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Increasing access to piped water for poor households: an analysis of water connection subsidy projects implemented by the GRET

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ABSTRACT

By 2030, Sustainable Development Goal 6 aims to ensure universal access to safe drinking water. The Royal Government of Cambodia has, thus, made a significant progress in improving the access to safe water supply in rural areas. However, results show only 26.9% of all poor households in a license area were connected when supported by the Groupe de Recherches et d'Echanges Technologique (GRET) programs compared to 45.6% of all households; nearly half of all poor households are located greater than 70 m or are of unknown location; and 56% of known households are within than 3 km. Logistic regression shows a negative relationship between household connections and increasing distance by 10 m, incremental water tariffs by 0.10 USD, and subsidized connection fees by 10 USD when compared to connections, with odds of connection decreasing in all cases (−23, −8.6, and −1%, respectively). Finally, 37% of unconnected households have never heard of the subsidy programs, indicating insufficient marketing programs. Recommendations include updating subsidies to cover all costs necessary for households to connect within 50 m of the distribution lines (an extra pipe, transaction fees, etc.); ensuring flat-rate connection fees paid by all poor households including all costs remaining 40 USD or less; subsidizing pipe extensions to reach unserved areas while maintaining fair tariffs for poor households and cost recoverability for piped water suppliers; shortening marketing and awareness programs to 3 months or less, with involvement from more local stakeholders; and adding poor household connection requirements to investment program requirements.

Key words: affordability, Cambodia, household water connections, piped water supply, poor households, subsidy

HIGHLIGHTS

- Sustainable development goals regarding the safe water supply.
- New solutions to reach poor households with clean water.
- Identification of innovative subsidies to reach poor households.

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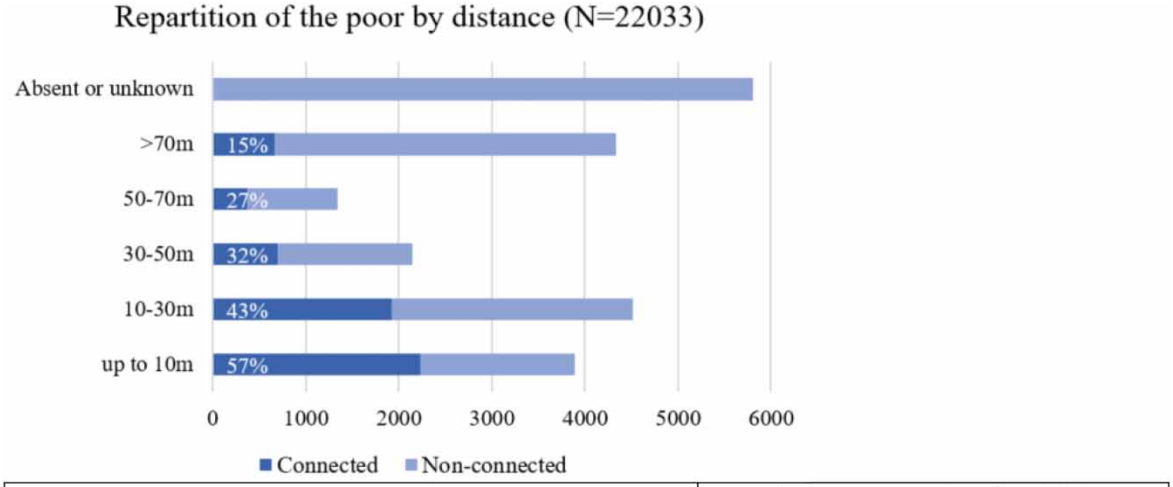
GRAPHICAL ABSTRACT



Independent Variables	Logistic Regression Coefficients
Increasing distance from the pipe network by 10 meter increments	-23%
Increasing the water tariff by 0.10 USD increments	-8.6%
Increasing the connection fees by 10 USD increments	-1%

INTRODUCTION

By 2030, Sustainable Development Goal 6 (SDG6) aims to 'ensure the availability and the sustainable management of water and sanitation for all' and includes goals for achieving universal, affordable access to safe drinking water (United Nations 2018) while the Human Rights to water emphasizes non-discrimination, sustainability, and accountability (United Nations 2014). The Royal Government of Cambodia and international donors have supported progress and an improved regulatory environment in the piped water sector through the Ministry of Industry, Science, Technology, and Handicraft (MISTI), resulting in services provided by 13 public and more than 400 licensed private water suppliers in all 25 provinces (Investing in Infrastructure, unpublished). Although the government aims to improve it (Cambodia, T. R. 2011), access to a piped water supply remains a challenge in rural areas, reaching 80% of urban households but only 17% of rural households in the country (WHO and UNICEF 2021) while the government aims to achieve 38 and 100% improved water supply access by 2025, respectively (Cambodia T. R. 2018).

For more than 20 years, the international NGO Groupe de Recherches et d'Echanges Technologique (GRET) in Cambodia has been supporting privately-owned, piped water suppliers in small- and medium-size towns (5,000–20,000 inhabitants) with improved planning, operations management, and infrastructure development. Many programs included pro-poor connection subsidies, where monitoring data anecdotally revealed that connecting the first ~30% of poor households in a license area is easy for operators, but connecting the last ~40% is difficult. Furthermore, one small study by Gret (2017) confirmed that subsidy programs do increase poor connection rates, but only reach just over a third of households; another similar study in Vietnam had similar findings, indicating that subsidies only marginally increase poor connection rates (Carrard *et al.* 2019).

The literature on poor households and subjects of water affordability is extensive, and seems to be largely focused on *consumption*, establishing that alternatives are more expensive (cited 10–32× more by Bakker 2007), and therefore piped water is the safest, most cost-effective, and sustainable resource for the poorest households. This also begs the evaluation of consumption subsidies and their inequality. While these subjects are not addressed in detail in this study, it is worth highlighting two multi-country studies regarding the ineffectiveness of subsidies: one compiled subsidy programs in 10 countries, finding that the wealthiest deciles, in fact, received the largest quantity of subsidy overall (Abramovsky *et al.* 2020), while a second evaluated the effectiveness of block tariffs, finding that they are not inherently pro-poor (Whittington & Nauges 2020).

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On the other hand, the evaluation of *connection* subsidies appears to be more limited. Cook *et al.* (2020) provide an overview of non-tariff programs across the world, including 77 assistance programs in 45 low- or middle-income countries, where 27% included connection subsidies. The authors point out that there are few empirical studies specifically aiming to understand if these programs actually benefit their intended beneficiaries, despite the widespread policy recommendations. This is surprising since concerns have been highlighted since the early 2000s; Kayaga & Franceys (2007) is an early one of many studies which point out the wide-ranging barriers in connecting to the water supply.

Indeed, limited analysis has been undertaken in Cambodia to evaluate data on why households remain unconnected even when subsidies are available. With a growing need to 'reach the last mile' to achieve the 2030 SDGs, this study assesses some of the drivers and opportunities to reach poor households with improved water supply. It first includes a brief overview of the water regulatory context in Cambodia and then describes the materials and methods used including quantitative and qualitative analyses. Later, the results of the analysis are presented and discussed, including findings from experience during projects implemented by GRET and an assessment of the location of poor households and connections rates, followed by a regression analysis to understand interactions between connection fees, distance from the water supply, and tariffs. Finally, a spatial 'cluster' assessment is provided to understand the location of unconnected households and evaluate water supplier expansion possibilities, followed by recommendations and conclusions.

CAMBODIA REGULATORY BACKGROUND

There are several regulations for water suppliers in Cambodia which provide context on licensing, service provision, and expansion. First is the regulation on water tariff calculations (MISTI 2016, Article 15) which requires all water operators licensed by the MISTI to expand their pipe network to reach 100% of their license area within 5 years. A license area is typically determined by administrative commune boundaries and the 'reach' is defined by the presence of even a small pipe network within each village of the commune. Additionally, the same regulation (MISTI 2016, Article 4) requires that all suppliers connect all households within 50 m of a pipe network; these are called 'connectable households', and the area in which they lay is called the 'coverage area'.

In practice, these definitions do not account for key issues: (1) typically pipe networks are constructed along roads, although many households may be scattered at distances more than 50 m from the road and (2) defining the license area according to administrative boundaries does not account for technical limitations in the pipe network reach all villages (geographic barriers, lack of road access, distantly isolated villages, etc.). Furthermore, in practice, operators typically only provide a water meter and up to 10 m of pipe, requiring households to personally invest in the pipe needed to reach between the meter and their house.

In response, a newer regulation (MISTI 2020) specifically requires operators to provide all materials to reach households up to 50 m and defines a maximum connection fee of up to 75 USD, although the impacts of this regulation have not yet been observed. Furthermore, a pro-poor regulation (MISTI 2021) now recognizes and regulates the need for consistency among poor household subsidies, defining that they should pay no more than 20 USD for a piped water supply connection regardless of distance (within 50 m). However, monitoring and enforcement remain a challenge in practice, therefore poor household distance, connection fees, and other limitations may remain as barriers.

METHODS

This study used ID-Poor data produced by the Ministry of Planning (2020) of Cambodia and data from water operators supported by GRET's projects. Field assessments were carried out and supported with:

- A desk review of relevant studies and compiling of data from previous projects supporting 36 private water operators.
- Field assessments at five different water suppliers across five provinces (Kampong Cham, Kampong Speu, Prey Veng, Kratie, and Takeo), including:
  - Household surveys Table 1 to understand perceptions and challenges in accessing piped water ($n = 419$, using the Cochran formula and a 95% confidence interval with a margin of error of 10%, based on budget availability for the sample size), divided proportionally into connected ($n = 111$) and non-connected

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Table 1 | The household survey sample sizes

District of water operator	No. of poor HH	No. of non-connected poor	No. of sample non-connected	No. of sample connected
Kampong Trabek	631	631	82	0
Steung Trang	661	528	61	0
Treang	1,832	1,205	65	0
Preak Prasab	527	151	59	77
Samraong Tong	189	123	41	34
Total	3,840	2,638	308	111

Note: HH, household.

($n = 308$) poor households in the five sites using previously collected GPS (Global Positioning System) data to randomly select households prior to data collection.
- Five Focus Group Discussions with local authorities (primarily commune chiefs or councils) in the license area to understand (i) their perception of water supply development and the gap in their area, (ii) their participation and engagement with water service providers, and (iii) their plan to contribute and invest for water supply development in their area.
- Five Water Operator interviews for understanding challenges in reaching the poor households including the capacity of water supply, water source issues, geography, market and demand, and connection promotion, especially for the poor households.
- Field observation (distance to the existing pipe network, road conditions, etc.) to identify possible barriers or solutions to reach poor households.

- Data analysis to present results in various ways, including:
  - Compiling lessons learned from subsidy programs to compare subsidy amounts, connection rates, and other lessons learned from 36 operators.
  - Using 16,224 household GPS data points for households and pipe network plans for 28 operators to understand distances of connected and unconnected poor households.
  - Undertaking statistical analysis (logistic regression) of poor households located within 70 m of a pipe network ($n = 11,894$) in Microsoft Excel to assess the impacts of connection fees, water tariffs, and distance of households from the water supply pipe on poor household connections.
  - Using QGIS, satellite imagery, knowledge of the areas, and GPS locations of unconnected poor households in license areas of 13 water operators to identify clusters of households, aiming to understand the physical and spatial possibility of densifying and/or extending pipe networks.

LIMITATIONS OF THIS STUDY

The databases were developed under previously implemented programs to monitor connections of poor households and manage subsidy disbursements. Some were part of larger programs to support overall increased water supply and connections, whereas others only provided subsidies for poor households. A more ideal analysis would compare location and connection rates for non-poor and poor households; however, non-poor households were not mapped and budget limitations only allowed recent field data collection to only undertake short surveys as well as to observe physical limitations for extending pipe networks. The databases also only include poor households deemed reasonably connectable (i.e. close to a road, therefore an existing or potential pipe). Finally, if not already mapped, reasonable assumptions were made regarding the locations of pipes based on the location of connected households.

Potential biases include the perceptions of local authorities, courtesy bias on behalf of respondents to the household survey, and the nature of focus group discussions. There is also inherent bias with GRET analyzing its own data, although the data were viewed as objectively as possible.

Finally, regarding densification and extension, neither quality of operator services nor limitations in the quantity of water sources and treatment facilities were evaluated to determine if water availability and treatment capacity are sufficient to support additional supply.

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FINDINGS

Projects supporting poor household subsidies

To begin to understand the limitations and successes of pro-poor programs, Table 2 presents the varying methods, achievements, and challenges after the implementation of GRET's pro-poor projects.

Program implementation was managed by locating and mapping ID-Poor households by GPS, allowing monitoring of connections and subsidy disbursement, followed by subsidy program marketing while operators were responsible for carrying out connections and claiming subsidies. Programs were also generally designed with varying flat-rate subsidies. Combined with varying connection fees (therefore unequal payment by poor households) and variation in tariffs across operators, this database creates an opportunity to evaluate the impacts of varying connection fees paid by households, distance from pipe networks, and tariffs on connection rates (regression analysis is given in the following).

Table 2 | A summary of past projects

Project	Description	Connection subsidy	Implementation period	Achievements	Challenges
Project 1 (2013–2017)	Kampong Cham and Kratie 3 operators	40 USD HHs pay: 0–25 USD	2–5 months	1,281 poor HHs identified 475 poor HHs connected Poor connection rate: 37%.	Short period of implementation of subsidy. Lack of interest from the water operators in the connection promotion since the poor must request the discount voucher from the commune.
Project 2 (2015–2019)	Countrywide 19 operators	40 USD HHs pay: varies according to the operator	1 year+	13,476 poor HHs identified 2,773 poor HHs connected Poor connection rate: 20%	Lack of interest from the water operators in the connection promotion. Late payment of subsidy disbursement due to the complex tool used for subsidy management.
Project 3 (2011–2017)	Kandal, Kampong Cham 10 operators	ID-Poor 1: 25 USD ID-Poor 2: 20 USD HHs pay: varies according to the operator	Around 6 months	2,331 poor HHs identified 806 poor HHs connected Poor connection rate: 35%	Delay for some poor households to save enough necessity for the fee during a short project period. The higher willingness of the operators to reach more poor households.
Project 4 (2018–2020)	Kampong Speu 2 operators	40+5 USD for 12 m additional pipe HHs pay: 15 or 25 USD	4 months	1,073 poor HHs identified 442 connected poor HHs. Poor connection rate: 41%	A short period of intervention that limits the connection installation and quickens the subsidy reimbursement process. Some poor could not afford the fee. One operator did not inform the poor about the subsidy; the other was very active.
Project 5 (2017–Present)	Kampong Speu and Kampong Chhnang 2 operators	Varies according to the operator fee: split between operator and project HHs pay: 10 USD	1 year+	558 poor HHs identified 64 poor HHs connected Poor connection rate: 11%	Water operators are not active in connection promotion; they rely on the support from the project and local authorities, but also must contribute themselves. The supply capacity of the water operator and network densification/expansion are key barriers for poor connecting to piped water.

Note: HH, household.

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One thing to note is that poor households (and therefore connection rates) are quantified using publicly available databases of ID-Poor cardholders as identified by systematic processes through the Ministry of Planning (MoP). This is an important and useful tool for Cambodia, as the identification of the poor can be one barrier to distributing adequate services, such as piped water subsidies (Cook *et al.* 2020).

It should also be noted that Project 4 intended to test a type of *progressive subsidy* as defined in Abramovsky *et al.* (2020): those which progressively distribute larger subsidies through wealth categories, resulting in the poorest receiving the largest quantity. It provided additional subsidies for the extra pipe to reduce the investment cost barrier, aiming to enable farther households to connect. This program did indeed result in higher connection rates, but this could also be due to one particularly motivated operator.

Finally, two anecdotal findings from experience stand out. The first is active marketing by operators, which likely promoted the programs to more households. The second is the generally short, urgent implementation and payment timelines (less than 6 months, excluding preparation and monitoring phases, which require more extensive time for planning) resulted in higher connection rates. Both are evaluated further later in the paper.

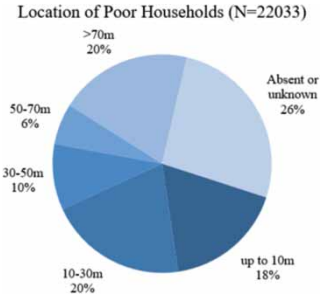
Distance from the water supply

Data from 28 water operators across the country demonstrate the situation of poor households in relation to the piped water supply. Within the license area of these operators (134,675 households (NCDD 2016)), there are a total of 22,033 households (16.4%) which hold ID-Poor cards issued by MoP, equivalent to about 110,000 people. It is noted, however, that only present and relatively 'connectable' poor households – those lying relatively near roads and therefore potential pipe networks – were mapped during the project implementation period, identifying a total of 16,224 households or 73.6% of ID-Poor. The remaining 26.4% were presumed to be absent or primarily scattered between villages and located far from roads. There is little evidence to suggest which is most likely; however, it is noted that during the implementation, it was rare for unmapped households to request subsidies.

The distribution of these households classified by distance is shown in Table 3. It should be noted that GPS accuracy is well known to vary; therefore, while the MISTI policy requires households within 50 m to be connected, the analysis includes ranges up to 70 m to capture a fuller picture.

Just over half (53.9%) of poor households are within the coverage area (less than 70 m) and the majority (38.2%) are located within 30 m of the pipeline. The other half of the total poor population live more than 70 m away from the pipe network (19.7%) or are unknown (26.4%), the latter of which lie farther than any

Table 3 | Location of poor households by distance categories

Categories	Description	Location of the poor ($n = 22{,}033$ households)
Poor ≤10 m	Poor households located within 10 m from the pipe network have a *high potential* for connecting to piped water.	
Poor 10–50 m	Poor households located between 10 and 50 m from the pipe network have a *lower potential* to connect, but operators are obligated to connect them according to their license.	
Poor 50–70 m	Poor households located 50–70 m from the pipe network in which operators are not legally obligated to connect, but *may still be connected*. This group is included in the assessment to (1) account for GPS inaccuracies and (2) understand where poor households are located in villages with piped water supply.	
Poor>70 m	Poor households located farther than 70 m from the pipe network which operators are *not legally obligated to connect* but were mapped because they were deemed connectable to *possible network extensions;* however, in many cases, whole villages remain without network coverage.	
Absent or unknown	Unmapped households, due to *absence or being physically scattered*, lying far from roads, villages, or pipe networks. Households may have been absent during mapping due to seasonal or other migratory activities, although this topic is not well understood.	

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potential network. While few studies were found to have physical measurements of poor household proximity to water supply (likely because poor household databases similar to Cambodia's are rare), several note similar concerns: poor neighborhoods in Jakarta are more likely to have low network density (Bakker 2007) while poorer households in Maputo are more likely to be further than the mandated connection range of 25 m (Zuin & Nicholson 2021). Perhaps more similar data compare neighborhoods in Nicaragua (excluding the capital city) by wealth quintile, revealing that only 44% of the poorest while 85% of the richest quintiles had at least one piped water supply connection in their neighborhood (Angel-Urdinola & Wodon 2012). Although location data for non-poor households were not collected during the projects, these results of poor household pipe network reach are similar to the previous findings.

Two findings are notable from the previous data: most poor households are located either very close to or very far from the network. Connection rates of those close to the network are evaluated further subsequently. For those which are too far, however, it is necessary to consider innovative solutions to reach them; the final analysis section (cluster analysis) will map the locations of the known households to evaluate the possibility of connection via pipeline extension.

Connection rates of poor households

Endline data were collected for all households for 12 operators and reveal significant disparity in overall connection rates: 45.6% of total households were connected (including poor, by NCDD data), whereas the connection rate of poor households is only 26.9% (by MOP data). A study in Vietnam (Carrard *et al.* 2019) found similar results: overall, fewer poor households were connected than non-poor households in the study areas.

For further evaluation, the location of connected and unconnected poor households was repartitioned according to the distance in Figure 1. Connection rates decrease gradually for farther households, with 57% of poor households connected within 10 m of the network down to only 15% for those located more than 70 m. Another notable finding is that a significant portion of households located within 10 m has not connected. Both are addressed further subsequently.

Logistic regression comparing distance, connection fee, and water tariff

A logistic regression was undertaken to evaluate poor household connection data for households within 70 m of a pipe network ($n = 11{,}894$) *after* the implementation of subsidy projects. Notably, other studies included several socioeconomic indicators in a similar analysis, overall linking poor access to low wealth and education; Abubakar (2019) provides a review of several studies while Basani *et al.* (2008) showed the connection between average expenditures and probably of connection in Cambodia. However, because the data were collected for connection monitoring purposes, socioeconomic data were not collected. Therefore, this evaluation includes the evaluation of the impact of (1) water tariff (ranging from 0.4 to 0.75 USD), (2) distance (m), and (3)

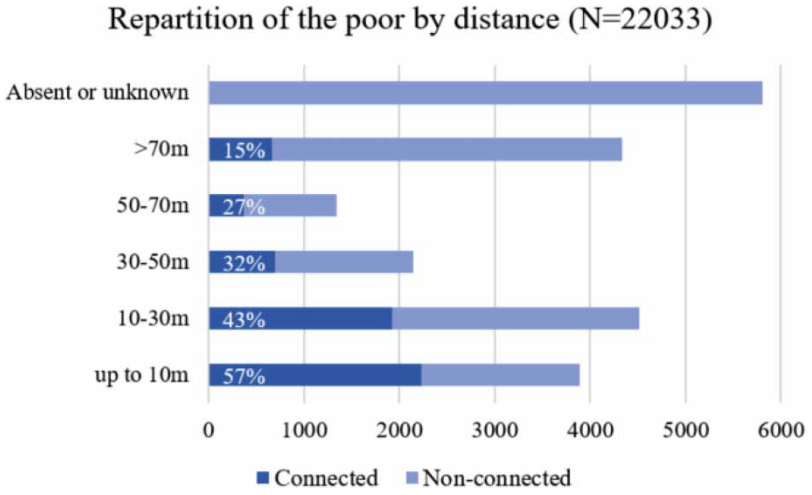

Figure 1 | A repartition of the poor by distance from their house to the pipe network ($n = 22{,}033$ households).

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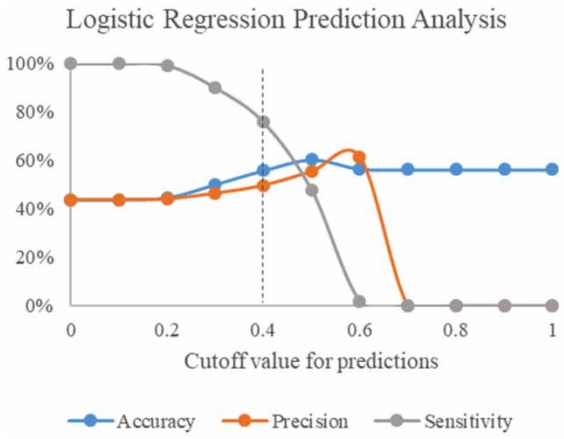
connection fee paid after subsidy (ranging from 3.75 to 42.55 USD) on connection rates (not connected: 0, connected: 1). The results are shown in Table 4.

Holding other values constant, the results show the following:

- For every 10 m farther that a poor household lies from a pipe network, the odds of connection decrease (−23%).
- Higher water tariffs have a negative impact on poor household connections: for every 0.10 USD increase in the water tariff, the odds of connection decrease (−8.6%).
- Increasing connection fees paid by poor households (after the subsidy) by 10 USD increments decreases (−1%) the odds of connection.

Accuracy, precision, and sensitivity are used to understand how well the data are connected and if the model is useful. Therefore, cutoff values were evaluated at 0.1 increments between to predict the rate of connection (value: 1) and non-connection (value: 2) and compared to the sample values (out-of-sample values were not compared).



CUTOFF **0.4**

Connections		Predicted 0	Predicted 1	Total
Actual	0	2690	3988	6678
Actual	1	1264	3950	5214
	Total	3954	7939	11892

Cutoff value: 0.4
Accuracy: 56%
Precision: 50%
Sensitivity: 76%

For poor household connections, it is more interesting to correctly predict connections (precision), albeit at the expense of higher rates of false positives (sensitivity). Choosing a cutoff value of 0.4, the accuracy is 56% and in fact only reaches a maximum of 60%. However, correctly predicted connections (precision) are limited at 50% and the model correctly identifies positive connections (sensitivity) only 76% of the time. The relatively low accuracy and precision indicate that the model should only be used as a general guide to draw conclusions rather than as an analytical tool, while there are likely other influential factors that were not evaluated. Therefore, the results are discussed in this manner.

Subsidized connection fee affordability

Increasing connection fees paid by poor households from 10 to 40 USD decreases the odds of connection slightly and are indeed nearly zero. This is consistent with a study completed in 2017 of one GRET program and two programs run by other implementers in Cambodia (GRET 2017), which concluded that there is no correlation between the achieved connection results and the subsidy amount, the connection fee cost, the contribution from households, nor the contribution from operators. However, this is contrary to findings from other studies, which conclude unequal subsidies also impact the connection rates (Grant *et al.* 2016).

Table 4 | Results of logistic regression

Independent variables	Logistic regression coefficients (%)
Increasing distance from the pipe network by 10-m increments	−23
Increasing the water tariff by 0.10 USD increments	−8.6
Increasing the connection fees by 10 USD increments	−1

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A study from Cambodia previously concluded that unsubsidized tariffs were indeed a barrier for connection and recommended that they be reduced for poor households (Basani *et al.* 2008). The results above, however, may indicate that affordability of poor connections may be up to 42 USD (the maximum paid by households in this study, resulting in 57% of households within 10 m to connect), but other issues are influencing their decision to connect. This is not dissimilar from the results in Maputo, where two-thirds of households connected when subsidized payments for the lowest quintile averaged 27.50 USD (Zuin & Nicholson 2021). Alternatively, for those who remained unconnected, it may indicate overall unaffordability for fees even of 10 USD. This is a complex issue with no clear answer. It is worth pointing out that while the overall result from the regression analysis indicates little impact from varying fees, this may be true for households located within 30 m, where the majority of connections lie. When the data are presented by distance and the subsidized connection fees in 10 USD increments (Figure 2), it appears that households beyond 30 m favor the lowest fees.

Distance from a pipe network as a barrier

The previously discussed results indicate that distance from the pipe network is a major barrier for connection. This is perhaps generally intuitive; Cook *et al.* (2020) also noted that households located farther than 12 m from the distribution lines were less likely to connect while Abubakar (2019) had similar findings, although the latter author consolidated studies mainly measuring the distance to public taps. This provides strong evidence for the theory that other investment costs, such as pipe to extend between the meter provided by the operator (only 10 m from the pipe network) and the household, are indeed barriers for connection. This notion would be consistent with other studies (Bakker 2007; Kayaga & Franceys 2007), which found that to actually achieve a connection, fees included pipe, road crossing costs, application fees, transportation, advance deposits, transactional costs for taking time to pay regular bills, and extra infrastructure needed for piped connections, adding up to 500 USD in one example in Uganda. It is, therefore, important to revisit the full costs for infrastructure and complexity of connection provided by the water supplier and then ensures subsidies and requirements are designed to cover these other invisible costs. This includes revisiting the issues regarding the densification of water supply in poor neighborhoods.

Water tariffs as a concern

Higher tariffs have a marginal, although less notable, impact on connection rates. Other studies have mixed results; Abubakar (2019) consolidated results from several urban studies which indicate that cost of water can also influence decisions about drinking water, while Basani *et al.* (2008) suggest that poor households in Cambodia may be able to afford tariffs after connecting. An important finding is that this is a more complex issue as highlighted in the introduction of this paper, particularly the issues about water alternatives and cost recovery.

Figure 3 shows the household distance from water supply pipes compared to the water tariff in 0.10 USD increments. It is worth noting that there are fewer of the highest tariffs included in this model (0.75 USD), as they are unusual in Cambodia, although the one suggests a larger percentage of poor households are located farther from

	# Water Operators	Counted Poor <=10m	Connected Poor <=10m	% Connected Poor <=10m	Counted Poor 10-30m	Connected Poor 10-30m	% Connected Poor 10-30m	Counted Poor 30-50m	Connected Poor 30-50m	% Connected Poor 30-50m	Counted Poor 50-70m	Connected Poor 50-70m	% Connected Poor 50-70m
Poor conection fee													
Up to 9.9 USD	2	70	49	27%	119	63	34%	88	38	21%	44	16	9%
10 - 19.9 USD	9	1530	857	37%	1708	740	32%	725	291	12%	556	183	8%
20 - 20.9 USD	8	1460	779	36%	1517	686	32%	670	230	11%	381	120	6%
30 - 30.9 USD	6	664	420	44%	1010	331	34%	604	104	11%	335	42	4%
>40 USD	3	169	127	47%	159	104	39%	62	30	11%	23	5	2%

Figure 2 | A comparison of connection fee and connection rate by distance of poor household.

	# Water Operators	Counted Poor <=10m	Connected Poor <=10m	% Connected Poor <=10m	Counted Poor 10-30m	Connected Poor 10-30m	% Connected Poor 10-30m	Counted Poor 30-50m	Connected Poor 30-50m	% Connected Poor 30-50m	Counted Poor 50-70m	Connected Poor 50-70m	% Connected Poor 50-70m	Counted Poor >70m	Connected Poor >70m	% Connected Poor >70m
Water tariff																
0.4 - 0.49 USD	4	503	287	12%	4513	1924	83%	188	77	3%	79	23	1%	294	14	1%
0.5 - 0.59 USD	12	2027	1076	34%	2364	983	31%	1074	363	12%	637	186	6%	3061	520	17%
0.6 - 0.69 USD	11	1287	861	42%	1308	691	34%	542	222	11%	440	143	7%	727	111	5%
0.7 - 0.79 USD	1	76	8	9%	369	17	19%	345	31	35%	183	14	16%	248	19	21%

Figure 3 | A comparison of water tariff and connection rate by distance of poor household.

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the network, resulting in more, farther connections. This could suggest that networks in less dense and more rural areas require higher tariffs to achieve cost recovery for the private operator. Nevertheless, fair and affordable tariffs are even more important for the poor here.

Household perceptions and other reasons for not connecting

To assess more complex reasons for connection and non-connection, a household survey was undertaken in select sites. Households considered that one main reason to connect to piped water (Figure 4, $n = 111$) was the access to subsidy on the connection fee (82%) along with the ease of access to the tap (84%) and the water quality (68%). Similarly, the two main reasons for not connecting to piped water (non-connected households, Figure 5, $n = 308$) were having alternative water sources (47%) and the low affordability for the connection fee (32%). In addition, when asked the support needed to connect to piped water, a subsidy on the connection fee is the most-needed solution (Figure 6), with 42% asking for a free connection and 36% wanting a discount or subsidy for the connection fee.

Less than half of non-connected households were aware of the subsidy programs from the implemented projects (42%), but when segregated by distance from the piped network, farther households tend to have less knowledge about the subsidy: only 47% of households living farther than 50 m from the network were aware of the program compared to 63% for households located less than 50 m from the network (Figure 7). However, when asked if they would connect, 65% of the unconnected households also reported they would if they had been aware of it. Regarding the households that indicated they were not interested in connecting to the piped network (35%), the main reasons are due to their satisfaction towards their current water sources (35%) and the lack of

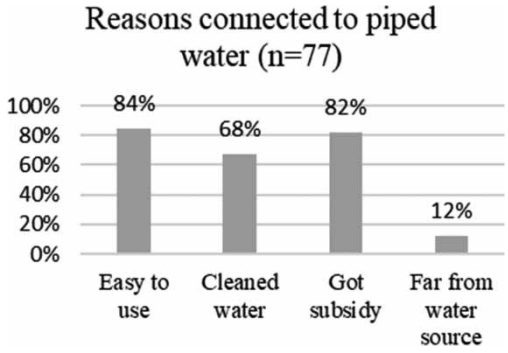

Figure 4 | Reasons for connecting to the piped network.

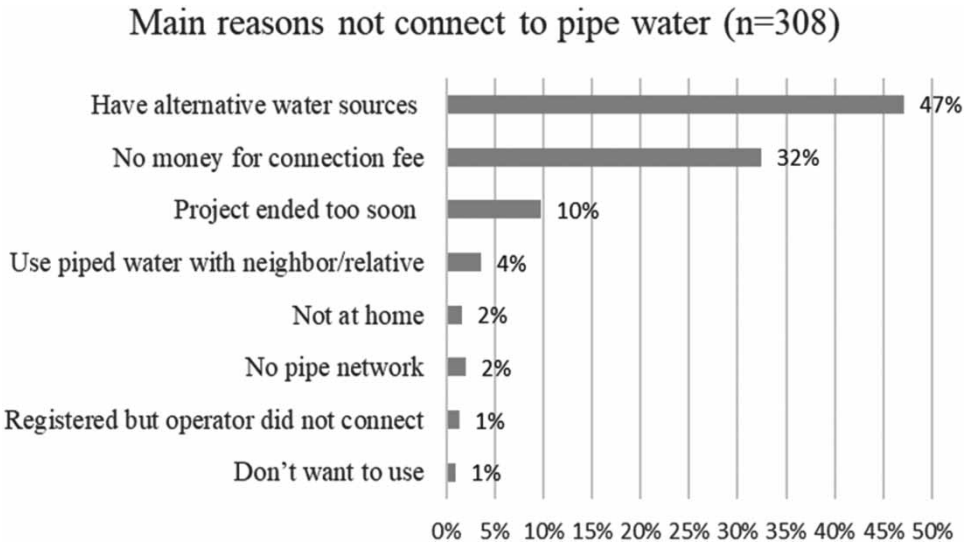

Figure 5 | Reasons for not connecting to the piped network.

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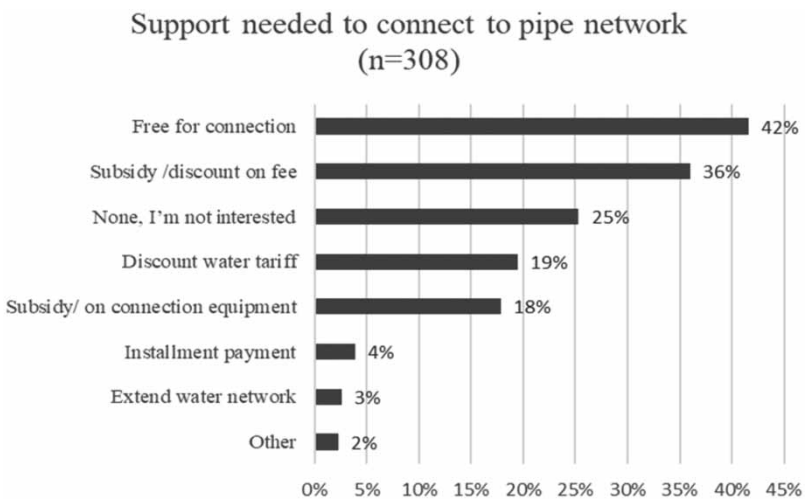

Figure 6 | The support needed to increase the connection rate.

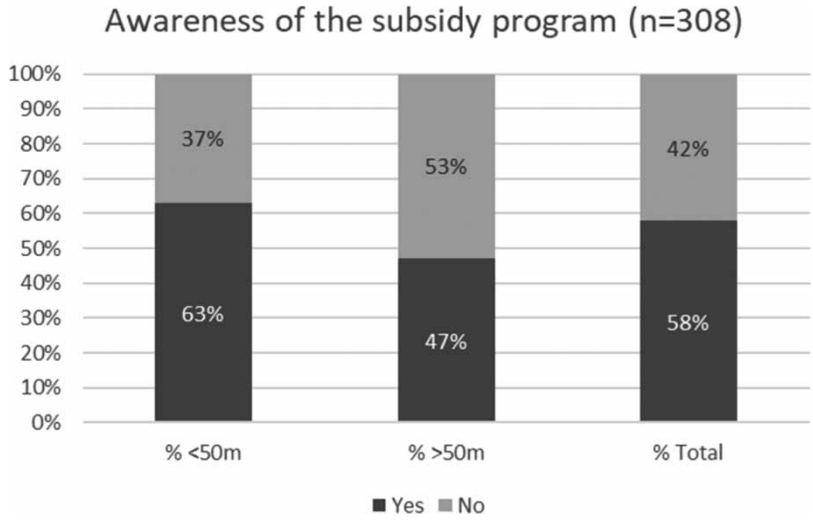

Figure 7 | Respondent's awareness of the subsidy program for connections.

capacity to pay for the connection fee even with a subsidy (37%). Similarly, local authorities in the focus group discussions raised concerns that poor households tend to lack knowledge about water and sanitation and many of them feel more comfortable with their water sources.

First is the concern of alternative water sources, although only a third of unconnected households cited their satisfaction with these as the reason for not connecting. As cited in the introduction, alternative sources can be significantly more expensive per volume. Another study from Jakarta suggested additional issues with alternatives: piped water quality can be perceived as lower than alternatives or competition from alternative vendors can be monopolistic and controlling (Bakker 2007). The use of alternatives is a complex behavior change issue not covered in this study; however, it remains an important consideration for future program implementation.

The second issue is about the perception of connection costs; households report affordability as a barrier, while the regression analysis showed that subsidized fees under 42 USD result in connecting a similar number of households, potentially indicating affordability. The household perceptions are relatively similar to those in Vietnam, where more than 50% of unconnected households reported unaffordability as the primary reason in service areas (Carrard *et al.* 2019), and in Maputo, where 36% perceived the connection cost to be too high (Zuin & Nicholson 2021). Interestingly, respondents in the latter study also reported that connection fees are an average of 20 USD *higher* than the actual fee. There are two possible reasons for this: other hidden fees are unaffordable or

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marketing of fees is insufficient. Furthermore, as discussed previously, subsidy programs must move away from flat-rate subsidies and instead focus on flat-rate fees paid by households for all within 50 m. This reaffirms the need for re-evaluating the full costs for connection, including extra pipe and transactional demands, to overcome the hidden fees, while promotional materials should make connection fees to be paid by households explicitly clear. It is also worth considering the use of 'connect now pay later' in installment campaigns (Zuin & Nicholson 2021), waiving down payments, and other flexibility in the delivery of payment (Bakker 2007), which have all proven to increase connection rates overall.

Finally, concerns about gaps in knowledge of subsidy programs are a consistent and notable issue across projects. In both Vietnam and Maputo, unconnected households reported being unaware of connection services (Carrard *et al.* 2019; Zuin & Nicholson 2021). There are several resources to suggest that this is likely connected to the anecdotal findings mentioned previously suggesting that inactive operators had lower overall connection rates and shorter implementation timelines which achieved higher connection rates. In Maputo, a few neighborhoods were targeted at a time in short targeted campaigns, which resulted in 80% of people receiving connection in a month or less and succeeded in connecting two-thirds of poor households (Zuin & Nicholson 2021). Results from Morocco showed that sending staff to the doorstep increased applicants by nearly 60% (Cook *et al.* 2020). In Vietnam, engaging with the local government and users early allowed empowerment and contributed to the overall success of the project, a women's union was engaged for some information and communication activities (World Bank 2013). Another study assessed overall bottom-up participation (by the community, local NGOs, etc.) across several studies, suggesting it can have an overall impact on improved access to individual taps, although the results are most significant in slums rather than general low-income areas (Narayanan *et al.* 2017).

As such, it is ideal to implement concentrated, short connection campaigns with a high level of marketing activity and involvement of more stakeholders in fewer villages or operators at one time in succession, rather than drawn-out programs supporting many operators simultaneously.

If too far to connect, where are the poor located?

The context of connecting poor households is not limited to connections alone; it also pertains to pipe network extensions. As per the law, all licensed water operators must expand their pipe network to cover 100% of their license area within 5 years, yet results show that less than 50% achieve this.

The aim of this 'cluster analysis' (Figure 8) was to understand the geographic distribution of groups of non-connected poor households which otherwise may have characteristics to be considered connectable and the feasibility of promoting pipeline expansion for 16 operators. The methodology is not an exact science: for example, a whole village that is not in the coverage area of a network may be considered a cluster, although groups of households set apart from the village centre may be as well. A total of 62 clusters identified as not having major barriers for connection (except perhaps distance, discussed subsequently).

The analysis shows that a significant number of poor households can be connected to the network with limited investment for the extension of the network (Table 5). Most clusters (53) range between 0 and 3 km from the existing piped network; this is a technically reasonable distance to plan extension lines and 56% of poor households lie within this range. Additionally, the larger clusters of households are farthest from the existing piped network. Beyond 3 km, however, while network extensions can be considered under certain conditions, it is ideal that alternative options be assessed. In particular, for the two clusters located more than 10 km away, the construction of independent piped water systems should certainly be explored.

Many authors agree that poor households are less likely to be located in service areas and to connect when they are in service areas, therefore both require subsidies (Kayaga & Franceys 2007; Angel-Urdinola Wodon 2012; Borja-Vega *et al.* 2019; Abramovsky *et al.* 2020). However, the suggestion to extend the water supply has no shortage of concerns. Complexity is one: multiple authors point out that the average cost per connection in poorer areas tends to be denser and disordered, leading to higher and more time for installation (Bakker 2007; Devkar *et al.* 2013; Grant *et al.* 2016). Others pointed out limited investment capacity by operators (Grant *et al.* 2016), lower tariffs for the poor reduced average revenue per volume of water, making cost recovery impossible (Bakker 2007), and operator reliance on connection fees for income (Grant *et al.* 2020). Adeoti & Fati (2020) specifically focus on the topic in their paper, citing in additional political interference, lack of organizational willingness, lack of government policy, and lack of budget funding.

While the analysis of this paper focused on poor household affordability, it is indeed important to balance the need to reach poor households with the viability of the water supplier: a World Bank study showed that the lack

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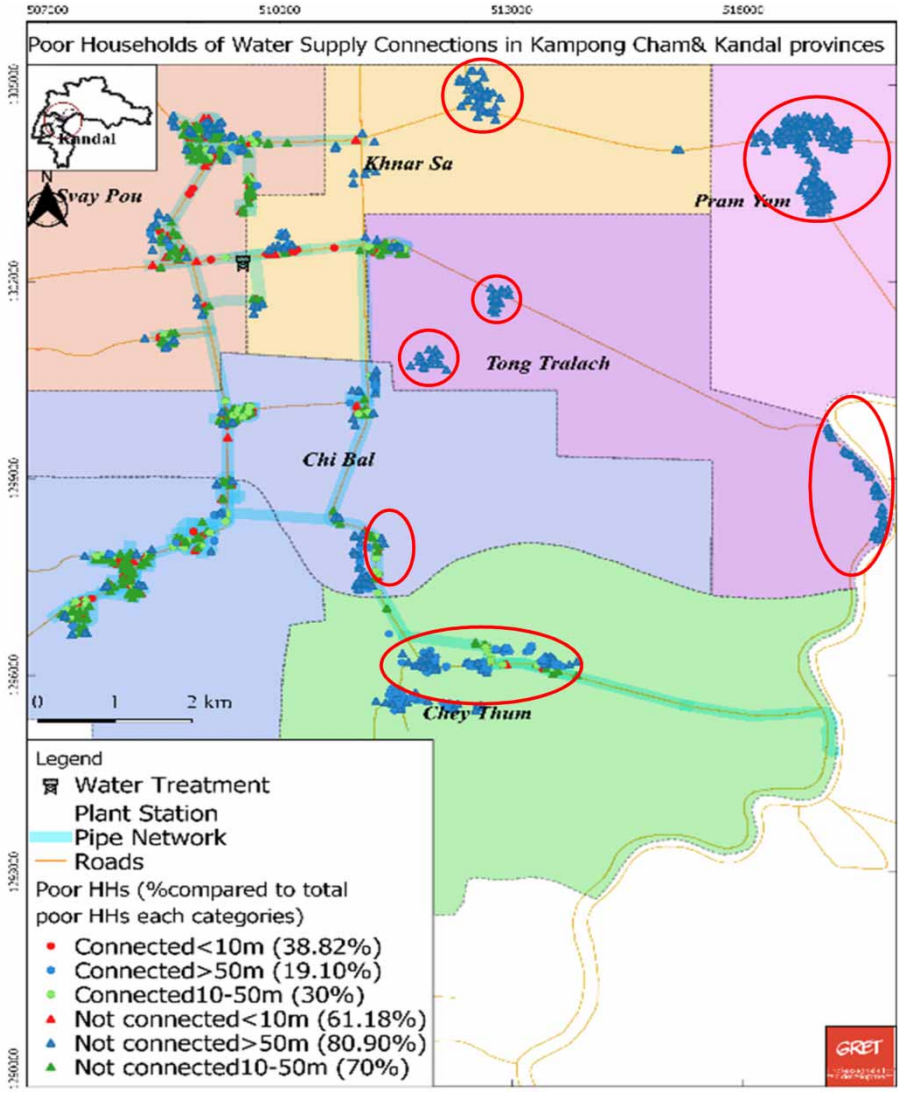

Figure 8 | The sample pipe network, location of poor households, and unconnected clusters.

Table 5 | Distance from the piped network and connectable households per cluster

		Estimated unconnected households (assuming 7–15% are poor)	
Distance along the road to the nearest pipeline (km)	**Total number of clusters**	**Average number of households per cluster**	**Estimated total number of households within the distance**
0–1	23	40–80	1,000–2,000
1–2	15	70–140	1,000–2,000
2–3	15	70–140	1,000–2,000
3–4	1	170–340	1,000–2,000
4–5	3	250–500	150–300
5–6	1	200–400	750–1,500
6–7	2	140–280	200–400
>10	2	490–980	300–500
Total	62	1,430–2,860	5,000–10,000

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of staff capabilities, varying water service, and limited piped expansion were the key barriers to private water in Cambodia (World Bank 2015).

This brings the discussion back to cost recovery. The findings earlier on showed that higher tariff rates decrease the likelihood of poor household connection to piped water; however, block tariffs can be anti-poor if targets require cost recovery over connections (Bakker 2007). Furthermore, one study of two cities in Kenya showed that establishing pro-poor units in combination with pre-paid meters improved collection recovery of monthly bills, reducing the utilities' concerns over cost recovery concerns while reaching poor areas (Kemendi & Tutusaus 2018). An entire body of studies is dedicated to the equality of tariffs for the poor, which must be studied in detail before concluding tariff structures; however, one point is clear: connection of poor households must be emphasized, which also requires extension subsidies.

CONCLUSION AND RECOMMENDATIONS

The findings suggest that while pro-poor connection subsidy programs are necessary, the ones in Cambodia may be insufficient for their intended beneficiaries. The regression analysis showed that varying subsidized connection fees below 42 USD resulted in similar connection rates overall, but there is a significant decrease in connection rates for households that lie farther from a pipe network. A review of other studies shows that extra pipe and other hidden fees actually increase the overall cost of connection and are often overlooked. A new regulation by the MISTI attempts to correct this, now requiring operators to provide pipe up to 50 m for the set connection fee, but any impacts have not yet been observed in practice. It is necessary to fully review all costs related to connecting to piped water supply and ensure that a flat-rate cost borne by poor households is consistent for everyone.

Furthermore, nearly half of all poor households are at located more than 70 m from a pipe network and 56% of known households are located within 3 km. Although data for non-poor households were not available to compare services of wealthier inhabitants, other studies also suggest that inequalities in the pipe network reach poorer areas. The complexity for operators to reach poor neighborhoods is a valid concern, including water source, production, and cost recovery, yet the need for expansion remains. This is especially important, as the regression analysis also revealed that higher tariffs also reduce connection rates, although to a lesser degree than distance. Support is necessary for extension programs while maintaining fair tariffs and supporting operators to improve services.

Finally, perceptions and awareness of subsidy programs reveal flaws in marketing programs. Despite the regression analysis suggesting that subsidized connection fees are fair, 78% of unconnected poor households requested a free or subsidized connection, while nearly half had never heard of the subsidy, and 65% of these respondents said they would connect if they were aware of the subsidy. Findings from the programs in Cambodia and elsewhere suggest that short, highlight targeted programs (perhaps at the village level), with fast connection timelines (3 months or less) and significant involvement from the community, local authorities, and/or other local stakeholders are likely to improve overall connection rates.

While this summary provides an overview of key concerns, many other factors may influence connection (Cook *et al.* 2020). Therefore, the importance of improving subsidy programs as well as governance is also essential; Bakker (2007) suggests that government-mandated pro-poor policies and the inclusion of pro-poor targets in contracts could improve connections. Piped water supply licenses in Cambodia already include connection targets; however, it is suggested that plans and targets specifically aimed at connecting poor and vulnerable households to be included in all investment programs.

In summary, the following are recommended to improve programs:

1. *Update subsidies to cover all costs necessary for households to connect*. This will require a detailed review of associated costs, especially pipes needed to reach households within 50 m of the distribution lines, transaction fees, etc.
2. *Ensure flat-rate connection fees paid by all poor households* including all costs that remain ~40 USD or less.
3. *Subsidize pipe extensions to reach unserved areas while maintaining fair tariffs for poor households and cost recoverability for piped water suppliers*, including adequate support for water suppliers themselves to provide improved water supply.
4. *Shorten marketing and awareness programs to 3 months or less and include more local stakeholders*, as well as improve messages about processes and costs.
5. *Add poor household connection requirements* to investment programs and government requirements.

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Recommendations for further analysis

To understand the true impact of subsidy programs, it would be useful to analyze poor household connection data compared to non-subsidized connection fees (ranging from 37.5 to 82.55 USD for this dataset, compared to 3.75 to 42.55 USD when subsidized) for older suppliers which have never received subsidies, which perhaps have been in operation for greater than 10 years. While the GRET collected poor household connection data before subsidies, it was not possible to account for old coverage areas versus newly expanded networks.

The issue of tariffs, expansion pipelines, and connection rates merits its own study, due to the complex interactions. It is ideal to consider investment programs' impacts on extension as well, to identify learned opportunities for future developments.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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