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The effectiveness of technological approaches to reducing power theft from electricity systems in emerging economies

A synthesis of lessons from EEG-funded research in Bangladesh, Ethiopia, India, the Kyrgyz Republic, and Pakistan.

This paper briefly reviews the wider literature on technological approaches to the mitigation of non-technical losses in electricity power systems and their impact on revenue and consumer behaviour. It then, in that context, considers the findings of five research projects executed under the auspices of the Applied Research Programme on Energy and Economic Growth.

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Oxford Policy Management

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The effectiveness of technological approaches to reducing power theft from electricity systems in emerging economies –

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Abstract

This paper considers the literature on technical approaches to reducing non-technical losses in power systems and then, against that background, reviews the lessons emerging from five research projects carried out under the auspices of the FCDO funded Applied Research Programme on Energy and Economic Growth (EEG), looking at the use of prepaid meters, smart meters and ariel bundled cables as means of reducing such losses. The paper explores both the effectiveness of the measures in terms of loss reduction and also the wider impacts the use of these technologies has on consumer behaviour. The paper also considers political economy issues around the deployment of these technologies that were identified in some of the research projects. The EEG-funded research findings:

1. Confirm findings in the wider literature that the introduction of pre-paid meters generally results in a reduction in household billed consumption of electricity services and highlights the lack of attention in the literature to the potential impact of such a decline in consumption on the wellbeing of poorer households.

2. Demonstrate that smart meters and aerial bundled cables could be effective technical approaches to reducing power theft, but only when combined with measures to tackle political economy issues that produce the conditions under which such theft occurs.

3. Caution that, in the absence of action to tackle the associated political economy issues, the costs of implementing technical solutions can be greater than any savings achieved by utilities from, for example, efficiency gains.

Acknowledgements

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Introduction

The financial cost to utilities worldwide from non-technical losses is reported to be as much $96 billion each year, with nearly a quarter of those losses, $23.2 billion, occurring in India, and with 17 other countries experiencing losses of over $1 billion per year (Bellero, 2017). In emerging markets, non-technical losses are a major issue for utilities and can be as high as 40% of the total electricity distributed (Glauner, Glaser, & et-al, 2018). As a result, utilities in many developing countries are trapped in a self-sustaining cycle that perpetuates non-technical losses. Low revenue recovery leads to under-investment by utilities in distribution networks, leading to fewer new connections and rationing, voltage fluctuations, and unreliable service for existing customers. The resulting restricted and low-quality supply, in turn, causes consumers to feel justified in making incomplete payments, so sustaining the downward cycle of sub-optimal revenue recovery and investment (EEG, 2016).

This paper briefly reviews the wider literature on technological approaches to the mitigation of non-technical losses in electricity power systems and their impact on revenue and consumer behaviour. It then, in that context, considers the findings of five research projects executed under the auspices of the Applied Research Programme on Energy and Economic Growth (EEG).

The EEG programme ran from 2016-2022 and was funded by the UK Foreign, Commonwealth & Development Office (FCDO). EEG focused on ground-breaking research on sector reforms, innovative technologies and practicable solutions to some of the most pressing energy-related challenges in Sub-Saharan Africa and South Asia. Priority research areas included energy access, renewable energy, power system reliability and the efficiency and productivity of energy uses.

Context

Non-technical losses

Non-technical losses in electrical power supply systems are caused by actions external to the system itself. Typically they can originate from four sources (NES, 2020):

- fraud (often physically tampering with the meter to reduce the record of the amount of power used to deceive the utility),
- theft (tapping into power lines illegally),
- billing irregularities (for example misreading of meters – which could be an unintentional mistake or a deliberate arrangement between meter reader and consumer),
- non-payment of bills.

Smart meters

Digitalisation, in the form of smart meters, is often put forward as a technical solution to the problem of non-technical losses (see, for example: (Boateng & Ghansah, 2015; Ramesh, 2021)). Digitalisation offers the opportunity to have greater scrutiny of the behaviour of users on an electrical supply system, which can support increased billing and payment security, reduced likelihood of corruption, and boost investor confidence in future revenue security (McKinnon, Mulhall, & Owen, 2019). Advanced Metering Infrastructure (AMI) smart meters do this by providing information about the location and timing of supply outages when they occur, helping utilities to identify problems in real time and fix them quickly. Smart meters can detect theft by identifying the location where losses are occurring more precisely than is otherwise possible, allowing utility staff to act. AMI smart meters offer two-way communication, allowing utilities to also be able to remotely disconnect non-paying consumers or transfer them to pre-payment without the intervention of revenue collection staff, avoiding possible problems of fraudulent collusion between them and customers. Finally, smart meters can also facilitate remote automated billing, removing the need for meter readers, improving accuracy of metering and, again avoiding opportunities for fraudulent collusion with consumers (EEG, 2016). Theoretically smart meters could also facilitate real time pricing, where consumers are charged more for consumption during peak demand periods and less at other times. In practice there are no examples in the literature of this latter option being implemented in emerging economies and a modelling of such an approach for Columbia suggests that, at least in that location, introducing it would be politically difficult as it would leave a relatively small group of consumers much worse off, whilst only very marginally benefiting the majority (McRae, 2015).

Examples of AMI meter rollout in Africa includes 20,000 meters in Mali, targeted to reduce losses by 20%; 30,000 points in Burundi, aiming to reduce energy losses by 22%; and 40,000 points in Cotonou, Benin, looking to reduce energy losses by between 5% and 10% (Nhede, 2020). Other examples include AMI projects in Angola, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Nigeria and South Africa (ibid), while recent examples in South Asia include India (Jones, 2021) Nepal (Shrestha, 2020) and Pakistan (Shoukat, 2022).

There are few studies reported in the literature that actually look at the impacts of smart meter deployment in emerging economies either on consumption or utility revenue recovery. Some references that purport to do this, actually focus on the introduction of pre-payment functions (which are dealt with in the following section of this paper) rather than broader smart features; for example in Ghana (Otchere-Appial, Takahashi, Yeboah, & Yoshida, 2021), and in Uzbekistan (ADB, 2021). A paper summarising the experience of implementing smart meter trials in South Africa (SAMSET, 2015) mentions "improved operational efficiency through remote meter reading, [and] more accuracy in billing information", "payment levels increased to 90%, resulting in increased revenues" and "improved quality of electricity supply due to reduced outages commonly caused by tampering" amongst the benefits derived from various trials of smart meters across Johannesburg, but provides no baseline against which to judge the quantum of these improvements.

The most referenced rigorous study in the literature seems to be one in Kyrgyzstan looking at the impact of the introduction of smart meters on the quality of electricity supply (Meeks, Omuraliev, Isaev, & Wang, 2021). The research found the two-way communication provided by the meter allowed the utility to access information on outages and other service quality problems (e.g., voltage fluctuations) within the distribution system, allowing faster and more targeted responses. In this case smart meters also included a function to automatically disconnect houses from the electricity supply when the voltage spiked or dropped, providing consumers with evidence of service quality issues to present to the utility to provide further stimulus to elicit action, while also protecting their appliances from damage. The research was based on an experiment focussed on 20 neighbourhoods (1,600 households) in one city. The transformers, and their respective households, were randomly assigned to treatment or control status, with smart meters installed in all 798 houses in the treatment group, while 846 control houses retained their old meters. Electricity prices remained the same across both groups during the study period. Results confirmed that the smart meters led to improvements in service quality, with reduced incidences of voltage fluctuations among the treated group, relative to the control (presumably because of quicker and more targeted responses to problems from the utility). Interestingly, treated households' monthly billed electricity consumption increased during months of peak demand (November to March) and decreased during off-peak months (April to October). Before the intervention took place the quality-of-service quality was lowest during the peak demand months, when outages and voltage fluctuations occurred frequently. The research concluded that increased consumption in peak months was consistent with the idea that the improvements to the electricity service quality provided space for greater consumption which, in turn allowed previously unmet demand to be expressed and met. The research also concluded that a likely explanation for the decrease in off-peak billed electricity consumption may have been that, having experienced increased bills for the higher electricity consumption in the first few months post-intervention (during the peak demand months), treated households may have invested in energy efficiency and household improvements to reduce costs.

It should be noted that while smart meter functionality that allows utilities to remotely disconnect non-paying users is regularly mentioned as an important feature in the literature, no studies could be found in this review that investigated the use or effectiveness of this feature.

Prepay meters

Prepayment meters are another technical option often proposed to deal with non-technical losses and many utilities in Sub-Saharan Africa are moving away from a post-paid to pre-paid electricity system. From the utility's perspective, the fact that consumers are automatically self-disconnected when their pre-paid credit runs out means supply can be matched to demand from consumers who are paying for the power while the problem of collecting revenue from customers who have consumed electricity but not paid for it is no longer an issue (Carr & Thomson, 2022). Additionally pre-paid meters can reduce the costs of supplying residential customers by eliminating the need for meter reading, simplifying bill payment, and bringing forward revenue. If prepaid meters reduce electricity use, and if electricity is subsidised, then they can further reduce the losses of electric utilities by reducing the total amount of subsidy required. Pre-paid meters can also reduce the political cost of disconnecting customers who don't pay as the disconnection 'decision' is made by the consumer (through their action of not topping up their balance) rather than by the utility having to take action to bar them from accessing power (Das & Stern, 2020).

Proponents of pre-pay meters claim there are benefits for the consumer in that they help people (especially those on low income) to budget and to avoid the 'bill shock' that can come at the end of the billing cycle. Research in Tanzania, for example, revealed broad support for the prepaid meter because economically vulnerable users expressed "greater fear of debt than of the dark, and were willing to cede control of their consumption to the new meter" (Jacome & Ray, 2018). There are potential downsides however. Users may occasionally have problems purchasing credit and be left in the dark as a result. For example, pre-paid meter users in Nigeria complain that they cannot buy credit on Sundays or on holidays. Frequent electricity or mobile outages will could also interfere in buying credit. Finally, customers are often required to pay for installing a pre-paid meter (Das & Stern, 2020). Prepaid metering has been implemented at scale in at least ten sub-Saharan African countries [Ethiopia (2018) Ghana (2014) Kenya (2013) Mozambique (2016) Nigeria (2015) Rwanda (1999) Sierra Leone (2015) South Africa (2011), Tanzania (2014) and Uganda (2018)] and two south Asian countries (Bangladesh (2014) and India (2018), with pilots in Nepal (2019) and Pakistan (2018)] (ibid).

There are not many studies of impact of pre-paid metering on consumption. Amongst those that do exist, studies that look at populations where there is an opt-in policy are subject to methodological concerns, as people who opt into such schemes are self-selected and may have different behaviours to those who are compulsorily switched. A rigorous study of 4,000 customers in suburbs of Cape Town who were forcibly switched to prepaid metering in 2014-15 is one of few to be conducted in a developing economy (Jack & Smith, 2020). As meters were changed in 27 randomised groups, the research was able to use customers not yet switched as control groups, allowing them to isolate the effects of the shift to prepaid meters from other influences. Jack and Smith found that pre-paid electricity metering reduced customers' electricity use by 14% (1.9 kWh per customer per day on average). Four other studies in the US and Canada show similar levels of reduction of consumption (11 – 15%) on the introduction of domestic pre-paid meters (Das & Stern, 2020).

Unlike the research cited above, a study of 1,666 households' pilot exercise in Accra in Ghana (Otchere-Appial, Takahashi, Yeboah, & Yoshida, 2021) during 2018-19, where 46.3% of that sample of households were switched to "anti-tamper, anti-fraud, and anti-theft smart prepaid meters" while the remainder stayed on post-paid meters, found that on average, the monthly metered customers' electricity consumption, based on utility billing data, actually increased (rather than decreased as in other studies) by 13.2% when a post-paid meter is replaced with a smart and tamper-proof prepaid meter. The study authors attributed this rise in metered consumption to previous widespread electricity theft through meter tampering across almost all residential customers[1]. In other words, for the vast majority of consumers a switch to pre-pay meters did not result in an actual increase in their consumption but a regularisation of elements of their existing levels of consumption they were not paying for. A review of the treatment effect (change in monthly KWh consumption recorded by the meter after a shift from post-pay to pre-pay by quantile of electricity consumption) showed consumption increasing for all quantiles except a small group around the 30th quantile, where treatment resulted in a decline in consumption. The policy recommendation from the research was that the utility should focus firstly on roll-out of pre-pay meters to high demand customers (75th to 90th quantile of consumption) as that would result in the greatest recovery of lost energy. While the results suggested that very-low demand customers (the 10th quantile) were also tampering with meters, the potential lost energy to recover was low and, given it was likely to be an affordability issue, changes to the lifeline tariff might be a better solution.

While it is clear that, in the Ghana case above the utility would benefit from high levels of revenue recovery as a result of 13% more of the energy it delivers being paid for, where the introduction of pre-paid meters results in a reduction in consumption the net impact on utility finances is not so obvious. Indeed there is an absence of studies that investigate the impact of pre-paid metering on utility revenue in emerging economies, with the Cape Town study referred to above being the only example found. In the Cape Town study, the switch to pre-paid meters was found to result in a 14% reduction in average domestic consumption of electricity[2]. However, the change also led to higher payment recovery, lower costs and the utility receiving payments in advance and avoiding costs associated with meter readers, bill calculation and enforcing disconnection for non-payers. The net effect was positive for the utility. The cost reductions to the utility outweighed the reductions in customer average consumption and payments, so the switch to prepaid meters was profitable overall. However the net returns (pre-paid vs post-paid) were positive from low-income customers and previous payment defaulters but negative among customers who had paid all of their previous bills, implying the profitability of a prepaid meter system depends on the context in which it is introduced (Jack & Smith, 2020).

[1] The study did not, beyond meter tampering, how other forms of power theft (line tapping, by-passing the meter entirely etc) might or might not have been affected by the change to tamper proof meters.

[2] It is important to note that when studies such as this rely on utility billing data to measure consumption, what is not ruled out is the possibility that there is an increase in unbilled consumption (electricity theft), which allows consumption to remain constant (or at least not decline as much). In such cases, the effects on the wellbeing of households are ambiguous.

Aerial Bundled Cables

A third technical option, for addressing losses, both technical and non-technical, is Aerial Bundled Cables (ABCs). Rarely mentioned in the literature, ABCs are an expensive upgrade from basic bare electrical wires used to distribute electricity over the last step from transformer to consumer, which are cheap but also exposed and easily tapped by illegal connections. With ABCs, the cables are twisted together and insulated with a tough coating resistant to weathering, abrasion, tearing, cutting, and chemicals. This makes creating illegal connections to the distribution system (by temporarily 'hooking' wires from houses directly to the distribution cables) more difficult (Ahmad A. , Ali, Meeks, Wang, & Younas, 2022). Prior to the EEG-sponsored research reported on below, there were no studies found in the literature on the impacts of ABC's on non-technical losses.

The political economy of tackling non-technical losses

Given non-technical losses cover fraud, theft, non-payment of bills and billing irregularities one would assume that tackling these problems would involve political economy challenges as well as technological ones. That said there is a surprising absence of studies discoverable in the literature reviewing such challenges during implementation of any of the three technological options discussed above.

Research questions emerging from the literature and relevant EEG research projects contributing findings to this paper

Based on the review of literature above several potential research questions arise:

1. What is the scale of the impact of the introduction of pre-payment meters on electricity consumption, is that impact is always negative, and what impact do such reductions in consumption, when they occur, have on lower income households with already very low levels of consumption?
2. Where smart meters have been introduced in developing economies what has the impact of 'smart' features such as post-paid automated billing, on-line bill payment, remote disconnection and reconnection capabilities and 'real time' information provision on utility performance?
3. What have been the impacts of the implementation of ABC's on electricity theft and utility revenue in emerging economies?
4. What are the political economy challenges associated with resolving non-technical loss problems and what evidence exists on how they can be resolved?

This remainder of this paper seeks to use the findings of 5 pieces of research sponsored by EEG between 2017 and 2022 to provide some insights and discussion around each of the above four research questions. The projects are summarised in the table below.

Research location / lead researcher(s) / Institution	Research description
India Sudarshan, A. University of Chicago	**Smart metering and electricity access: the effect of smart metering on revenue collection, electricity access and supply**. A Jameel Poverty Action Lab, South Asia led study evaluating the ability of smart metering with prepayment to break the cycle of low payment leading to restricted and low-quality supply in India. It aims to answer whether smart metering can improve cost recovery, and thereby energy reliability and access.
Kyrgyzstan & Pakistan Meeks, R. Duke University	**The role of metering and infrastructure improvements in power system resilience during COVID-19**. A Duke University led study analysing the impact of COVID-19 on electricity distribution companies and exploring how the pandemic has affected the efficacy and resilience of metering systems and infrastructure upgrades in reducing loss and/or increasing cost recovery.
Ethiopia Beyene, A.	**Impacts and drivers of policies for electricity access: micro- and macro-economic analysis of Ethiopia's tariff reform**. A Policy Studies Institute led

Policy Studies Institute	micro- and macro-level analysis of Ethiopia's tariff reform, but also a study of the effect of prepaid metering on household electricity use.
Bangladesh / global Das, DK; Stern D I; National University of Australia	**EEG Energy Insight: Pre-paid metering and electricity consumption in developing countries**. Combined literature review and Bangladesh-based study commissioned by EEG on recent developments in the adoption of pre-paid metering in sub-Saharan Africa and South Asia. Examines the effects of pre-paid metering on electricity consumption documented in the literature and reports on an experiment on the same in Dhaka Bangladesh.
Global McKinnon, S; Mulhall, R; and Owen, E	**EEG Energy Insight: Disruptive innovations in smart electricity systems: Opportunities and challenges for sub-Saharan Africa** A literature review of continuing advances in renewable generation technologies, the increase in the use of 'smart' systems, and the further electrification of heat, transport, and cooking make electricity.

Prepaid metering – impacts on consumption

Prepaid meters and reduced consumption in Ethiopia (Beyene, et al., 2022)

As part of a broader study of the impacts and drivers of policies for electricity access in Ethiopia the Policy Studies Institute looked at the adoption of pre-paid meters in Addis Ababa, whether they reduce consumption of electricity, their impact on ownership of appliances, level of satisfaction, and cooking behaviour (Beyene, et al., 2022). A total of 1182 households were interviewed for the study.

Following on from an earlier pilot the Ethiopia Electricity Utility (EEU) started installing prepayment meters widely in 2008. Currently about 25% of the more than 2 million domestic customers have pre-paid meters. EEU's rationale for installing the meters is that they will help to reduce non-technical losses and improve understanding of energy use, improving planning and thus facilitating improvement of customer service quality. Householders have to top up their meter account by buying a fixed amount of electricity from a local payment centre. Customers are disconnected if they fail to maintain a credit balance, but the meter does not cut out immediately zero is reached, to give time for the customer to top up if it occurs, for example, late at night.

More than 89% of the households sampled in this study had an electricity meter in their house, while the remaining 11% got their electricity from a neighbours' house (meter sharing is commonplace in Addis Ababa). Amongst the households with meters covered by the survey, 56% were post-paid meter users, and the remainder pre-paid subscribers.

The research found "strong and consistent evidence" that the use of pre-paid meters reduces household electricity consumption, with pre-paid meter users having 13% lower monthly average electricity expenditure and 19% lower monthly average electricity consumption than post-paid meter users. The study looked at whether the pre-payment system led to the adoption of energy-saving devices. Analysis by appliance type did not reveal statistically significant impacts on ownership of specific categories of appliances, with the exception of the adoption of energy efficient light bulbs. The role of prepaid meter on cooking behaviour in the sampled households was also analysed. Results showed that prepaid meters were not found to have any meaningful impact on household cooking behaviour, as reflected by the number of cooking and baking episodes per week, or on the use of electric stoves.

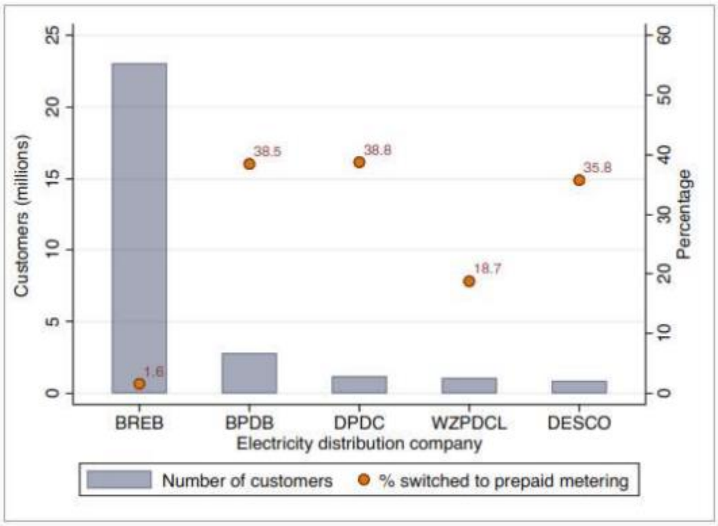
Finally the study found that electricity consumption decreases for both low-income and high-income groups with pre-paid meters, but that the effect is greater for higher-income households[3].

Prepaid meters and reduced consumption in Bangladesh (Das & Stern, 2020)

[3] The study found some heterogeneity of impact across customers, in that those who are more educated, who have higher income, or who do not share meters tend to reduce electricity use more than other customers.

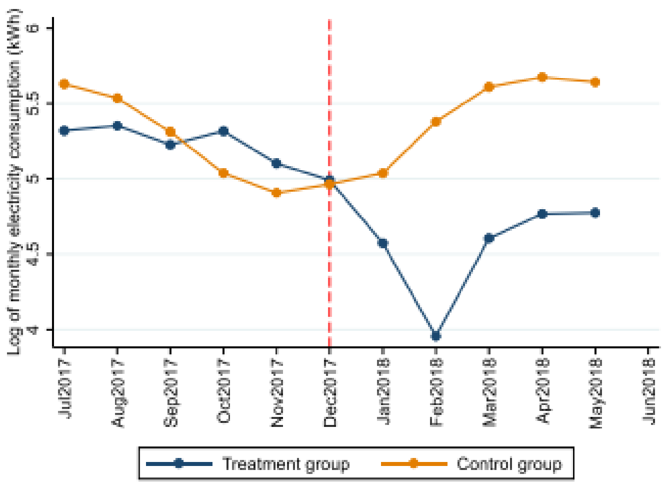
In Bangladesh pre-paid metering of electricity was first piloted in Dhaka by the by Bangladesh Power Development Board (BPDP) in 2004 to help reduce non-technical losses. In 2011 five utilities started a unified programme to replace post-paid meters with pre-paid ones. As Figure 1 shows, for three utilities pre-paid maters have reached over 35% penetration, although for two others, including the largest, BREB, the figure is much smaller.

Figure 1: Current adoption of pre-paid meters by Bangladesh Utilities (Das & Stern, 2020)[4]



An EEG-sponsored study, led by the Australian National University (Das & Stern, 2020), reviewed monthly billing data for 7,954 customers of the Dhaka Power Distribution Company from two areas: Ramna and Khilgaon from July 2017 to June 2018. Customers from Khilgaon were shifted to pre-paid meters in December 2017 and were considered the treatment group in this study, while those in Ramna remained on post-paid meters and provided the control sample. The study used difference in difference technique to control for seasonal consumption patterns and found that, after an initial temporary reduction of over 30%, customers' monthly electricity consumption settled at an average of a 17% reduction when they were switched from post-paid to pre-paid metering, compared to those who remained on post-paid meters (see Figure 2).

Figure 2: Effects of switching to pre-paid metering in Dhaka, Bangladesh (Das & Stern, 2020)

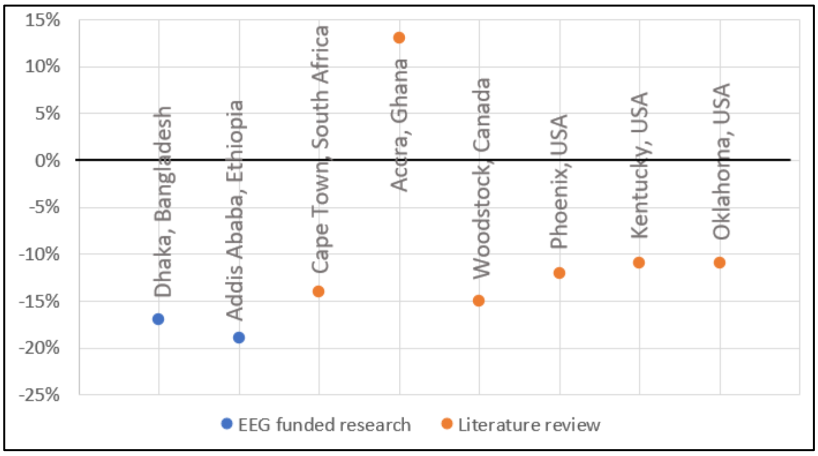


Comparison with the literature

[4] BREB: Bangladesh Rural Electrification Board; BPDB: Bangladesh Power Development Board; DPDC: Dhaka Power Distribution Company Ltd; WZPDCL: West-Zone Power Development Company Ltd; DESCO: Dhaka Electricity Supply Company Ltd

The above two studies in Bangladesh and Ethiopia add to the findings from the literature review earlier in this paper, that the introduction of pre-paid meters generally leads to a reduction in metered consumption of electricity by households, with the Ghana study (Otchere-Appial, Takahashi, Yeboah, & Yoshida, 2021) remaining the only example of a contrary finding (see Figure 3).

Figure 3: Average change in household metered electricity consumption after a shift from post-paid to pre-paid meters[5]



Although (Beyene, et al., 2022) found impacts on households in Addis Ababa limited to the adoption of energy efficient light bulbs, with no meaningful change in cooking arrangements (likely to be the most energy intensive activity in households), overall there remains very limited data on the impact of the reduction in energy consumption resulting from the introduction of smart meters on welfare, particularly in poorer households where electricity consumption is relatively low.

The impact of the deployment of 'smart' features of smart meters

Perception of impacts of deploying 'smart' meter features in the Kyrgyz Republic (Isaev, Meeks, & Omuraliev, 2022)

This research study (Isaev, Meeks, & Omuraliev, 2022) was a follow-up to the earlier study of smart meters in the Kyrgyz Republic mentioned above (Meeks, Omuraliev, Isaev, & Wang, 2021) and sought to understand, from the perspective of distribution companies, whether the efficacy of these smart meters in reducing losses and improving quality of supply demonstrated in the earlier study helped with power system resilience during the COVID pandemic.

Four distribution companies provide electricity across the Kyrgyz Republic. Reducing non-technical looses has been a priority, with smart meter installation seen as part of the solution part. The distribution companies have been in installing smart meters for a number of years with around 215,000 consumers having had the meters installed by 2020, equivalent to around 15% of the nation's total connections.

This study targeted the 43 local offices of three of the four distribution companies (Osh Electric, Sever Electric and Vostok Electric). Each local office includes two departments: engineering and finance, and the study set out to get responses to a web-based survey from an engineer and an accountant from each office. Ultimately responses were secured from 57 individuals across the 43 offices. Table 1 shows the 43 offices concerned covered just under 2 million residential and industrial consumers, of which a fifth or the former and a third of the latter were connected to the grid via smart meters.

[5] Based on data from the following studies: Dhaka (Das & Stern, 2020), Addis Ababa (Beyene, et al., 2022), Cape Town (Jack & Smith, 2020), Accra (Otchere-Appial, Takahashi, Yeboah, & Yoshida, 2021), Woodstock **Invalid source specified.**, Phoenix **Invalid source specified.**, Kentucky **Invalid source specified.**, Oklahoma **Invalid source specified.**

Table 1: Summary of smart meter adoption across the 43 distribution company offices of the three utilities surveyed.

Customer type	Total number of customers	Number with smart meters	% with smart meters
Residential consumers	1,799,946	362,398	20.1%
Industrial consumers	184,867	62,407	33.8%
Total	1,984,813	424805	21.4%

The study found that, because each distribution company managed its own procurement process for smart meters, there was heterogeneity across meter type and functionality between the companies. For instance, 79% of the respondents use their meters' smart features to remotely disconnect and reconnect customers, when necessary (for example for non-payment of bill or where electricity theft is identified), while 16% don't (Figure 4). On the other hand very few (apparently just 7%) use smart meters' remote billing functionality, with the vast majority of bills still issued manually (see Figure 5).

Figure 4: Use meters to remotely disconnect customers

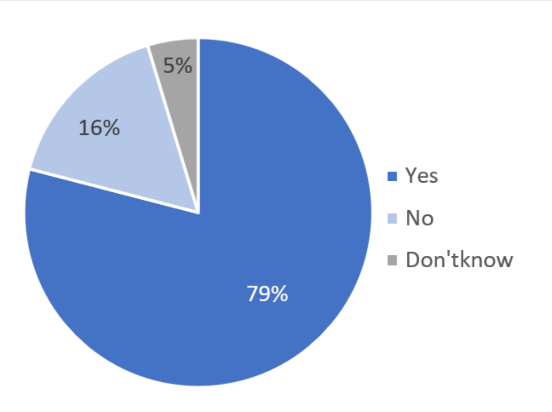
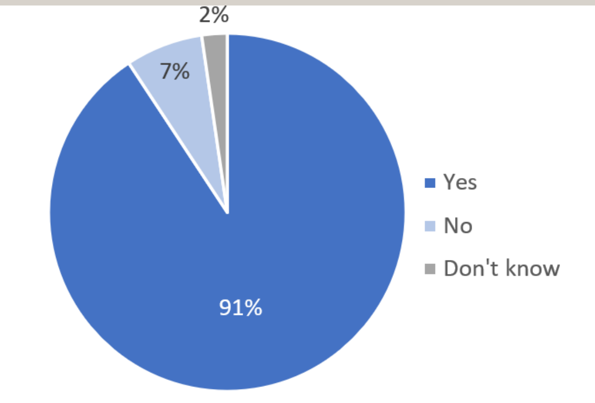


Figure 5: Use meter readers to visit customers to deliver bills



Just over 81% of respondents felt the smart meters' in-built protection features against voltage fluctuation were important to protect the grid and consumers' electrical equipment, a finding that tied in with the earlier study (Meeks, Omuraliev, Isaev, & Wang, 2021) that found these features led to improvements in service quality. Around 63% of distribution company respondents felt that smart meters reduced the frequency of complaints and appeals from customers.

The first cases of COVID-19 were seen in the Kyrgyz Republic in March 2020 and the country was subsequently affected by lockdowns and social distancing measures. The study asked distribution company staff about the impacts of these restrictions on their operations; 51% mentioned illness prevent ed workers from doing their jobs and 72% that there were problems with consumers paying their bills on time, with reasons given as: government providing extended grace period for payment (72%), financial hardship (51%) and illness preventing bill payment in person (54%). That said, only 14% of respondents felt these difficulties resulted in higher technical losses or lower revenue recovery compared to the period immediately pre-pandemic, with 63% of respondents feeling that smart meters mitigated the challenges and pressures on the distribution companies as a result of the pandemic (although there was no further data on why that was so).

Impacts of deploying 'smart' meter features in Haryana, India (EEG, 2017)

This large-scale neighbourhood-level randomised control trial in Haryana, India, was undertaken in the towns of Karnal and Gurgaon where a smart meter rollout was being implemented and over 60,000 smart meters had already been installed. At the time of the start of the study, the meters were functioning as traditional electromagnetic meters with 'smart' features such as remote disconnection, real-time data transfer, remote billing, or pre-payment options not yet activated. Individual 'smart' features could be switched on remotely by software functions, providing an experimental environment to compare the impacts of smart and traditional meters.

The experiment was a cluster-based design, where selective batches of consumers called binders (as per the Haryana administration), had some or all their consumers shifted to online billing and also made eligible for remote disconnections (for non-payment of bills), while others remained with their meters functioning in a manner equivalent to traditional analogue meters as the 'control' population (with manual meter reading, billing and, where required, disconnections). The experiment design was completed and approved in December 2020 and involved a total sample of 23,541 consumers spread across 125 binders across two treatment arms for (1) online billing and (2) remote disconnections.

The remote billing experiment was started in March 2021 and ran to September 2021 (at which point all the consumers in the manual billing control group were also moved to remote billing) and involved consumers across 100 binders in four sub-divisions (Abdul Latif Jameel Poverty Action Lab, 2022). In order to analyse the impact of remote billing on billings, payments and consumption patterns of the consumers, these consumers were divided into following 3 groups (see Table 2).

Table 2: Grouping of consumers for comparison of automated remote meter reading and billing (AMI) vs manual meter reading and billing (Non-AMI)

Treatment Group	Treatment Status	Description	Number of consumers
0% Group	Non -AMI	0% consumers with remote billing	4,369
80% Group	Non-AMI	20% of consumers with manual billing	2,781
	AMI	80% of consumers with remote billing	11,131
100% Group	AMI	100% of consumers with remote billing	5,260

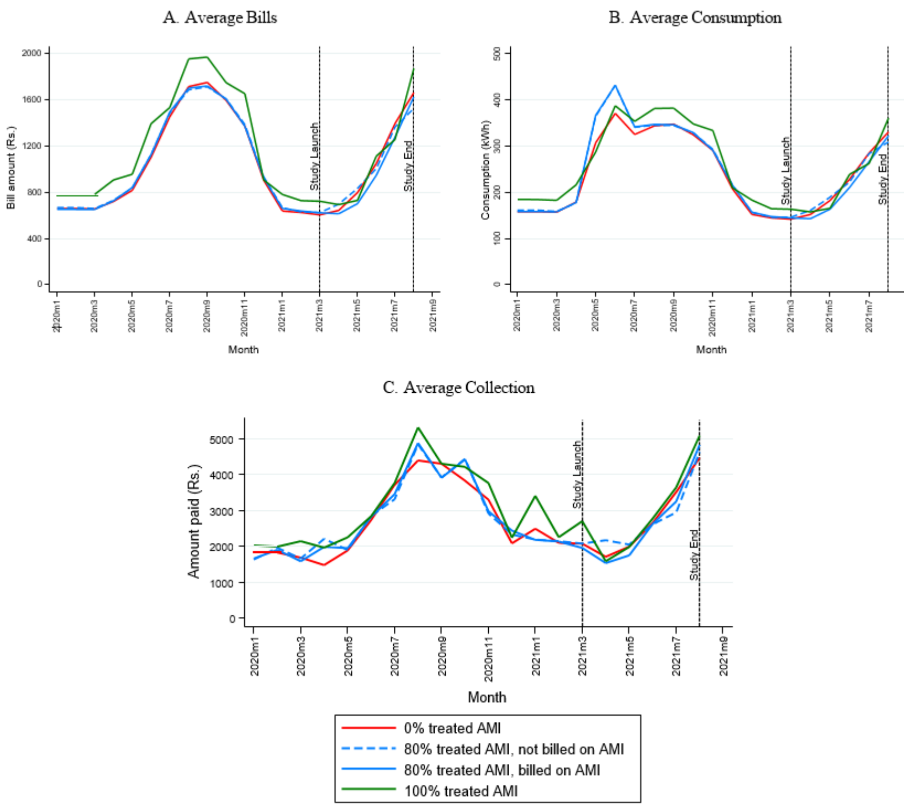
Alongside this, following discussions with the appropriate teams in the utility, and with the approval of the Principal Secretary (Energy) of the Government of Haryana, a treatment and control list of payment defaulters was prepared in order to compare the effectiveness of using a protocol for remote disconnections using the smart meter functions against traditional decision making and manual disconnection of consumers with persistent high arrears. These lists were provided over the period July 2021 to April 2022.

Analysis of the results of the automated billing trial looked at three variables – average billing, consumption and collections. Figure 6 shows the average of these variables for consumers at the starting point for the automated billing feature being switched on in the treatment groups' meters. The majority of the difference in these variables throughout the year are due to seasonal variation, with peak consumption in the summer months. The experiment found that all three variables decreased slightly in populations where consumers switched to online billing. Billed amounts fell by about 6 per cent where 80% of the populations were switched to online billing and by 8.5 percent where there was 100% online billing. Consumption also reduced by similar amounts, while collections fell by 4.8% for the population where 80% were using online billing and 2.9% for those where 100% online billing was implemented, although these estimates were described as "more noisy" (Sudarshan, Burgess, & et_al, 2022, p. 9).

The research notes that "(t)his translates to a small decline in revenue collection, albeit estimated somewhat imprecisely. This change is not in itself undesirable since it may correct manual billing inaccuracies, and ex-ante it is not obvious whether these are more likely to be biased upwards or downwards" (ibid).

For reasons discussed later in this report under the political economy section, the remote disconnection trial was not successful. In practice field officials disconnected only 17 percent of the consumers flagged for disconnection in the lists provided, with no statistical difference in the probability of disconnection in treatment (manual disconnection) and control (remote disconnection). The failure to implement the remote disconnection protocol meant the utility effectively chose to forgo its main lever to improve revenue recovery or remove persistent non-payers from the network (and in the process potentially provide a more reliable service for the remaining consumers). This in turn threw into question the validity of the decision to replace old meters with expensive new smart meters in the first place, a move which involved considerable capital expenditure. In this case, the electricity utilities were incurring costs of INR 103 per month per consumer over an eight-year period from the vendors who installed the meters but were only seeing cost reductions as a result of switching from manual meter reading to on-line billing of INR 9.62 per month per consumer.

Figure 6: Average bills, consumption, and collection overs time (two month moving average) (Sudarshan, Burgess, & et_al, 2022)



The impact of the use of Aerial Bundled Cables (ABCs)

The impact of ABCs in Karachi, Pakistan (Ahmad A. , Ali, Meeks, Wang, & Younas, 2022)

This study (The Economic and Environmental Effects of Infrastructure Improvements: Evidence from Pakistan's Electricity Sector) was part of a broader piece of research looking at the impacts of infrastructure improvements on power system resilience in the face of COVID 19. The study focussed on the effects of one type of infrastructure improvement, aerial bundled cables (ABCs), in Karachi, Pakistan. The city's utility, Karachi Electric, has a distribution network that covers an area of over 6,500 square kilometres, with 2.5 million residential, commercial, agricultural and industrial customers. Transmission and distribution losses were high across the city in the early 2000's and, from 2009, Karachi Electric aggressively focused on reducing losses through the allocation of outages (load shedding) according to past losses, infrastructure improvement programs, metering, and customer facilitation initiatives. As a result, the average transmission, and distribution losses declined from 35.9% to 19.1% and revenue recovery improved from 88.6% to 92.6% over the period 2009 to 2019.

Isolated areas across the city still experienced high losses, however. The network is divided into 30 local offices, 12 of which are categorised as high loss areas, with average losses exceeding 30% and bill payment rates averaging below

80%. These high loss areas have higher proportions of lower income informal settlements where people on low and fluctuating incomes may find it difficult to pay formal electricity bills in full on time and where local poor local law enforcement and political conditions make it difficult to remove illegal connections, which often exist in large numbers. High levels of planned (and unplanned) outages in these areas in these areas means that the daily experience of electricity service provision is also poor, leading to mistrust in the utility. The introduction of ABC's was part of a wider set of initiatives[6] to try to reduce power theft and improve reliability and revenue recovery in these high loss areas.

This quantitative study used differences in the timing of the introduction of ABCs across Karachi over time to measure its effects on economic outcomes relevant to both the electricity utility and consumers. Since the roll-out of ABCs created variations across feeder lines and over time, the research used a staggered difference-in-differences approach to identify the causal effect of ABC conversion on feeder-level losses and revenue recovery. For the utility, the research estimated the impacts of ABCs in terms of changes in financial losses and revenue recovery, using a feeder-level monthly panel dataset from Karachi Electric that covered the period between January 2018 to late 2020 and extended to 2,163 feeder lines. It also looked at the extent to which ABCs helped Karachi Electric to mitigate the pandemic's impacts on these financial outcomes. In addition to this analysis, a sample of 3,000 households were surveyed to collect information relevant to electricity consumption (including house characteristics, appliance ownership and electricity and non-electricity household expenditure) as well as perceptions of neighbours' theft and payment practices and respondent's beliefs about the utility's electricity service quality, tariff, and billing practices.

The study found, firstly, that the introduction of ABCs reduced losses by between 6 and 8.2% and increased revenue recovery by 5%, with the greatest reduction in losses occurring in the feeders that had previously had the highest losses, and thus lowest revenue recovery. In other words the gains from ABC installation were highest for areas that were the worst performing prior to ABC installation. The study found that that ABC installation also led to a significant increase in the number of formal utility customers, most likely as a result of households who had previously obtained their electricity through illegal connection finding they were no longer able to tap the distribution wires themselves, thus being forced to register as formal customers to continue to have electricity access.

A second major finding of the study was that the roll-out of ABCs provided some technical resilience to the disruptions caused by the COVID-19 pandemic. Losses appear not to have been affected by the pandemic in feeders with ABCs (relative to those without ABCs). This suggests that the pandemic did not lead to an increase in theft in areas with ABC wiring. Revenue recovery, which is dependent on customers' ability to pay bills, was impacted by the onset of the pandemic however, even in areas in which ABCs were installed. Together these suggest that the ABCs increased utility resilience to electricity theft, but not bill non-payment.

Finally, ABC installations led not only to a growth in formal utility customers, but also to residential consumers significantly increasing their billed electricity consumption (both in terms of kWh and value), as well as to reductions in documented theft and irregular billing. The household survey provided insights into how residential consumer behaviour was influenced, with customers in areas with ABCs report experiencing significantly fewer outages than areas without ABCs and, consistent with that, those households invested in more appliances and reported a greater number of hours of appliance use per day.

The political economy challenges associated with resolving non-technical loss problems and evidence on how they can be resolved

As the research project findings above imply, there maybe multiple factors driving non-technical losses, including poverty and inability to pay, mistrust in the utility, political considerations, poor law enforcement, and fraudulent collusion between consumers and utility staff such as meter readers. In such circumstances it is unlikely that solutions will be purely technical. The following section reviews the political economy challenges faced by utilities in the course of tackling non-technical losses revealed in two of the above research projects, and the solutions found by the utility in one of those two cases.

Political economy challenges faced during the installation and use of smart meters in Bihar and Haryana, India

[6] Discussed more under the Political Economy section later in this paper

The RCT experiment with smart meter installation in Haryana mentioned earlier in this paper faced two major challenges during its implementation related to political economy issues with the roll out of smart meters.

Firstly, the project site was originally intended to be in Bihar, but the utilities' plans there were met with public demonstrations against smart meter installations in Arwal and Kanti (the pilot towns). The resulting low take-up by rural and semi-urban consumers led the utilities to pause the mass rollout of smart meters[7]. Preliminary analysis suggested that low take-up might be due to low consumer awareness about the reliability of smart meters and prepaid recharging processes and the utilities therefore temporarily switched from meter installation to a comprehensive consumer awareness programme (Abdul Latif Jameel Poverty Action Lab, 2019).

In response, the research project was moved to Harayana, where significant progress had already been made on installing smart meters, but where their 'smart features' were yet to be turned on. As explained earlier, the research experiment involved looking at the impact of the implementation of the remote billing and remote disconnection features of smart meters in a treatment group of households compared to a control group using pre-existing manual processes. Testing the impact of using the remote disconnection feature however ran into problems. A treatment and control list of defaulters was prepared. These were consumers with persistent high arrears. Unfortunately, in practice field officials disconnected only 17 percent of consumers flagged for disconnection with no statistical difference in the probability of disconnection in treatment and control groups. Discussions with the utility led to the researchers being informed that it would be impossible to follow a rule-based protocol for disconnections, as disconnection requests arrive from multiple directives and officials and that sub-divisions have to factor in reasons based on demography, political connections, etc. that cannot always be put on paper. In brief, utility field officials proved both unwilling to give up discretion in their enforcement choices and unwilling to take consistent action against households with high arrears. These operational / policy decisions suggest that the technology used to meter is not the primary constraint in effective enforcement, and thus revenue recovery (Sudarshan, Burgess, & et_al, 2022).

Political economy challenges faced, and solutions adopted during the installation of ABCs in Karachi, Pakistan

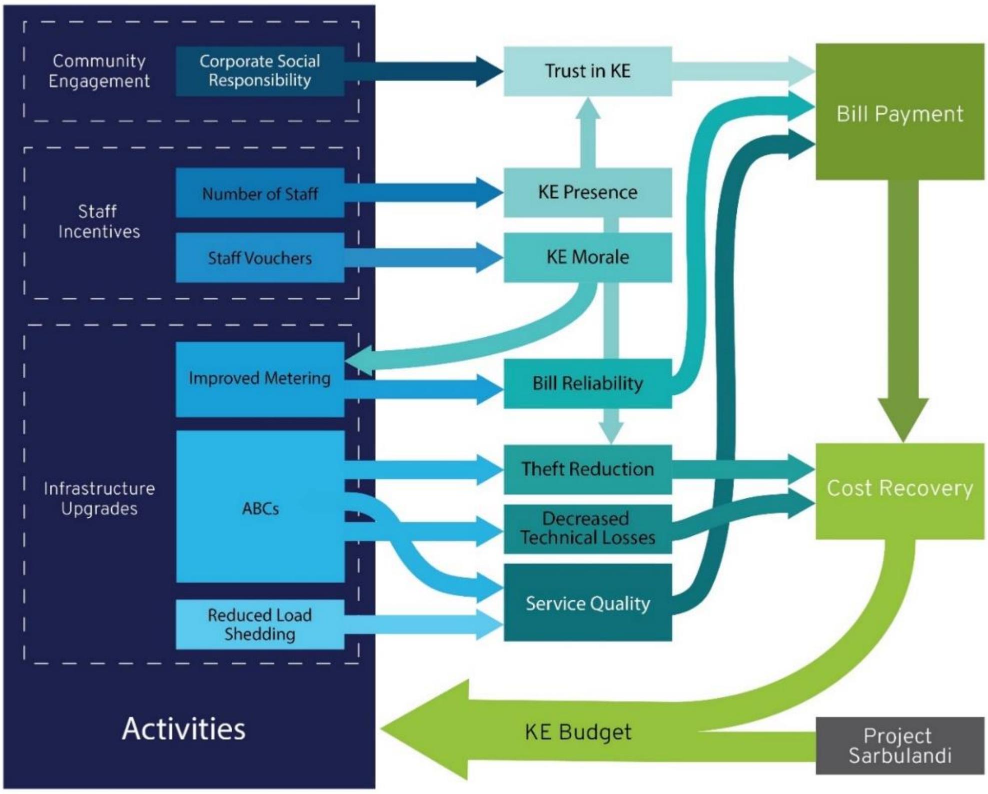
Alongside the quantitative study referenced above into the financial impacts of the installation of ABCs in Karachi, the same research team carried out a qualitative study to understand the political economy of the Karachi Electric utility's efforts ultimately successful efforts to pursue ABC installation and reduce non-technical losses (Ahmad H. , et al., 2022).

The research project interviewed General Managers (GMs) for all six local offices that had already begun implementation of phase one of Project Sarbulandi and two of the local offices that had not yet begun implementation but would do so under phase two. Questions covered the perceived impacts of each intervention, the challenges encountered, and issues surrounding electricity theft and bill payment. The interviews with two local offices to be included in phase two of the project allowed researchers to compare perceptions of the impact Project Sarbulandi from offices that were yet to implement it to those who already had.

Responses from the GM interviews demonstrated that the utility's approach to reducing non-technical losses recognised that the introduction of new technology (ABCs) had to be accompanied by attitudinal and behavioural changes by both consumers and utility staff. The approach taken by Karachi Electric was pursued under the banner of "Project Sarbulandi", and interventions consisted of: (1) infrastructure upgrades, (2) staff incentives, and (3) customer engagement. The relatively complex interactions between these three areas of intervention, their outcomes and how that led to improvements in cost recovery and bill payment is summarised in Figure 7 and described in more detail below.

[7] Although at the time of the study the authorities in Bihar struggled to implement smart meter roll out, the programme was later re-started, with a focus on using the smart meters in pre-payment mode. The utility has attempted to make prepaid billing more attractive by including a proposal to pay interest on what consumers deposit (on the basis that a prepaid deposit is basically an advance given to the utility) and the provision of slightly more attractive tariffs (changes in fixed costs). As a result smart meter installation has now moved ahead (personal communication with author).

Figure 7: Project Sarbulandi's multiple routes to addressing non-technical losses (Ahmad H. , et al., 2022)



One of Project Sarbulandi's targets was to convert all distribution cables in high loss areas to ABCs. There was some flexibility given to local offices concerning the approach they used to achieve this. Although all target areas had large numbers of illegal connections, GMs indicated that they normally started with areas where it was likely there would be the lowest resistance from consumers. GMs also moved, at least temporarily, from a policy where areas with high non-technical losses were 'punished' by being scheduled for more relatively hours of load shedding, to one involving "special approvals" to reduce load shedding on feeders with recent ABC installations. This combination of approaches allowed them to complete initial conversions to ABCs successfully and create early demonstration effects of improved service delivery in those areas.

According to the GMs interviewed, these visible improvements in the quality-of-service increased support for the utility's staff team amongst customers and led to more of an acknowledgement that bill payment and quality of service were related. Soe of the resulting reported impacts was quite drastic with, for example, one area seeing a decrease in losses from over 50% to 15% and an increase in cost recovery from 30% to over 90% with the installation of ABCs and new meters.

A second feature of Project Sarbulandi was an increase in staff incentives in the form of vouchers for grocery purchases, paid out when local offices reached their monthly targets. These incentives were flet to have had a major impact on staff morale and motivation.

The third feature of the Project Sarbulandi interventions was customer engagement. This took several forms that varied between local offices, but which included medical camps to provide treatment services for local residents and gifts, sports events or 'fun galas' for children. These events were often run one or two days before electricity bills were due and were all part of a process to improve public relations and to mitigate the "resistance" demonstrated by consumers that now had to pay for electricity.

Discussion

Table 3 summarizes the findings of the research reviewed by this paper.

Table 3: Summary of interventions addressing non-technical losses studied under the EEG programme

Intervention	Recorded impact	Mechanism suggested	Relevant study	Not measured
Prepaid meters introduced	Metered consumption drops Losses fall, revenue recovery increases	Nudges / efficiency measures Additional revenue exceeds costs	Bangladesh, Ethiopia, South Africa South Africa	Any changes in losses or revenue recovery The cost of implementation (except South Africa)
	Metered consumption (but not necessarily actual consumption) rises. Losses fall, revenue recovery increases	Theft reduced by prevention of meter tampering. Consumers forced to use legal connections.	Ghana	The cost of implementation.
Smart meter remote billing	Slight reduction in consumption and receipts. Cost of smart meters exceeds savings from reduction in meter reading costs.	No change to enforcement of disconnections means no improvement to revenue recovery.	India	Impact of reduction in consumption on households' wellbeing
Smart meter remote billing + remote disconnection + spike protection	Consumption increases, appliance ownership increases overall revenue and revenue recovery increases, losses fall	Utility has better information and quicker response to outages, system more stable and reliable (greater consumer confidence), disconnection policy enforcement	Kyrgyz Republic	Cost of implementation
ABCs introduced	Consumption increases, appliance ownership increases losses fall (Impact on losses holds over COVID but not on revenue recovery – ability to pay is a factor)	Routes to power theft blocked, but utility also ensures lines fitted with ABCs see a reduction in blackouts, carries out other activity to improve customer relations while also incentivising staff.	Pakistan	Cost of implementation Relative role of smart meters (that were also introduced alongside ABCs)

Prepaid metering

The two EEG-funded studies on pre-paid metering in Ethiopia (Beyene, et al., 2022) and Bangladesh (Das & Stern, 2020) align with other studies in the literature to show that, in emerging economies, the introduction of pre-paid metering tends to result in an average reduction in household monthly consumption of electricity of between 17 and 19%. Although there is some evidence from the Ethiopian study that critical functions such as cooking are not being compromised by this reduction in energy use, the research in general does not throw much light on how these reductions in consumption are being achieved by households and the extent to which they matter in terms of welfare. Prepayment makes the cost of energy more visible and allows discretion to be exercised at the point of purchase, which may nudge behaviour and cause people to budget more carefully and waste energy less. Under such scenarios pre-paid metering may benefit the consumer by reducing unnecessary expenditure on energy and so release funds in the household budget for other expenditure. At the other end of the spectrum however, households that have previously been accessing some or all of their electricity through illegal connections or who have been serial defaulters on their bills because they cannot afford the full cost of their usage, may find those routes to electricity access cut off with the introduction of pre-paid meters. For such households' pre-paid meters could mean a genuine reduction in welfare. The absence of research into the mechanism by which reductions in consumption are being achieved means that the impacts of the introduction of pre-paid meters on poor households' welfare remains unclear.

Smart meters

The EEG-funded study in Haryana, India (Sudarshan, Burgess, & et_al, 2022) demonstrated that non-technical losses cannot be addressed by technological solutions alone. Moreover, without a commitment within the utility to uniformly implement a disconnection policy for persistent non-payers, the cost of installing smart meters can significantly exceed any savings possible from efficiency gains. Conversely, the Kyrgyz Republic study (Isaev, Meeks, & Omuraliev, 2022) demonstrates that, with the right supporting policies implemented, smart meters can be an important part of a solution that leads to a reduction in losses, improvements in reliability, and increased revenue from increased consumption.

Ariel Bundled Cables (ABCs)

The two studies in Pakistan looking at the impacts of the installation of ABCs reinforced the message from the Kyrgyz Republic study mentioned above. The studies showed that technological solutions to theft prevention can be an important element of approaches to reduce non-technical losses, when supported with policy actions that recognise and address the political economy issues surrounding such losses, notably a lack of confidence and trust amongst consumers in the utility, based on past performance and poor system reliability.

Further Research

A number of potential areas for further research arise from the above discussion:

1. <u>The impact of reductions in electricity consumption after prepayment meter installation</u>: Much of the research on pre-paid meters indicates that their introduction results in a reduction in electricity consumption by households. While there may be positive aspects to this in terms of households being more conscious of their electricity usage and reducing waste, there is little evidence available in the literature of the impact of such reductions on the wellbeing of poorer households where electricity consumption is already low.
2. <u>The political economy of addressing non-technical losses</u>: The Karachi study cited above (Ahmad H. , et al., 2022) provided good insights into an effort to combine technical approaches to theft reduction with an understanding of the political economy such losses are embedded in, more case studies would be useful to demonstrate successful approaches to incentivizing both consumers and utility staff to support changes that lead to a reduction in theft and improvements in reliability of electrical services.
3. <u>The returns on investment of different approaches to power theft reduction:</u> Many of the studies reviewed in this paper are selective in what costs they consider and what they ignore in reviewing the effectiveness of approaches to non-technical loss reduction. In many cases the actual cost of implementation (for example the cost of new smart meters, or of incentives to improve staff productivity, or the cost of consumer outreach campaigns) are not included in an overall assessment of costs and benefits. More extensive analysis in this area would be instructive.
4. <u>Longer term studies:</u> Many of the studies referenced above consider the impacts of technical solutions to non-technical losses over a relatively short period after installation (for example 1 year (Jack & Smith, 2020; Otchere-Appial, Takahashi, Yeboah, & Yoshida, 2021) or 6 months (Das & Stern, 2020))or are cross-sectional studies at a fixed point in time (Beyene, et al., 2022). Further research to understand the long-term impacts on utility's performance, service quality and household level outcome variables (e.g., appliance ownership, energy consumption, etc.) would also be useful

References

Abdul Latif Jameel Poverty Action Lab. (2019). *The Effect of Smart Metering on Revenue Collection, Electricity Access and Supply - December 2019 progress report.* Unpublished interal monthly progress report to the Energy and Economic Growth Applied Research Programme.

ADB. (2021, November 19). *Smart Meters for Energy Efficiency.* Retrieved July 11, 2022, from Asian Development Bank: https://www.adb.org/news/videos/smart-meters-energy-efficiency

Ahmad, A., Ali, A., Meeks, R., Wang, Z., & Younas, J. (2022, April). *The Economic and Environmental Effects of Infrastructure Improvements: Evidence from Pakistan's Electricity Sector.* Retrieved July 6, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/index.php/publication/economic-and-environmental-effects-infrastructure-improvements-evidence-pakistans

Ahmad, H., Ali, A., Meeks, R., Plutshack, V., Zhenxuan, W., & Younas, J. (2022). Breaking the culture of non-payment: A qualitative analysis of utility intervention Project Sarbulandi in Karachi Electric, Pakistan. *Working paper (submitted for publication)*.

Bellero, L. (2017, May 10). *Utilities worldwide lose $96B each year from nontechnical losses, study says*. Retrieved July 7, 2022, from S&P Global Market Intelligence: https://www.spglobal.com/marketintelligence/en/news-insights/trending/abhemb-9pog6vtjy1i8iia2

Beyene, A., Jeuland, M., Sebsibie, S., Hassen, S., Mekonnen, A., Meles, T., . . . Pattanayak, S. (2022, May). *Policy Brief: Pre-paid meters and household electricity use behaviours in Addis Ababa, Ethiopia.* Retrieved July 6, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/index.php/publication/policy-brief-pre-paid-meters-and-household-electricity-use-behaviours-addis-ababa

Boateng, K., & Ghansah, I. (2015, February). Low Cost Early Adoption Procedures for mplementing Smart Prepaid Metering Systems in African Developing Countries: An effective way of dealing with energy crises. *Journal of Multidisciplinary Engineering Science and Technology (JMEST), 2*(2), 240-250.

Carr, D., & Thomson, M. (2022, March 18). Non-Technical Electricity Losses. *Energies, 15*, 2218. doi:https://doi.org/10.3390/en15062218

Das, D., & Stern, D. (2020, October). *EEG Energy Insight: Pre-paid metering and electricity consumption in developing countries.* Retrieved from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/publication/pre-paid-metering-and-electricity-consumption-developing-countries

EEG. (2016). *Smart metering and electricity access, The effect of smart metering on revenue collection, electricity access and supply*. Retrieved July 8, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/node/271

EEG. (2017). *Smart metering and electricity access; The effect of smart metering on revenue collection, electricity access and supply*. Retrieved July 24, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/index.php/node/271

Glauner, P., Glaser, C., & et-al. (2018, May). *Non-Technical Losses in the 21st Century: Causes, Economic Effects,Detection and Perspectives.* Retrieved July 7, 2022, from Researchgate: https://www.researchgate.net/publication/325297875_Non-Technical_Losses_in_the_21st_Century_Causes_Economic_Effects_Detection_and_Perspectives

Isaev, R., Meeks, R., & Omuraliev, A. (2022, March). *Policy Brief: Power Systems and COVID-19: Understanding the Role of Smart Meters in the Kyrgyz Republic.* Retrieved July 6, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/publication/policy-brief-power-systems-and-covid-19-understanding-role-smart-meters-kyrgyz-republic

Jack, K., & Smith, G. (2020). Charging Ahead: Prepaid Metering, Electricity Use, and Utility Revenue. *AMERICAN ECONOMIC JOURNAL: APPLIED ECONOMICS, 12*(2), 134-68.

Jones, J. (2021, September 8). *India's smart meter rollout - 250 million meters by 2025*. Retrieved September 19, 2022, from Smart Energy International: https://www.smart-energy.com/industry-sectors/smart-meters/indias-smart-meter-rollout-250-million-meters-by-2025/

McKinnon, S., Mulhall, R., & Owen, E. (2019, June). *EEG Energy Insight: Disruptive innovations in smart electricity systems: Opportunities and challenges for sub-Saharan Africa.* Retrieved July 6, 2022, from Energy and Economic Growth Applied Research Programme: https://www.energyeconomicgrowth.org/publication/eeg-energy-insight-disruptive-innovations-smart-electricity-systems-opportunities-and

McRae, S. (2015, June 1). *Efficiency and Equity Effects of Electricity: Evidence from Columbia.* Retrieved July 11, 2022, from Shaun McRae: https://www.sdmcrae.com/publication/efficiency-and-equity-effects-of-electricity-metering/efficiency-and-equity-effects-of-electricity-metering.pdf

Meeks, R., Omuraliev, A., Isaev, R., & Wang, Z. (2021, June 14). *Smart Meters and the Benefits from Electricity.* Retrieved July 6, 2022, from Robyn Meeks.com: http://www.robynmeeks.com/wp-content/uploads/2021/06/Smart_meters_202106.pdf

NES. (2020, June 30). *Energy Theft and Fraud Reduction*. Retrieved July 7, 2022, from Smart Energy International: https://www.smart-energy.com/industry-sectors/energy-grid-management/energy-theft-and-fraud-reduction/

Nhede, N. (2020, April 3). *AMI penetration in Africa: a comparison with global progress*. Retrieved July 8, 2022, from Smart Energy International: https://www.smart-energy.com/industry-sectors/smart-meters/penetration-in-africa-a-comparison-with-global-progress-advanced-metering/

Otchere-Appial, G., Takahashi, S., Yeboah, M., & Yoshida, Y. (2021, March 26). The Impact of Smart Prepaid Metering on Non-Technical Losses in Ghana. *Energies, 14*(7), 1852. doi:https://doi.org/10.3390/en14071852

Ramesh, M. (2021, June 27). *Can smart meters turn around discoms?* Retrieved September 21, 2022, from The Hindu - Business Line: https://www.thehindubusinessline.com/specials/clean-tech/can-smart-meters-turn-around-discoms/article64578185.ece

SAMSET. (2015, July). *Smart Metering: Overview and Considerations for South African Municipalities.* Retrieved July 11, 2022, from SAMSET - Supporting Sub-Saharan African Municipalities with Sustainable Energy Transitions: http://samsetproject.net/wp-content/uploads/2016/02/Smart-metering-overview-and-consideration-for-South-African-municipalities.pdf

Shoukat, A. (2022, January 19). *Enabling smart metering in Pakistan: FINCA and SBEEC*. Retrieved September 19, 2022, from GSMA Mobile for Developmenyt: https://www.gsma.com/mobilefordevelopment/blog/enabling-smart-metering-in-pakistan-finca-and-sbeec/

Shrestha, A. (2020, August 12). *NEA starts installing smart electricity meters in Kathmandu*. Retrieved September 19, 2022, from techlekh.com: https://techlekh.com/nea-smart-electricity-meters/

Sudarshan, A., Burgess, R., & et_al. (2022). *The Effect of Smart Metering on Revenue Collection: Evidence from an Experiment in Harayana* . Oxford: Applied Research Programme on Energy and Economic Growth.

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