Economy-wide Cost of Electricity Load Shedding in Nepal[1,2]

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Abstract: This study estimates the economic costs of electricity load shedding in Nepal over the period 2008–16. We show that in the absence of load shedding, annual gross domestic product, on average, would have been almost 7 percent higher than it was during the period of power outages. The load shedding particularly strongly affected investment that would have been 48 percent higher with the reliable power supply. Although reliability of power supply in the residential sector has recently improved because of better electricity load management, and an increase in electricity production and imports, the industrial sector still faces significant load shedding. Unless the electricity load shedding is eliminated, Nepal will continue to suffer a heavy economic loss.

Key Words: Electric power outages, Electricity load shedding, Electricity supply, Economic growth, Nepal

JEL: C22, C68, O53, Q43

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1. Introduction

Nepal, a small country on the lap of the Himalayas, is one of the poorest countries in the world in terms of infrastructure and economic development. In 2013, per capita electricity consumption in Nepal, for example, was 427 times lower than that in Iceland, the country with the highest per capita electricity consumption in the world; 182 times lower than that in Norway, a country with hydropower as the primary source for electricity supply, like Nepal; 101 times lower than that in the United States; 81 times lower than that in the Republic of Korea; 30 times lower than that in China; and 6 times lower than that in neighboring India.[4] As of January 31, 2018, Nepal has about 1,000 MW of power generation capacity for its almost 30 million population. Of this total installed capacity, which is mostly run-of-river type, 70% is not available during the dry season (March-April). The lack of electricity generation capacity and further unavailability of the existing capacity due to very low river discharge in the dry season, combined with poor electricity load management and growing demand for electric power resulted in a huge load shedding over the decade starting in 2008. In the dry season in 2015 and 2016, the country faced up to 14 hours of load shedding in a typical day.[5]

More recently, starting from 2017, the situation has improved and regular electricity supply to households in major urban areas, including the capital city, Kathmandu, has been resumed. Several factors, including an innovative load management system adopted by the state electricity utility - Nepal Electricity Authority, increased domestic supply due to commissioning

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[4] Calculated based on data from the World Bank's online database available at
http://databank.worldbank.org/data/home.aspx.

[5] The Himalayan Times, January 03, 2016. https://thehimalayantimes.com/kathmandu/.

of a few new power plants and increased imports of electricity from India facilitated by the completion of a 400 KV, 1,000 MW cross-border transmission line. However, many parts of the country still face load shedding, and demand for industrial customers is still unmet. In a personal communication, representatives from the Federation of Nepalese Chambers of Commerce and Industry (FNCCI) of Nepal claim that the current industrial sector load alone exceeds 3,000 MW, whereas the country has less than 1,000 MW of total installed capacity. Lack of reliable grid electricity supply increases the production costs of larger industrial firms and adversely affects their competitiveness, as they have to rely on more expensive diesel-based captive generation (or self-generation) for their electricity supply (Foster and Steinbuks, 2008; Steinbuks and Foster 2010). For small and medium enterprises, lack of quality electricity supply is even greater problem for their business, as they often financially constrained and cannot afford captive power generation (Steinbuks, 2012). Thus, lack of adequate electricity supply capacity and load shedding are one of the major barriers to Nepal's economic development and its goal to alleviate poverty.

The purpose of this study is to assess the economic costs of electricity load shedding in Nepal, specifically accounting for:

(i)   Firms' direct costs resulting from the industrial output loss due to lost shedding. These costs are especially large for small and medium size enterprises that cannot afford expensive back-up systems;

(ii)   Firms' indirect costs resulting from diminished investment in the electricity-intensive capital.

(iii)   Households' costs of purchasing imported backup technologies, such as batteries and inverters.[6]

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[6] Due to data limitations we do not explicitly account for households' direct utility loss resulting from power outages, such as e.g., their impeded ability to access lighting, media and telecommunication services.

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Our paper relates to several earlier studies that attempt to estimate the economic costs of load shedding in Nepal (see e.g., Jyoti et al., 2006, and Shrestha, 2010). However, these studies have narrow scope as they focus only on the loss of power sales from the utility. They do not account for either direct economic costs due to the disruption of production in the manufacturing and service sectors or for any indirect economic losses. This study aims to contribute in filling this research gap.

Beyond the specific context of Nepal, the study is also contributes to the growing body of literature assessing economic costs of unreliable electricity supply. Many studies have estimated the cost of unreliable power supply in both developed and developing economies. Key studies include Foster and Steinbuks (2009), Steinbuks and Foster (2010), Abdullah and Mariel (2010), Braimah and Amponsah (2012), Kaseke and Hosking (2012), Steinbuks (2012), Oseni and Pollitt (2013), Chakravorty et al., (2014), Fisher-Vanden et al., (2015), Allcott et al (2016), and Oseni (2017). Some of these studies deal with unplanned electricity outages and use a methodology where potential consumers are surveyed asking their willingness to pay (WTP) to have reliable supply of electricity. For example, Abdullah and Mariel (2010) use a choice experiment method to determine the willingness to pay for improved electricity services, surveying 200 households in Kisumu District, Kenya. Braimah and Amponsah (2012) survey 320 micro and small industries from three industrial clusters within the Kumasi metropolis in Ghana to explore the relationship between frequent and unscheduled electricity outages to micro and small-scale industries. Bose et al. (2006) use a two-stage random sampling survey of 500 manufacturing firms and 900 farmers to assess willingness to pay for reliable supply of electricity in Karnataka in India. Oseni (2017) uses data collected from a sample of Nigerian households, and the results of his econometric analysis reveals that engagement in self-generation is positively correlated

with WTP for reliability. These studies are different from the current study in two respects. First, they deal with unplanned electricity outages and do not necessarily deal with the planned outages or load shedding the current study is investigating. Second, these studies estimate only direct economic costs of not getting a reliable supply of electricity. These studies thus are not able assess the overall economic costs of either unreliable supply or electricity supply shortages.

Other studies, such as Steinbuks and Foster (2010), Kaseke and Hosking (2012), Oseni and Pollitt (2013), Chakravorty et al., (2014), Fisher-Vanden et al., (2015), and Allcott et al., (2016) assess econometrically the impacts of electricity outages or load shedding. Kaseke and Hosking (2012) estimate the economic costs of load shedding in the mining sector in Zimbabwe. Steinbuks and Foster (2010) and Oseni and Pollitt (2013) estimate economic costs of unreliable power supply using cross-sectional data on electricity outages collected by the World Bank Enterprise Survey in African countries. Chakravorty et al., (2014) estimate the returns to household income due to improved access and reliability of electricity based on a representative panel of more than 10,000 households in rural India. Fisher-Vanden et al., (2015) use a large panel of 23,000 energy-intensive Chinese firms to examine how firms responded to severe power shortages in the early 2000s. Allcott et al., (2016) analyze the impacts of weekly "power holidays" or load shedding in the manufacturing industry in India. All these studies analyze only partial equilibrium effects of unreliable power supply and capture only the direct costs of load shedding. They do not include the economic costs due to interlinkages of industries and

economic agents.[7] These indirect impacts are important because, depending upon the structure of an economy, the size of indirect impacts could be higher than the size of direct impacts.

To assess the economic costs of load shedding in Nepal we use a computable general equilibrium (CGE) model. This CGE model can capture both direct and indirect economy-wide effects of load shedding's. The load shedding either constrains supply of electricity for firms or households, or increases costs of electricity service. This, in turn, results in reduction of electricity use and higher costs of output of electricity-intensive industries. This further increases the output prices of other industries that rely on domestic inputs produced by energy-intensive industries. As a result, the overall output of the economy is curtailed and prices of most goods and services of domestic industries do rise. Households' utility falls both directly (from consumption of unreliable electricity), and indirectly (as they face higher prices of other goods and services). Also, as domestic production becomes more expensive as compared to their international counterparts, domestic industries become less competitive and exports fall. Our CGE model accounts for all these effects of load shedding.

To validate the results of CGE model, we also estimate vector error correction model (VECM) of co-integrated electricity consumption and GDP variables. Using VECM estimates we conduct impulse response analysis to evaluate GDP response to power outage shocks.

Nepal could not meet, on average, 20 percent of its total electricity demand in each year over the period 2008-2016. Our analysis suggests that if the power supply was reliable over that period, Nepal's GDP would have been 7 percent higher, the total investment would have been 48

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[7] Fisher-Vanden et al., (2015) capture some cross industry effects by finding that Chinese firms re-optimize among inputs to production by substituting materials for energy. Their analysis, however, does not investigate any general equilibrium effects.

percent higher, and the total sectoral output would have been 7.5 percent higher. Both imports and exports would have also increased.[8] We also find that relying on diesel fired back-up systems to avoid load shedding has a relatively small effect on reducing economic costs of load shedding in Nepal.

The rest of the paper is organized as follows. Section 2 briefly presents the CGE model and econometric framework used for its validation, followed by a brief description of data in Section 3. Section 4 describes the simulated load shedding scenarios. Section 5 presents and discusses key results. Section 6 concludes and draws some policy remarks.
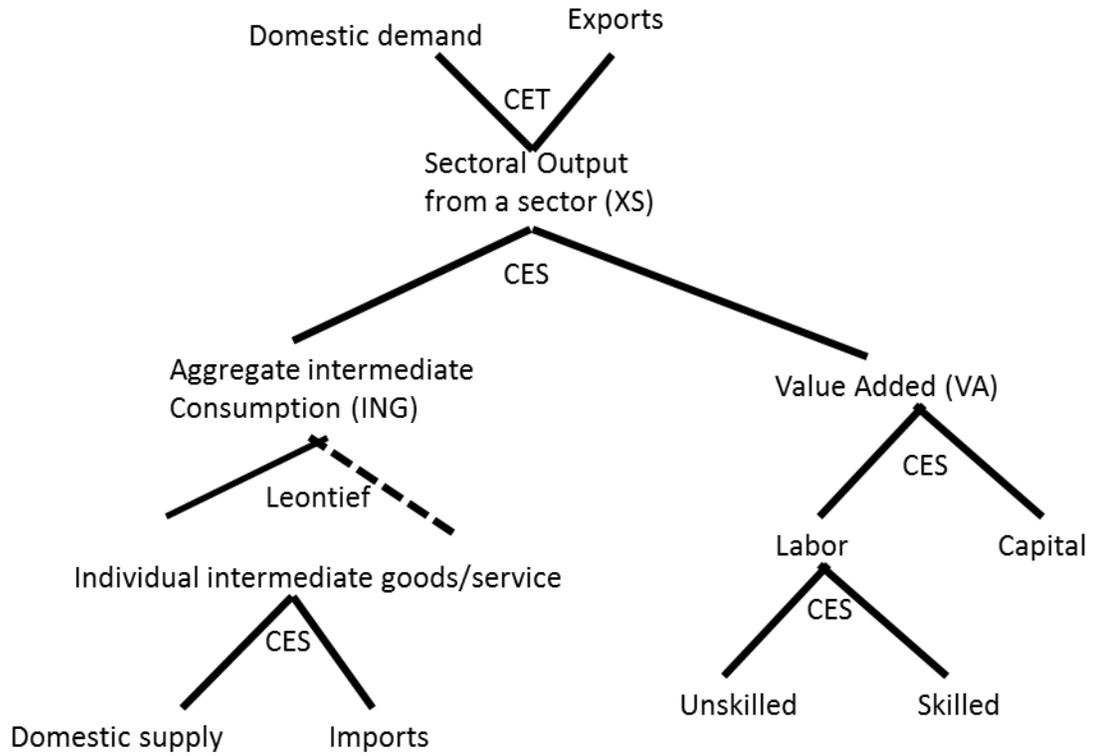
2. Analytical Framework

Below we describe two different methods that we use to assess the economic effects of load shedding in Nepal. We first show the computable general equilibrium (CGE) model to quantify economic effects of load shedding. We then present the time-series vector error correction model (VECM) we employ to validate the predictions of the CGE model.

2.1 CGE Model

We use a single country static general equilibrium model that is calibrated based on Nepal social accounting matrix (see section 3). This is a standard CGE model with detailed representation of factor markets, product markets and household welfare. It follows the rich literature on single country CGE modeling, such as Shoven and Whalley (1984, 1992), Coady and Harris (2001), and Decaluwé et al. (2005). The structure of the model is briefly described below. The detailed description of the model is available in Timilsina et al. (2018).

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[8] Falling oil prices after 2014 may have lowered the costs of load shedding (both direct and indirect) for two years out of ten years considered in the analysis. However, capturing this effect is complicated and beyond the scope of this paper analysis.

Figure 1: Simplified structure of modeling production sectors

Domestic demand   Exports

CET

Sectoral Output
from a sector (XS)

CES

Aggregate intermediate
Consumption (ING)

Value Added (VA)

CES

Leontief

Labor   Capital

Individual intermediate goods/service

CES

CES

Domestic supply   Imports

Unskilled   Skilled

Sectoral production: For this analysis, we consider 15 sectors.[9] The production structure of agriculture and non-agriculture sectors is differentiated because land is the main input in the agriculture sector, and not in the other sectors. Figure 1 illustrates the basic structure of modeling the production sector. At the highest nesting level of the production structure, sectoral output is a constant elasticity of substitution (CES) combination of sectoral value added and total intermediate inputs. While a sectoral value added is CES combination of labor and capital inputs, total intermediate input is a Leontief aggregate of individual intermediate inputs.[10] The capital in the agriculture sector is a Cobb-Douglas function combining agricultural capital and land. The composite labor is a CES aggregate of skilled and unskilled labors in each sector. This hierarchical nested specification allows different scale of substitution among primary factors (Despotakis, 1980).

Foreign trade: We divide imports into competitive and non-competitive categories. We model the competitive imports with Armington assumptions (Armington, 1969) and non-competitive imports with the Leontief fixed coefficient technology. For a competitive or tradable good, we derive import demand based on a CES combination of a domestically produced component and an imported component. We use a constant elasticity of transformation (CET) function to allocate total domestic production or domestic output of a good or service to domestic consumption and exports. The standard small-country assumption implies that no good or service produced in Nepal can affect the international price of that good or service.

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[9] The number of sectors and commodities can be changed as needed. For the sake of clarity, we further aggregated the sectors when results are presented and discussed. For example, five agriculture (crop) sectors, and a forestry sector are combined into single 'agriculture and forestry' sector.

[10] Leontief specification does not allow substitution between intermediate consumption in a production sector. Since this specification does not allow structural adjustment through input substitutions, the reported impacts are likely overestimated. More flexible forms, such as CES, resolve this issue. However, key parameters of the CES specification, particularly the elasticity of substitution, are not available.

Households and government: We use Stone-Geary linear expenditure function[11] to model household consumption. We compute Hicksian equivalent variation to measure household welfare effects of counterfactual simulation, here the "load shedding" scenario. We derive household savings based on exogenously specified marginal propensity to consume. Government collects taxes, makes public expenditures and saves, receives and provides transfers.

Macroeconomic closure: The model we develop for this analysis is a static model, where the investment rate is assumed to be in its steady state. Total investment is financed through domestic savings (household savings, government savings, firm's savings) and foreign savings (or borrowing from foreign countries or institutions). The supplies of primary factors (i.e., labor, capital and land) are fixed for a given year. For labor, in fact, the working-age population for a given year is exogenous and fixed. However, the model allows labor to move across the sectors. The agricultural capital is mobile (can be moved from one crop to another based on their profitability) while industrial capital is sector specific. The model closes keeping foreign saving (current account balance) as exogenous. The exchange rate is fixed and the real exchange rate acts as the price numeraire.

2.2 Vector Error Correction Model

To validate the results of the CGE model, we estimate a vector error correction model (VECM), where electricity consumption and GDP are simultaneously determined. The VECM is a framework for estimation, inference, and forecasting of difference stationary multivariate time

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[11] The Stone-Geary function is appropriate representation of household demand when households have a "subsistence" level of consumption irrespective of the prices of goods for subsistence consumption and household income. After subsistence quantities are satisfied, households choose further consumption based on standard microeconomic assumptions. It serves as a basis for the linear expenditure system (LES) of consumer demand (Stone, 1954; Frisch, 1954).

series, which has been extensively used in the energy economics literature.[12] A brief formal representation of the VECM is documented below. For advanced textbook treatment of the VECM, please refer to Lütkepohl (2005) and Enders (2010). Before estimating the VECM we need to establish that electricity and GDP series are difference stationary. To test for this hypothesis we run four popular unit-root tests: (i) the Augmented Dickey-Fuller (or ADF) test (Dickey and Fuller, 1979), (ii) the modified Dickey–Fuller (or DF-GLS) test (Elliott et al., 1996), the Phillips and Perron (1988) test, and the KPSS test (Kwiatkowski et al., 1992). We then estimate the VECM, whose general form representation with lag order p is given by

$$\Delta \mathbf{y_t} = \mathbf{\Pi} \mathbf{y_{t-1}} + \sum_{i=1}^{p-1} \mathbf{\Gamma_i} \Delta \mathbf{y_{t-1}} + \mathbf{B} \mathbf{x_t} + \mathbf{\epsilon_t} \quad (1)$$

where $\mathbf{y_t}$ is the K×1 vector of endogenous variables (i.e., electricity consumption and output, both in natural logarithms), $\mathbf{\Pi}$, $\mathbf{\Gamma_i}$ and $\mathbf{B}$ are matrices of coefficients, $\mathbf{x_t}$ is the M×1 vector of exogenous variables, and $\mathbf{\epsilon_t}$ is the K×1 vector of white noise innovations. As we are primarily interested in the dynamics of electricity-GDP relationship, we do not include any exogenous terms, so the third term on the right hand side of equation (1) disappears. We set the maximum number of lagged terms, p, and equal to four, and choose the optimal number of lags based on Schwarz/Bayesian Information Criterion (BIC). If the variables $\mathbf{y_t}$ are difference stationary, the matrix $\mathbf{\Pi}$ in equation (1) has rank $0 \leq r < K$, where r is the number of linearly independent cointegrating vectors. As matrix $\mathbf{\Pi}$ has reduced rank the cointegrating vectors are not identified without further restrictions. We apply standard normalization restrictions suggested by Johansen (1995). After the VECM is estimated we test for cointegration via Johansen's max-eigenvalue statistic and trace statistic. We also evaluate the stability of the estimated VECM by testing if the

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[12] Bruns et al. (2014), Ozturk (2010) and Payne (2010) are good surveys of this literature.

moduli of the remaining *r* eigenvalues are strictly less than unity. After all robustness checks are performed, we calculate impulse response functions (IRFs) to measure the effects of a shock to electricity consumption on GDP. As the simple IRFs give biased results when the shocks are contemporaneously correlated, we follow the standard literature (see e.g., Sims, 1980) and perform Cholesky decomposition to orthogonalize the covariance matrix of shocks.

3. Data

To calibrate the CGE model, we use the social accounting matrix (SAM) of year 2007, which was prepared based on GTAP database. We use the 2007 SAM by design, because this is the last year when there was no load shedding. The market for electricity services was cleared, and all sectors and households have received the full demanded amount of electricity services. After 2007, when load shedding started, a SAM may misrepresent electricity input because:

(i)   the technical or input-output coefficient likely overestimates the marginal product of electricity input in a sector;

(ii)   a portion of the technical coefficient for electricity (i.e., ratio of output from sector to its electricity input) may have diverted to oil if the sector used captive power running its own diesel fired backup generators.

The SAM of any year after 2007 thus needs an adjustment if used for this type of analysis. The SAM of 2007 serves as a benchmark for the analysis of the economic impact of load shedding. All share parameters and other parameters are calibrated based on the 2007 SAM. The values of the elasticity of substitution in the CES and CET nests are based on the CGE modeling literature (see e.g., Timilsina and Shrestha, 2002; Timilsina et al. 2018).

The time-series data for the econometric CGE model validation comes from two sources. The net electric power consumption (i.e., excluding transmission, distribution, and transformation losses) series come from the IEA World Energy Statistics and Balances database (IEA, 2017). The GDP series (in 2010 US dollars) come from the World Bank World Development Indicators (WDI) database. Both series are available starting from 1971. We estimate the VECM over the period 1971-2007, when the power supply was reliable.

4. Designing the Load Shedding and Back-up Supply Scenarios

We consider two scenarios. The first scenario reflects the real situation of load shedding occurred during the 2007-2016 period. This is the main scenario as this is the focus of the analysis. The second is a hypothetical scenario that assumes what would happen if the load shedding were avoided through diesel-based generation back -ups operated by the utility.

Table 1 presents electricity supply and demand balance for over the 2007-2016 period, which is the basis of the main scenario. In 2007, the electricity supply met the demand. After 2007, the electricity supply is always lower than the demand for electricity, thereby causing load shedding. For year 2008, the electricity deficit was 9 percent of the demand. Between 2009 and 2014, the supply deficit was around 20 percent of the demand. Though for 2015 and 2016 we could not obtain electricity requirement data and thus calculate deficit, we know that it was higher than in previous years as the country faced most serious load shedding. We assume that, on average, 20 percent of the annual demand for electricity was not met by the supply. Therefore, we simulate the economic effects of a 20 percent reduction in electricity supply in each year.

Table 1. Electricity supply and demand balance in Nepal during 2007-2016 (GWh)

Year	NEA Supply	IPP Supply	Domestic Supply	Import	Total supply	Demand	Deficit	% Deficit
2007	1,761	329	2,090	962	3,052	3,000		
2008	1,802	425	2,228	958	3,186	3,490	-304	-9%
2009	1,849	356	2,205	926	3,131	3,859	-728	-19%
2010	2,122	639	2,760	591	3,352	4,367	-1,015	-23%
2011	2,125	694	2,820	1,039	3,858	4,833	-975	-20%
2012	2,359	746	3,105	1,074	4,179	5,195	-1,016	-20%
2013	2,292	790	3,082	1,176	4,258	5,446	-1,188	-22%
2014	2,298	1,319	3,617	1,070	4,687	5,909	-1,222	-21%
2015	2,367	1,370	3,737	1,269	5,006	n.a.	n.a.	n.a.
2016	2,168	1,173	3,342	1,758	5,100	n.a.	n.a.	n.a.

Source: Nepal Electricity Authority (NEA). Annual Reports for the period between 2007 and 2017.

One of the limitations of shocking the load shedding under this scenario is that it does not capture captive power generation to back up electricity supply during the load shedding. While not all industries can afford backup power generation, large industries invest in backup power supply. In such a case, large industries would not cut their production during the load shedding, instead they pay a higher price for electricity supplied through the backup system. Unfortunately, we do not have the detailed data on the captive power generation capacities and their utilization. Moreover, households also use devices (e.g., invertors), which store electricity when electricity supply is available and dissipate the stored electricity for certain applications (e.g., lighting, cell phone charging) when there is load shedding. Again, we do not have detailed data on the stock and utilization of storage devices. To fully capture the economic implications of captive power and storage devices that could have been used to fully avoid load shedding, we design a hypothetical 'back-up' scenario.

This hypothetical scenario assumes that diesel-fired generators are installed in the electricity sub-stations to supply power when hydropower, the main source of electricity in Nepal, is not available. In this scenario, we assume that the 20% of shortage of annual electricity demand can be met using diesel fired back up generators. Using necessary data, such as

overnight construction costs (US$600/kW for diesel and US$2,200/kW for hydro), average diesel price (US$ 0.96/liter), heat rate of diesel fired plants (10.55GJ/KWh/), capacity factors (85% for diesel plants and 50% for hydro plants), economic lives (20 years for diesel plants and 40 years for hydro plants) and discount rate (7%), we estimate levelized costs of diesel fired power generation (US$297/MWh), and hydro power generation (US$41/MWh). When the total electricity mix accounts for 20% of diesel-based generation and 80% of hydro generation, the supply costs would be 2.25 times {(0.2*299+0.8*41)/1.0* 41} higher than when the entire electricity is supplied by hydroelectric sources. In other words, the price of electricity would have been 2.25 times higher with the diesel back-up system to avoid the load shedding.
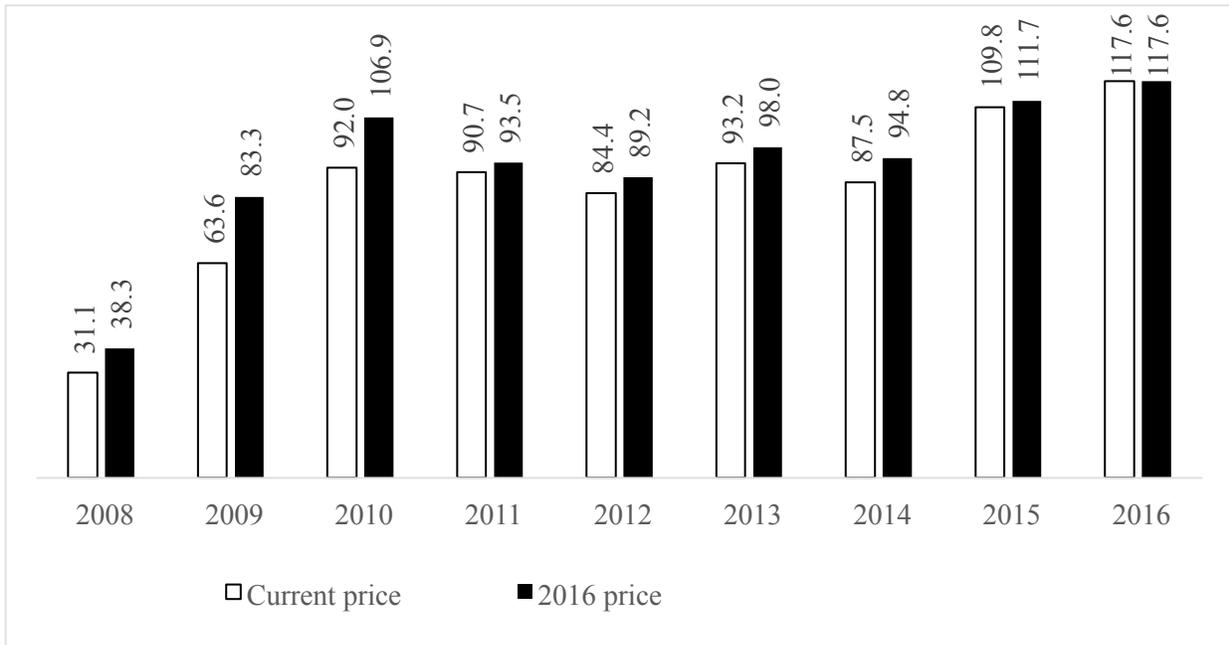
5. Results

This section describes the main findings of our analysis. We first show estimates of the direct costs of load shedding, followed by the results of simulated CGE model scenarios and their validation based on the VECM model.

5.1 Direct costs of load shedding

We assess the direct economic costs of electricity load shedding by calculating the value of lost sales. Using the electricity deficit in a given year and the average price of electricity in that year we calculate the monetary value of lost electricity sales due to the load shedding (Figure 2). The white columns in Figure 2 show the value of electricity losses at current prices; the back columns represent the value of losses in 2016 constant prices. The value of electricity loss (in current prices) have increased every year, starting from US$ 31.8 Million in 2008 to US$ 117.6 Million in 2016. The total current price value of electricity loss due to load shedding during 2008-2016 period amounts to US$770 Million. If the loss is expressed in 2016 prices, it amounts to US$ 833 Million.

Figure 2. Direct costs of electricity load shedding in Nepal (Million US$)

Total loss during the 2008-2016 in current price = US$ 770 Million
Total loss during the 2008-2016 in 2016 price = US$ 833 Million

5.2 CGE model results

### 5.2.1 Scenario with no back up power generation

Figure 3 presents the effects of load shedding on key macroeconomic variables in the scenario where the electricity shortages cannot be avoided. The results are expressed as the average annual deviation compared to a hypothetical situation where load shedding would not have occurred.

The results reveal that load shedding caused a reduction of 6.4% of annual GDP, on average, during the 2008-2016 period. This means if there were no load-shedding annual GDP would have been almost 7 percent higher, on average, as compared to what it was during the

2008-2016 period.[13] The worst impacts can be observed on the investment side. The load shedding caused almost 33 percent loss of investment demand as compared to the baseline. In other words, if there were no load shedding, the average annual investment would be more than 48% higher as compared to the level during 2008-2015. Due to the lower investment and production loss caused by the load shedding, total industrial outputs decreased by almost 7%. As production activities decrease, international trade would also decrease; due to the load shedding, annual exports and imports were estimated to be decreased by, on average, 2.8% and 5.4%, respectively during the 2008-2016 period.

Figure 3: Impacts on key macroeconomic variables

Annual average deviation from the CGE model baseline (%) during the 2008-2015 period

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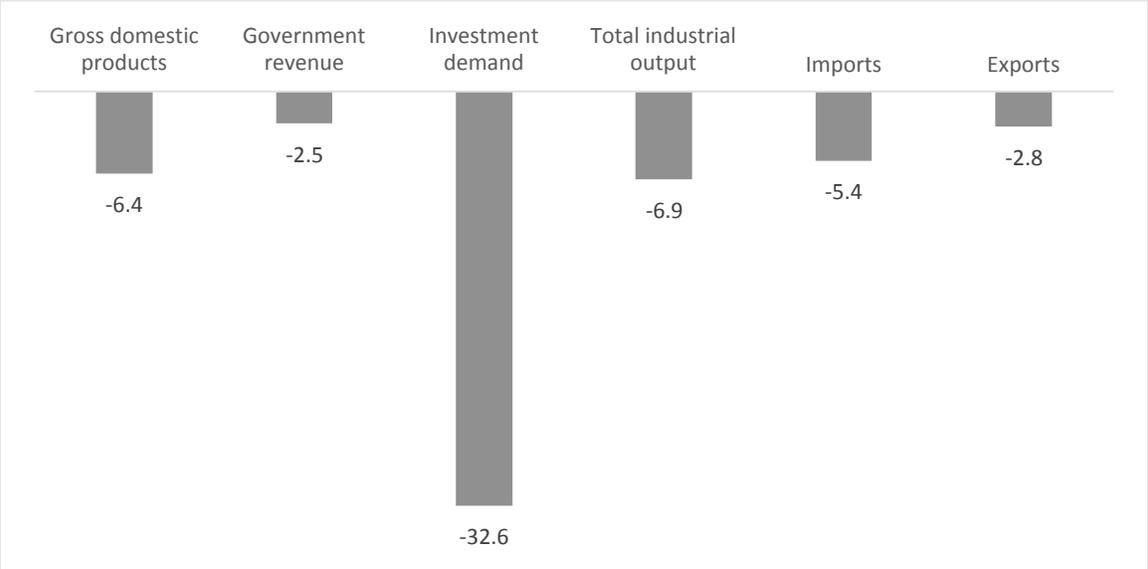
[13] This means the actual GDP (with load shedding) is 6.4% smaller as compared to the baseline (without load-shedding). If we consider the actual GDP, with the load shedding, as the base, the hypothetical GDP would be $[\{100/(100-6.4)\}-1]*100 = 6.9\%$.

We also estimate the total or cumulative economic loss Nepal might have experienced due to the load shedding during the 2008-2016 period. Figure 4 presents actual GDP (measured in current prices) and the GDP the country would have realized if there was no load shedding. Our estimates suggest that Nepal has lost a total of US$11 billion value of GDP in nine years over the period of 2008-2016 because of the electricity load shedding. This amount is almost equal to Nepal's GDP in year 2008. If the annual GDP loss is expressed in 2016 prices using the corresponding GDP deflator values, the total GDP loss over the 2008-2016 period amounts to US$14.5 billion.

Figure 4: Actual GDP and estimated GDP if there were no load shedding (Billion US$ current price)
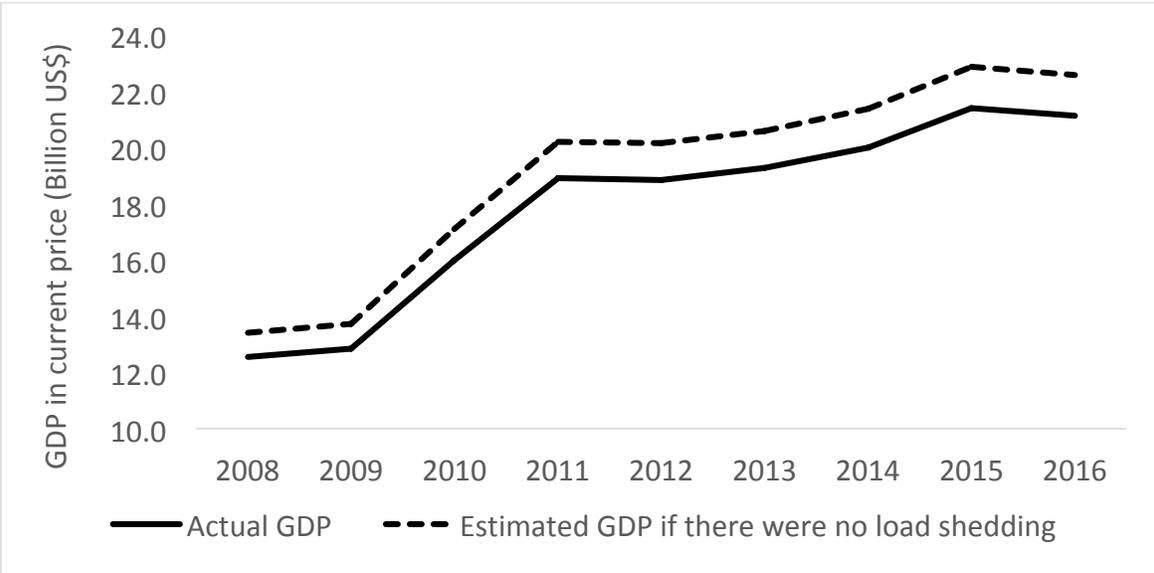
5.2.2 Scenario with back up generation

The back-up supply policy offsets some of the negative impacts of load shedding, however, economic losses are still high. Our results show that if the load shedding were

completely avoided through back-up electricity generation, the country would still suffer a 3.4 percent GDP loss. The total sectoral output decreases by 5.4 percent and total consumption of the households by 3.8 percent. The main reason behind these economic losses is that the expensive diesel fired back-up system increases electricity supply costs and, therefore price of electricity, by 225 percent. This result suggests that expensive diesel-based back-up electricity supply system to avoid load shedding can only to a limited extent mitigate economic costs of load shedding in Nepal.

5.2 CGE Model Validation Using VECM

In this section we discuss the diagnostics and the results of the estimated VECM model to validate the CGE model predictions. We start with the results of the four unit root tests (see Appendix Table A.1). The ADF, DF-GLS and Phillips-Perron tests all cannot reject the null of unit root, whereas the KPSS test rejects the null of stationary series. We can thus conclude that both GDP and electricity consumption series are non-stationary.

We then evaluate the estimated coefficients of the VECM equations (see Appendix Table A.2). In the GDP equation, the lagged error correction term, ECT, is negative and statistically significant, representing the negative feedback necessary in real GDP to bring the electricity consumption back to equilibrium. The lagged coefficients in this equation are also negative and significantly different from zero. In the electricity consumption equation, as expected, the lagged error correction term is positive. That is, if the electricity to GDP ratio (or electricity intensity) is above it long-run equilibrium, either GDP must fall or electricity consumption must increase. The short-run coefficients are not significant, with an exception of second lag of electricity consumption, which is positive and statistically significant from zero.

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As regards the diagnostic tests, we observe the results of Johansen tests for cointegration (see Appendix Table A.3). The trace statistic indicates that we can reject the null of 0 cointegrating vectors, and cannot reject the null of 1 cointegrating vector. We can thus conclude that there is one cointegrating vector. We also see that the moduli of the remaining five eigenvalues are strictly less than unity (Appendix Figure A.1). The eigenvalues thus meet the VECM stability condition.

Figure 5: Cumulative Orthogonalized Impulse Responses

Note. E: Electricity Consumption.
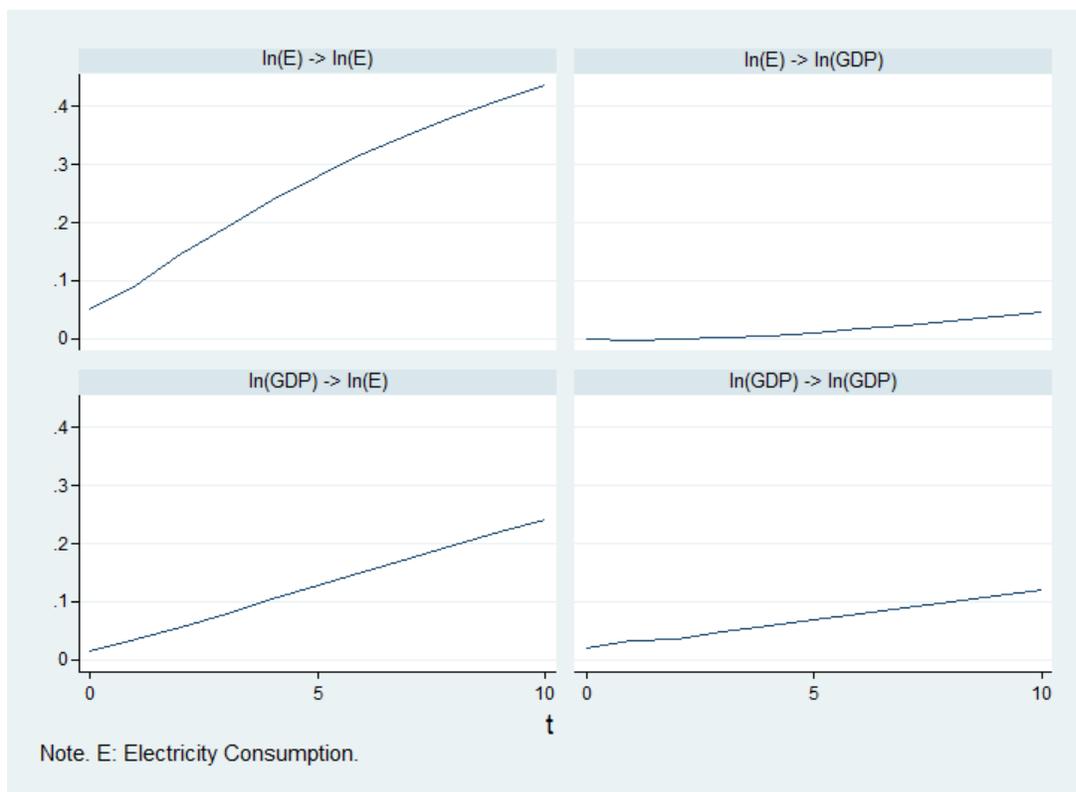
Finally, we conduct the impulse response analysis to measure the reaction of electricity consumption and GDP to the exogenous shock at the time of the shock and over subsequent points in time. Figure 7 and Table A.4 show cumulative orthogonolized impulse response

(OIRF) functions, which plot the accumulation of the impact of the shock to electricity consumption and GDP across time. We compute the OIRF up to 10 periods ahead. Figure 5 shows that electricity consumption is positively affected by a GDP shock both upon impact and that as time goes on (lower left panel). GDP does not immediately respond to the electricity consumption shock, however, it does increase as the time goes on. Table A.4 shows that over 10 periods, a 1 percent increase (decline) in electricity consumption cumulatively results in a 0.045 percent increase (decline) in GDP. Following the assumption in the CGE model that Nepal has experienced a 20% deficit in electricity consumption over the consecutive period of nine years, the cumulative effect of power supply deficit based on the VECM impulse response analysis comes to about 8 percent decline in GDP. This is in line with the CGE model predictions.

6   Conclusions and Further Remarks

Over the last 10 years, electricity load shedding created severe welfare losses to households and posed a major barrier to economic development in Nepal. The problem started in 2008 and peaked in 2016 when the country faced up to 14 hours of power cuts in the dry (winter and spring) season. Recently, the situation has improved for residential consumers. However, industrial consumers are still facing load shedding that causes either production cuts or increased production costs due to adoption of expensive self-generation systems.

Our study estimates that Nepal has lost a total of US$11 billion value of GDP in nine years over the period of 2008-2016 due to electricity load shedding. This amount is almost equal to Nepal's GDP in 2008. If the annual GDP loss is expressed in 2016 prices based on corresponding GDP deflator values, the total GDP loss over the 2008-2016 period amounts to

US$14.5 billion. On average, the country lost more than 6% of its GDP annually during that period. All sectors experienced cuts in their outputs, due to either lack of electricity supply (small and medium sized industries which cannot afford back-up power) or increased electricity costs (e.g., large industries which can afford expensive back-up generation). Load shedding has particularly strongly affected investment. Our analysis suggests that in the absence of load shedding, annual investment, on average, would have increased by 48 percent during the 2008-2016 period. Lower investment and corresponding production losses caused by the load shedding resulted in a 6.9 percent decrease in the industrial output. Nepal's international trade has been also affected. Over the period of 2008-2016, the load shedding caused a 2.8 percent reduction in exports and 5.4 percent reduction in imports. Our results also suggest that the diesel-fired back-up system to avoid load shedding could only to a small extent reduce the economic costs of load shedding in Nepal.

As the estimated effects are based on the CGE model simulations rather than on a panel data econometric analysis with credible identification strategy, the numbers presented in this study should be interpreted with caution. These results are indicative also because the estimates change, though not significantly, if some model parameters, such as the elasticity of substitution, are altered. Also, the effects of load shedding are only relevant for the customers already connected to the national electricity grid and does not fully include economic loss in many areas not served by the national grid or off-grid/distributed generation systems. This study also does not account for economic losses of not avoided greenfield investment in large-scale electricity intensive industries, such as fertilizer factories, chemical industries. A further investigation would be needed to assess the extent to which these potentially confounding factors are significant.

All in all, while the recent reduction of load shedding in the residential sector has certainly helped reduce the welfare losses faced by households, the economic losses would still persist because industries are continuously facing load shedding or higher electricity expenditure due to expensive back-up supply provisions. A complete elimination of load shedding, particularly from the industrial sector, is crucial to avoid millions of dollars of economic loss in years to come.

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Appendix

Table A.1 Unit Root Test Statistics

Test / Variable	E	GDP
Augmented Dickey-Fuller test	-2.66[*]	-0.23
DF-GLS test	-2.24	-2.1
Phillips-Perron test	-1.71	0.91
KPSS test	0.24[***]	0.18[**]

Notes. E: Electricity Consumption. The null hypothesis for DFGLS, ADF and PP tests is presence of unit root. The null hypothesis for KPSS test is absence of unit root.

[***] $p < 0.01$, [**] $p < 0.05$, [*] $p < 0.1$.

Table A.2 VECM Estimates

Variables	(1) $\Delta\ln(GDP)$	(2) $\Delta\ln E$
ECT_{t-1}	-0.097[***]	0.21[**]
	(0.032)	(0.082)
$\Delta\ln(GDP)_{t-1}$	-0.36[**]	0.31
	(0.16)	(0.4)
$\Delta\ln(GDP)_{t-2}$	-0.44[***]	-0.11
	(0.151)	(0.38)
$\Delta\ln(E)_{t-1}$	-0.099[**]	-0.1
	(0.048)	(0.12)
$\Delta\ln(E)_{t-2}$	0.013	0.38[***]
	(0.048)	(0.12)
Constant	0.091[***]	0.04
	(0.014)	(0.036)
Observations	34	34

Notes. E: Electricity Consumption. ECT: Error Correction Term.
Standard errors in parentheses. [***] p<0.01, [**] p<0.05, [*] p<0.1.

Table A.3 Johansen Tests for Cointegration

Rank	LL	Eigenvalue	Trace Statistic
0	133.7		22.49 (15.41)
1	143.3	0.431	3.32 (3.76)
2	144.9	0.092	
Observations		34	
Lags		3	

Notes. LL: Log-Likelihood. 5% critical values are in parentheses.

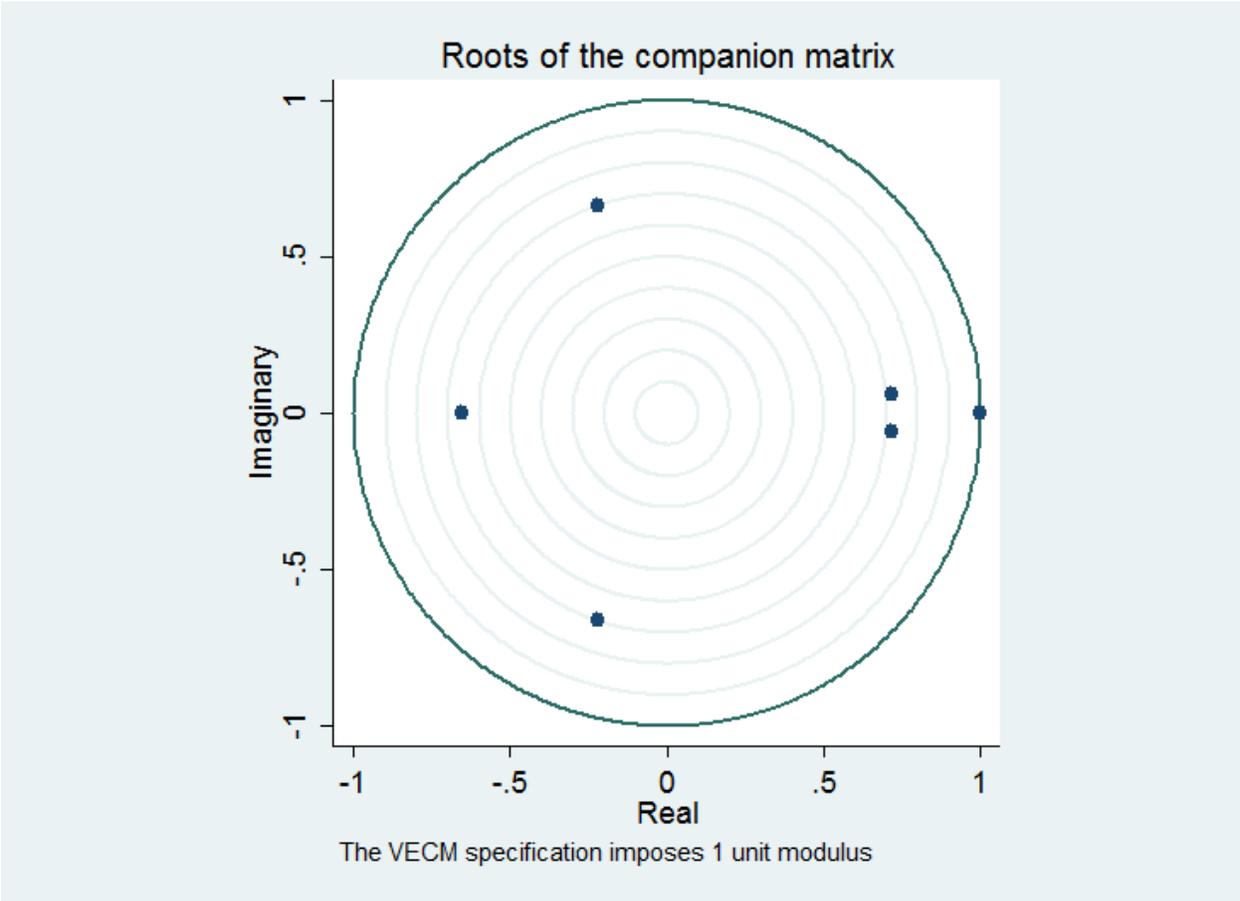Figure A.1 Eigenvalue stability conditions

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Table A.4 Cumulative Orthogonolized Impulse Responses

t	I	II	III	IV
0	0.02	0.01	0.00	0.05
1	0.03	0.04	-0.003	0.09
2	0.04	0.06	-0.0003	0.15
3	0.05	0.08	0.002	0.19
4	0.06	0.10	0.005	0.24
5	0.07	0.13	0.01	0.28
6	0.08	0.15	0.016	0.32
7	0.09	0.17	0.023	0.35
8	0.10	0.20	0.03	0.38
9	0.11	0.22	0.037	0.41
10	0.12	0.24	0.045	0.44

Notes. (I) Impulse = ln(GDP), and response = ln(GDP); (II) impulse = ln(GDP), and response = ln(E); (III) impulse = ln(E), and response = ln(GDP) (IV) impulse = ln(E), and response = ln(E). E: Electricity Consumption.