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Lifelines: The Resilient Infrastructure Opportunity

Background Paper

Infrastructure Disruptions

How Instability Breeds Household Vulnerability

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Abstract

This review examines the literature on the welfare impacts of infrastructure disruptions. There is widespread evidence that households suffer from the consequences of a lack of infrastructure reliability, and that being connected to the grid is not sufficient to close the infrastructure gap. Disruptions and irregular service have adverse effects on household welfare, due to missed work and education opportunities, and negative impact on health. Calibrating costs of unreliable infrastructure on existing willingness to pay assessments, we estimate the welfare losses associated with blackouts and water outages. Overall, between 0.1 and 0.2 percent of GDP would be lost each year because of unreliable infrastructure—electricity, water and transport.

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Infrastructure disruptions: How instability breeds household vulnerability

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1. Introduction[1]

The infrastructure gap is large. Today, 940 million individuals are without electricity, 663 million lack improved sources of drinking water, 2.4 billion lack improved sanitation facilities, 1 billion live more than 2 kilometers from an all-season road, and uncounted numbers are unable to access work and educational opportunities due to the absence or high cost of transport services (Rozenberg & Fay, 2019). And yet, infrastructure services are central for public health and individual welfare, and thus for economic development.

Access to improved water supply has been found to efficiently improve health and reduce mortality. The incidence of diarrhea episodes in children decreased by 21 percent in households with access to piped water in India (Jalan & Ravallion, 2003) and duration of diarrhea was shorter when access was in-house. The impacts on welfare are widely known. Households evaluated in a project in Tangier, Morocco reported to have better quality of life due to the increased water availability and time savings resulting from access to piped water supply (Devoto et al., 2011).

There is plenty of evidence on the benefits of sanitation. Improved sanitation has been estimated to reduce diarrhea prevalence between 20 percent and 37 percent (Bose, 2009; Kumar & Vollmer, 2011; Waddington et al., 2009). Access to improved sanitation has additional proved impacts on children's health improvement, adult's disease prevention and time saving. In Guatemala, access to improved sanitation facilities was found to increase by 18 percent the average child z-score for height-for-age, a measure of chronic health (Poder & He, 2011) and time savings due to the use of household individual latrines were estimated at 40 to 60 minutes a day for 20 villages in the state of Orissa, India (Dickinson et al., 2011).

Electricity access can also improve lives in many ways. For instance, it can extend the length of active days via lighting, free up time, at least for women who can afford labor-saving household electric appliances, and can have positive health impacts thanks to e.g. refrigeration or the replacement of kerosene lamps.

Better transportation infrastructure reduce travel times and transport costs, which in turn improve people's access to schools and hospitals in rural areas (BenYishay & Tunstall, 2011 ; H. Levy, 2004) and can raise productivity and income. Reduced transport time and costs also give workers access to employment opportunities over a wider area, and increase regional and inter-regional trade (Gannon & Liu, 1997 ; Volpe Martincus & Blyde, 2012).

However, development economists remain divided as to the extent of the benefits of electrification. On education, some studies show no to very little impact (Bensch, Kluve, & Peters, 2011; Lee, Miguel, & Wolfram, 2016) while others show a significant increase in school enrollment (Khandker, Barnes, & Samad, 2009) or years of schooling (Kumar & Rauniyar, 2011). On health, Brass et al. (2012) and Samad et al. (2013) find the same lack of clear evidence. Most electrification impact evaluation studies show a significant effect on income and female employment (Dinkelman, 2011; Grogan & Sadanand, 2013; Rud, 2012; van de Walle et al., 2017) while others don't (Lee, Miguel, & Wolfram, 2016). And some studies focusing on rural electrification in Africa, show that electrification may reduce social welfare when electrification costs outweighs its benefits (Lee, Miguel, & Wolfram, 2016; Peters & Sievert, 2015). Allen & Arkolakis (2019) show that transportation infrastructure improvement in the US lead to a substantial welfare gains, albeit highly dependent on context and congestion baseline.

[1] All the costs reported in this paper are in 2018 USD unless differently specified.

Similarly, the impacts of transport investments are not always clear. A meta-analysis of 776 estimates of elasticity of production with respect to transport infrastructure finds that the estimated effect of investing in transport infrastructure varies from -0.06 to 0.52, with the effect depending on the type of infrastructure and the economic sectors (Holmgren & Merkel, 2017). Investments in air transport seem to have the highest impact for the agricultural and service sector, road investments on production in construction and manufacturing and port infrastructure on the agricultural sector. Roberts, Melecky, Bougna, & Xu (2018) review the impacts of investments in transport corridors on welfare, social inclusion, equity, and the environment across 78 papers and find that transport investments always have a positive impact on real income and poverty. However, some have negative impacts on equality (with regions winning and others losing from the investments) including sometimes absolute negative impacts on some groups.

Two possible explanations may account for these varied findings. First, it may be that access to infrastructure is not necessarily a priority for extremely poor households who may face other binding constraints, cannot afford appliances or machinery, have limited access to market centers, and may struggle to cover the cost (even subsidized) of electricity, water or transport. There is evidence in a variety of places that poorer households either have no service or have illegal connections –with no or low payments–. When there is infrastructure development, they cannot afford the price of the connection or the fees and experience a 'worst' service than before. Infrastructure development also induce a greater control over the networks and the invoicing/consumption which tightens further the issues. Second, it may be that expansion of infrastructure in some countries has come at the cost of unreliable service: increasing investments in new infrastructure contributes to stretching resources for operations and maintenance and tends to increase the networks vulnerability.

Indeed, being connected to infrastructure is not enough: the quality of the service and its reliability also matters, and the lack of reliability can affect households through many channels. There are several channels through which infrastructure service disruptions affect households (Table 1). Some channels are linked to each individual disruption and include the direct short-term consequence of not having access to electricity, safe water, transport, or communication. For instance, activities affected by power outages include cooling and heating (and health implications), economic activities and income, studying of children and education outcomes, social and leisure activities, and regular household tasks such as cooking and cleaning (Pasha & Saleem, 2013). But some effects may materialize only over the long term, and as a result of the repetition of outages, such as the decision not to invest in food refrigeration or air conditioning due to lack of power reliability. In those cases, each individual outage does not have a cost associated to it anymore, since households give up on some types of energy use. Finally, in addition to the impact of outages, households incur additional costs linked to investments to mitigate the impact of outages. Self-generation for electricity, water reservoirs for water supply, or the ownership of a vehicle to compensate for inadequate public transit can be extremely costly for households.

Table 1. Infrastructure disruption services have multiple impacts on households

	Examples of effects of the lack of services	Examples of additional costs to replace services
Effect of individual disruptions	Student not being able to work at night and food turning bad in a fridge due to a power outage, inability to reach emergency services for health issues during communication outage, diarrhea due to consumption of bad water in association with a water outage, time and income (or even job) lost during a transport disruption	Cost of gasoline or batteries, cost of water bottles or time spent to fetch water during a pipe water outage, taxis to replace public transit, etc.
Effect of repeated disruptions	Decision not to invest in a fridge due to unreliable electricity, or decision not to take a job due to uncertainty in ability to commute)	Additional investment in self-generation, water reservoirs, or individual means of transportation.

Each of these effects are driven by a number of different mechanisms, partially overlapping. This complexity makes it difficult to estimate with precision the impact of infrastructure disruptions on households. This note reviews the literature on the different impacts and the mechanisms through which infrastructure disruptions affect households and cover four main networked infrastructure systems: electricity, potable water, transport, and communication. When possible, it estimates the economic cost of infrastructure disruptions through the willingness-to-pay of households to avoid them. While highly uncertain, these estimates can provide a sense of the magnitude of the problem.

1. The impact of electricity outages

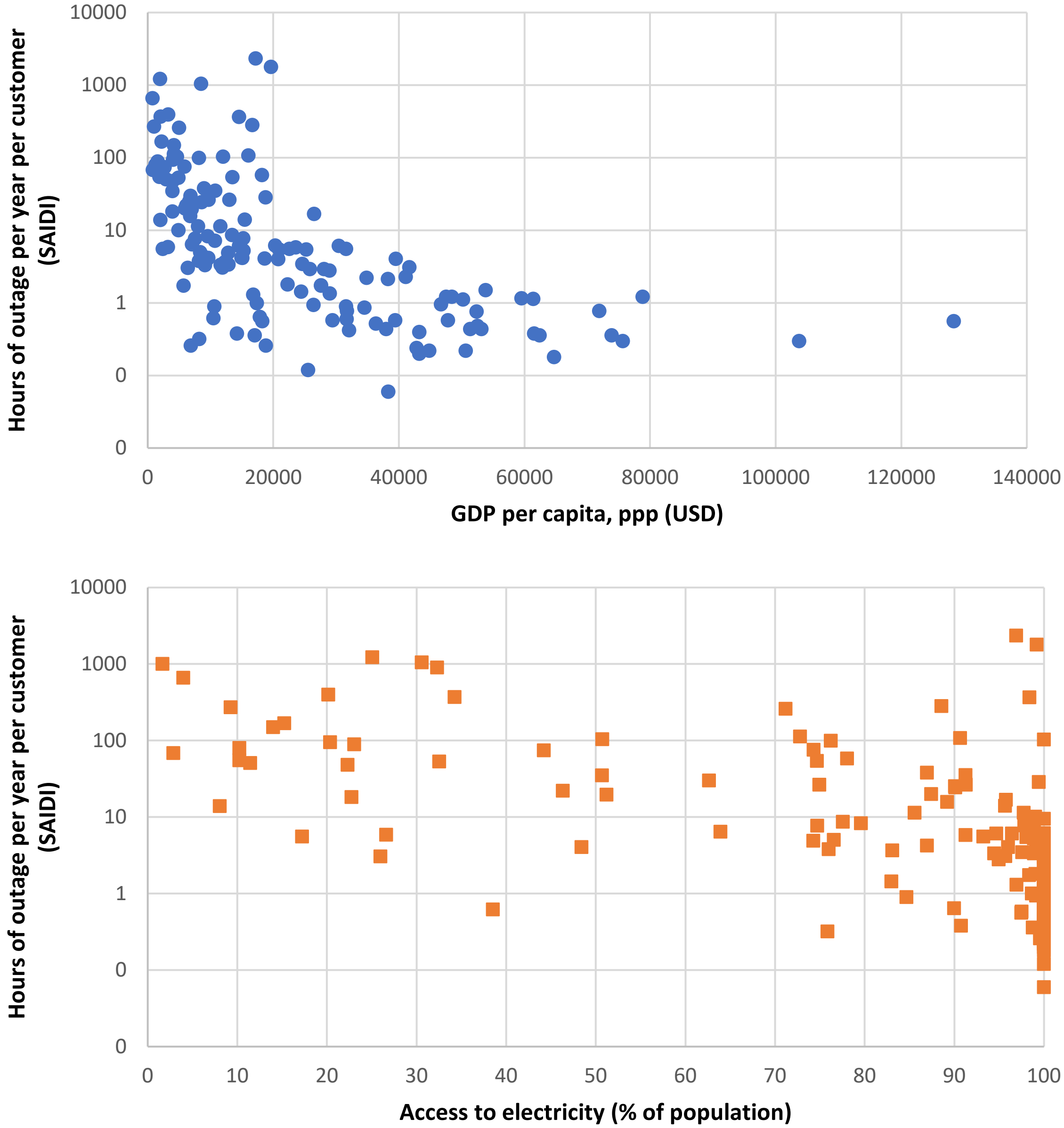
1.1. Electricity supply is often unreliable with measurable consequences on households

In many emerging countries, power outages are regular occurrences. As shown in Figure 1, many countries experience more than 100 hours of outage per customer and per year[2], on average. Poor countries tend to experience more outages, even though the variance is very large, especially at low income levels. The figure at the bottom illustrates the number of outages per customer per year on average in relation to electricity access as percent of population. It shows no clear relationship between coverage and reliability – many of the countries with high coverage also have poor reliability. However, countries with low access to electricity more consistently tend to also have poor reliability.

Outages are not the only disruptions of the electric systems. *Brownouts* refer to a drop in the voltage of an electric system, which constrains the use of high-voltage appliances (such as refrigerators, televisions, and air conditioners) and often result in malfunction of electric appliances. However, we explore here the impact of power *outages*, i.e. complete interruptions of power supply through the grid.

[2] Data retrieved from the Doing Business study http://www.doingbusiness.org/en/data

Figure 1: Electricity supply reliability improves with income and electrification.

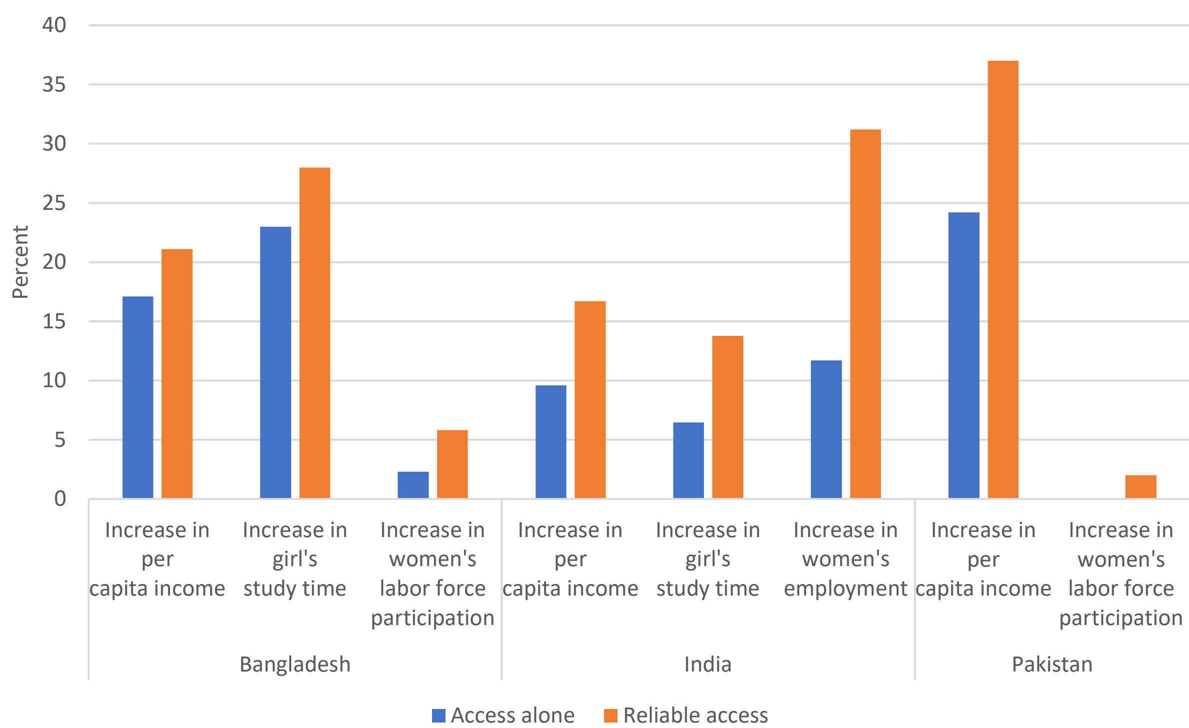


Source: authors based on IEA, Doing Business and World Bank data.

There is consistent evidence showing that the quality of electricity provision matters for household income. "The provision of reliable electricity affects economic transformation through at least three pathways: lowering the cost of doing business, thereby increasing business entry; increasing the performance of existing firms through higher productivity and revenue; and increasing the welfare and quality of life of households, thereby enhancing the offer of productive labor services." (World Bank, 2019). Chakravorty, Pelli, & Marchand (2014) find that better quality electricity measured in higher daily supply is associated with higher income among rural households in India. Results from their analysis using a representative panel of more than 10,000 households show that during the study period (1994-2005), access to electricity led to a 9% income increase among rural non-agricultural households, while being connected to the grid and having access to better quality electricity with fewer disruptions increased income by 28.6%. Their results show that electricity disruptions have clear economic implications for households. Similar results are found by Rao (2013) focusing on household enterprises in India. He uses a subset of 8,125 urban and rural households that manage a non-farm enterprise. While he primarily finds strong evidence for a positive income effect of connectivity to the grid, he also identifies suggestive evidence of a positive effect of better supply availability. He estimates that the benefit from the income effect of improving supply to 16 hours a day or more would reflect 0.1% of GDP on an aggregate level. In Pakistan, a study finds that the middle class pays the highest cost of electricity outages in relation to its income (Pasha & Saleem, 2013).

As explored in Zhang (2019), the benefits from electricity access are magnified if the access is reliable. In the three countries included in the study, Bangladesh, India, and Pakistan, access to electricity is associated with higher income and better social outcomes. But the impact is much stronger if the electricity is reliable (Figure 2). In some places and for some metrics, for instance the effect of electricity access on women employment in India and Bangladesh, benefits are two or three times larger if access is reliable.

Figure 2: Impacts of access to electricity and network reliability on income and social outcomes in South Asia

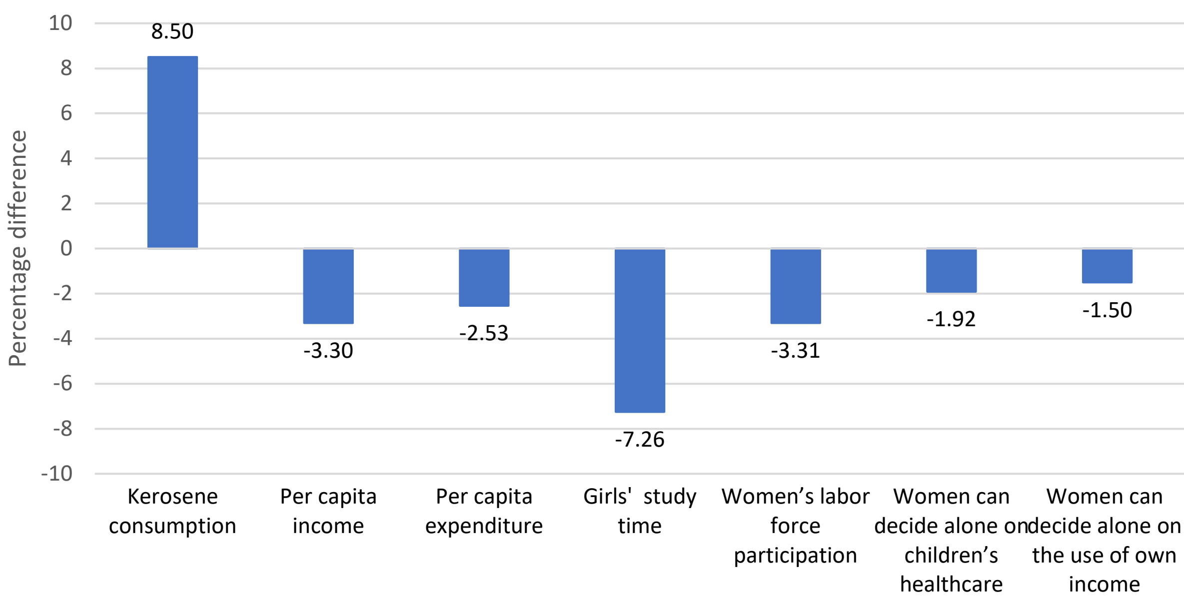


Source: Zhang (2019). Note: The effects of electrification on girls' study time and the effects of power outages on women's labor force participation in Pakistan are not estimated because data are not available.

The cost of outages is made up by different components whose importance depends on the context. In Pakistan, the total annual outage cost for households adds up to 6.7% of annual expenditure (Pasha & Saleem, 2013). The largest source of this cost is the cost of self-generation – making up 56% of total costs. Other costs include monetization of utility cost and foregone economic activity due to outages that account for 22% of the cost in the whole sample. Disaggregating the wealth dimension draws a slightly different picture: for poorer households, monetization of utility loss makes up the largest source of losses at 44%, since they usually cannot afford self-generation.

Unreliable access to electricity negatively affects the welfare of households. Frequent outages limit households' ability to engage in productive, educational, and recreational activities during nighttime (Lenz et al., 2017). For instance, with regular access to electricity, children can study at night, thereby improving their educational outcomes (Dasso, Fernandez, & Ñopo, 2015). An unreliable power network also impact women's welfare: in Bangladesh, Zhang (2019) finds that long power outages are associated with a decrease in women's labor force participation, likely because the lack of electricity is associated with an increase in the time needed for domestic work (Figure 3): time has to be spent collecting or buying fuel and making fires to cook and heat water; and, due to lack of refrigeration, to shopping on a daily basis (Chant, 1996). Outages also have an impact through access to and income from jobs. In Africa, for instance, outages reduce the probability of employment by approximately 35 percent, and probability of nonfarm employment by 55 percent (World Bank, 2019).

Figure 3: Difference between grid-connected households with and without at least 20 hours of electricity daily in Bangladesh



Source: Zhang (2019). Note: Each regression estimate refers to the estimated change based on econometric analysis.

Poor quality electricity network can also affect public health: during power disruption, levels of air pollution increase. Farquharson, Jaramillo, & Samaras (2018) estimate the change in CO_2, $PM_{2.5}$, NO_x and SO_x due to backup power generation in firms in Sub Saharan Africa. $PM_{2.5}$ have a documented impact on health, and emissions increase by between 0.01 and 0.15 kilograms per person with electricity access per year when replacing grid electricity with backup diesel generators during power outages. As a point of comparison, baseline $PM_{2.5}$ emissions range from 0.01 to 0.32 kilograms per person with electricity access per year in Sub-Saharan Africa. Moreover, these estimates are likely to be underestimating the impact of backup power generation since it only takes into account firms' expenditures, leaving aside the households' response –such as indoor generation or traditional cooking using coal and firewood, which have strong impact on indoor air quality.

Further, health care provision can be disrupted if electricity access is not reliable, and there is evidence that the mortality rate increases during power outages. Many essential devices used in health care require significant electricity supply. According to Kishore et al. (2018), difficulty to access health care was one of the main causes of indirect deaths after the hurricane Maria in Puerto Rico. A review of electricity access in health facilities in 11 Sub-Saharan African countries finds that 26% of health facilities have no access to electricity and that only 28% of health care facilities have reliable access (Adair-Rohani et al., 2013). Power outages impact health during extreme weather events by, for example, making it more difficult to access health care for people with chronic diseases and disaster related affections, maintain front line service and cause indirect health impacts due to loss of refrigeration (e.g. food-borne diseases and vaccine spoilage) and heat-related deaths (Beatty et al, 2006; Klinger, Landeg, & Murray, 2014). An assessment of the 2003 power outage in New York City finds that mortality rates for accidental deaths increased by 12% and non-accidental deaths by 25% (Anderson & Bell, 2012).

Power outages have repercussions on other infrastructure all the more so as networks are connected. Water systems in particular tend to rely on power supply and only the parts which are gravity fed can function during blackouts. Transport systems in dense urban areas are also highly reliable on electricity due to increasing complexity of traffic management and signals. While impacts of the lack of telecommunication on households is rarely documented in the literature, some studies put in evidence consequences on emergency systems and public health structure. In the aftermath of hurricane Maria in Puerto Rico, Kishore et al. (2018) report that 8.8% of the surveyed population in the most remote areas of the island were not able to reach emergency services. Beatty et al. (2006) point out the need of improvement of communication during an electricity outage in a hospital setting. Kile et al. (2005) reach the same conclusion after conducting semi-structured interviews on the impact of a power outage in 2003 in the Midwest and Northeast of the US. Respondents underlined the fact that communication was limited, and that public health surveillance was affected along with emergency responses.

1.2. The economic cost of electricity outages to households is high

The cost of electricity outages depends on length and timing. Carlsson & Martinsson (2008) provide evidence that the willingness to pay (WTP) to avoid unplanned power outages varies depending on the time of the week and the season. The 2,400 households who responded to their choice experiment survey in Sweden reported being more affected by outages occurring during a weekend and during the winter. Households also place more value on the reduction of long electricity service interruptions. Equivalent studies based on survey methods in other developed countries reach the same conclusion about the non-linear impact of outage durations on WTP and costs, and therefore on well-being.

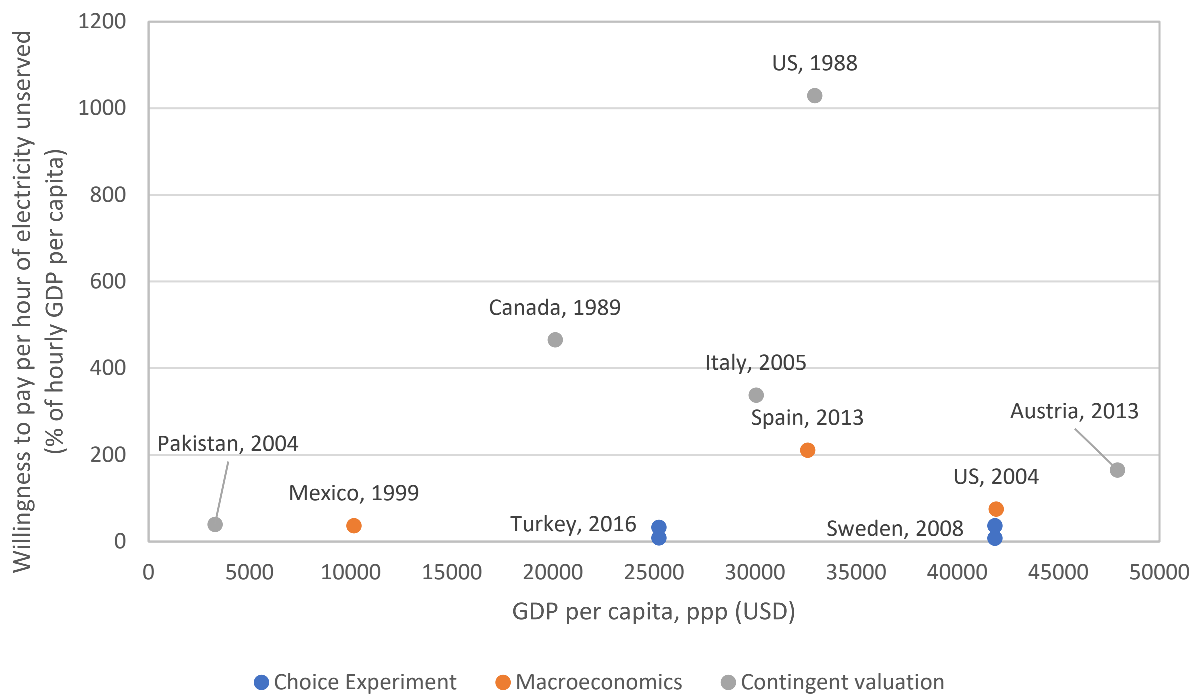
Estimates of the WTP to avoid power outage yield very different results across countries and methodologies (Figure 4)[3]. According to the referenced studies, the average cost revealed by contingent valuation and choice experiments surveys are USD 11.9 and USD 0.74 per unserved hour respectively. This difference is coherent with theory: in contingent valuations, people tend to overstate their WTP as they think it will have an impact on the problem while not being directly charged to them. There is no clear

[3] Detailed figures on WTP for a reliable electricity network can be found in the Appendix section (Table 5).

relationship between the WTP to avoid power outages and GDP per capita, but the WTP is consistently much larger than electricity tariffs (Figure 4).

In addition to the small number of studies, the wide range of results might come from fundamental differences in experience design and different frequency and duration of considered outages. Most of the papers – listed in Appendix (Table 4) – are applied to advanced economies where dependency on electricity is high and power outages are infrequent. In poorer countries, the cost of electricity outages will fall on those with access and relatively high dependence on electricity – for example those whose livelihood depends on it (Pasha & Saleem, 2013).

Figure 4: Distribution of willingness to pay for avoiding power outages



Source: authors based on World Bank data and estimates from the literature. A country-year is matched to the closest non-missing value of GDP per capita.

The global cost of power outages for households cannot be accurately estimated. Assessments fall between 0.002 and 0.15% of GDP (in purchasing power parity) per year, which corresponds to a range of 2.3 to 190 billion in 2018 USD[4]. While a precise estimate of the cost of power outages on households is impossible, we propose here an assessment of its order of magnitude. From Table 4 (Appendix), we calculate a range for the willingness to pay per hour unserved in terms of daily GDP[5]. After excluding the

[4] Here we use the World Bank 2018 estimate for global GDP, ppp, retrieved from https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD

[5] We do not make any distinction between weekdays and weekends, and between seasons: what boils down to assuming that outages occur at random, independently from the time of the week and the time of the year. The range of WTP can be interpreted as an average WTP over days and season.

bottom and top 10% observations, WTP range from 0.36 to 19.4% of daily GDP per hour of electricity unserved. We disregard many important dimensions, assuming that the WTP of an individual to prevent power outage is proportional to GDP per capita in the country and disregarding the dependency of this WTP to the frequency and duration of power outages. This leads to underestimating the cost in countries with few and short outages and overestimating it in countries with many and long outages. We then use the data from the annual Doing Business survey[6] to estimate the duration of outages in 139 countries, leading to the estimate between 0.002 and 0.15% of global GDP. For reference, the cost of power outages would be valued at 0.001% of global GDP (USD 1.3 billion per year) if non-served electricity was priced with electricity tariffs, and at 0.007% of global GDP (USD 9 billion per year) if GDP per hour was used to value one hour of power outage.

This cost of power disruption underestimates the real impact on the well-being of households. First, there is a large uncertainty in the estimates of people's WTP to prevent power outage, and it is unclear whether they include all relevant components, and in particular health effects, impacts through jobs and salaries, cost of generators, etc. In particular, electricity outages have a significant and large impact on firms' output, what indirectly decrease household's wellbeing through wage reduction (Rentschler et al., 2019b). However, it is likely that such an indirect impact is disregarded or underestimated in household's monetization of lost utility. Moreover, it is unclear whether households consider their generator as a sunk cost: once the up-front cost of the generator is paid, there is little incentive for household to pay for service improvement, possibly reducing the WTP. Second, the Doing Business survey is considering outages for the average firm in the capital city, possibly leading to a large underestimation of the number and magnitude of disruptions. Moreover, not all countries are included in the Doing Business survey and the missing countries are mostly in the bottom 50% of the GDP per capita distribution, and therefore the most likely to experience numerous outages (Figure 1). This would increase the likelihood of underestimating the cost of outages. Finally, using a WTP to estimate the well-being impact of power outage creates a strong bias against the poorest. Since these disruptions affect mostly people in poor countries where WTP are mechanically low – due to the wealth effect –, the impact expressed in dollars may appear small, hiding significant implication for immediate well-being, but also for the ability of households to prosper and escape poverty.

2. The impact of water disruptions

2.1. Water disruptions have a strong impact on health

The few studies focusing on health impacts of water provision disruptions and dysfunctions consistently show negative effects on health due to water disruption episodes (Figure 5)[7]. Water outages can affect health through a number of different channels. Disruptions may force households to use unsafe alternative water sources. It may also affect household hygiene practices. Water disruptions (including low-pressure episodes) may increase risk of water supply contamination, what affects consumption once water is accessible again. Contamination may occur if water is unsafely stored during disruptions or filtration and purification systems are malfunctioning. Most of these papers focus on systemic water intermittencies while fewer focus on one-off water disruptions.

In medium to low income countries, frequent disruptions to potable water supply are widespread (Kumpel & Nelson, 2016). From 2004 to 2013, the International Benchmarking Network (IBNET), documented

[6] Retrieved from https://datacatalog.worldbank.org/dataset/doing-business.

[7] Detailed numbers may be found in the Appendix (Table 6).

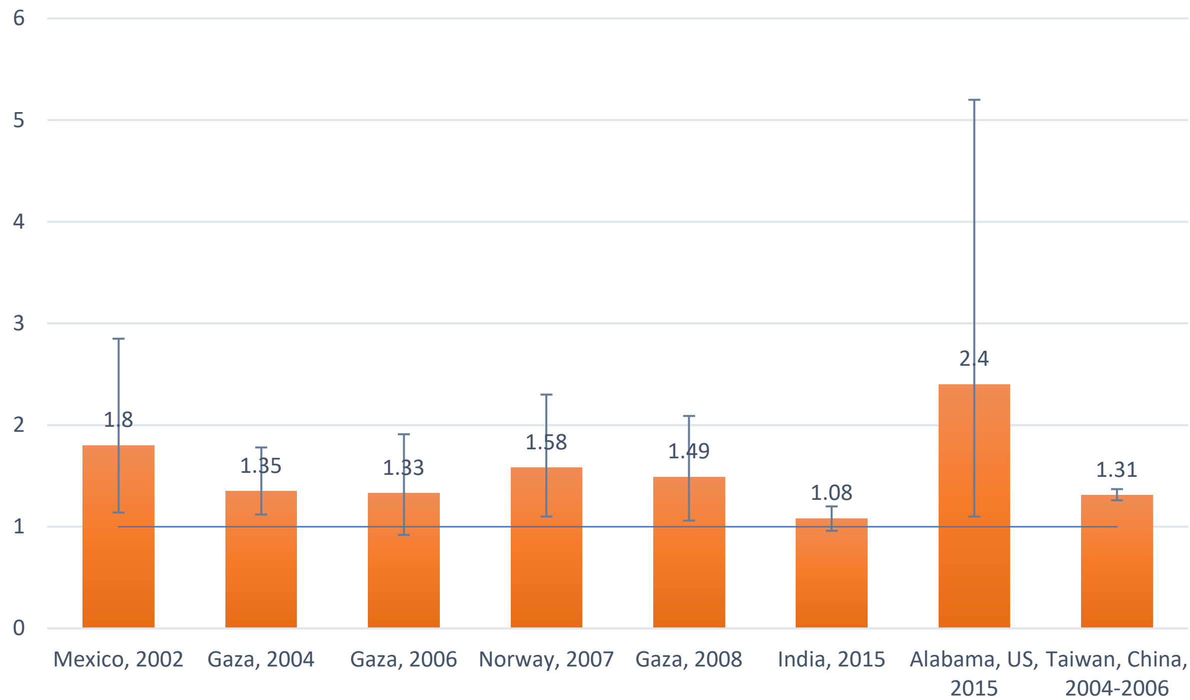
water supply lasting less than 24 h per day in 44 of the 102 countries included in the database (Danilenko et al., 2014). In 2000, the World Health Organization (WHO) estimated that 60% of the population served by piped water in Latin America and the Caribbean were served by Intermittent Water Supply (IWS) and that at least one in three urban water supplies in Africa and one in two in Asia operated intermittently (WHO, 2000). Overall, 1 billion people suffer from IWS according to WHO/UNICEF Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP).

The impact of intermittent water supply is significant, particularly on poor households. Health impacts caused by water disruptions tend to be more severe for low-income households and affect households that consume tap water (Ercumen et al., 2015; Jeandron et al., 2015; Nygård et al., 2007). In India, Ercumen et al. (2015) look at the relationship between water supply interruptions and waterborne illnesses using panel dataset with matched cohorts of households. The impact of water supply interruptions on child diarrheal illnesses depends on household income. Children from low-income households with continuous water supply have 37% lower prevalence of infectious diarrhea than low-income households with intermittent supply. In higher-income households, there is no significant evidence of the impact of continuous water supply on child diarrheal illnesses, compared to intermittent supply. Results also show that households with continuous water supply report 42% fewer cases of typhoid fever than households with intermittent water supply, regardless of their level of income.

Studies using official information on water outages and clinic admission data identify a strong and consistent relationship between outages and health impacts. In the Democratic Republic of Congo, Jeandron et al. (2015) link water interruptions to increased cholera incidence rate using time series data combining admission information from a Cholera Treatment Center and daily variations of water supplied by the water treatment plant. They find that the suspected cholera incidence rate typically increases by 155% over the next 12 days following one day of outage, compared to the incidence rate following optimal water provision. Ashraf et al. (2017) find that water outages in Lusaka, Zambia, are associated with increased incidence of a number of diseases, such as diarrhea and respiratory infections.

Case studies of specific water disruptions also find significant impacts of health. Huge diarrhea outbreaks caused by cholera and *Escherichia coli* infections are observed after floods (Ahern et al., 2005; Qadri et al., 2005). Diarrheal pathogens can spread through direct contact with floodwater or through compromised water sources. However, their impact is temporary and prevalence of diarrhea in exposed and non-exposed groups are equal in the long-run (Joshi et al., 2011). A case study from Alabama, US, looks at the effect of a freeze-related water emergency on diarrheal and respiratory illnesses. The researchers find a significantly higher risk of contracting diarrhea for households experiencing water disruptions and low water pressure and prevalence increases with the length of disruption (Gargano et al., 2015). The diarrhea outbreak in Milwaukee which affected 403,000 individuals, was caused by a filtration system that malfunctioned after a heavy storm releasing the bacteria *Cryptosporidium oocysts* in the water distribution system (Hoxie et al., 1997; Mac Kenzie et al., 1994).

Figure 5: Risk comparison of contracting diarrhea for households consuming intermittent water (compared with reliable supply)



Source: Bivins et al. (2017) and modified by authors. In Mexico, 2002 and Gaza 2004, risk ratios are derived from odd ratios and diarrhea prevalence in the population at risk as prevalence in the control group is not available. Note: This means that, for instance in Mexico, a household with intermittent water supply has 1.8 times the risk of diarrhea compared to a household with reliable supply.

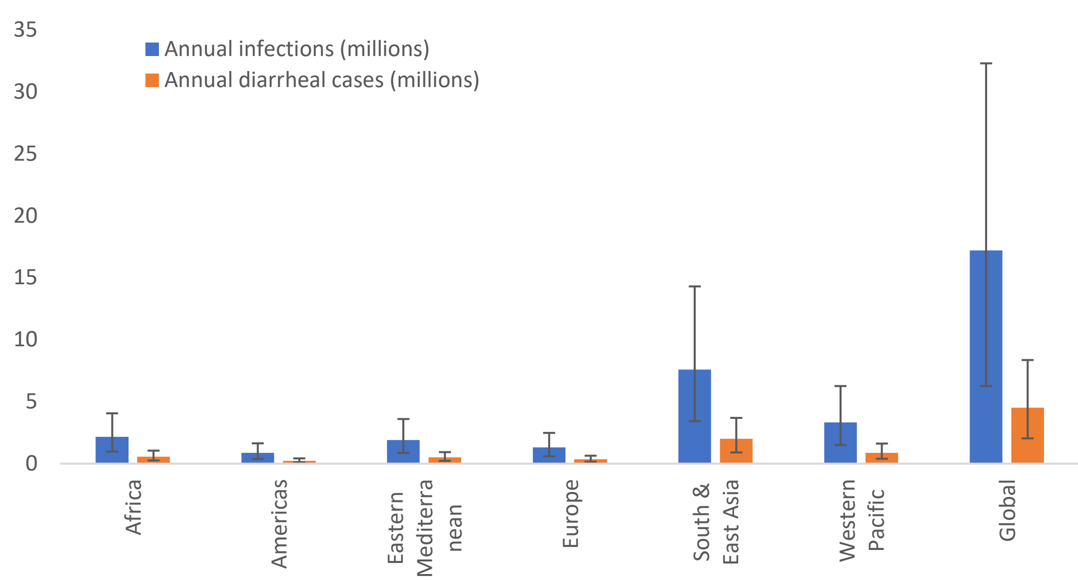
Even though the impact of IWS on mortality seems limited, the effect on morbidity is large. The impact of IWS on health are documented by Bivins et al. (2017). They use quantitative microbial risk assessment to characterize the risk of infection for fecal-oral pathogens associated with IWS and the attributable burden of diarrheal disease. Their results are reproduced in Table 2 and Figure 6. Overall, the three considered pathogen agents – which are likely to be found in water when intermittently served – are not strong drivers of mortality but are significant factors of morbidity, causing several millions of infections and diarrhea cases every year in all parts of the world, especially in South and East Asia, and Western Pacific. These findings support the claim that improving health conditions go through the improvement of health care but also through actions on disease vectors, spread by ineffective water distribution systems.

Table 2: Annual Infections, Diarrheal Cases, DALYs, and Deaths Attributable to three bacteria* assuming consumption of fecally-contaminated tap water from an IWS

Region	Population served by IWS (millions)**	Annual infections (millions)****	Annual diarrheal cases (millions)****	Annual Deaths****	Annual DALYs (thousands)****
Africa	116	2.16 *(0.973-4.06)*	0.5666 *(0.256-1.05)*	196 *(88-395)*	13.5 *(6.12-28.0)*
Americas, LMI***	47	0.874 *(0.384-1.64)*	0.229 *(0.104-0.424)*	79 *(36-160)*	5.55 *(2.48-11.3)*
Eastern Mediterranean, LMI	103	1.91 *(0.864-3.60)*	0.503 *(0.227-0.930)*	174 *(78-351)*	12.2 *(5.43-24.8)*
Europe, LMI	71	1.32 *(0.596-2.48)*	0.346 *(0,157-0.641)*	120 *(54-242)*	8.38 *(3.75-17.1)*
South East Asia	409	7.60 *(3.43-14.3)*	2.00 *(0.902-3.69)*	691 *(309-1,390)*	48.3 *(21.6-98.6)*
Western Pacific, LMI	179	3.33 *(1.5-6.26)*	0.874 *(0.395-1.62)*	302 *(135-609)*	21.1 *(9.44-43.2)*
Global	925	17.2 *(7.76-32.3)*	4.52 *(2.04-8.36)*	1,560 *(699-3,150)*	109 *(48.8-223)*

*Source: Bivins et al. (2017). *Campylobacter, Cryptosporidium, and Rotavirus ** Dataset assembled by projecting prevalence of IWS found in IBNET onto JMP measures of access to piped-on-premise water supplies. *** LMI = Low-middle income. **** 95% confidence intervals within parenthesis.*

Figure 6: Impact of Intermittent Water Supply on health.



Source : Bivins et al. (2017)

2.2. The economic cost of water disruption

The economic value of IWS on health most likely exceeds US$3 billion per year. Assuming that a diarrheal disease leads to between 4 and 7 days of loss of productive work –for the sick or the caregiver–and that treatment costs are between USD 2 and 4 (Rozenberg & Hallegatte, 2015), then the cost is estimated to be between USD 650 and 1,100 millions each year (Table 3). Furthermore, if we consider that each infection attributable to the three studied bacteria – *Campylobacter*, *Cryptosporidium*, and *Rotavirus* – lead to a similar episode of diarrhea, the estimate of the overall cost of intermittent water supply escalates to between USD 3,100 and 5,480 millions. The total economic cost – without considering the direct well-being impact of being sick – already reaches between USD 3 and 6 billion per year.

Table 3: Annual health cost of Intermittent Water Supply.

Region	Cost of infection (in millions of USD), low impact scenario	Cost of infection (in millions of USD), high impact scenario	Cost diarrhea (in millions of USD), low impact scenario	Cost of diarrhea (in millions of USD), high impact scenario	Total cost (in millions of USD), low impact scenario	Total cost (in millions of USD), high impact scenario
Africa	91.43	161.08	23.98	42.25	115.41	203.33
Americas, LMI*	139.72	244.95	36.61	64.18	176.33	309.13
Eastern Mediterranean, LMI	286.95	503.11	75.57	132.50	362.52	635.61
Europe, LMI	292.43	512.41	76.65	134.31	369.08	646.73
South East Asia	559.77	983.40	147.31	258.79	707.08	1242.18
Western Pacific, LMI	548.37	961.32	143.93	252.31	692.30	1213.63
Global	2328.58	4083.62	611.93	1073.14	2940.51	5156.76

*Source : authors based on Bivins et al. (2017) and Rozenberg & Hallegatte (2015). * LMI = Low middle income countries*

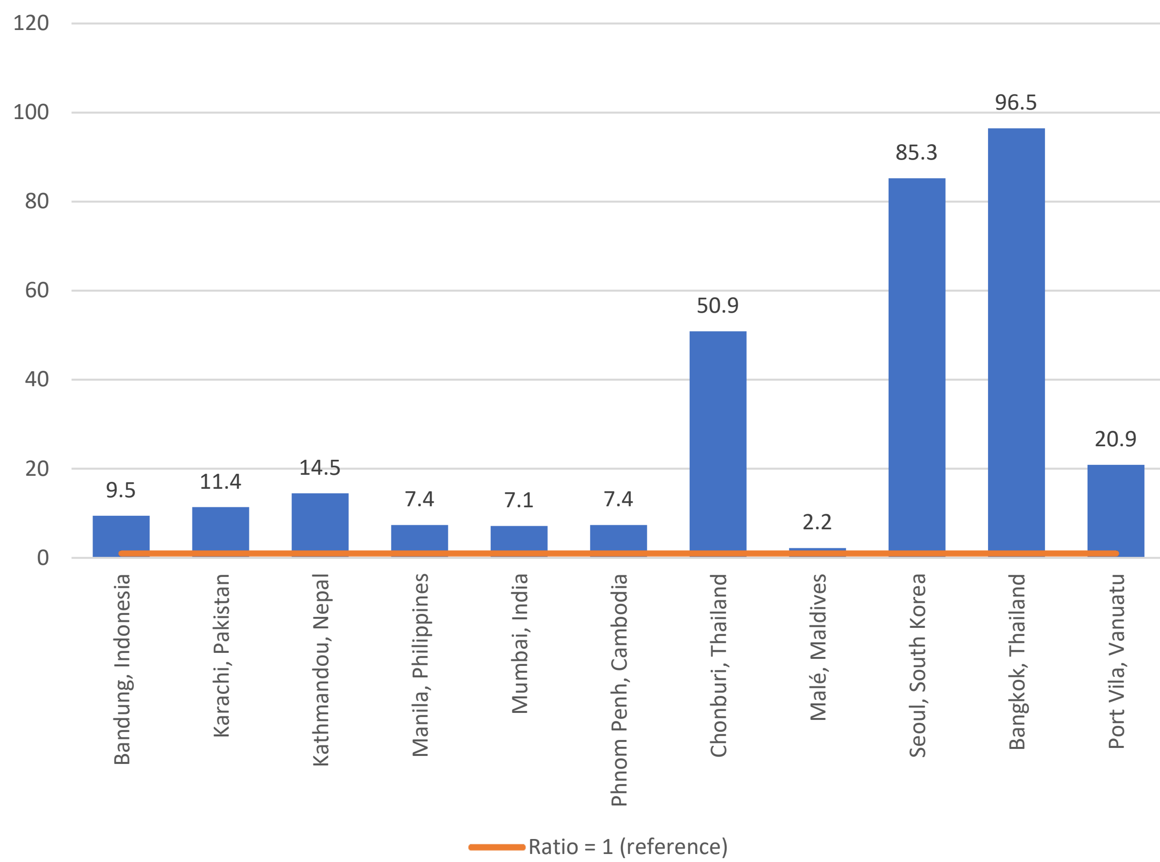
Unreliable water network also impacts gender equality. When water services are limited, this vital resource needs to be collected from public standpipes, wells, bore holes, rivers or storage drums served by private tankers, with WHO data estimating that 72 per cent of this burden falls on women (Birch, 2011). Evidence in Lusaka, Zambia, shows that outages increase the time young girls spend at their chores, possibly at the expense of their education (Ashraf et al., 2017). In respect of sanitation, too, women living in poorly served settlements are characteristically responsible for disposing of fecal matter in their compounds, or accompanying their children to appropriate sites (Chant, 2007). Even if journeys are short in terms of distance, they may take long to execute where crossing inhospitable terrain, or queuing at outlets, is involved.[8] Furthermore, it is now widely reported in a range of settings that women and girls

[8] Data on the time spent to fetch water are usually for rural households with no piped connection. No estimate of the time needed for connected households who experience a water supply outage could be identified.

are at particular risk of attack in and around toilet facilities located some distance from their homes (Cornman-Levy et al., 2011; McIlwaine, 2013; Sommer et al., 2015)

Other costs associated with water disruptions are incurred through the direct cost of alternative source of water. During long water interruptions, people have no choice but to rely on alternative sources of water, which are all more expensive than piped water. Some households may be able to use their own well, but energy for pumping can be expensive. Also, many households subject to IWS use some form of water storage, what increases the amount of water consumed, poses health risks due to poor storage, and carries some costs. In most cities, people without reliable access to water have to rely on water kiosks, street vendors, or tanker trucks. All these solutions come at a higher cost than piped water. As documented in Kjellen (2000) for Dar es Salaam and UN-Habitat (2003) for 19 cities, these alternative sources of water can be ten to 100 times more expensive than piped water (Figure 7).[9] These additional costs, combined with negative health outcomes, have a direct impact on the economy: in Lusaka, Zambia, financial transactions decrease in times of water outages, with particularly adverse effects on the poorest (Ashraf et al., 2017).

Figure 7: Ratio of water prices: comparison of water vendors and house connection prices



Source: (UN-Habitat, 2003). Based on consumer surveys by Asian Development Bank.

[9] Detailed tables on water prices in Dar es Salaam and in Asian cities may be found in the Appendix section (Table 6 ; Table 7).

Willingness to pay for improved water service quality and reliability is designed to account for all the costs mentioned above. However, as with electricity, estimates are rare and very heterogenous (Appendix – Table 8). To our knowledge, most assessments of the willingness to pay for improvement in the water distribution service are applied in developed countries. After a choice experiment, Hensher et al. (2005) find that in Canberra, the willingness to pay to reduce the frequency and duration of water disruptions depends on the current state of water services reliability. The respondents were willing to pay 113.32 Australian dollars (USD 102) per year to avoid one outage if they have to face one outage every ten years, but only 9.48 Australian dollars (USD 8.87) per year when they experience monthly outages. There are two reasons for this difference. First, if customers face more interruptions, they are more likely to take actions to reduce their impact, such as storing water. Second, from a psychological perspective, a reduction from 12 to 11 outages seems less important than a reduction from 2 to 1. Another interesting point is that surveyed people are generally willing to pay much more to avoid an outage than the corresponding price of water (Appendix – Table 6 and Table 8).

The willingness to pay to reduce the duration of the outage also decreases with the baseline duration. Respondents value a reduction of the duration of the water outage by one hour at 54.75 Australian dollars (USD 49.5) in the case of a one-hour disruption but only 12.17 Australian dollars (USD 11.81) in the event of an 8-hour shortage. Similar results were found in the US (Thacher, 2011). A second study in Australia finds that people are willing to pay 1.45 Australian dollars (USD 1.52) per hour of outage and 7.95 Australian dollars (USD 8.38) per outage (MacDonald, Morrison, & Barnes, 2010). Here, the relation between outages and willingness to pay is linear: there is no evidence of the increasing cost as the water distribution network improves. In China, the question was framed in terms of volume of water unserved. The resulting cost for households is much lower than MacDonald Morrison, & Barnes (2010)'s findings in Australia: USD 0.03 for 1000 liters unserved (Wang, Ge, & Gao, 2018). Parameters such as demographic and economic factors could be at the origin of such a low price. Details about cost estimates are summarized in Table 8.

It is difficult to separate water supply reliability and water quality. In Mexico, Vásquez et al. (2009) find that the median sampled household would pay 229.75 Mexican pesos (USD 20.83) more in their monthly water bill for a reliable system providing safe drinking water 24 hours per day and every day of the year, which is 7.55% of the reported median income. Similarly, the evidence of high maximum willingness to pay for access to better water and sanitation systems in El Salvador suggests that there is room for profitable private investments (Perez-Pineda & Quintanilla-Armijo, 2013). However, in Tanzania and Bangladesh, even though the population is conscious about the importance of having access to safe water, their willingness to pay stays below the retail price for the tested improvements (Burt et al., 2017; Khan, Brouwer, & Yang, 2014). As mentioned earlier, this is also associated with the issues of consumers not being willing to pay for a service. The direct implication for policy making is that scaling-up improvement in water service systems might require subsidies, which might be difficult in countries where the Non Revenue Water – the volume of water the facilities do not get paid for, usually made of leaks, illegal connections and marginal use (e.g. firefighting) – represents a large share of the facilities' revenues.

Using existing WTP estimates, and data on water outages in 123 countries from the World Bank's Enterprise Survey[10], water interruptions are estimated to cost between 0.11-0.19% of GDP, ppp each year, what corresponds to USD 88 and 153 billion globally. The method of estimation comprises some limitations that increase uncertainty. First, the WTP used to assess the global cost are issued in two

[10] Data available here: http://www.enterprisesurveys.org/

developed countries[11] and assumed linearly related to daily GDP per capita. It is likely that those estimates are overestimated due to the wealth effect and the fact that WTP usually decreases with the reliability of the water distribution system (Hensher et al., 2005). Second, the countries included in the ES correspond to the middle of the global GDP distribution: the 123 countries cover 49% of the global GDP, preventing an accurate extrapolation of the global total annual cost of water outages for households. Third, the ES reports water outages experienced by firms and not households. Depending on the country's regulation, households or firms may be served following an order of priority in case of a water supply disruption what would suggest that they do not experience the same outages.

3. The impact of transport disruptions

3.1. Transport disruption and congestion affect all cities

Road congestion is a growing issue in cities. INRIX, a transport-data company found that a driver spent on average 36 hours in gridlock in 2013 in French, British, German and American metropolitan areas (Cebr, 2014a). The time lost to congestion increases threefold to 111 hours when additional planning time is included.[12] The study used GPS data from some 300 millions of cars and devices to measure when and where traffic slowed to a crawl along 5 million miles of roads, spanning 1,360 cities in 38 countries.[13] Capital cities in developing countries suffer the most from traffic because roads and public-transit systems have not kept pace with population growth. In Thailand, drivers loose an average of 56 hours a year to congestion at peak travel times; Indonesia and Colombia come second and third with 51 and 49 hours. Similarly, the worst place to drive in Europe is Russia, which accounts for five of the continent's ten most congested cities.

Weather events have an adverse effect on travel time for households by affecting driving abilities and contribute to congestion. A literature review of existing evidence from the US and the UK on the impacts of weather conditions on travel time finds that travel time delays increase by 11% in wet conditions and by more than 12% in the presence of precipitation, high winds, low visibility or slick pavement (Goodwin, 2002). Flows of traffic can be reduced by between 6% and 30% depending on road conditions and time of day. In rainy and wet conditions, speed reduction ranges from 10% to 25% in the reviewed studies.

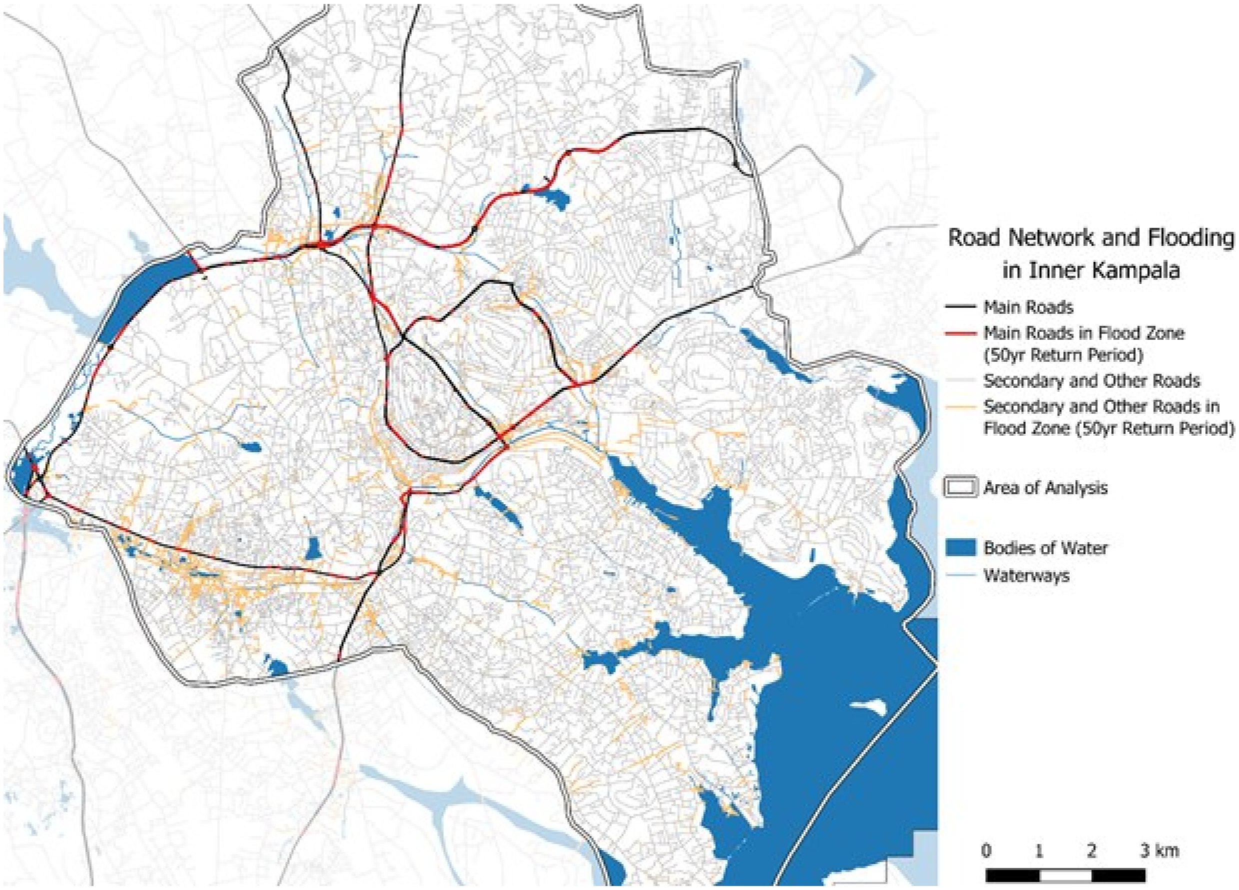
Urban flooding is a major cause of transport disruptions in cities across the world. For instance, in inner Kampala, Uganda, 11% of primary roads are located directly in zones of high flood risk (11.8km out of 108.2km) (Figure 8). When floods do occur, vast parts of the urban road network are cut off. This illustrates that road users across the city will be affected by flooding, regardless of whether they are located in flood zones or not. This implies severe disruptions to the road network and, consequently, the operations of firms, the delivery of services, and the accessibility of jobs. A forthcoming study by the World Bank provides evidence from Dar es Salaam, Kampala, Bamako, and Kigali, and shows that infrastructure disruptions are by no means limited to certain low-income neighborhoods. While infrastructure disruptions indeed physically occur with increased frequency and intensity in certain hotspots, infrastructure systems are networks that transmit the disruptions due to urban flooding across wide areas. This is true both for the severe flooding which are relatively rare and the nuisance floods, very localized, disrupting traffic without stopping it, which is a daily issue in tropical cities and regular occurrence in most cities of emerging countries.

[11] Australia and the US, see Table 7.

[12] Planning time is the time lost due to uncertainty in travel speed, because drivers have to leave earlier to make sure they arrive on time (here, at least 95 percent of the time).

[13] http://inrix.com/scorecard/

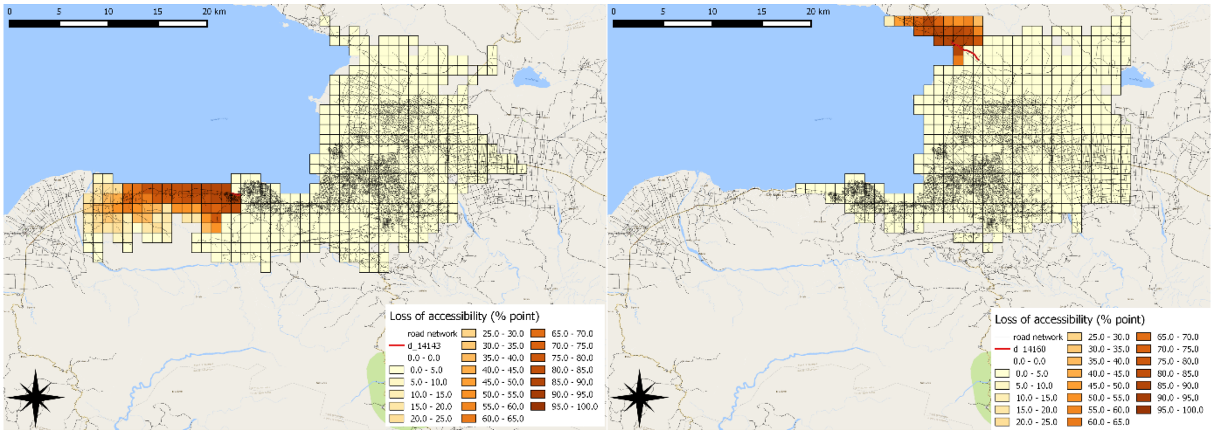
Figure 8: Flooded parts of the road network (50-year return period) in Kampala



Source: Rentschler et al (2019a)

By making road segments unusable, floods can severely impact the functioning of labor markets in urban areas. As the Kampala example above shows, disruptions from floods can affect a large share of the road network across urban areas. But even very localized disruptions can have strong impacts on the ability of residents of specific neighborhoods to reach jobs. In Port-au-Prince, a criticality analysis was undertaken by individually removing road links from the network, re-computing travel times with the altered networks and evaluating the share of the job opportunities that could be accessed within 60 minutes. While the aggregate results show limited impacts on overall accessibility (maximum 5% decrease of the average accessibility over the urban area) localized impacts can be much higher, reaching 80% for specific neighborhoods (Figure 9). These results are a lower bound estimate for the impact of flood disruption on access to job opportunities as when floods occur they typically impact a larger share of the road network (Lozano-Gracia & Garcia Lozano, 2018).

Figure 9: Maps of loss of accessibility to opportunities relative to the baseline (in percentage points) for disruption of 2 of the most important road links in the urban area of Port-au-Prince.



Source: (Lozano-Gracia & Garcia Lozano, 2018)

3.2. Transport disruptions and congestion impact health, education, food access and income of households

Congestion inflicts both direct –value of fuel and time wasted– and indirect costs –high consumer prices caused by the elevated shipping prices resulting from congestion. According to INRIX, congestion across the UK, Germany and the US cost almost $450 billion in 2016 or $971 per capita (INRIX Research, 2018). Congestion also influences the optimal investment plan for infrastructure. Allen & Arkolakis (2019) show that the magnitude of welfare gain derived from an improved transport network depends on the context: in the US, while the welfare gains of adding 10 additional lane-miles range from $10 to $20 million for three quarters of the highway segments, they estimate substantially larger gains for segments within metropolitan areas and along important travel corridors, with the returns exceeding $500 million for two highway segments in the New York City metropolitan area. Moreover, congestion and other market failures associated with agglomeration and dispersion spillovers have important implications for which segment improvements have the greatest welfare impact.

INRIX underestimates the per capita cost of congestion as they do not include environmental costs and health impacts. Levy, Buonocore, & Von Stackelberg (2010) evaluate the public health impacts of ambient exposures to fine particulate matter (PM2.5) concentrations associated with a business-as-usual scenario of predicted traffic congestion in 83 urban areas in the US. A monetized estimate of PM2.5-related mortality attributable to congestion in 2000 was approximately 2007 USD 31 billion. Cebr (2014) and . Levy, Buonocore, & Von Stackelberg (2010) predict a sharp increase in the cost attributable to congestion due to increased waste of gas and time. Projections are less clear for deaths and diseases attributable to PM2.5 emissions. In 2030, France and Germany will see their costs increased by a third, the US by 50% and the UK by 63% (Cebr, 2014b). Impacts on health are less clear: according to. Levy, Buonocore, & Von Stackelberg (2010), in future years, public health impacts will decrease to USD 13 billion in 2020 before increasing to USD 17 billion in 2030, given increasing population and congestion but lower emissions per vehicle.

Furthermore, road disruptions can impede access to health care, with particularly dire consequences in disaster aftermaths. After hurricane Maria in Puerto Rico, delays and disruptions of health care provision was the primary cause of death. Overall, 30% of households reported experiencing an issue in accessing health care after the shock. In 12% of the cases, these disruptions were caused by road damages (9%) and transport issues (3%) (Kishore et al., 2018). More than half of the respondents in flood affected areas of Hanoi, Vietnam, reported not being able to access their usual health care or medication for one month after a big flood event in 2008. The main reason for this was road disruptions (69%) and transport issues (33%). In the affected areas, a higher incidence of dengue fever, pink eye, dermatitis and psychological problems was observed a month after the flood (Bich et al., 2011).

Road disruptions make it more difficult for households to access food and other essential goods, as well as potentially cause price shocks affecting the economy of an area more broadly. Having been collecting data on food losses since 1961, the Food and Agriculture Organization notes that distribution wastes tend to be larger in countries with hot humid climate and lacking reliable transportation infrastructure, with a particularly strong impact on perishable food. Baez et al. document the impact of Agatha, a tropical storm that struck Guatemala in 2010, in urban areas. They observe an increase in poverty by 18% in the aftermath of this climatic disaster, mainly because of higher food prices. This inflation, as documented by the authors, was likely to be caused by increased frictions along the food supply chain, including transportation links. Safir et al. (2013) found a 4% decrease in food consumption in areas of the Philippines recording precipitation levels below one standard deviation from the mean. The same pattern was observed after the 2015 flood in South Carolina. Even if there were no major food disruptions in the aftermath of this disaster, Cutter (2017) documents an impact on the longer-run, at the local level: the flood affected livelihoods and food security of many residents and small farmers. This impact is partly attributable to transportation disruptions: the flood caused more than 365 road closures, including parts of the main corridor for commerce along the US East Coast. The finding suggests that well-connected areas are less vulnerable to the consequences of natural disasters on food security.

Transport disruptions increase the risk of children not being able to go to school. In Dar es Salaam, a recent survey finds that 81% of households that report having at least one member of the households missing school due to heavy rainfall or flooding indicate that it is primarily due to inaccessible roads (Erman, Tariverdi, Obolensky, & Hallegatte, 2019). This result is corroborated in focus group discussions carried out in Dar es Salaam in April 2018, in which households report that it is commonplace for children to stay home after heavy rains due to transport disruptions and flooded roads. In one district in Zimbabwe, teachers observe that school absenteeism peaks during the rainy season. On average, half of the students were not attending school during this time and accessibility is seen as one of the main reasons (Mudavanhu, 2014). In Lagos, Nigeria, an assessment of the impacts of flood on urban poor communities shed light on mobility reduction and damages to road. These disruptions result in children not being able to go to school, but also, more generally affect social relationships as some respondents report suffering from more isolation in times of flooding (Adelekan, 2010).

Transport infrastructure connect households to labor and consumption markets, and disruptions impacts wages and business incomes. Findings from focus group discussions with households in Dar es Salaam that live both in areas directly impacted by recurrent flooding and households in proximity to those areas, indicate that flooding makes it more difficult to generate income (Erman et al., 2019). This is particularly true for owners of household enterprises. Transport disruptions impede the flow of clients to businesses and make it more difficult to transport goods to and from the business location and access inputs from providers. Some enterprise owners shut down their businesses completely during the rainy season for these reasons[14]. Finally, transport disruptions can affect wages: Mueller & Quisumbing (2009) find that the 1998 "flood of the century" in Bangladesh had a negative long-term impact on wages, primarily in

[14] Notes from focus group discussions in Dar es Salaam in March, 2018 (A. Erman et al., 2019).

non-agricultural sectors. They find that areas further from centers of economic activity are more vulnerable to flood-induced wage losses, because the flood cut their access to the labor market, for example by disrupting road networks.

4. Conclusions: natural disasters and infrastructure disruptions

Infrastructure disruptions have many causes, and natural hazards explain only a fraction of them. In the US, half of power outages are due to natural causes. In particular, electric lines located in wooded areas are particularly vulnerable in case of strong winds and thunderstorms (Rentschler, Obolensky, & Kornejew, 2019). On the contrary in Bangladesh, only a fraction of the daily outages can be explained by natural disasters in period of monsoon and pre-monsoon ; the vast majority of the electricity outages are due to poor-quality infrastructure.

However, natural hazards and disasters remain important causes of infrastructure disruptions, which magnify the direct impact of the shock. After a disaster, households will experience two different types of impacts. Direct impacts are related to the effect of the disaster on assets and health. Indirect impacts are caused by the economic disruptions caused by the disaster, including through critical infrastructure.

Indirect impacts of disasters on households sometimes equate or even dominate direct impacts. Noy & Patel (2014) compare income losses between households that have been directly impacted by the 2011 flood in Thailand with those being indirectly impacted and finds that they lost almost the same amount. The bulk of these income losses are made up of decrease in business income. Similarly, Poapongsakorn & Meethom (2012) finds negative spillover effect on expenditure levels for households not directly affected by the 2011 flood in Thailand, while Desbureaux & Rodella, (2019) link drought events to negative impacts on labor participation and wages in Latin American cities: increased frequency of electricity outages affects firms output and productivity and decreased reliability of water provision affect households health and ability to work. Investigating the impact of the 2004 hurricane season in Florida on household displacement, Smith & McCarty (2009) find that among the 21% of households forced to move out of their homes after a disaster, 50% had to do so because of loss of utilities (e.g. no running water), income losses due to not being able to go to work because of flooded roads, health impacts caused by water disruption or electricity outages making it impossible to maintain economic activities. Only 37% had to move because of structural damages to their house. Therefore, the indirect impacts are likely to be more costly than direct impacts since they affect significantly more people and are difficult to prevent or prepare for. Moreover, they are intrinsically difficult to identify and measure, what leads to an underestimation of the true cost of natural hazards.

Infrastructure disruptions caused by natural hazards include transport, water, electricity and telecommunication. In Puerto Rico, after being hit by Hurricane Maria, households spent an average of 84 days without electricity, 68 days without water, and 41 days without telecommunication (Kishore et al., 2018). As factors affecting the perceived welfare loss of households exposed to hurricane Wilma in Florida, water and electricity disruptions were the most important ones behind reported monetary losses. Telecommunication also impacted perceived well-being but not to the same extent (Chatterjee & Mozumder, 2015). These disruptions have a number of different implications for household, including effects on income and health. In addition, utility disruptions caused by disasters are not limited to areas affected by the disaster per se and can lead to spillover effects in the rest of the country by disrupting service provision and supply chains.

Such disaster-related infrastructure disruptions are widespread in developing countries. From descriptive studies of survey results, we know that households in both affected and not affected areas suffer from indirect impacts of disasters. For example, in Ghana, 29% of all households that reported being affected either indirectly or directly by the 2015 flood in Accra, Ghana, experienced electricity, water or road disruptions (Erman et al., 2018). Preliminary results from a household survey in Dar es Salaam, show that 62% of households that reported being affected by floods in any way stated that roads were inaccessible because of floods and 75% and 22% reported experiencing electricity and water disruptions respectively (Erman et al., 2019).

Building infrastructure reliability by improving operation and maintenance help mitigate the impacts of natural disasters. Picarelli, Jaupart, & Chen (2017) provide evidence that performant infrastructure, and in particular high-quality drainage systems, help reduce the impact of climatic shocks on health. In Dar es Salaam, heavy rainfalls are associated with high rates of cholera incidence, but the impact is lower in neighborhood with a functional drainage system that prevents water from stagnating. Well-maintained roads of high-voltage transmission line corridors might play the role of firebreaks –gap in vegetation that slows down or even stops a fire progression– or have an influence on flood flows (Jones et al., 2000.

All the evidence presented in this analysis tend to conclude that building resilient infrastructure would directly benefit households, improving health conditions, educational, and professional outcomes as well as building household resilience to natural disasters. There is also widespread evidence that resilient infrastructure allows firms to thrive (Braese, Rentschler, & Hallegatte, 2019). Therefore, in addition to closing the infrastructure gap, policies should seek to improve the quality of local infrastructure. While building consensus and acknowledging the strategic importance of infrastructure in mitigating the impacts of natural disasters, we now need evidence on large-scale policy intervention to understand priority-investments that increase resilience.

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6. Appendix

Table 4 - Studies estimating the cost of electricity disruption for households

Country	Method	Outage Cost	Homogenized Outage Cost per kWh (in USD)*	Homogenized Outage Cost per hour unserved (in USD)*	Homogenized outage cost per hour unserved (in % of hourly GDPpc (Figure 4))	Source
Pakistan, 2013	Contingent valuation and macroeconomic	PKR 23.94 per kWh	0.41	0.11	40.03	(Pasha & Saleem, 2013)
US, 2004	Macroeconomic	USD 2.70 per hour unserved	0.64	2.70	75.43	(Berkeley, 2004)
US, 1988	Contingent valuation	USD 6 per kWh	6.00	24.96	1029	(Doane Hart man, and Woo1988)
Canada, 1989	Contingent valuation	CAD 1.40 per kWh	1.08	5.25	465.7	(Wacker & Billinton, 1989)
Spain, 2013	Macroeconomic	EUR 4.39 - EUR 6.35 per hour unserved	3.58	7.25	211.2	(Linares & Rey, 2013)
Turkey, 2016	Choice experiment	USD 0.24 - USD 0.92 per hour unserved	0.14 – 0.53	0.24 – 0.92	8.674-33.31	(Ozba & Jenkins, 2016)
Sweden, 2008	Choice experiment	SEK 2.13 - SEK 10.00 per hour unserved	0.09 – 0.40	0.32-1.50	7.744-36.63	(Carlsson & Martinsson, 2008)
Mexico, 1999	Macroeconomic	MXN 2.724 (1993) per kWh	0.27	0.28		(Jenkins, Henry, & Gangadhar, 1999)
Italy, 2005	Contingent valuation	EUR 3.75 per kWh	4,95	8,97		(Bertazzi, Fumagalli, & Lo Schiavo, 2005)
Austria, 2013	Contingent valuation	EUR 2.5 per kWh	3,25	8,33		(Reichl, Schmidthaler, & Schneider, 2013)

Source: authors based on World Bank data and estimates of the WTP found in the literature.

Conversions are computed in three steps: (1) Computation of the WTP per kWh (hour unserved) in the national currency. (2) Conversion in USD in the year of the study. (3) Conversion into 2018 USD. Hourly electricity consumption data are retrieved from the World Bank Microdata portal. https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

Table 5 - List of studies focused on the health impact of water provision interruption and dysfunction*

Country, year	Population	Exposure/Control	Outcome	Measure of effect	Source
Mexico, 2002	Children under-5 (n=732)	Consumption of water from IWS/Consumption of water from CWS	Caretaker reported diarrhea	RR = 1.80 (1.14 – 2.85)	(Cifuentes et al., 2002)
Gaza, 2004	Households (n=1625)	Consumption of water from IWS/Consumption of water from CWS	Self-reported diarrhea	RR = 1.35 (1.12 – 1.78)	(Abu Mourad, 2004)
Gaza, 2006	Gaza residents (n=141)	Consumption of water from greater than 1 day intermittency/Consumption of water from 1 day or less intermittency	Self-reported diarrhea	RR = 1.33 (0.92 – 1.91)	(Yassin, Amr, & Al-Najar, 2006)
Norway, 2007	Households (n=1200)	Consumption of water from low pressure episode due to mains breaks or maintenance of dist. system / Consumption of water from unaffected dist. system	Self-reported diarrhea	RR = 1.58 (1.1 – 2.3)	(Nygård et al., 2007)
Gaza, 2008	Khan Yunis Governorate residents (n=200)	Consumption of water from greater than 1 day intermittency/Consumption of water from 1 day or less intermittency	Self-reported diarrhea	RR = 1.49 (1.06 – 2.09)	(Abu Amr & Yassin, 2008)
India, 2015	(i)Households with children under 5 (n=3,922) (ii) Low income households with children under 5 (n=1,961)	Consumption of water from IWS/ Consumption of water from CWS	(1) diarrhea (2) typhoid fever	(i.1) RR = 1.08 (0.96 – 1.20) (ii.1) RR = 1.59 (1.15 – 2.17) (2) CIR = 1.72 (1.28 – 2.44)	(Ercumen et al., 2015)
Alabama, US, 2015	Households (n=470)	Lost water service for >7 days / Normal service	Self-reported diarrhea	RR = 2.4 (1.1 5.2)	(Gargano et al., 2015)

Figure 5: List of studies focused on the health impact of water provision interruption and dysfunction (continued)

Country, year	Population	Exposure/Control	Outcome	Measure of effect	Source
Taiwan, China, 2004-2006	Insurance claims (n=1,000,000 insured persons)	Number of insurance claims during outages**/Number of insurance claims during a normal period	(1)Gastroenteritis (2)Skin diseases (3) Eye diseases	(1) RR = 1.31 (1.26 – 1.37) (2) RR = 1.36 (1.30 – 1.42) (3) RR = 1.34 (1.26 –1.44)	(Huang et al., 2011)
Zambia, 2017	District month (n=1230)	Impact of the number of outstanding water supply complaints per month on the number of health clinic admissions	(1)Diarrhea (2)Typhoid fever (3)Respiratory infection (4)Measles	(1)1.00 (0.42)*** (2)0.002 (0.001) (3)2.4 (0.91) (4)0.035 (0.01)	(Ashraf et al., 2017)

Source: Bivins et al., (2017) and modified by authors.
** 95% confidence intervals within parenthesis.*
*** Water outages because of typhoons and floods were excluded.*
**** Number of additional cases of waterborne illness per additional day of outstanding complaint (standard error of estimate within parenthesis)*
OR = Odds Ratio, RR = Risk Ratio, CIR = Cumulative incidence ratio.
In Mexico (Cifuentes et al., 2002) and Palestine (Abu Mourad, 2004), reported odd ratios were transformed in risk ratios. The diarrhea prevalence is not available in the control population (e.g. not exposed to IWS). Therefore, we use RR = OR / (1 – p + (p x OR)), where p is the diarrhea prevalence in the treated population (e.g. exposed to IWS).
When the incidence of an outcome is low (<10%), the odds ratio is very similar to the risk ratio. However, the odds ratio becomes exponentially more different from the risk ratio as the incidence increases, which here, will tend to exaggerate the risk effect.

Table 6: Water price in Asian cities

City	Cost of water per cubic metre (US$)		
	House connections	**Public taps**	**Water vendors**
Bandung (Indonesia)	0.38	0.26	3.60
Bangkok (Thailand)	0.30	–	28.94
Chennai (India)	0.30	0.58	–
Chonburi (Thailand)	0.38	–	19.33
Colombo (Sri Lanka)	0.04	0.02	–
Dhaka (Bangladesh)	–	0.08	0.84
Hanoi (Vietnam)	0.09	0.55	–
Karachi (Pakistan)	0.10	–	1.14
Kathmandu (Nepal)	0.18	0.24	2.61
Lae (Papua New Guinea)	2.20	5.96	–
Malé (Maldives)	5.08	–	11.20
Manila (Philippines)	0.29	–	2.15
Mumbai (India)	0.07	0.07	0.50
Phnom Penh (Cambodia)	0.13	–	0.96
Port Vila (Vanuatu)	0.42	0.86	8.77
Seoul (South Korea)	0.25	14.13	21.32
Shanghai (China)	0.08	0.06	–
Tashkent (Uzbekistan)	0.01	0.02	–
Thimphu (Bhutan)	0.03	0.05	–

Source: UN-HABITAT (2003) *Water and Sanitation in the World's Cities. Local Action for Global Goals.* Earthscan, London, Table 2.8. Based on consumer surveys by Asian Development Bank, reported in McIntosh, A.C. and Yñiguez, C.E. (1997) *Second Water Utilities Data Book.* Asian Development Bank, Manila.

Table 7: Water price in Dar Es Salaam (Tanzania)

Source	Price/payment	Shillings/ litre	US$/$m^3$
Own connection	Monthly lump sum, flat rate, based on:	0.27	0.34
Neighbour's tap / water kiosk	20 shillings per 20-litre container	1.00	1.25
Pushcart water vendor	70–200 shillings per 20-litre container	3.50–10.00	4.38–12.50
Tanker truck (10,000 litres)	60–80,000 shillings per truckload	6.00–8.00	7.50–10.00

Sources: Kjellén, M. (2000a) Complementary water systems in Dar es Salaam, Tanzania: The case of water vending, *Water Resources Development* 16(1): 143–154; and Kjellén, M. (2000b) *Uuzaji wa Maji katika Jiji la Dar es Salaam.* Environment and Development Studies Unit (EDSU), Stockholm. Data source: Water Vendor Survey 1998/1999.

Table 8: List of willingness to pay (WTP) estimates for improved water provision quality and reliability

Country	Method	Improvement	WTP as reported in the papers	WTP per hour unserved (in 2018 USD*)	WTP per cubic meters* unserved (in 2018 USD)	Source
Mexico	Contingent valuation	Safe and reliable water service system	MXN 9.11 per month to have access to a reliable** drinking water system	USD 0.82 per month to have access to a reliable** drinking water system		(Vásquez et al., 2009)
Australia	Choice experiment	Less frequent and shorter water outages	AUD 9.58 – AUD 113.20 per year per additional outage AUD 4.38 – AUD 54.75 per year per hour unserved	USD 8.87 – USD 102.42 per year per additional outage USD 3.96 – USD 49.53 per year per hour unserved	USD 15.21 – USD 190.2 per year per cubic meter unserved	(Hensher et al., 2005)
US	Contingent valuation	Less frequent and shorter outages	USD 0.78 per month per additional outage USD 0.72 per month per hour unserved	USD 0.88 per month per additional outage USD 0.81 per month per hour unserved	USD 24.37 per year per cubic meter unserved	(Thacher, 2011)
Australia	Choice experiment	Less frequent and shorter outages	AUD 7.95 per year per additional outage AUD 1.45 per year per hour unserved	USD 8.38 per year per additional outage USD 1.52 per year per hour unserved	USD 7.58 per year per cubic meter unserved	(MacDonald et al., 2010)
China	Choice experiment	Water supply safety improvement	RMB 0.18 per m3 unserved	See notes***	USD 0.03 per cubic meter unserved	(Wang, Ge, & Gao, 2018)

**Authors' calculations. Price conversions are computed in two steps: (1) Computation of the outage cost in USD in the studied year. (2) Conversion of this figure into 2018 USD. Conversion from WTP per hour unserved to WTP per cubic meter unserved are computed using the hourly freshwater consumption per household over the course of the year of the study.*

*** Reliable: Continuous water supply, 24 hours per day every day of the year.*

**** Wang, Ge, & Gao (2018) study is conducted in suburban areas where no data on water outage could be found. Therefore, the WTP could not be converted to an amount in USD per hour of outage.*