Research Paper

Life-cycle costs approach for private piped water service delivery: a study in rural Viet Nam

Melita Grant, Tim Foster, Dao Van Dinh, Juliet Willetts and Georgia Davis

ABSTRACT

Sustaining rural water services in Viet Nam requires an improved understanding of the costs and relative opportunities, especially given the government's support for private sector involvement in expanding water schemes. In particular, the life-cycle costs associated with the delivery of safe and sustainable water services in rural Viet Nam, as indeed elsewhere, are not well known, potentially compromising their long-term sustainability. To address this gap, this study assessed the cost structures of 14 water schemes in Viet Nam managed by private enterprises. Results showed that both capital and operational expenditures varied widely across the schemes assessed, reflective of the diversity of the age and characteristics of the schemes studied. Twelve of the 14 schemes generated a cash profit in the most recent calendar year; however, when taking into account depreciation, as well as historical subsidies and connection fee payments, only four of the schemes were profitable based on a 20-year design life assumption. The study complements previous research demonstrating barriers to achieving universal access when relying on user-pays systems. The results provide a useful reference point to inform business planning for enterprises, as well as policy and support mechanisms important for securing sustainable rural water supply services.

Key words | costs, enterprises, finance, life-cycle, private, water

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HIGHLIGHTS

- This study assessed cost structures for 14 privately operated water supply schemes in rural Viet Nam.
- Capital expenditure varied significantly, from USD 55 to USD 522 per connection and operational expenditures were driven by labour and electricity costs.
- Reported expenditure on asset renewal was low, which could compromise long-term service sustainability.
- Only four of the 14 schemes appeared financially sustainable based on a 20-year design life assumption, requiring attention to life-cycle costs informed financial management.

INTRODUCTION

The rural water sector in low- and middle-income countries (LMICs) has been characterised by a move away from an infrastructure-focused model to a service delivery model in recent years (Moriarty *et al.* 2013), though the extent to which this shift is taking place in reality remains unclear. This shift has been spurred by the growing recognition of non-functional and unsustainable systems, hindering the realisation of the health and welfare benefits that would normally be expected to flow from improvements in water supply infrastructure (Burr & Fonseca 2013). A service delivery model requires the

doi: 10.2166/washdev.2020.037

full costs of WASH services to be better understood and managed, so that systems can be maintained, potentially expanded and sustained in the long term (World Bank 2017).

The required costs and investment to expand and sustain services is a critical issue facing the sector. The higher bar set by the Sustainable Development Goals (SDGs) for targets 6.1 and 6.2 requires countries to aim for 'safely managed' services rather than provision of access to 'improved' infrastructure alone. 'Safely managed' in the water services context means that water supplies must be located on premises, available when needed and free of faecal and priority chemical contamination (UN 2017). Hutton & Varughese (2016) found that capital investments required to achieve SDG targets 6.1 and 6.2 amount to about three times current investment levels, and that financial and institutional strengthening will be critical for ensuring any increase in capital investment leads to sustainable services. This research contributes to the broader call for strengthening the enabling environment through an improved understanding of the real costs associated with delivering sustainable water supply services in rural areas, so that these costs can be met through a range of sources. The WASH enabling environment has been defined as a 'set of interrelated sector functions that enable governments and public and private partners to engage in a sustained and effective WASH service delivery development process' (UNICEF 2016, p. ix).

There is growing support for the life-cycle cost approach (LCCA) as a tool for driving sustainability improvements in the rural water supply sector, including in Viet Nam. In a water service context, life-cycle costs refer to the full set of costs associated with delivering an adequate water service indefinitely (Fonseca *et al.* 2010). For our study, we included capital expenditure, operating and minor maintenance expenditure, capital maintenance expenditure and cost of capital. We did not include expenditure on direct support and expenditure on indirect support (see Supplementary Material, Table S1). The application of LCCA to WASH in countries in the Global South is nascent, but has been spurred by the WASHCost initiative, which aimed to make LCCA methodologies more accessible to the rural WASH sector (Fonseca *et al.* 2011). Few peer-reviewed studies have analysed revenue and expenditure (costs) of small-scale rural water services in LMICs. Rather, LCCA has primarily been used for urban systems in well-resourced countries (Jones *et al.* 2012). Prior to the present study, LCCA had yet to be applied to rural water services in Viet Nam and is not known to have been applied to privately operated rural water services in LMICs more generally. This is despite growing acknowledgement among policy-makers of the need to better understand the true costs associated with providing rural water services. Illustrative of this is Viet Nam's National Action Plan, which articulates a desire for the development of regulations on cost norms (referred to as technical-economic standards in Viet Nam) for clean water supply in rural areas in pursuit of SDG target 6.1 (Government of Viet Nam 2017). Without rigorous life-cycle cost analysis of rural water supplies, sustainability improvements in the rural water sector will not be realised.

In the Global South, implementing an LCCA for water scheme options is difficult because there is limited available data and water system design is dependent on the local context (Jones *et al.* 2012). One study assessed water provision costs in 43 villages in Andhra Pradesh, India, finding that unit costs were substantially higher than the prescribed cost norms, and that norms were unrealistic (Reddy *et al.* 2012). Reddy *et al.* (2012) also found that the allocations to rural drinking water were low at the design and implementation stage, which resulted in more needing to be spent later on due to *ad hoc* interventions. Another study on primary schools in Kenya estimated current expenditures on WASH to be only 60% of requirements to meet minimum standards and recurrent costs (Alexander *et al.* 2016). A study of rural water supplies in Kenya analysed water committee records and found expenditure levels varied greatly across schemes, with both operational model and seasonality influencing the magnitude and timing of operation and maintenance costs (Foster & Hope 2017). These studies show LCCA to be useful to identify financing gaps and economic sustainability issues which, if unaddressed, can lead to non-functional or under-performing water schemes.

Background: privately operated piped water services in Viet Nam

Rural Viet Nam has seen rapid growth in piped water service coverage in recent years due to a supportive policy environment. From 2000 to 2016, around 16,200 piped water schemes were constructed in rural areas (Mansour

2016), increasing piped water access from one million people in 2000 (1.7% of the rural population) to 13.7 million people (22.1% of the rural population) in 2015 (UNICEF/WHO 2020). This trajectory is likely to continue, with Vietnam's Country Strategy on Rural Water Supply and Sanitation to 2020 setting the target that by 2020: 'all rural residents use clean water meeting national standards, and access at least 60 litres/person/day' (CERWASS 2000). The elevated SDG ambition of safely managed water services, with its requirement of being 'on premises' and free from contamination, provides further impetus to accelerate the expansion of piped water systems.

Government and development actors in Viet Nam have increasingly promoted private sector management models through a range of policy levers and funding support. According to the Viet Nam Government's Ministry for Agriculture and Development (MARD), private enterprises manage 13% of rural water supply systems in Viet Nam, with the community managing 70% and the Provincial Centre for Rural Water Supply and Sanitation (pCERWASS) and state boards managing 17% of schemes (Directorate of Water Resources 2018). In the Vietnamese context, private water enterprises are entities that have invested private funds in a water system and own and/or operate the system under a formal or informal agreement with a Provincial People's Committee (PPC) or a Commune People's Committee (CPC). Policy support for private sector involvement in the delivery of rural water services in Viet Nam dates back almost two decades. The National Rural Clean Water Supply and Sanitation Strategy 2020 (developed in 2000 and updated in 2011) stated that the Viet Nam Government would encourage the private sector to invest in and to construct rural water facilities, especially piped water supply systems. This encouragement extends to taking over from government and community-based schemes, as well as the establishment of new schemes in areas that are currently unserved.

Despite the policy incentives, there is limited understanding of the financial viability of private water enterprises (Willetts *et al.* 2017). This is an important issue to clarify in light of government data that suggests approximately 14.4% of rural piped systems in Viet Nam are not working, and a further 16.8% are performing poorly (Directorate of Water Resources 2018). As noted by Moriarty *et al.* (2013), the first step to ensuring the financial sustainability of services lies in identifying the full life-cycle costs of service provision and the revenue sources that can meet those costs.

This study collected empirical cost data and identified how those costs are met and allocated between different stakeholder groups. This includes, for example, how much of the total cost is passed on to customers, to what extent services are subsidised, by whom and for whom. The broader purpose of the study was to provide the Government of Viet Nam (at Central, Provincial and Commune level) and its development partners a better understanding of the costs and revenues of small-scale piped water systems over time. The findings can support government agencies to develop evidence-based policies, regulations and incentive structures, aid private enterprises in business planning and structuring connection fees and tariffs, and inform efforts of development partners to design and implement targeted support mechanisms.

METHODS

This investigation adapted the LCCA process developed by WASHCost (Fonseca *et al.* 2011) to quantify the costs associated with delivering piped water services for 14 schemes in rural Viet Nam (see Supplementary Material, Figure S1). The study also identified the factors that drive and influence those costs and assessed the ability of scheme operators to cover those costs. The LCCA included the aggregate financial costs for service providers across capital expenditure, operating and minor maintenance expenditure, capital maintenance expenditure and cost of capital. As the research scope was limited to the costs incurred by the service providers themselves, no data were collected on direct support (capacity of local government to regulate) or indirect support (planning and policy development) expenditure, as would ideally be included in the WASHCost methodology (see Supplementary Table S1 for further explanation).

Financial data were collected from 14 privately owned and operated piped water supply schemes between December 2016 and March 2018. The data collection tool was piloted in December 2016 with two schemes and then refined. The sites were selected through a purposive sampling process, with four located in the northern part of the country and ten in the South. This geographical representation was considered important given variability in technical, institutional and hydrogeological characteristics. For example, in the North of Viet Nam, private enterprises are often larger than those in the South/Mekong region and draw from surface water sources (as opposed to groundwater) to a greater extent. The original research design included equal numbers of schemes in the North and the South; however, due to unforeseen human resources constraints, only four schemes were able to be studied in the North of Viet Nam.

Data collection instruments were designed to capture a comprehensive set of costs associated with construction, operation and maintenance of small-scale piped water services. The structure and content of the questionnaire were informed by the WASHCost LCCA framework. Additional questions on technical and operational characteristics (e.g., size, service level and water source) were also included.

Data on the various costs, revenues and system characteristics were provided by the individual responsible for the overall management of each scheme. The interview process was conducted in Vietnamese and typically lasted half a day or more. Financial information was drawn from various sources, including accounting records, invoices and respondent recall, which is a limitation of the study (see Supplementary Material for additional explanation of limitations which include loss of documentation, selection of schemes, age of schemes impacting on availability of cost documentation, issues related to per connection calculations, due to large industrial or institutional customers not being able to be accounted for, wide range of schemes in terms of size and type, and potential unwillingness of scheme owners to share sensitive financial information). Follow up was undertaken where data were ambiguous, anomalous or missing. Ethics approval for the study was obtained from the University of Technology Sydney.

For each scheme, individual cost items were aggregated and assessed for each category as defined by the WASHCost methodology. Operational expenditure (OpEx), cost of capital (CoC) and capital maintenance expenditure (CapManEx) were annualised for consistency, and all costs were converted to US dollars in 2016 by applying deflator factors and a period average exchange rate of USD 1 equal to VND 21,935 (World Bank 2018a, 2018b). Costs were overlayed with reported revenue to assess the profitability of schemes. To compare the WASHCost LCCA methodology with Viet Nam government-endorsed accounting practices for water service providers, annual depreciation was calculated based on a straight-line method applied to capital expenditure. To identify major cost drivers, OpEx was disaggregated into five key categories: labour, electricity, chemicals, taxes and 'other'. Average costs were also compared across different factors and dimensions, including water source, season, scheme size, age and service level.

RESULTS

Scheme characteristics

While all schemes included in the study were rural piped water schemes, they had diverse characteristics. The 14 schemes varied in age, size and production capacity (Table 1 and Supplementary Material, Tables S3–S7 for more detail). The age of the schemes ranged from 4 to 21 years and on average supplied water for 20 h/day. The average tariff for each connected property (across all property types) ranged from USD 0.26 to USD 0.38, and average connection fee was US$53. Half of the schemes drew on surface

Table 1 | Summary characteristics of the schemes included in the research ($n = 14$)

Attribute	Mean	Standard deviation	Min	Max
System age (years)	14.2	6.3	4	21
Hours of service per day	19.5	5.4	7	24
Number of connections	1,633	986	720	3,555
Production capacity (m^3/day)	1,144	783	120	2,400
Water supplied per connection (l/day)[a]	311	136	125	556
Tariff (USD/m^3)	0.32	0.04	0.26	0.38
Connection fee charged (USD)	53	49	0	153

[a]Note that the number of connections includes business and community institutions (hotels, schools and water consuming businesses), and so, this does not reflect domestic use per connection.

water, and the other half drew on groundwater. Based on WASHCost definitions of water service levels, the schemes typically performed to a high standard against quantity and accessibility, to an intermediate to high standard in terms of reliability, while the extent to which schemes provided water of acceptable quality was unclear. It is important to note that these service standards were self-reported by scheme operators and were not independently verified. Within our sample, there was little variability in service standards as reported by the operators, with 13 of the 14 schemes reported to work most of the time with an average of 19.5 h of service per day (see Supplementary Material, Table S2).

Capital expenditure

Capital expenditure (CapEx) reported by scheme operators averaged USD 324 per connection and varied between USD 55 and USD 522 per connection (Table 2, and Table S3 in Supplementary Material). Around one-quarter of capital investment related to system expansions subsequent to initial construction. For those schemes reporting the source of financing, 80% of capital investment was financed by the scheme owners either directly or via loans taken out from a bank/lender, 9% by NGOs, 7% by government and 4% by households. However, extrapolation of water connection fees suggests up to 20% of capital investment may have

Table 2 | Mean expenditure reported by schemes across key cost categories and scheme characteristics

		Capex (cumulative)		Opex (annual)			CapManEx (annual)			CoC (annual)		
Characteristic	***n***	**Total**	**Per connection**	**Total**	**Per connection**	**Per m³**	**Total**	**Per connection**	**Per m³**	**Total**	**Per connection**	**Per m³**
All schemes	14	524,208	324	33,038	23.9	0.22	2,652	2.60	0.02	1,462	0.98	0.01
Source type												
Groundwater	7	386,719	274	28,871	18.9	0.22	2,406	1.75	0.02	2,019	1.02	0.01
Surface water	7	661,698	374	37,206	28.8	0.23	2,898	3.44	0.02	905	0.95	0.01
Scheme size												
<1,500 connections	9	317,327	337	26,866	27.7	0.26	3,202	3.66	0.03	907	0.94	0.01
≥1,500 connections	5	896,594	302	44,148	16.9	0.16	1,662	0.68	0.01	2,462	1.07	0.01
Treatment												
Yes	11	519,170	316	33,985	25.4	0.22	2,897	3.04	0.02	1,861	1.26	0.01
No	3	542,680	354	29,569	18.1	0.23	1,755	0.96	0.02	0	0.00	0.00
Service continuity[a]												
<24 h supply	7	765,609	426	30,778	20.6	0.22	3,226	3.50	0.03	423	0.49	0.00
24 h supply	6	251,458	217	33,629	27.5	0.24	2,207	1.86	0.02	2,918	1.74	0.02
Scheme age												
<10 years	5	821,032	380	35,206	16.3	0.19	1,310	0.86	0.01	2,827	1.43	0.01
≥10 years	9	359,306	294	31,834	28.0	0.24	3,398	3.56	0.03	704	0.74	0.01
Region												
North	4	936,455	471	36,632	23.7	0.20	3,576	4.61	0.03	285	0.40	0.00
South	10	359,310	266	31,601	23.9	0.23	2,283	1.79	0.02	1,933	1.23	0.01
Tariff (USD/m³)												
<0.31	7	722,704	355	34,516	20.6	0.20	3,013	3.13	0.02	163	0.23	0.00
≥0.31	7	325,712	294	31,561	27.1	0.24	2,291	2.06	0.02	2,762	1.75	0.02

[a]Information on service continuity could not be obtained from one scheme.

been covered by households. External subsidies constituted a larger proportion of system upgrades and expansions compared with initial construction cost (27% vs. 10%). Schemes that were younger than 10 years tended to report higher levels of CapEx per connection (USD 380 vs. 294), as did schemes drawing on surface water as opposed to groundwater (USD 374 vs. 274), and schemes without a water treatment plant (USD 354 v. 316). (Based on the information provided by water scheme owners, three of the schemes had no centralised treatment.) Larger schemes (≥1,500 connections) reported slightly lower CapEx per connection than smaller schemes (USD 302 vs. 337).

Recurrent expenditure

Operational expenditure (OpEx) reported by scheme operators averaged USD 23.9 (range USD 11–48.4) per connection per year and USD 0.22 m^{-3} (range USD 0.09–0.34 m^{-3}) (Table 2). Only one scheme reported unit OpEx that exceeded their volumetric tariff, indicating that OpEx was likely covered by tariffs in most of the schemes involved in this study.

Labour and electricity constituted the major operational cost categories, amounting to 43 and 25% of the average costs, respectively, followed by taxes (10%) and chemicals (9%) (Figure 1). Taxes reported by scheme operators typically included a 5% tax for environmental protection, though some reported the tax to be between 1 and 6%, calculated based on the amount of water abstracted from the system. The water resource upon which a scheme relied had an influence on OpEx: schemes lifting groundwater spent almost 41% more on electricity (per cubic meter of water supplied) than those drawing on surface water, but their chemical costs were 79% lower. Scheme size – particularly when measured by volume of water supplied – exhibited a negative association with unit operational costs ($p < 0.001$), indicative of economies of scale. OpEx incurred by schemes in the South appeared to be heavily influenced by monthly rainfall, suggestive of rainwater harvesting practices diminishing demand for piped water (Figure 2).

Scheme operators reported additional costs, albeit relatively minor, relating to capital maintenance (CapManEx) and cost of capital (interest repayments) (see Supplementary Material, Tables S5 and S6). For the CapManEx attributed to the replacement of specific infrastructure components, 53% related to pipes and meters, 19% to pumps and 16% to treatment plant. In aggregate terms, the annualised CapManEx amounted to 8% of operational expenditure, perhaps raising questions about whether recall bias may have resulted in an underestimate. Most schemes reported historical CapManEx, though the average annualised amount was relatively small (USD 2.60 per connection per year; 0.02 m^{-3}). Older schemes reported higher levels of CapManEx, with systems more than 10 years old recording CapManEx four times that of schemes under 10 years. Six schemes reported paying interest on loans; when averaged across all schemes, these payments amounted to USD 0.98 per connection per year (USD 0.01 m^{-3}).

Profitability

Twelve of the 14 schemes generated a cash profit in the most recent calendar year, though three of the profitable schemes

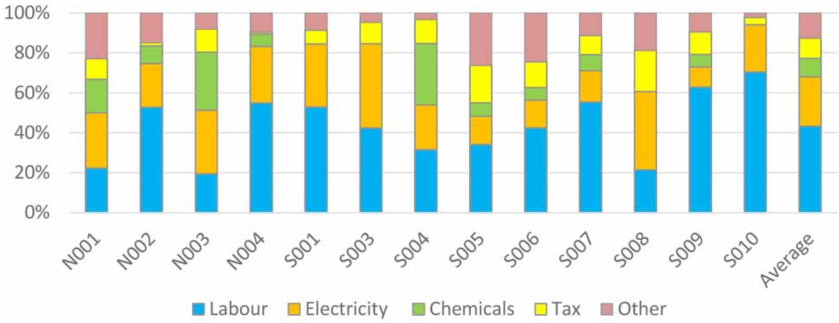

Figure 1 | Disaggregation of operational expenditure by major cost categories. *Note*: Category 'Other' includes materials, water quality monitoring, rental costs, fuel and other administrative expenses. Data did not allow for disaggregation of costs for scheme S002. N in this table denotes North, and S denotes South.

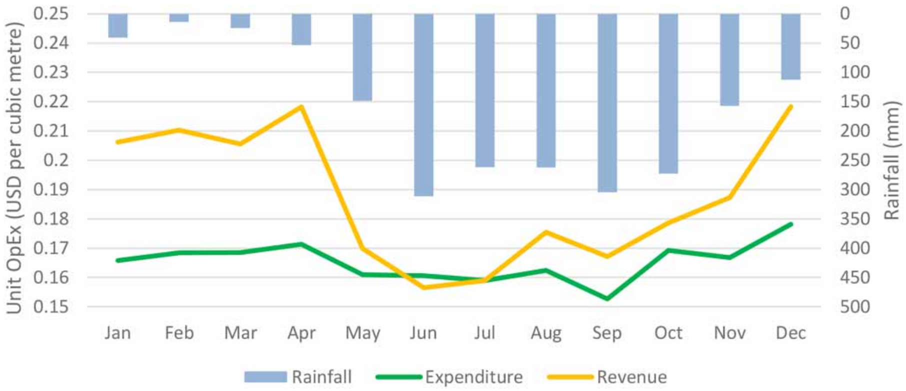

Figure 2 | Operational expenditure and rainfall by month in southern Vietnam (seven schemes in Bên Tre and Long An Province) (*Note*: This is a subset of the data that was able to be disaggregated by month ($n = 7$). Not all scheme owners were able to complete, or did not wish to share, the month by month break down of expenses and revenue).

generated a surplus of less than USD 1,000 (see Supplementary Material, Table S7). Only one scheme reported making a substantial loss, and this scheme also happened to have the lowest tariff. When taking into account depreciation, historical subsidies and connection fee payments, four of the schemes were profitable based on a 20-year design life assumption.

DISCUSSION

This study is the first to quantify a broad suite of costs associated with privately owned and managed water service delivery in rural Viet Nam. It is also the first to document service delivery costs incurred by privately owned and operated schemes in LMICs more broadly. In doing so, the analysis generated a range of new insights relating to cost variation, cost drivers, capital maintenance and depreciation, tariff determination and connection fees, evidence gaps and the financial sustainability of small-scale piped schemes.

The results demonstrate how unit life-cycle costs can vary dramatically. This variation makes it challenging to define standardised cost norms (technical-economic standards) in the Vietnamese context. Rather, if cost norms are developed, as was planned for some jurisdictions in Viet Nam, they should take into account a range of key factors and be flexible to local circumstances. Key factors which influenced costs included scheme size, water resources (source, quality and reliability), climate and service level. These multiple influences mean that generalised cost norms or benchmarks should be interpreted and employed carefully and in light of contextual factors. Moreover, formulation of such norms should be premised on a range or distribution of values that are appropriate to rural small–medium size water schemes, rather than being based on urban water utilities norms or single numerical values or averages.

Some of the drivers of cost variability in this study align with previous research, while others are novel observations. The relationship between cash flows and rainfall is similar to that documented in rural Kenya (Foster & Hope 2017), while Burr & Fonseca (2013) also noted that a drop-off in water use can impact LCCA. However, in contrast to Burr and Fonseca, this study found only modest economies of scale when it came to capital investment. Rather, it was unit operational expenditure that reduced most substantially with scheme size. Variation of costs based on context, while unsurprising, was an important finding of this study with significant policy implications for Viet Nam and other countries wishing to set cost norms to inform connection fees and tariffs.

Reported CapManEx (expenditure on asset renewal) was, on average, surprisingly low. While costing of rural piped services elsewhere have found annual CapManEx to be of the same order of magnitude as annual OpEx (WASHCost 2012), our results reveal annualised CapManEx to be an order of magnitude lower than annual OpEx. On the one hand, this could be a consequence of adequate levels of spending for operational expenditure (i.e., regular maintenance that prevents the need for asset replacement); on the other, it may reflect infrastructure being pushed beyond its limit in a bid to defer its renewal. The reported low levels of CapManEx could also have been a result of respondent recall issues, notwithstanding the systematic and rigorous data collection processes employed by the study. The difficulty of obtaining reliable cost data is a known challenge of conducting research into water service costs in rural areas of LMICs (Burr & Fonseca 2013), so some costs such as CapManEx are likely to have been underreported. Record keeping was at times poor, making it difficult to verify data provided. This applies particularly to historical costs that were incurred more than 12 months prior to the time of data collection, meaning the challenge of collecting robust information was most acute for CapManEx and CapEx associated with older schemes. Inadequate financial record-keeping processes by service providers were compounded by the fact that older schemes were more likely to have changed hands (either in ownership or managerially) since the initial construction. It is, therefore, likely that estimates for both of these cost categories suffered from measurement error. Implications of low CapManEx, whether it be as a result of under-reporting or under-investment, point to the need for a better understanding of how assets are being maintained or upgraded such that they can provide long-term services for the community. Our study found that insufficient documentation contributed to the inability for enterprises and authorities to calculate the life-cycle costs accurately.

Beyond the reported CapManEx collected through this study, depreciation was also calculated as a way to consider whether reported CapManEx costs were likely to be sufficient to maintain assets. Depreciation is a critical consideration, not least because it is promoted by relevant policy instruments in Viet Nam. For example, Circular 45 (Guiding regulation on management, use and depreciation of fixed assets) sets out the way depreciation is to be calculated for fixed assets, and includes an annex which identifies a minimum and maximum design life over which a range of fixed assets should be depreciated (Government of Viet Nam 2013). This study found that a simple straight-line depreciation of capital investment that assumed a design life of 20 years resulted in an average of USD 16.20 per connection per year, which was six times greater than the CapManEx estimate. Again, this may point to under-investment, under-reporting of CapManEx or a combination of the two. Whatever the case, the findings point to a broader maintenance and financing challenge that water service providers will need to overcome in Viet Nam and beyond.

Most of the schemes appeared to be cash flow positive in the previous calendar year. However, given the low level of reported CapManEx, this may not have been reflective of the life-cycle costs required to ensure ongoing sustainability of the scheme. While some of the schemes had been in place for more than a decade, their continued operation may have only been possible due to subsidies provided by government or development partners in previous years. When depreciating capital investment using a straight-line method and factoring in historical subsidies and connection fee payments, only four schemes appeared to be profitable under a 20-year design life assumption. The study found that older schemes had much higher CapManEx which demonstrated that these costs can be expected to increase over the life of a system (unless proactive maintenance is undertaken). The results suggest that subsidies will be needed to ensure ongoing commercial viability in the face of depreciating assets and related capital maintenance costs, and to reach people who are poor and/or marginalised. Additionally, the viability of schemes could be improved by adjusting tariffs, taking into account equity and obligations under the Human Rights for Water and Sanitation, different uses of water (e.g., commercial and domestic use), to ensure affordable and sustainable services for all.

Tariff levels appeared to be adequate to cover operational expenditure, but not likely the full life-cycle costs. Tariffs for piped water supply in Viet Nam are capped by provincial authorities, and in the 14 schemes included in this study, the tariff ranged from USD 0.26 to USD 0.38 m^{-3}. As the profitability analysis suggests, these were generally sufficient to cover operation and maintenance costs, and in some cases (33% of schemes studied) capital investment too. In Viet Nam, there are various policy instruments in place to encourage pricing to be set with reference to real costs (such as Circular 75, 2012), but these instruments have been found not to be applicable to rural water supply and sanitation contexts, given their focus on larger urban utilities. The prescribed tariff setting methodology in the water supply sector globally considers a range of key principles including that the user pays; cost-recovery; the principle of the human right to water based on UN Resolution UN 64/292; that the price is affordable and if not, then subsidies are offered; water conservation and natural resources management and economic efficiency (Vucijak *et al.* 2015). In this study, there was little evidence that the tariff rate charged to customers had been set with consideration of the key principles outlined above, and in some provinces, tariffs were not tailored to each scheme based on its unique costs, but the maximum tariff allowed was charged. Questions remain as to whether or not CapManEx is adequately resourced; however, if such costs are factored in to the life-cycle costs, then tariff levels may not be sufficient to cover all costs associated with a small-scale piped water scheme. To further clarify this area, systems for tracking financial flows would need to be put in place to ascertain the full range of costs over the longer term, with consideration of how to ensure tariffs remain affordable for all.

Connection fees are an important source of revenue for private enterprises to meet the costs faced in early phases of establishment of their business. Connection fees in this study were found to vary from USD 153 to no fee. Some schemes offered free or low-cost connections if households were located close to an existing pipeline or were deemed to be poor. Research on equity dimensions of small-scale private water schemes in Viet Nam revealed that connection fees were a key barrier for poor households to connect to piped water services in rural contexts (Grant *et al.* 2016a, 2016b; Carrard *et al.* 2019). Further consideration of how connection fees contribute to overall revenue sources and commercial viability for enterprises will be important for understanding any related requirement for government subsidies to avoid exclusion of the disadvantaged.

Life-cycle costs vary across country and local contexts, and relate strongly to the relevant water supply service level. Both the OpEx and CapEx reported in this study were substantially higher than those documented by the WASHCost initiative in Burkina Faso, Ghana, Mozambique and India (Burr & Fonseca 2013) (This comparison was done by converting the costs from this study to USD in PPP terms per person.) This disparity is somewhat similar to the findings of Hutchings *et al.* (2017) who also found higher costs than those reported by WASHCost, and there are a number of possible explanations for this discrepancy. First, the schemes assessed in this investigation offered a higher service level than those included in WASHCost. In particular, all schemes served only private connections, whereas public taps are a common feature of rural piped schemes in India and sub-Saharan Africa. This is likely to have a major impact on both the upfront capital investment and recurrent expenditure when measured on a per capita basis. Clearly, it is likely to be more expensive to construct, operate and maintain a system that supplies 100 people through 20 private connections than through one public tap. In addition, most of the 14 schemes examined in this investigation had water treatment processes in place, which may not have been the case in the WASHCost systems. Another contributing factor could be the degree to which funds are directed towards routine, preventive maintenance rather than reactive CapManEx items. Notably, CapManEx reported by WASHCost schemes was considerably higher than schemes in this assessment, which may indicate that the WASHCost schemes were spending an insufficient amount on OpEx to mitigate costly equipment replacement (Nyarko *et al.* 2010). Further research is needed in the Vietnamese context to characterise how levels of OpEx influence CapManEx requirements in the long-term, including in relation to the relevant water supply service level.

CONCLUSIONS

This study sought to quantify the life-cycle costs associated with privately operated water services in rural Viet Nam. The results provide a valuable reference point for the development of cost norms (technical-economic standards), both in terms of the magnitude of costs and the drivers and distribution of those costs. Our study can inform the design of regulations for tariff formulation, support mechanisms such as subsidies and other incentives, initiatives to assist operators with business planning and data collection requirements and tools to aid these processes. We confirmed that even within a country, costs and 'cost norms' vary, and published studies demonstrate that this is also the case between countries. While life-cycle costs of water schemes are highly contextualised to the environment in which they exist, the process undertaken in this study to collect and analyse costs is highly relevant for, and transferable to, other countries and contexts.

The findings address an important knowledge gap in the Vietnamese rural water sector, and if responded to, would support Viet Nam to move towards achieving SDG target 6.1. Our study reveals the need for further nuanced and carefully contextualised LCCA, especially in combination with service delivery assessment, given that results show that both operational and capital expenditures varied widely. A range of factors influence unit costs, including scheme size, water source, climate and service level, while labour and electricity stand as the key operational cost drivers. Promisingly, most enterprises appeared to be financially viable, though further investigation is needed to determine whether tariffs are sufficient to cover future capital maintenance requirements and whether current levels of investment in capital maintenance are sufficient in light of capital depreciation.

It is important to stress that a good understanding of life-cycle costs is only one element of rural water sustainability and functionality. Conducting LCCA is an important step, but does not obviate the need to support other key building blocks related to service delivery and sector-level governance.

ACKNOWLEDGEMENTS

This study was funded by the Australian Department of Foreign Affairs and Trade (DFAT), though DFAT did not have involvement in the study design or in the collection, analysis and interpretation of data or writing of the report. The authors thank the research team who carried out this study including Doan Quang Huy Institute for Economics and Water Resources Management; Nguyen Hong Quan, Hanh Nguyen, Per Ljung and Thuy Bui Thanh from East Meets West Foundation, Viet Nam. The research team sincerely thank private enterprise owners and government representatives who were part of this study and who generously gave their time and shared their financial records and knowledge in support of the study.

CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

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

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First received 21 February 2020; accepted in revised form 15 September 2020. Available online 5 October 2020