How Valuable is the Reliability of Residential Electricity Supply in Low-Income Countries? Evidence from Nepal

Anna Alberini,[a] Jevgenijs Steinbuks,[b] and Govinda Timilsina[c]

ABSTRACT

We use contingent valuation to estimate the willingness to pay (WTP) for improved electricity service in Nepal following the end of the country's load-shedding crisis of 2007–2016. Using a nationally representative survey of grid-connected Nepali households, we calculate the WTP per outage-day avoided and the value of lost load (VoLL) for residential customers and analyze their key drivers, including income, education, and investments in own generation or electricity storage equipment. Households are willing to pay, on average, 123 NR ($1.11) per month for improved quality of power supply. In other words, they would be prepared to see a 65% increase in their monthly bill to avoid outages. Our preferred estimates of the VoLL range from 5 to 15 NR/kWh (¢4.7–¢14/kWh). These estimates are below the marginal cost of avoided load shedding, and are virtually the same as valuations at the beginning of the load-shedding crisis.

Keywords: Electricity Reliability, Nepal, Value of Lost Load, Willingness to Pay

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1. INTRODUCTION

Access to reliable electricity services is essential for poverty reduction and economic growth (World Bank, 2017). However, many developing countries, particularly low-income countries in South Asia and Sub-Saharan Africa, face severe electricity shortages, leading to frequent power shedding.[1] Underpricing of public electricity services combined with high technical and commercial losses in these countries limits the utilities' ability to recover capital and operational expenditures and affects the reliability of the power supply (Blimpo and Cosgove-Davies, 2019; Zhang 2019). Valid estimates of the willingness to pay (WTP) for reliable power supply are thus critical for both power system planning decisions and regulatory policies aimed at improving the quality of the electricity services. This is especially important for the residential sector, where low energy consumption makes electricity cost recovery a challenging problem (Trimble et al., 2016; Blimpo and Cosgove-Davies, 2019; Lee et al., 2020).

This paper estimates the value of lost residential electricity service in Nepal, a low-income country that has experienced chronic load shedding in the last decade. The load-shedding crisis

1. Ayaburi et al. (2020), for example, find that more than 3.5 billion people worldwide lack access to "reasonably reliable" electricity services.

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over the period 2007–2016 has imposed high economic costs on Nepal's economy.[2] At the end of 2016, however, the daily load shedding of residential customers ended due to improved electricity dispatch, increased electricity production, and imports from India, though households may still experience some unscheduled outages (World Bank, 2019).

Assessing the value that households place on a reliable power supply is a difficult problem, especially in developing countries. Technical constraints and ethical considerations make it very difficult to randomly assign load-shedding schedules and prices, preventing experimental inference of the WTP increasingly common in other infrastructure settings (Berry et al., 2020; Do and Jacoby 2020; Grimm et al., 2020).

We use contingent valuation to elicit the willingness to pay of residential customers in Nepal for improved power supply. This allows us to get around the issue that it is not possible for us to structurally estimate properly specified residential electricity demand functions and infer the value of lost electricity service from them.

Stated preference methods have been previously used in developing countries to estimate the value of access to the electricity grid and/or a more reliable electricity supply (Kateregga, 2009; Abdullah and Mariel, 2010; Twerefou, 2014; Oseni, 2017, Blankenship et al., 2019, Deutschmann et al., 2021). Our unique empirical setting, the specific valuation scenario, and the econometric estimation techniques advance the existing literature in several ways. First, as Deutschmann et al. (2021), and unlike other developing country studies (e.g., Abdullah and Mariel, 2010; Bose et al., 2006; Twerefou, 2014; Oseni, 2017; Blankenship et al., 2019), we rely on a nationally representative survey of Nepali households, thus avoiding WTP sample selection bias or issues of limited regional coverage.

Second, our experimental design exploits the fact that the survey was done shortly (i.e., less than a year) after the residential load shedding had been eliminated. The respondents were asked to indicate their willingness to pay to avoid the number of days with outages they had experienced before the termination of the load shedding schedule of October 2016. This takes advantage of the respondents' *actual experience* with improved reliability of power supply, and by construction avoids unfamiliarity with the good to be valued (Mitchell and Carson, 1989), a problem frequently faced in similar stated preference studies in developed economies (see, e.g., Layton and Moeltner, 2005; Carlsson and Martinsson, 2007, 2008; Hensher et al., 2014; Ozbafli and Jenkins, 2016) and when the valuation task requires some technical knowledge (Broberg et al., 2021).[3] Finally, using supplemental data on *actual outages* at the transformer substation level, we can validate the quality of respondents' recall—an issue in contingent valuation studies, for which typically there is no easy solution (Hanemann, 1994).

Our analysis starts with calculating the WTP per kWh lost (i.e., the Value of Lost Load, VoLL) given assumptions about the load or exact information about the kWh used in a typical day. We then calculate the WTP per outage-day avoided and analyze its key drivers. Finally, we assess the internal validity of our estimates by regressing the WTP on the number of outage-days reported by the respondents, controlling for a variety of households' characteristics. To our knowledge, our study is the first contingent valuation study to address measurement error in the good to be valued, thus avoiding biased inference, by instrumenting for it. Specifically, we instrument for the number of outage-days using the frequency of all types of outages at the substation level.

2. Timilsina et al., (2018), for example, estimates that load-shedding could have cost the country up to 7% of its GDP annually.

3. Attention in this paper is restricted to residential customers. See Morrison and Nalder (2009) and Goett et al. (2000) for stated preference studies focused on businesses' valuation of reliability and other aspects of supply quality.

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The results from our study are striking for a number of reasons. First, unlike studies of other low-income economies, particularly the Sub-Saharan Africa region (Blimpo and Cosgrove-Davies 2019, Lee et al., 2020), we find that households, on average, attach economically significant value to a reliable power supply. The average WTP is about 123 NR ($1.11) per month, or 65% of the actual average monthly bill at the time of the survey, even though about 26% of the households are not willing to pay anything at all, and even though respondents are likely *under*stating their WTP. When we convert the WTP to a VoLL (i.e., the WTP per kWh lost), our preferred estimates are in the range of 5 to 15 NR/kWh (¢4.7 to ¢14/kWh), and thus bracket the average price per kWh from the grid paid by the respondents at the time of the survey. We also find that the WTP increases significantly—but slowly—with income and education levels. This result is consistent with the recent finding that households value the consumption of subsistence goods more than the availability of electricity services when they are poor (Sievert and Steinbuks, 2020).

Second, quite surprisingly, our average VoLL estimates do not seem to be any larger than those from a survey conducted more than a decade ago, when the load-shedding crisis started (Karki et al., 2010), even though the country's GDP per capita has grown by 42% since. Third, for the sample as a whole, the VoLL is higher for service lost in unscheduled outages than for service lost during scheduled load shedding. This finding is consistent with evidence from developed economies (Carlsson and Martinsson, 2007). But when we restrict the analysis to the ”attentive” respondents—namely those who appear to have recollected exactly the number of outages in the month a year before the time of the survey—the VoLL is identical for unscheduled and scheduled lost electricity consumption.

Fourth, households that use rechargeable batteries (i.e., inverters) or solar equipment as backup equipment report systematically *lower* WTP. This result is in sharp contrast with earlier studies (Oseni, 2017), where households that own diesel generators with high running costs reported a higher WTP for reliable power supply. However, when we adjust the VoLL of those with rechargeable batteries and solar equipment to the VoLL implicit in the purchase of such equipment, we obtain higher estimates ranging from 9 to 22 NR/kWh. These results indicate that, in the absence of effective public policies, households internalize their WTP for reliable power supply by investing in power backup equipment.

Finally, although most households have an economically meaningful willingness to pay for a reliable power supply, our VoLL figures appear to be below the marginal cost of avoided load shedding (i.e., utilizing high-cost operating reserves or importing electricity at times of high demand). These findings suggest that if the government's goal is to improve the quality of residential electricity consumption, it must either lower the cost of generation, transmission, and distribution or resort to demand response—if technologically feasible and acceptable to the public.[4]

The remainder of this paper is organized as follows. Section 2 provides background information. Section 3 describes our data. Section 4 presents the methods and section 5 the results. Section 6 concludes.

4. Demand response may include pricing aimed at moderating demand at times of especially high load and/or direct load control measures (see https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response). With direct load management, for example, households voluntarily allow the utility to take control of some of the appliances (e.g., air conditioners) during critical peak hours (see Faruqui and Sergici, 2010, for a review). This approach is not feasible in Nepal, where the national electricity grid lacks the necessary degree of technical sophistication and the main electric appliances used in the home have low power requirements. Additionally, one would expect a very high level of public distrust, which turned out to be a major obstacle to the success of such experiments even in developed economies (Stenner et al., 2017).

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2. BACKGROUND

A. Nepal and Its Electricity Supply

Nepal, a landlocked country in South Asia, is one of the poorest countries in the world. As of 2018, its GDP per capita was USD 1039 (current USD), placing the country squarely in the bottom quintile worldwide.[5] In part because of the country's low level of development, and in part because of the disruption of the electricity supply (which we describe below), electricity demand in Nepal is much less than that of its neighboring countries. Per capita electricity consumption was 146 kWh in 2014 and approximately 245 kWh in 2018. For comparison, India's was 1,181 kWh per capita and China's 4,973 kWh per capita in 2018.

As of December 2020, Nepal has about 1,303 MW of power generation capacity for its almost 30 million population, 97% of which is hydropower.[6] Almost all hydropower plants are of the run-of-river type, and up to two-thirds of this capacity is not available during the dry season (November-June). As a result, Nepal suffered a severe shortage of electricity supply during the decade from 2007 to 2016, which forced the national power company—the Nepal Electricity Authority (NEA)[7]—to implement extensive load shedding (World Bank, 2019).[8]

Figure 1 plots the hours with no electricity (as per the scheduled outages) each month from January to December 2016—one of the worst load-shedding years—based on the schedules publicly announced by the NEA.[9] In the early months of the year, people were without power for about half of the time. Load shedding occurred every single day between July and October 27, 2016. In July and the first half of August 2016, there was no electricity for about 9 hours a day. The load shedding lasted seven hours every day in the second half of August, September, and the first three weeks of October 2016. In late October 2016, the outage schedule was suspended indefinitely, bringing the load shedding hours to zero in November and December 2016.

NEA was consistently operating at a loss during the 2007–2016 decade. For example, in 2016, the cost of supply was 12 NR/kWh. Transmission and distribution (T&D) loss in that year was 30%, and the average revenue (from all types of customers) only 9.6 NR/kWh.

At the end of 2016, the load shedding situation improved due to increasing imports from India, the addition of new generation capacity, and more effective management of the electricity load. At present, no scheduled load shedding exists in Nepal. Unscheduled power outages are commonplace due to the aging and/or overloading of the electricity distribution infrastructure.

5. See https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=NP and https://globaledge.msu.edu/countries/nepal/economy.

6. See https://www.doed.gov.np/.

7. The electricity market in Nepal is a vertical monopoly, as the NEA is responsible for the generation, transmission and distribution of electricity throughout the country, although there is some degree of competition in generation, since independent power producers are allowed. Deregulation plans have been formulated, but it will take several years to implement them.

8. Shrestha (2014) reports that there were at most 2 hours daily of load shedding in 2005, and 3 in 2006. Starting in 2007 the situation appears to have worsened considerably, with 8 hours/day in 2007, 16 in 2008, 18 in 2009, 14 in 2010, 12 in 2011, 10 in 2012, and 12 and 8, respectively, in January and July 2014.

9. The load-shedding schedule is announced in advance by the NEA, and is communicated to the public via flyers, mail, and published in the newspapers. NEA has divided the country into a total of 14 regions (7 for the Kathmandu region and 7 for the region outside Kathmandu), and each gets the same number of outage-hours, rotated across regions over the week in terms of what time the outages start and what time service resumes.

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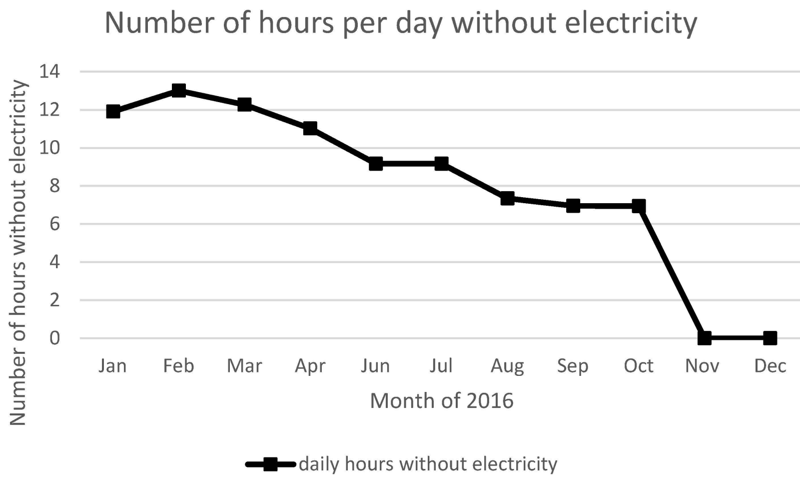
Figure 1: Scheduled load-shedding outages in Nepal in 2016.



Notes: The graph displays the daily number of hours without electricity due to NEA scheduled load-shedding outages. NEA has divided Nepal into fourteen service regions. Each gets the same number of load-shedding hours per day.

B. What is the VoLL?

We adopt the definition of the VoLL as "value attributed by consumers to unsupplied energy."[10] It is the willingness to pay to avoid the loss of one kWh in an outage, or—assuming no income effects—the willingness to accept the loss of one kWh in a service interruption.

Sanghvi (1983) argues that the only theoretically correct way to value, say, a one-hour loss of power, is to estimate a system of hourly demand functions to accommodate the household's ability (or inability) to shift consumption to a different time. The consumer surplus under the corresponding one-hour demand curve provides an approximation to the compensating variation, the correct welfare loss from the supply interruption. Knowledge of these hourly demand functions would allow the analyst to determine whether the VoLL in an unscheduled outage is greater than that for an otherwise similar, but scheduled, outage (Schroeder and Kuckshinrichs, 2015).

We are unable to implement the theoretically correct approach described in Sanghvi (1983) in this paper, given its exacting data requirements. Even we were to settle for an "average hourly demand function" or a "monthly demand function"—as discussed, and shown to be theoretically incorrect, in Sanghvi (1983)—we would be unable to fit such functions in Nepal, where electricity tariffs are the same everywhere, haven't changed in 7–8 years, and are based on increasing monthly block rates, with no variation in tariffs throughout the day.

C. Using Contingent Valuation to Elicit the WTP

We use contingent valuation (CV) to elicit residential customers' WTP for improved power supply. In our CV question, respondents are asked to report information about their WTP to avoid returning to the load shedding and unscheduled outages they experienced in 2016.

In most CV surveys, respondents are asked to place a value on a hypothetical good or policy. Aspects of the good or policy, such as its scope or cost, are often varied at random across the

10. See e.g., https://www.emissions-euets.com/internal-electricity-market-glossary/966-value-of-lost-load-voll

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respondents. An obvious advantage of this approach is randomization (Alberini, 2019), but sometimes this comes at the price of respondent unfamiliarity with the policy to be valued. By contrast, we ask the respondents to describe their experience with outages to us, and then to tell us how much they would be prepared to pay to avoid going back to that situation. By construction, this scenario is well known to the respondent. Should their memory be faulty, or should there be other measurement error issues, in our regressions of the WTP on respondent-reported outage-days we instrument for outage-days using NEA's data about outages at the 132 kV substation level.

One concern with CV surveys is that, since respondents value a hypothetical policy or scenario, but no actual transaction takes place, there may be a tendency to over- or under-report the true WTP. This may happen because respondents fail to take their economic circumstances into account, or because they intentionally manipulate their responses in hopes of influencing the provision of the good or policy. Economic theory (Carson and Groves, 2007) shows that when the valuation question is framed as a referendum with a simple vote in favor or against a proposed policy at a given cost to the respondent, it is in the respondent's best interest to answer truthfully.

It was not practically feasible to frame the valuation question as a referendum on a public program or reassure respondents about the consequentiality of their WTP responses (Johnston et al., 2017) in our survey. The respondent's outages in our valuation scenario are a private good. In principle, in this kind of scenario, respondents may either overstate their WTP, if they hope that doing so will encourage the electricity authority to provide the desired reliability improvement, or understate it, if they are afraid that they will be held responsible for payment. In practice, we feel that it is unlikely that respondents spent much time devising strategic answers during the survey, as the valuation question was only one of the myriad questions in the questionnaire. We believe however that the WTP responses are likely to understate the true WTP for the mere reason that the Nepali are accustomed to "haggling" and negotiating prices during normal market transactions (Whittington, 1998).

3. DATA

A. Household Characteristics and their Experience with the Grid

Our analysis is based on a nationally representative survey of Nepali households, collected as part of the World Bank Multi-Tier Framework (MTF) for Assessing Energy Access Program. The MTF survey gathers extensive information about households, dwellings and housing tenure, expenditures on various consumption and durable items, cooking equipment and habits, access to electricity, experience with electricity outages, equipment used for lighting or powering appliances during outages, and sources of energy.

The survey was conducted between July and November 2017 and resulted in 6000 completed questionnaires. Almost 90% of the interviews were completed in August and September.[11] We draw most of the information for this paper from section C of the MTF questionnaire (focused on unscheduled outages) and section E (focused on all outages, both scheduled and unscheduled).

A total of 4047 out of 6000 households reported that they were connected to the NEA grid.[12] Attention in this paper is restricted to the 4047 NEA-supplied households. Some 640 households

11. A detailed documentation of the survey sampling strategy is available in World Bank (2017). The response rate in the field was over 90%.

12. Of the households not connected to the NEA grid, 812 were connected to a pico-, mini-, or micro-grid. About 1022 of the remainder reported using some form of solar device, usually solar lighting systems (891 of these 1022 households). Based on the MTF survey, the World Bank Sustainable Energy for All (SE4ALL) database estimates that 93% of the Nepali households had access to some form of electricity—from the grid or otherwise—in 2018.

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produced the most recent electricity bill, which displays the exact consumption in kWh during the latest billing cycle. The remaining households reported their typical bill in Nepalese Rupees (NR), and we are able to compute their monthly consumption in kWh by matching the bill amount with the NEA tariffs. Figure 2 shows two histograms of the distribution of monthly electricity consumption. Figure 2.a is based on the exact consumption in kWh from the bill. Figure 2.b is based on either exact consumption, when available, or calculated consumption if the respondent merely reported the bill in NR. The two distributions are very similar: The average consumption is 61 kWh, and the

Figure 2.a: Distribution of monthly electricity consumption (exact household consumption, available for 638 households).

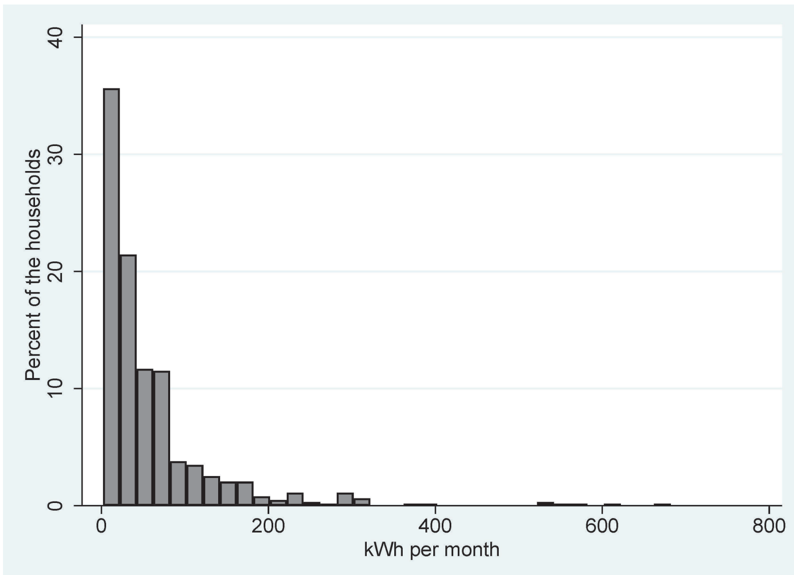
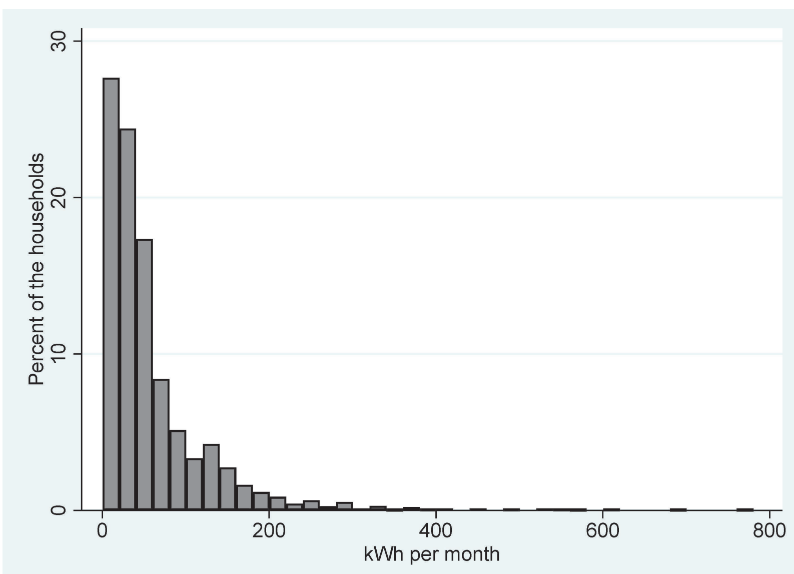


Figure 2.b: Distribution of exact or calculated monthly electricity consumption (N=3941).



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median is 34 kWh for the sample with exact consumption data, and 38 kWh for the blended exact and calculated consumption sample, indicating that Nepali households use about 1–2 kWh/day.[13]

Section C of the questionnaire asks respondents to indicate whether there were some months every year that were worse than the others in terms of unscheduled electricity outages (Appendix A, question C.26 from the MTF questionnaire). Based on a total of 1543 responses, people experience, on average, 76.8 outages (median 40.5) and 92.38 hours (median 63) per month during the worst months. In practice, this means that there are unscheduled outages every day, for a total of 2–3 hours a day with electricity gone without warning.[14] The situation appears to be better in the "typical" month (Appendix A, questions C.32 and C.33), when, as reported by the full sample, there are, on average, 40 outages (median 22.5) and some 30 hours (median 13.5) without electricity per month.

Table 1 shows that when there is no electricity, households power their lights using rechargeable batteries, disposable batteries (used with flashlights and task lights), kerosene lamps, solar lanterns (i.e., lanterns powered by a photovoltaic cell), and solar lighting (somewhat more elaborate devices that are capable of charging cell phones and powering radios in addition to supplying lighting). Only 50 households in our sample have solar home systems on the premises.

Table 1: Backup equipment used for lighting or appliances during outages.

Equipment used for lighting in case of an outage	Percent of the sample connected to the grid (N=4047)	Percent of the sample who still experience outages (N=2725)
Rechargeable batteries	29.06	30.04
Disposable batteries*	14.46	15.23
Solar lantern*	3.71	3.60
Solar lighting	17.79	16.0
Solar home system	1.43	1.14
Kerosene lamp*	13.52	15.60
Has no backup for appliances	69.51	71.52

* Lighting only.

As to appliance use during outages, about 70% of grid-connected households have no backup for appliances. Only about 500 households use rechargeable batteries and storage to power their appliances during service outages.

Ownership of appliances and electronics can be summarized into the watts of the equipment. The average household owns equipment worth 1.550 kilowatts, but the median is only 0.770. Only 5% of the households own appliances worth more than 5 kilowatts. Some 28% of the households own a refrigerator, 58% have one or more electric fans, and 23% a flat-screen color TV.

13. To further elaborate on this, 1 kWh is the median daily consumption and 2 kWh is the mean daily consumption per household. NEA reports indicate that in 2015–16, mean residential consumption was 1.76 kWh per day. This figure has increased slightly to 1.94 kWh/day in 2016–17, 1.99 kWh/day in 2017–18, and 2.00 kWh/day in 2018–19 and 2019–20 (NEA Annual Report, 2020).

14. We checked whether volunteering information about the worst months is significantly associated with location, income, and ownership of backup equipment. We fit linear probability models where the dependent variable is "volunteering worst month," finding that this is significantly associated with the Province of residence, and with some of the simplest and least expensive backup equipment (disposable batteries, solar lanterns, solar lighting, kerosene lamp). Household income, which we proxy with expenditure for all consumption goods except electricity, is not important—whether or not we control for the backup equipment. When we regress the number of unscheduled outages per week or per month during the worst months, the association between them and the above mentioned regressors is generally weak, and results in regressions with R^2 no greater than 0.03.

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Section T of the questionnaire elicits households' opinions on a variety of issues, ranging from the quality and cost of electricity service to trust in the institutions. When asked whether they would be willing to pay higher tariffs for a more reliable electricity supply (Appendix A, question T.12), 61.37% of the households said that they would. When asked whether they agree with the statement that reliability can improve if higher tariffs are charged (Appendix A, question T.13), 33.12% indicated that they agreed with that statement. Finally, 63.17% said that they would be willing to pay more for electricity if the government used the revenue to subsidize poor households (Appendix A, question T.23).

B. Willingness to Pay for Improved Reliability

Section E of the questionnaire asks the respondents whether they still experience power outages at the time of the survey (Appendix A, question E.2). Did these respondents also experience outages—scheduled *and* unscheduled — this month but a year ago (henceforth referred to as MONTH 2016)? If so, how many?

How much—the questionnaire continues—would the respondent be willing to pay each month, on top of the regular monthly electricity bill, to avoid going back to that situation (Appendix A, question E.5)? To make the respondent's valuation task easier, we suggested one amount drawn at random from an array of pre-selected figures (100, 200, 300, 400, and 500 NR). This question was followed by inviting the respondent to indicate exactly how much he or she would be willing to pay (Appendix A, question E.6).[15]

A total of 2893 out of the 4047 respondents (about 71.5%) connected to the national electricity grid said that they still experienced outages at the time of the survey. Of these, 2725 had experienced outages in 2016. On average, they had experienced 20 days with outages "this month a year ago." About 36% of the respondents reported 30 or more days with outages, effectively telling us that, a year earlier, there were outages every single day.

Figure 3.a displays the histogram of the number of days with outages, showing a small mode at low counts, a relatively uniform distribution from approximately 10 to 29 outage-days, and a spike at 30 or more. We consider these respondents "attentive," because, even ignoring the unscheduled power interruptions, there were scheduled load shedding outages *every single day* in every part of the nation until October 27, 2016.[16] The other respondents may or may not have misremembered the exact number of days with outages. Perhaps some of the scheduled load shedding occurred at times or on days when they were away from home, and hence were not directly experienced. Based on enumerator debriefs and discussions with the local survey team, it is also possible that some respondents may have failed to notice that the survey questionnaire, which was previously focused on *un*scheduled outages, had now turned to both unscheduled *and* scheduled outages.[17]

15. This approach is in sharp contrast with Deutschmann et al. (2021), who repeatedly query Senegalese respondents by suggesting progressively higher (lower) amounts, until the respondent's answer turns from a "yes—I would pay that amount" ("no") to a "no" ("yes").

16. We estimated a linear probability model relating 30 or 31 days of outages "this month last year" to a number of covariates. The likelihood that the respondents announces 30 or 31 days of outages varies meaningfully across Provinces, is (as expected) much lower when the survey took place in October or November 2017, and is negatively related to income. Subsequently entering education and dummies for lighting and backup equipment in the regression brings little additional explanatory power.

17. Recall error is by no means unique to the locale of our study or its specific topic (the number of days with electricity supply disruptions). Baker et al. (1989) use household-level data from the UK, and discuss the quality of respondent recall for infrequent purchases, such as home heating fuels. Battistin et al. (2003) use two surveys conducted by two separate govern-

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Figure 3.a: Distribution of respondent-reported outage-days in MONTH 2016 (full sample, N=2723).

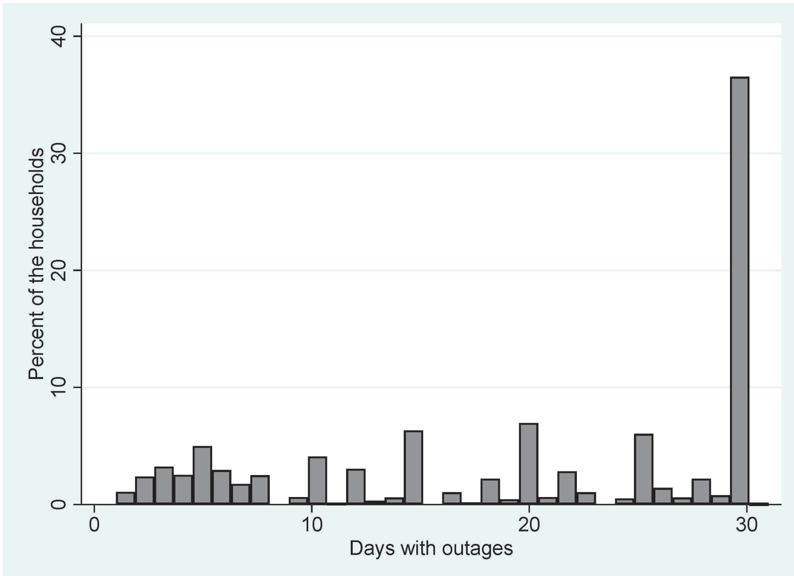
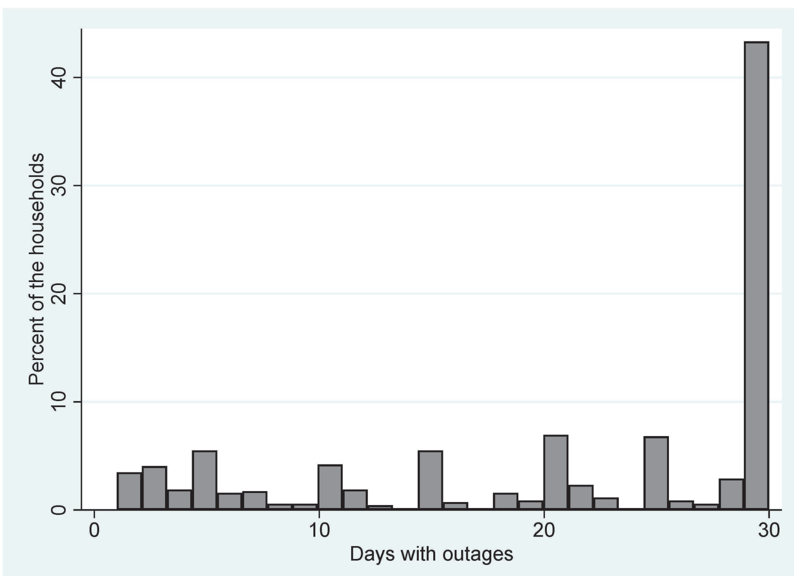


Figure 3.b: Distribution of respondent-reported outage-days in MONTH 2016 (only respondents with zero WTP, N=709).



NEA does not collect information about, nor provide maps of, service disruption at individual residential addresses that can be used to assess the quality of the respondent-reported data. However, as shown in Figure 4, the respondent-reported number of days with outages 12 months earlier

ment entities, and suggest three approaches for handling recall data. They note that recall data—food expenditures and other categories of consumption expenditures—are affected by heaping, rounding up problems, and time averaging errors.

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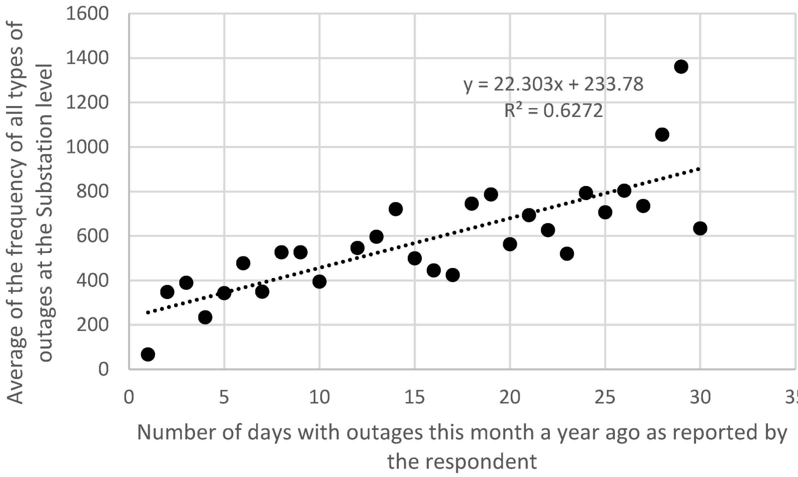
Figure 4: Total outages at the substation (SS) that serves the respondent's municipality v. respondent-reported outage-days.



Notes: The graph plots the average number of outages at the transformer substation serving the respondent's municipality against each possible number of outage-days reported by the respondents.

correlates well with the total frequency of outages—scheduled and unscheduled—reported by NEA over the same period at the 132 kV transformer substation that serves the municipality where the respondent resides.[18] The outages at the substation level may cause disruptions throughout the territory they serve (which neither the respondent nor the township where he or she resides has any control over). Additional outages may occur locally "downstream" from the substation, suggesting that the number of total outages at the substation level is a valid instrument for respondent-reported outage-days, should we need one in our regression analyses below.[19]

Regarding the WTP, as shown in Table 2, the share of respondents willing to pay the bid amount that was proposed to them declines systematically as the bid increases, as suggested by economic theory. "Open-ended" WTP responses—like the ones to our follow-up question—are generally interpreted as understating the true WTP (Welsh and Poe, 1998). Indeed, about 26% of the sample stated that they were not willing to pay at all. Yet, the data suggest that a reliable supply *is* valuable: The average WTP was 123.32 NR (or $1.11) per month and represents, on average, 65% of the actual monthly bill (median 25%). The median WTP is 100 NR, the 75th percentile 200 NR, and the 95th percentile 500 NR.

We wondered whether the zero WTP responses came primarily from the people that reported few outage-days. Figures 3.a and 3.b show that the distribution of respondent-reported outage-days is very similar across those who announced zero WTP and those with positive WTP. This comparison suggests that the zero WTP responses may include some "protest" responses on the part of subjects who actually do value grid electricity. It also helps dispel the concern that respondents might have had "selective memory" when reporting the number of days with outages from twelve

18. There is a total of 35 132-kV substations in Nepali, which serve a total of 242 municipalities. One municipality is served by only one substation, but the same substation can supply more than one municipality. In 2016, the average substation experienced approximately 493 outages per month.

19. We argue that outages at the substation level are correlated with (and often the cause of) the outages experienced at the respondent's residence, which determine his or her WTP to avoid them, but do not have an independent effect of the respondent's WTP, since the respondent is presumable unaware of where along the grid the failures occur and of the effects of substation-level outages at other locales.

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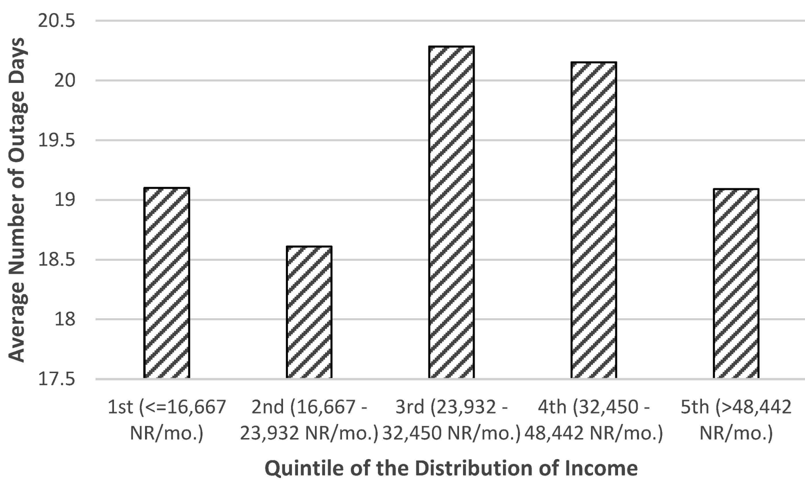
Table 2: Responses to the initial bid amount in the WTP question.

Bid amount (NR)	Percent willing to pay the indicated amount.
100	65.46
200	35.15
300	22.38
400	22.90
500	20.11

months ago, in the sense that those respondents who value electricity the most might also be reporting the most numerous outages (because they would remember sharply something they regarded as very aggravating), and vice-versa. Also, we find that the number of outage days from a year ago does not vary much by equipment owned, although they do vary somewhat by Province, and, as shown in Figure 5, do not just affect the poor.

Figure 5: Average number of respondent-reported outage-days in MONTH 2016 by income quintile.



Tables B.1 and B.2 in Appendix B explore reasons for the zero WTP responses. The likelihood of announcing zero WTP varies with income, education, and the equipment owned by the household and the geographical area of residence, but its most important predictors appear to be beliefs about the cause, effects, and burden of outages. Monthly electricity consumption at the time of the survey does not have any additional explanatory power, but suggests that the higher the consumption, the less likely is the respondent to announce zero WTP.

4. METHODS

A. Computing the VoLL

Our survey respondents announced their WTP to avoid the number of days with outages they had experienced in the MONTH 2016. To convert the WTP into a VoLL, we must, therefore, divide it by an estimate of the kilowatt-hours lost to outages during that month. We proceed as fol-

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lows. First, we compute an estimate of the number of hours without electricity in MONTH 2016 due to unscheduled outages. If, for example, the survey took place in July, and this respondent had listed July among the worst months in terms of electricity service, we take his or her estimate of the total hours of unscheduled outages per month in the worst months. If the respondent did not flag July as one of the worst months, we take his or her estimate of the unscheduled outage hours during a typical month. We then add the hours of scheduled load-shedding outages (in this example, those of July 2016; see figure 1), obtaining the total number of hours without electricity in MONTH 2016.

The kWhs lost are thus the total hours of service lost, times the household's average hourly consumption *now*, at the time of the survey (which is equal to monthly consumption, divided by 30 days, and divided again by 24, the number of hours in a day).[20] Finally, we compute the VoLL as the WTP divided by the kWhs lost. This calculation results in respondent-specific VoLLs. About a quarter of them will be equal to zero if we take the respondent's WTP responses at face value.

However, some respondents had invested in durable equipment to generate or store electricity. For these respondents, it is possible to impute an alternate VoLL—whether or not they announced zero WTP. Specifically, the value of a kWh lost must be the quantity V such that solves the equation:

$$C = \frac{1 - \exp(-\delta T)}{\delta} \cdot V \cdot E, \tag{1}$$

where C is the price of the equipment, E is the annual consumption lost to outages (which presumably the equipment makes up for), T is the lifetime of the equipment, and δ is an appropriate discount rate.[21] Equation (1) exploits the notion that the value of the equipment should be equal to the discounted flow of its electricity supply services. We omit scrap or resale value from the right-hand side of (1) because inverters and solar equipment depreciate very fast.

The first term in the right-hand side of (1) is the discount factor, based on continuous exponential discounting.

B. VoLL for Scheduled and Unscheduled outages

Economic theory, and common sense, suggest that the value of lost electricity consumption should be greater for unannounced outages (Schroeder and Kuckshinrichs, 2015). This is because

20. At the time of the survey the electricity supply situation in Nepal had much improved, and load-shedding outages had been discontinued, suggesting that electricity consumption was much closer to or at the desired level. We thus assume that, had there been no outages in 2016, electricity consumption would have been the same as that observed at the time of the survey.

21. The survey questionnaire elicits high-quality data about the cost, age and financing of solar lighting, solar lanterns and solar home systems, which we use to estimate a value per kWh-equivalent generated from this equipment. We assume a rate of return to the investment of 7%, which is appropriate for Nepal according to World Bank guidelines based on the Ramsey rule (Hepburn, 2007). We assume 12 years for solar home systems, 9 years for solar lighting systems, and 3 years for solar lanterns. Out of the 545 people who answered the WTP question and reported solar equipment type, cost and age, only 30 indicated that they had had made down payments and had paid (or were still paying) instalments. The remainder had paid in full (383 households) or had received the equipment for free (140 respondents). We used only the information from those who had paid in full to solve equation (1). All costs were converted to 2017 Nepali Rupees. We were able to compute an implicit VoLL (V in equation (1)) for 312 respondents with solar equipment, plus for 734 respondents with rechargeable batteries with storage as backup for lighting or appliances. The questionnaire did not collect information about the cost of the rechargeable batteries (essentially, inverters that store grid electricity for later use), but it is reasonable to conservatively assume a price of 10,000 NR and a lifetime of 5 years.

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electricity customers can presumably avoid or mitigate some of the damages from power outages when sufficient warning of service interruption is given.

We empirically test this hypothesis in Nepal by regressing the WTP per outage-day on the estimate of the kWhs lost per day through unscheduled outages and the estimate of the kWhs lost per day as a result of the announced load shedding. We use WTP per outage-day (i.e., WTP divided by the number of outage-days reported by the respondent) because we prefer to avoid entering outage-days in the RHS of the regression, as we suspect this latter variable to be affected by measurement error.

Specifically, we fit the regression equation:

$$WTP\_DAY_i = \theta_1 \cdot kWh\_SCHED_i + \theta_2 \cdot kWh\_UNSCHED_i + u_i, \quad (2)$$

where *WTP_DAY* is the WTP divided by respondent-reported outage-days, *kWh_SCHED* and *kWh_UNSCHED* are the kWhs lost to scheduled and unscheduled outages, and θ_1 and θ_2 are the VoLL per unscheduled kWh loss and unscheduled kWh lost, respectively. Equation (2) is easily amended to control for equipment type, as equipment may be an important determinant of the WTP to reduce outages.[22]

C. Internal Validity of the WTP Responses

We rely on answers to questions involving hypothetical transactions, so it is important to check that the WTP responses meet internal validity criteria (Bishop and Boyle, 2019). We regress the WTP on the number of outage-days reported by the respondents, income and education, and other determinants. Formally,

$$WTP_i^* = \beta_0 + \beta_1 \cdot OUTDAYS_i + \beta_2 \cdot HHINC_i + \beta_3 \cdot EDUC_i + \mathbf{x}_i \boldsymbol{\beta}_4 + \varepsilon_i, \quad (3)$$

where *OUTDAYS* are the respondent-reported outage-days, *HHINC* is household income, *EDUC* educational attainment, and **x** is a vector of equipment and household controls.

Economic theory suggests that the WTP should increase with the number of outage-days, income, and education, and should depend on the equipment the respondent has invested in to generate and store electricity. Coefficient β_1, coupled with an estimate of the kWh lost in an outage-day, provides an additional estimate of the VoLL.

Fitting equation (3) is complicated for several reasons. First, about a quarter of the WTP responses are zero, and the remainder is positive. This observation would suggest fitting a Tobit model. However, the Tobit model relies on an underlying normal distribution for the latent WTP* variable in equation (3), which is a poor fit for the right-skewed, lumpy distribution of the WTP responses in our survey. We considered finite mixtures of zeros and distributions defined on the positive semi-axis, but, again, the fit was poor. For these reasons, we refrain from models that rely on a distributional assumption and simply specify a linear regression.

Second, the number of outage-days may be affected by measurement error, which, if classical, would render the OLS estimates inconsistent and biased towards zero. We instrument for the

22. It is, however, possible that unobserved taste for a stable, reliable, and abundant electricity supply influences both the WTP for reduced outages and the choice of generation or backup equipment, making them econometrically endogenous (McRae, 2010). To address this issue following Dubin and McFadden (1984) we estimated a multinomial logit model for the choice of backup equipment, which we then used to create predicted probabilities of adopting each possible backup option. We then used these predicted probabilities to form terms that are added to the RHS of the regression to capture and account for the endogeneity. These terms were not statistically significant and did not affect estimates of q_1 and q_2 in equation (2).

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number of outage days using the frequency of all types of outages at the 132 kV substation serving the respondent's municipality in MONTH 2016. This approach should clean out the measurement error. In implementing this approach, we assume that all of the other terms in the right-hand side of equation (3) are exogenous.

5. RESULTS

A. VoLL Estimates

We compute that the average respondent lost approximately 269 hours of service in MONTH 2016, some 49 of which were due to unannounced outages. This translates into just under 1 kWh lost per outage-day (on average 0.80 kWh).

Table 3 presents a summary of the VoLL estimates. The figures in this table are striking. First, even though one-quarter of the sample stated that they would pay nothing at all, it is clear that people *are* willing to pay for improved service. For comparison, the average price per kWh from the grid paid by the respondents at the time of the survey is 7–8 NR/kWh. Second, there is considerable heterogeneity across respondents in the value they place on grid electricity.

Table 3: Summary of calculated VoLL. All figures in NR/kWh.

VoLL for…	N	mean	25th perc.	median	75th perc.	90th perc.	95th perc.
Full sample	2281	15.25	0	5.10	13.85	29.03	48.08
Households that use rechargeable batteries*	734	12.08	0	3.77	10.77	23.09	40.57
Households that use disposable batteries*	311	18.29	3.43	8.88	18.71	37.40	67.05
Households that use kerosene lamps*	398	11.14	0	5.28	12.58	28.01	46.44
Households that use any type of solar equipment*	436	22.15	0	4.68	15.52	31.63	57.22
max {WTP-based VoLL, VoLL implicit in the purchase of durable equipment, if any}	2281	22.29	3.88	9.37	20.81	39.61	60.89

* denotes that the indicated equipment is used during electricity outages.

In the first row of Table 3, we take the WTP responses at face value and use the full sample. The median and mean VoLL (5.09 NR and 15.25 NR, or 4.71 and 14.1 US cents, respectively) thus bracket the actual average price per kWh. These results are comparable to two recent studies of lower-middle-income countries (Twerefou, 2014; Oseni, 2017), which report average VoLL estimates of 14–16 US cents. As shown in Figure 6, the distribution of the VoLL is positively skewed.

Rows 2–5 of Table 3 summarize the VoLL among groups of respondents that rely on specific types of equipment during outages. Households with rechargeable batteries and storage appear to place a lower value on grid electricity than those that are forced to use disposable batteries. They announce a zero WTP more often (30.96% of the times v. 23.80% for all others) and report lower positive WTP amounts (on average 158.05 NR v. 170.19 for all others). They also report a lower WTP per outage-day (on average 12.10 NR v. 15.91 for all others), even though their monthly consumption is greater (mean 66.64 kWh v. 51.24 for all others) and they lost more kWhs to outages (mean 22.42 kWh v. 17.73).

When we "correct" the VoLL of those with rechargeable batteries and solar equipment, imputing the larger between the original VoLL and that implicit in the purchase of equipment (see section 4.A), households are prepared to pay on average 22.29 NR/kWh (median 9.37) (row 6 of Table 3).

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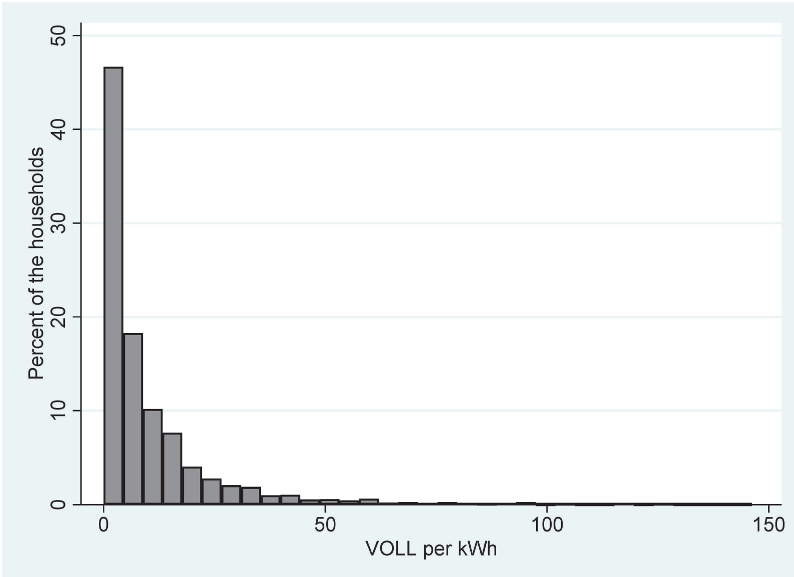
Figure 6: Distribution of VoLL in the sample.



B. Scheduled- and Unscheduled-outage VoLL

Table 4 displays the results of regressions relating the WTP for an outage-day to the kWhs lost per outage-day from unscheduled outages and to KWhs lost per outage day from scheduled load

Table 4: Regression results. Dependent variable: WTP per outage-day.

	(1) All households	(2) Thirtydays=1	(3) All households	(4) Thirtydays=1
kWh lost to unscheduled outages	14.655***	4.057***	13.272***	1.868**
	(1.054)	(0.966)	(1.035)	(0.897)
kWh lost to scheduled outages	8.527***	4.066***	3.759***	1.520***
	(0.685)	(0.307)	(0.851)	(0.349)
Rechargeable batteries and no backup (1 = Yes)			–6.049***	–2.211***
			(1.612)	(0.589)
Rechargeable batteries and backup (1 = Yes)			–5.888***	–1.554**
			(1.903)	(0.661)
Disposable batteries (1 = Yes)			4.422**	1.061
			(1.792)	(0.739)
Solar lighting (1 = Yes)			–2.601	–1.901***
			(1.703)	(0.626)
Solar lantern (1 = Yes)			2.091	1.193
			(2.661)	(1.174)
Solar home system (1=Yes)			–3.539	–0.472
			(5.015)	(1.727)
Kerosene lamp (1 = Yes)			–7.011***	–1.111*
			(1.695)	(0.605)
Constant			9.311***	4.205***
			(1.292)	(0.537)
Observations	2,251	769	2,251	769
R-squared	0.215	0.343	0.125	0.093
Test: $\theta_1=\theta_2$ (p-value)	16.97 (0.00)	0.00 (0.99)		

Note. Standard errors in parentheses. “Thirtydays=1” means that the sample is restricted to those respondents who reported experiencing 30 or more days with outages “this month one year ago.”

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shedding. Columns (1) and (2) use the simplest possible specification but different samples. While col. (1) uses all of the respondents who were administered the WTP question, col. (2) uses only those who reported 30 or more outages in MONTH 2016.

The sample as a whole appears to place a higher value on consumption lost to unscheduled outages, whereas the "more attentive" sample (thirty or thirty-one outage days, consistent with the load shedding schedule) appears to place virtually the same value on each kWh lost. Moreover, for the latter group, the value per kWh lost is considerably lower than either of the two coefficients from the full sample. A Wald test rejects the null that two VoLLs are the same for the full sample (Wald statistic 16.97, a p-value less than 0.0001), but fails to reject it for the sample of col. (2).

Adding controls for the type of the equipment owned by the respondents changes the point estimates of the VoLL (cols. (3) and (4)), but not the substance of the findings: The VoLLs are different from each other in the full sample, but identical for the more "attentive" sample.

We also computed standard errors clustered at the municipality level (see Appendix Table B.3), should there be unobserved municipality-level characteristics. This effectively doubled the standard errors around the VoLL in the full-sample regressions, to the point that one can no longer conclude that the two VoLLs are different. By contrast, clustering did not change the standard errors much in the regressions for the subsample that reports 30 or 31 days with outages.

C. Internal Validity of the WTP

Our respondents stated that they were willing to pay, on average, 123.32 NR per month to avoid going back to the outage situation they faced in MONTH 2016.[23] The reported WTP varies widely across the sample. Is this variation systematically linked to the household's experience with shortages, its economic circumstances, or the respondent's attitudes towards the national electricity provider?

To answer this question, we fit regressions where the dependent variable is the WTP, and the independent variables are the number of outage-days reported by the respondents, income, the highest educational attainment in the family, dummies for the equipment used to make do in the event of electricity outages, and dummies capturing attitudes towards the electricity supply. We instrument for the number of outage-days to address possible measurement errors. The excluded instrument is the number of outages (planned and unplanned) at the 132-kV substation level in MONTH 2016. We exclude from the sample households in the bottom and top 1% of the distribution of monthly consumption expenditures.

Table 5 displays the 2SLS results. The first two columns of Table 5 report first- and second-stage estimates from regression model (3). The specification in the last two columns of table 5 further includes dummies for the responses to the attitude questions.[24] Whether or not the attitude

23. This mean WTP is based on the "open-ended" response, namely the figure reported by the respondent when asked question E.6 in Appendix A. it is also possible to infer the mean or median WTP by fitting parametric binary-data model to the yes/no responses to question E.5 in Appendix A. For example, if one is prepared to assume that the latent, unobserved WTP is normally distributed, a probit model that regresses the yes/no responses on the initial, randomly assigned bid results in an estimate mean and median WTP of 153.49 NR (s.e. 12.03 NR). If one assumes that the latent WTP is lognormally distributed, the right-hand side of the probit model uses the log bid instead of the original bid, and results in an estimated median WTP of 149.02 NR (s.e. 6.68). The estimate of the mean based on the "open-ended" responses is lower than both of these estimates based on the yes/no responses to question E.5 in Appendix A because 26% of the respondents disclose zero WTP.

24. Table 5 shows that the first-stage F statistics are 22.0 in one specification, and 20.77 in the other. This shows that our instrument, the total number of outages 12 months before the survey at the transformer substation that serves the respondent's municipality, is strong.

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Table 5: Results from IV estimation of WTP equations.

Stage	First	Second	First	Second
Variables	Dep. Var.: Outages	Dep. Var.: WTP	Dep. Var.: Outages	Dep. Var.: WTP
Days of power outages in a typical month		6.877***		6.967***
		(2.508)		(2.500)
Monthly expenditures (NR thousand)	–0.0122***	0.258***	–0.0108***	0.213***
	(0.00354)	(0.0625)	(0.00355)	(0.0597)
Monthly expenditures not reported	4.521***	–46.70***	4.788***	–60.26***
(1 = Yes)	(0.709)	(18.10)	(0.717)	(18.43)
Hill Kathmandu region (1 = Yes)	–4.011***	0.559	–4.223***	21.40
	(0.837)	(18.13)	(0.838)	(18.11)
Highest education: secondary	0.890	23.62**	0.976	10.15
(1 = Yes)	(0.644)	(11.02)	(0.644)	(10.74)
Highest education: higher (1 = Yes)	1.147*	42.96***	1.228*	27.78**
	(0.679)	(11.70)	(0.681)	(11.43)
Highest education: vocational	3.219*	9.814	3.112	2.711
(1 = Yes)	(1.940)	(33.25)	(1.933)	(32.07)
Highest education: graduate (1 = Yes)	0.407	51.72***	0.329	38.85***
	(0.780)	(12.99)	(0.781)	(12.60)
Highest education: postgraduate	–0.826	114.6***	–0.832	92.87***
(1 = Yes)	(1.164)	(19.46)	(1.165)	(18.88)
Rechargeable batteries and no backup	3.006***	–32.70**	4.200***	–77.55***
(1 = Yes)	(0.640)	(12.88)	(0.624)	(15.27)
Rechargeable batteries and backup	–1.716	–7.962	5.031***	–50.60***
(1 = Yes)	(1.085)	(18.76)	(0.708)	(17.32)
Disposable batteries (1 = Yes)	3.077*	–51.64*	2.002***	–23.46**
	(1.812)	(30.99)	(0.649)	(11.14)
Solar lighting (1 = Yes)	4.587***	–74.63***	3.010***	–32.22**
	(0.678)	(17.79)	(0.638)	(12.59)
Solar lantern (1 = Yes)	–0.0122***	0.258***	–1.592	–10.35
	(0.00354)	(0.0625)	(1.082)	(18.06)
Solar home system (1=Yes)	4.521***	–46.70***	2.942	–45.57
	(0.709)	(18.10)	(1.805)	(29.86)
Kerosene lamp (1 = Yes)	–4.011***	0.559	4.474***	–64.78***
	(0.837)	(18.13)	(0.677)	(17.25)
Attitude: Subsidies (1 = Yes)			–0.591	2.096
			(0.427)	(7.034)
Attitude: Reliability I (1 = Yes)			0.518	83.10***
			(0.444)	(7.283)
Attitude: Reliability II (1 = Yes)			–1.949***	23.57***
			(0.427)	(8.591)
Substation-level	0.00350***		0.00343***	
Outages	(0.000596)		(0.000593)	
Substation-level	0.738		0.793	
Outages Missing	(0.520)		(0.519)	
Constant	15.15***	–8.087	15.74***	–62.66
	(0.785)	(42.42)	(0.829)	(43.86)
Observations	2,598	2,598	2,598	2,598
R-squared	0.107		0.115	
IV F-stat		22		20.77

Notes. (i) Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
(ii) Attitude questions are as follows. Subsidies: "Would pay more if the government used the revenue to subsidize the poor." Reliability I: "Would pay more if the supply was more reliable." Reliability II: "Agrees that higher prices would lead to better service."

dummies are included, the WTP increases by 6.87—6.97 NR for each additional day with outages.

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Since we estimate our respondents to lose on average 0.80 kWh per outage-day, this coefficient implies a VoLL of (6.92/0.80=) 8.65 NR/kWh, which is consistent with the results in section 5.A.[25]

The WTP increases significantly—but slowly—with income: At the sample average, the WTP increases by 0.21–0.26 NR for each additional 1000 NR gain in household income—here proxied by household expenditures. This implies an income elasticity of 0.07. Education also has an important positive effect on WTP. Compared to the households with primary education (our reference category), the households with higher, graduate, and postgraduate education levels are willing to pay 30, 40, 100 additional NR, respectively, for improved reliability of power supply. These results are consistent with earlier studies emphasizing the role of income (Kateregga, 2009; Twerefou, 2014; Oseni 2017) and educational attainment (Twerefou, 2014) in explaining the WTP for improved power supply in developing countries.

The WTP for reliable power supply falls significantly if households own power backup equipment, such as rechargeable or disposable batteries, and solar lighting, lanterns, or home systems. Depending on the type of backup equipment owned and the inclusion of attitude dummies in the model specification, households are willing to pay 25—75 NR *less* for a more reliable power supply. Owning a kerosene lamp also reduces the WTP by 65 NR. However, the economic and statistical significance of this estimate vanishes if the attitude dummies are removed from the model.

These results are in sharp contrast with those from a recent study in Nigeria (Oseni, 2017), where the households that own backup appliances were willing to pay *more* for better power supply. A notable difference between our study and Oseni (2017) is that in Nigeria households were mostly using diesel generators with high running costs, while Nepali households rely on solar generation and storage, whose marginal running cost (net of grid electricity expenses for storage) is zero. The lower stated WTP, however, does not, however, imply a lower VoLL. As we show in section 4.A, the owners of solar and battery backup have higher VoLL when the VoLL is inferred from their ownership of this equipment.

Finally, among the attitude variables, the indicator variables for if the respondent agrees that he or she would pay more for electricity if service were more reliable, or that higher prices would lead to better service, are both associated with higher WTP for the reliable power supply. This finding confirms the internal validity of the data and is consistent with earlier studies that confirm the importance of social attitudes in support of policies that impose higher prices in exchange for a more reliable power supply (Blankenship et al., 2019).

6. CONCLUSIONS

Using a contingent valuation question that asked respondents to report their WTP to avoid going back to the same number of days with power outages as they had experienced a year before, we have placed a value on the electricity service disruptions experienced by households in Nepal. Due to data limitations, we must assume that every hour of service lost is worth the same amount of money, regardless of the time of the day or day of the week when the outage occurs. Still, the data allow us to distinguish between the WTP to avoid scheduled and unscheduled outages.

Compared to their electricity expenditures, households have a high valuation of reliable electricity services. They are willing to pay, on average, an additional 123 NR ($1.1), or 65% more than the actual average monthly bill, to avoid the outages experienced in the month one year before

25. The marginal WTP for each additional day is virtually unchanged, and equal to about 7 NR, if we further add the kilowatts of the appliances and electronics owned by the household in the right-hand side of the regression.

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the survey. Richer and better-educated households are willing to pay even more for reliable power supply.

As always, our estimates must be interpreted with caution. One-quarter of the respondents stated that they were not be willing to pay anything at all for improved service. This, the private-good setting of the valuation scenario, and cultural factors suggest that most likely our estimates understate the true WTP and VoLL. For this reason, when possible we seek to infer the value of lost load from the ownership of backup or solar generation equipment. Doing so raises the VoLL slightly.

Even so, these valuations—which are high in relative terms—are not large enough in absolute terms. Our preferred estimates of the VoLL (5—15 NR/kWh, or ¢4.7—¢14/kWh) are low when compared with the marginal cost of adding capacity or delivering electricity when the demand is high. Imports from India have a marginal cost of approximately 30 cents per kWh during the times of highest demand. The highest marginal cost for the limited oil-based generation in Nepal is 20–30 cents/kWh. The cost of spinning reserve shortfall is likewise estimated at about 20 cents/kWh.[26] Each of these alternate estimates of the marginal cost of bringing additional electricity to the grid exceeds the residential VoLL. Raising residential electricity tariffs to the residential WTP levels will likely not be sufficient to improve the quality of residential power supply.

Adding to the skepticism, our estimates of the VoLL, based on data collected in 2017, are no larger than the figures obtained by Karki et al. (2010) in a survey in 2008–2010 in the early stages of the load-shedding crisis, despite the fast economic growth in Nepal over the decade since that survey. All in all, this suggests that residential households have managed to adapt to the unreliable power supply by consuming less electricity or investing in backup equipment, limiting the economic effectiveness of policies promoting cost-recovery of residential electricity service.

Echoing recent studies of electricity access (Lee et al., 2020, Sievert and Steinbuks, 2020), our findings suggest that low willingness to pay can be a significant barrier for improving the reliability of residential electricity supply in developing countries, particularly for rapidly growing and urbanizing low-income economies. The government of Nepal, for example, estimates that electricity demand will grow at the astounding rate of 10% per annum in the near decade and will require an additional 15 GW of generation capacity by 2030 (Government of Nepal Water and Energy Commission Secretariat, 2017). Coping with these demand pressures will be particularly difficult in countries like Nepal, where national utilities have historically experienced high operating losses.[27] Overcoming this problem requires additional policies that complement textbook recipes of higher electricity tariffs. Such policies could include both supply-side interventions, such as lowering the cost of electricity service, as well as demand-side policies. Indeed, the drastic reduction of transmission and distribution losses in Nepal from 26% in 2016 to 15% in 2020 caused the cost of electricity supply to drop by about 20% and helped to eliminate the country's load-shedding crisis. Demand-side policies aimed at greater flexibility of residential electricity demand could be equally important. Evidence from another low-income country, the Kyrgyz Republic, for example, suggests that smart meters can improve electricity quality and reduce commercial losses (Meeks et al., 2020). Prepaid meters and share-electricity meters (Jack and Smith, 2020) can be options for lower-income consumers, benefitting poorer customers the most.

26. Dr. Debabrata Chattopadhyay, head of the World Bank's Energy Planning Team, personal communication, 2 January 2020.

27. Fiscal year 2018–19 marked the first time in the NEA's 35 years history when the utility made operating profit.

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APPENDIX A: SELECTED QUESTIONS FROM THE MTF SURVEY.

[Information about outages. Section C of the questionnaire refers to unscheduled outages.]

C.26: Are there certain months/seasons every year when the household experiences bad electricity service from the national grid?

Yes/no

C.27 If yes: What are the worst months for service from the grid?

____

For the average month:

C.32: How many outages/blackouts occur in a week?

____

C.33: What is the total duration of all the outages/blackouts in a week?
__________(hours and minutes)

[Valuation scenario and WTP question. In Section E of the questionnaire, the respondents were asked to think of both scheduled and unscheduled outages.]

Section E of the Questionnaire (only for households connected to the NEA grid):

Willingness to Pay for Improved Electricity Supply

For each household, please randomly assign one of the five amounts in the placeholder { }: 100 NRs, 200 NRs, 300NRs, 400NRs or 500 NRs.

E2. Do you experience electricity outages? Yes/no

E3. If yes: Did the household experience power outages 1 year ago? Yes/no

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E4. If yes: How many days of electricity outages did you experience a year ago this month?

____

E5. Would you be willing to pay an additional { RANDOMLY SELECTED AMOUNT } on top of your monthly electricity bill to avoid going back to the experience of the power outages from 1 year ago?

Yes/ no

E.6. How much would you be willing to pay, at most, on top of your monthly electricity bill to avoid experiencing same level of electricity outages as one year ago?
________NR

[Attitude questions from Section T of the questionnaire]

T.12. "I would be willing to pay more for public electricity if the supply was more reliable."

Agree/disagree/no opinion

T.13. "Higher public electricity prices would lead to a better service."

Agree/disagree/no opinion

T.23. "If the government used some of the money to compensate poor households, I would support higher prices."

APPENDIX B

Table B.1: Percentage of zero WTP responses by equipment, attitudes, and ecological region. N=2725.

A. by equipment	
Equipment used for lighting in case of an outage	Percent of respondents
Rechargeable batteries and backup for appliances	25.87
Rechargeable batteries and no backup for appliances	34.03
Disposable batteries	14.84
Solar lantern	22.68
Solar lighting	26.40
Solar home system	25.81
Kerosene lamp	29.41
Other types of backup lighting	24.29
B. by attitudes	
Attitude	Percent of respondents
Subsidies (would pay more if the government used the revenue to subsidize the poor)	21.80
Reliable 1 (would pay more if the supply was more reliable)	11.14
Reliable 2 (agrees that higher prices would lead to better service)	22.89
C. by ecological region of residence	
Ecological region of residence	Percent of respondents
Mountain	25.25
Hill	20.40
Terai	30.35
Hill Kathmandu Region	25.00

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Table B.2: Probit models of the zero WTP responses.

Variables	(1) zeroWTP	(2) zeroWTP	(3) zeroWTP	(4) zeroWTP
Monthly expenditures (NR thousand)	–0.004***	–0.004***	–0.004***	–0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Monthly expenditures not reported	–0.074	–0.063	–0.077	0.038
	(0.100)	(0.101)	(0.103)	(0.113)
Highest education: secondary (1 = Yes)	–0.297***	–0.290***	–0.263***	–0.164*
	(0.089)	(0.089)	(0.090)	(0.097)
Highest education: higher (1 = Yes)	–0.310***	–0.289***	–0.261***	–0.116
	(0.094)	(0.095)	(0.098)	(0.104)
Highest education: vocational (1 = Yes)	0.103	0.150	0.179	0.310
	(0.270)	(0.272)	(0.275)	(0.295)
Highest education: graduate (1 = Yes)	–0.457***	–0.427***	–0.394***	–0.319***
	(0.110)	(0.112)	(0.117)	(0.124)
Highest education: postgraduate (1 = Yes)	–0.300*	–0.246	–0.199	0.055
	(0.164)	(0.168)	(0.172)	(0.182)
Monthly electricity consumption (kWh)		–0.001	–0.001	–0.001*
		(0.000)	(0.001)	(0.001)
Rechargeable batteries and no backup (1 = Yes)			0.192**	
			(0.088)	
Rechargeable batteries and backup (1 = Yes)			0.163	
			(0.103)	
Disposable batteries (1 = Yes)			–0.388***	
			(0.102)	
Solar lighting (1 = Yes)			–0.076	
			(0.160)	
Solar lantern (1 = Yes)			0.123	
			(0.092)	
Solar home system (1=Yes)			0.331	
			(0.259)	
Kerosene lamp (1 = Yes)			0.061	
			(0.096)	
Own a Fridge (1 = Yes)			–0.111	
			(0.074)	
Attitude: Subsidies (1 = Yes)				0.153**
				(0.068)
Attitude: Reliability I (1 = Yes)				–1.540***
				(0.071)
Attitude: Reliability II (1 = Yes)				0.429***
				(0.071)
Constant	–0.256***	–0.236***	–0.264**	0.271***
	(0.083)	(0.084)	(0.103)	(0.096)
Observations	2,568	2,568	2,568	2,568
Pseudo R-squared	0.018	0.019	0.035	0.214

Notes. (i) Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
(ii) Attitude questions are as follows. Subsidies: "Would pay more if the government used the revenue to subsidize the poor." Reliability I: "Would pay more if the supply was more reliable." Reliability II: "Agrees that higher prices would lead to better service."

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Table B.3: Dependent variable: WTP per outage-day.

	(1) All households	(2) Thirtydays=1	(3) All households	(4) Thirtydays=1
kWh lost to unscheduled	14.655**	4.057**	13.272**	1.868
outages	(7.080)	(1.802)	(6.116)	(1.591)
kWh lost to scheduled	8.527**	4.066***	3.759	1.520***
outages	(3.585)	(0.444)	(4.291)	(0.400)
Rechargeable batteries and			–6.049***	–2.211**
no backup (1 = Yes)			(2.032)	(0.962)
Rechargeable batteries and			–5.888***	–1.554
backup (1 = Yes)			(2.148)	(0.990)
Disposable batteries			4.422	1.061
(1 = Yes)			(2.887)	(1.258)
Solar lighting (1 = Yes)			–2.601	–1.901**
			(2.522)	(0.941)
Solar lantern (1 = Yes)			2.091	1.193
			(3.623)	(1.373)
Solar home system (1=Yes)			–3.539	–0.472
			(4.670)	(2.253)
Kerosene lamp (1 = Yes)			–7.011***	–1.111
			(1.814)	(0.791)
Constant			9.311***	4.205***
			(1.840)	(0.940)
Observations				
R-squared	2,251	769	2,251	769
Test: $\theta_1=\theta_2$ (p-value)	0.44 (0.51)	0.00 (0.99)		

Note. Standard errors clustered at the municipality level in parentheses. "Thirtydays=1" means that the sample is restricted to those respondents who reported experiencing 30 or more days with outages "this month one year ago."

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