Modeling the Formalization of Water Provision in Lebanon: Economic Implications of Strategic Sectoral Investments Using a CGE Framework

Zein Khraizat[1] **Alvaro Calzadilla**[1]

[1] Institute for Sustainable Resources, University College London, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom

[*] Corresponding author: Zein Khraizat (z.m.khraizat@ucl.ac.uk)

Keywords: *Informal Water Sector, Computable General Equilibrium Models, Dynamic CGE Analysis, Infrastructure Investments, Economic wide Impacts, Lebanon*

Abstract

Abstract: Lebanon's deepening water crisis—exacerbated by economic collapse and decades of underinvestment—has led to widespread dependence on informal water markets, where prices far exceed formal tariffs and disproportionately burden low-income households. To assess the economic and distributional implications of reversing this trend, a dynamic, country-specific computable general equilibrium model is developed, explicitly integrating formal and informal water provision into household consumption and production. Simulation of three investment scenarios—focused on non-revenue water reduction, network expansion, and storage infrastructure—demonstrates that formal supply can increase from 336 to 905 million m^3/year by 2050, reducing informal reliance from 45% to below 5%. Real GDP rises by up to 3.35% relative to the baseline, with sectoral output expanding by 12% in agriculture, 2.0% in manufacturing, and over 2.1% in services. Household welfare improves across all income groups, with the greatest gains among the poorest, who reduce informal water expenditures by up to 12%. The results demonstrate that targeted investments in formal water infrastructure increase real GDP and improve welfare distribution, with the largest equivalent variation gains accruing to low-income households.

1 Introduction

Lebanon's water sector is under mounting pressure due to a convergence of long-standing structural challenges and acute economic disruption (Verdeil 2008, GVC 2016, Merheb et al. 2024). The country's financial collapse, which began in October 2019, has triggered currency devaluation, inflation, and institutional paralysis, severely undermining the provision of basic public services, including water supply (World Bank 2021, 2024). These shocks have compounded the effects of chronic underinvestment, fragmented governance, and inefficient service delivery that have characterized Lebanon's water infrastructure for decades (Constantine et al. 2017, Choueiri & Vantaggiato 2023, Fayssal et al. 2024). As a result, the water sector now faces widespread system failures that threaten both economic stability and public welfare.

As public utilities have become increasingly unable to meet rising water demand, informal water markets have emerged as critical—albeit unregulated—alternatives to fill the supply gap. These

systems, including tanker deliveries, bottled water vendors, and small-scale private suppliers, now serve a significant share of households across urban and peri-urban areas (Constantine et al. 2017, Choueiri & Vantaggiato 2023). However, they typically operate outside formal regulatory oversight, lacking enforceable water quality standards, price controls, or sustainability mechanisms. This institutional vacuum not only exposes consumers to quality and reliability risks but also imposes disproportionately high costs on households, particularly those with limited income. As a result, informal water provision reinforces existing socioeconomic disparities and deepens household vulnerability to economic and service shocks (World Bank 2009, Choueiri et al. 2022).

Informal water provision imposes high financial costs across Lebanese households, but these costs are disproportionately borne by lower-income groups, who spend a larger share of their income on basic water needs. In the absence of reliable public supply, many households are forced to purchase water through private markets, where prices are significantly higher than those charged by formal utilities. For example, water delivered via tanker trucks costs between USD 3.25 and USD 7.92 per cubic meter—almost twenty times the official network rate of USD 0.43 per cubic meter (Constantine et al. 2017, MoEW 2020). Households reliant on jerrycan refills from water shops typically spend around USD 10 per week, while bottled water from licensed manufacturers can push this figure even higher (Verdeil 2008, WorldBank 2014, Bloominvest 2016). For low-income families, these expenses can absorb a substantial portion of monthly income, crowding out spending on other essential needs such as food, healthcare, or education. The resulting economic strain not only reinforces existing inequalities but also contributes to deeper cycles of exclusion and vulnerability.

Despite the widespread reliance on informal water provision in Lebanon and its growing economic significance, there remains a notable absence of quantitative analysis examining its macroeconomic and distributional impacts. Existing research has largely focused on issues of water quality degradation, governance failures, and affordability at the household or community scale (WorldBank 2010, Choueiri & Vantaggiato 2023, Fayssal et al. 2024). Studies have documented the structural inefficiencies of the sector and the financial strain placed on consumers, particularly in urban and peri-urban areas, where informal water markets have become dominant (Verdeil 2008, Constantine et al. 2017, Choueiri et al. 2022, Choueiri & Vantaggiato 2023, Merheb et al. 2024). While this literature offers critical insights into the functioning and implications of informal provision systems, it does not capture how these markets interact with the broader economy, nor does it assess the potential role of infrastructure investments in mitigating household-level burdens or promoting more equitable outcomes. In particular, there is a lack of integrated economic modeling capable of simulating the dynamic interplay between formal and informal water systems, household welfare, and sectoral performance over time.

To address this gap, this study develops a dynamic, country-specific Computable General Equilibrium (CGE) model calibrated to Lebanon's 2011 Social Accounting Matrix. The model explicitly incorporates multiple water provisioning channels—including public network supply, tanker-delivered water, and bottled water—within household consumption and production structures. Unlike partial equilibrium or micro-level approaches, CGE models offer a system-wide analytical framework capable of capturing feedback effects across sectors, changes in resource allocation, and income-disaggregated welfare outcomes. This allows for a comprehensive assessment of how infrastructure investments in the water sector influence macroeconomic

performance, sectoral output, and household-level welfare across income groups. Lebanon provides a compelling case for such analysis due to its degraded infrastructure and widespread reliance on costly informal water services—both of which are explicitly represented in the model through differentiated water sources and expenditure shares across household income quintiles.

This study simulates a set of policy intervention scenarios to assess the macroeconomic and distributional impacts of water infrastructure investments, based on strategic priorities outlined in Lebanon's National Water Sector Strategy (NWSS) (MoEW 2010, 2020). These scenarios represent a spectrum of interventions aimed at reducing non-revenue water, expanding network coverage, and enhancing storage capacity. Each scenario is evaluated through 2050, capturing the gradual transition from informal to formal water provision as infrastructure investments enhance accessibility and affordability. The model quantifies the resulting effects on key macroeconomic indicators—including GDP, sectoral output, and employment—as well as on household welfare across income groups. This approach enables a comprehensive assessment of how investment strategies shape both economic performance and equity outcomes. By explicitly modeling the shift from informal to formal water provision, the analysis highlights not only the aggregate returns to infrastructure rehabilitation, but also its role in alleviating the financial burden on lower-income households and promoting more inclusive development.

2 Methodology

The analysis employs a recursive dynamic CGE model for Lebanon to evaluate the macroeconomic effects of government-planned investments aimed at enhancing water supply infrastructure. It assesses the broader economic repercussions, particularly on households, while addressing the gradual elimination of the informal water sector. The model captures the interplay between formal sector investments and reduced reliance on informal water sources, reflecting the limited capacity and intermittent nature of the public water system.

Building on this framework, a specialized investment module is incorporated into the model to simulate the complete lifecycle of government-sponsored water projects. This module provides a rigorous framework for evaluating infrastructure development, spanning construction and operational phases, while accounting for the gradual increase in water supply from public water sources over time.

The simulation scenarios evaluate the macroeconomic and sectoral impacts of various investment strategies aligned with the National Water Sector Security Plan (MoEW 2020):

- **Baseline Scenario:** No additional investments; water network continues to expand at historical rates, while GDP and population growth follow SSP2 trajectories, as outlined by Riahi et al. (2017).
- **Scenario 1 - Non-Revenue Water Reduction (NRW) Scenario:** Reduces water losses from leakages, theft, and inefficiencies.
- **Scenario 2 - NRW Reduction + Network Expansion:** Combines efficiency gains with network expansion to unserved households, reducing informal sector reliance.

- **Scenario 3: NRW Reduction + Network Expansion + Increased Storage Capacity:** Adds storage improvements to NRW reduction and network expansion, ensuring year-round water availability and climate resilience.

3 Results

The CGE simulation results highlight the economy-wide impacts of three investment scenarios aimed at formalizing Lebanon's water provision system. Each scenario varies in scale and scope—from targeted efficiency improvements to comprehensive upgrades combining network expansion and storage capacity. The results presented below demonstrate how these interventions affect water access, household welfare, macroeconomic performance, and sectoral output, offering insight into the trade-offs and distributional outcomes associated with each investment pathway.

3.1 Public water supply expansion and informality reduction

All investment scenarios demonstrate substantial progress in formalizing household water supply. Under the Baseline, where no additional interventions are undertaken, water supply is projected to reach 336 million m^3/year by 2050. This modest increase, driven by ongoing projects such as the Awali Project and new dams, is partially offset by the planned decommissioning of overexploited and contaminated wells and springs. As a result, over 45% of household water needs are expected to be met by informal sources by 2050.

In contrast, Scenario 1—focused on reducing non-revenue water through efficiency improvements—adds 215 million m^3/year by addressing system losses without developing new sources. This reduces reliance on informal sources to 22%. Scenario 2 builds on this by incorporating network expansion and developing new wells and springs, adding a further 233 million m^3/year and bringing the total supply to 569 million m^3/year. This significantly lowers informal reliance to 11%. Scenario 3, the most ambitious, combines leakage reduction, network expansion, and the construction of additional storage infrastructure such as dams and reservoirs. With an additional 121 million m^3/year, total supply reaches 905 million m^3/year, reducing informal water usage to below 5% by 2050.

3.2 Household welfare and expenditure reallocation

Improved access to formal water sources yields significant welfare gains across all scenarios. By reducing dependence on high-cost informal water, households experience a notable decline in water-related expenditures.

Scenario 3 produces the largest welfare impacts, with equivalent variation (EV) gains indicating marked improvements in living standards across most income groups. In lower-income households, where water costs previously consumed a higher proportion of disposable income, these reallocations are especially transformative. On average, households reduce informal water spending by 6% to 12%, depending on the scenario, enabling enhanced consumption of basic needs and a reduction in vulnerability to price shocks.

3.3 Economy-wide impacts

At the macroeconomic level, all investment scenarios result in higher aggregate output relative to the Baseline. Real GDP increases cumulatively by 2.01% in Scenario 1, 3.17% in Scenario 2, and 3.35% in Scenario 3 by 2050.

The comprehensive intervention in Scenario 3 yields the highest macroeconomic return, reflecting the compound benefits of efficiency, access, and climate resilience. Notably, even Scenario 1, which involves modest capital investment relative to the others, delivers measurable macroeconomic improvements by reducing inefficiencies and operational losses within the existing system.

3.4 Sectoral output impacts under investment scenarios

Sector-level results reveal substantial variation in how infrastructure investments affect the broader economy. Agriculture experiences the most pronounced expansion, with output rising by up to 12% in Scenario 3. Scenario 2 generates agricultural growth of 8.6%, while Scenario 1 yields more moderate gains at 5.3%.

Manufacturing also benefits, particularly in water-intensive industries such as food processing and textiles, where output increases by up to 1.96% in Scenario 3. The services sector, especially health, education, and hospitality, expands by 2.18%, supported by increased household consumption and improved operational conditions. These results reflect the broader economic response to expanded water infrastructure and reduced reliance on informal services.

4 Conclusion

This study quantifies the macroeconomic and distributional effects of formalizing water provision in Lebanon using a dynamic Computable General Equilibrium (CGE) model calibrated to the national Social Accounting Matrix. By incorporating both formal and informal water sources, the model extends conventional water-sector modeling frameworks to capture the full economic and distributional implications of infrastructure reform in fragile settings.

The results demonstrate the substantial economic and social returns associated with strategic infrastructure rehabilitation. Formal water supply is projected to increase from 336 to 905 million m^3/year by 2050, reducing household reliance on informal markets from over 45% to below 5%. Real GDP rises by up to 3.35% in the most comprehensive investment scenario, while sectoral output expands by 12% in agriculture, nearly 2% in manufacturing, and over 2.1% in services. Welfare gains are observed across all income groups, with the largest equivalent variation gains accruing to lower-income households, who also experience a reduction in informal water expenditures of up to 12%.

These findings highlight the central role of infrastructure investments in improving service efficiency and correcting distributional imbalances within Lebanon's water sector. By reducing household dependence on unregulated and high-cost water sources, the transition to formal provision has the potential to drive more inclusive and resilient economic development. Moreover, the modeled outcomes show that even modest interventions—such as non-revenue water reduction

alone—generate significant macroeconomic and welfare benefits, thereby supporting the rationale for phased or sequenced investment strategies aligned with fiscal and institutional constraints.

More broadly, this study demonstrates the value of explicitly modeling formal and informal water provision within an economy-wide analytical framework to inform infrastructure policy in institutional contexts marked by service delivery fragmentation and limited operational capacity within public utilities. By representing public network supply, tanker-delivered water, and bottled water as distinct provisioning channels, the model reflects the structural realities of Lebanon's water system, where informal markets remain a major source of access. Scenario simulations aligned with national investment priorities allow for quantification of macroeconomic, sectoral, and distributional outcomes across income groups. This structure enables policymakers to evaluate the trade-offs associated with different investment strategies and to identify those that most effectively reduce household reliance on costly informal water sources while supporting more equitable and efficient service delivery.

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