UNDERSTANDING IMPACTS OF POWER INTERRUPTIONS ON QUALITY OF LIFE: OPPORTUNITIES FOR SOCIALLY-OPTIMAL POLICY AND DEMAND-SIDE RESILIENCE

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Overview

When talking about climate change, what are often glaring are rising temperatures, extreme weather conditions, and depletion of natural resources. What is not immediately obvious and often obscured from public attention is the heightened possibility of more frequent and longer power interruptions in the future, in part due to climate change. Being in an era of aging critical electrical infrastructure, software vulnerabilities and cyberterrorism, and unpredictable geopolitical and market movements only magnifies the weaknesses of the already fragile electrical systems that power our daily lives. It has been noted that the three goals of energy policy, i.e. sustainability, security of supply, and competitiveness often conflict with one another [1]. Nonetheless, it is imperative to work towards addressing risks systematically, assessing through various lenses.

Power systems, more than being technological creations, are strongly if not totally tied to modern life. Supply and network failures have direct and indirect consequences to the economy, institutions, and the general quality of life of people. Aside from industries and businesses being paralyzed, actual survival of vulnerable individuals is put on the line in the worst of cases [2]. Unfortunately, among the sectors in the demand side of energy, the impacts of power interruptions on individuals and the residential segment are less tangible and measurable than those in firms and industries [3]. In 2019 alone, at least 48 billion human hours were impaired by power interruptions.[1] Putting a number even on intangible impacts may serve as sound guidance or benchmark for policy-making, electric utility operations and investments, rate design, and disaster response and resilience-building.

Most of the work done in this field are on calculating the "Value of Lost Load" (VoLL), i.e. cost per unit of electricity not delivered, and customer interruption costs (CIC), i.e. damage cost per unit time [4]. While already guiding policy especially in European countries, concerns about its lack of a standard methodology and international comparability, models being "black boxes", and potential speculativity have also been raised [1], [4], [5]. This is the gap that this study tries to bridge.

With existing qualitative literature outlining impacts of power interruptions on individuals and households and quantitative studies imputing encompassing economic values such as VoLL, this study opens up the "black box" and breaks down the economic indicator into its constituent drivers. This study proposes a Power Interruption Impact Assessment (PIIA) Model that draws from the framework of Life Cycle Impact Assessment (LCIA) and substantiated by concepts from power systems, psychology, and economics. Such a model is applied and validated through a case study of one of the Philippines' most power-interrupted provinces. The model is intended to be context-flexible and easily understandable especially to policy-makers. Another unique contribution of this study is its application to detailed actual power interruption data from the case study area and its subsequent comparison to a production-function approach currently employed for industrial and commercial segments.

Methods

The Power Interruption Impact Assessment (PIIA) model proposed in this study is based on an "endpoint-type" LCIA, which quantifies and plots the "flows" of raw impacts, classified among "impact categories", towards "areas of protection". In this model, the areas are protection are "life roles" based on Nevill and Super's "Salience Inventory", which were chosen to be proxy components of quality of life. The outcome of the model is used to explain a damage cost and VoLL obtained through iterative bidding and payment cards contingent valuation (willingness-to-pay (WTP) to avoid certain durations of power interruptions) and analyzed using logistic regression for durations of 5 minutes, 15 minutes, 1 hour, 4 hours, and 8 hours. Raw impacts that will flow through the model are scored based on actual power reliability indicators of duration and frequency (magnitude), respondents' electricity dependence (sensitivity), and salience of impacts (exposure).

Through a questionnaire survey, respondents describe the performance of their life roles and their subjective assessment of their electricity dependence throughout a typical week. They then declare the impacts of power interruptions on their lives and rate how each impact affects the performance of their life roles. Their answers comprise the electricity dependence and impact salience components of the raw impact scores. Respondents' locations are used to identify their respective power interruption frequency and duration statistics. The model is designed such that the relative prevalence of unscheduled and momentary interruptions amplifies the impact scores.

[1] Author's estimation based on The World Bank Doing Business Report 2020

After characterizing raw impacts, they are aggregated according to impact categories to which they are classified. Aggregated scores per impact category are distributed among affected life roles. Respondents' answers on how they value their life roles are used as weights to account for differences in value judgments. Each step of the flow (i.e. impact categories, impact on life roles, and weighted impact of life roles) are then normalized to provide useful insight based on relative differences in impact.

On the other hand, the obtained median WTPs for the specified durations are fitted to a power model, which is used to estimate the total damage cost and VoLL of the study area from 2015 to 2018. Comparisons of model outputs across different parts of day are also performed. Valuations are also compared against GDP-based industry damage costs using production-function approach.

Results

The Power Interruption Impact Assessment model reveals that health and comfort-related impacts (e.g. sleeping difficulty, hypertension, discomfort) affect people in the study area the most (24%); followed by household management problems (e.g. cannot cook food and do chores, difficult to care for vulnerable members) (18%), work and livelihood disruptions (e.g. income loss, stalled work) (16%), and limited use of information and communication technologies (ICT) and concerns on data security (14%), among others. Functioning as a household/family member is the most affected life role (39%); followed by occupation (32%), personal care (26%), and leisure (3%). Impacts on the "learning/studying" and "community involvement" life roles are negligible, most likely as an effect of the demographic characteristics of the respondents or that these life roles are usually not electricity-dependent or both. Being mostly household heads, the distribution of impacts matches expectations. Varying time ranges reflect changes, especially on the impacts on life roles; for instance, personal care is highly vulnerable to impacts within the 6 PM to 6 AM window.

In 2018, the average damage cost for each consumer for every hour of interruption is estimated at PhP3.05 (US$0.06), and the VoLL is PhP19.69 (US$0.39) per kWh. The VoLL value shows that on average, uninterrupted power gives a consumer surplus approximately equal to the price of electricity (i.e., PhP10.44 per kWh). Even though the nominal value increases with time, the rate of change decreases exponentially. Applying the model with actual power interruption data yields PhP 136 million (approx. US$ 2.7 million) equivalent damage to quality of life in 2018. This is approximately 9.5% of estimated costs on the residential segment. Using the Philippine government's approximation method of industrial-commercial losses based on GDP, calculated damage on this segment comprises 30% of the total cost of power interruptions in Albay.

Conclusions

The results show that residents are most vulnerable to health and comfort-related impacts, household management problems, work and livelihood disruptions, and limited use of ICT and data security risks, among others, which have significant implications on peoples' performance of their life roles, especially as a household member, worker, and in taking care of themselves. This hierarchy of impacts will help policy-makers prioritize mitigation strategies especially on the most vulnerable aspects of residents' quality of life. In terms of disaster-induced power interruptions, the same prioritization can be used by both the government and electric companies to allocate limited power and resources where they will be needed more at which times and places. The same values may also be used as an empirical reference in budgeting for demand-side resilience enhancements and supply-side capacity augmentations.

This study, being the first or one of the first of its kind, effectively puts the quality of life of the ordinary consumer on the discussion table for policy and investment discussions. This can also supplement in evaluating the performance of electric companies in franchise areas, or if necessary, as reference for performance-related dispute settlements. As a flexible framework, the same method with minor modifications may also be applied for other utilities (e.g. water, internet, transportation).

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