.g., SPAN, PLANMalaysia), WST 2040 documents, industry reports, conference proceedings and previous dissertations

This review helped to identify knowledge gaps, conceptual frameworks, and key variables required for virtual water data integration.

Primary Data Collection: Semi-structured interviews were carried out with ten professionals from public agencies, water utilities, engineering firms, and academia. Participants were selected based on knowledge, skills or expertise in LCC, virtual water, or infrastructure planning. Key interview topics included:

- Awareness of virtual water
- Current LCC practices
- Data availability and quality
- Barriers to data integration
- Strategies for VW integration

Interviews were transcribed and analysed thematically using software to extract key themes.

The study proposed a four-stage research strategy:

- Stage 1: Literature Synthesis and Data Mapping
- Stage 2: Expert Input via Semi-Structured Interviews
- Stage 3: Gap Identification in Current LCC Practice
- Stage 4: Framework Development for VW Integration into LCC

This method aims to build a foundational structure to guide future implementation of VW-inclusive LCC frameworks.

RESULTS AND DISCUSSION

While the research is in progress, preliminary insights suggest four expected insights:

1. Limited Awareness and Lack of Guidance: Many practitioners lack familiarity with virtual water. Current LCC guidelines focus mainly on financial metrics, neglecting water-use or environmental impacts. This highlights the need for educational initiatives and updated guidance.
2. Fragmented and Inaccessible Data: Data related to virtual water, energy use, and infrastructure costs are decentralized, outdated, inconsistent or incomplete records. This fragmentation prevents accurate lifecycle analysis and reduces the effectiveness of LCC.

3. Misalignment with WST 2040 Objectives: Although WST 2040 promotes sustainability, there is no standardized framework for including VW in LCC. This gap reveals a disconnect between policy intent and operational tools.
4. Strong Stakeholder Support: Despite challenges, professionals show strong support for integrating VW into LCC. Many view it as a timely innovation to enhance transparency, improve decision-making, and align Malaysia with global ESG standards.

CONCLUSION

This research demonstrates that integrating virtual water into LCC represents a significant leap forward for Malaysia's water sector. This study has proposed a methodology that enhances cost estimation accuracy through virtual water-inclusive analysis and promotes data-driven decision-making. It directly supports the goals of the Water Sector Transformation 2040 (WST 2040), particularly in strengthening resilience and sustainability. Moreover, it aligns infrastructure planning and development with global benchmarks such as Sustainable Development Goal 6 (SDG 6) and environmental, social, and governance (ESG) standards. Beyond its policy implications, the research significantly contributes to the quantity surveying field by expanding traditional cost models to incorporate environmental considerations. Moving forward, the next phase of the research will involve refining the integration framework and testing its applicability across selected case studies to ensure practical implementation.

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