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The Opportunity Cost of Electricity Outages and Privatization of Substations in Nepal

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Abstract

The unreliability of electricity supplies is a major cause of the high cost of manufacturing in developing countries. In this paper we are able to measure the cost imposed by power outages and suggest some feasible mitigating measures. The study employs a rich, if not unique, set of data from three large manufacturing enterprises in Nepal. Using it the opportunity costs to the enterprises from lost production from electricity outages can be estimated accurately. Power outages due to substation failure can be separated from other electricity systems failures. An analysis is carried out on the feasibility of privatized electricity substations. We find that this is a very worthwhile capital investment for the private sector to undertake, even when additional generation capacity to improve overall electricity reliability is not justified.

JEL Classifications: L94, Q41, Q48

Keywords: electricity supply, reliability, opportunity costs, privatization,

1 Introduction

For many developing countries the unreliable supply of electricity is the norm rather than the exception. For industries power outages increase production costs, and increase the operating uncertainty that enterprises face[1]. Production losses arise from loss in output, spoilage of in-process materials and even damage to machinery, all translating into financial losses. Often the cuts in power supply cause production losses lasting beyond the duration of the outage.

A number of previous studies have attempted to estimate the economic costs of unreliable electricity supplies, using a variety of techniques. Some of the most important of these studies were by Mohan Munasinghe and Mark Gellerson (1979), Munasinghe (1979), Neil M. Swan (1980), Benjamin Bental and S. Abraham Ravid (1982), Michael Beenstock and Ephrain Goldin (1997), and Roy Billinton and Wijarn Wangdee(2005). Neil M. Swan (1980), estimated the social cost of electricity outages for residential consumers. He makes the point that the time is not necessarily wasted when an outage takes place since that time could be utilized in some other activity and later the time for this activity would replace the time of the original activity. He notes, however, that certain leisure time is indeed irrevocable. Munasinghe (1979) classifies outage costs as direct and indirect. Direct costs are those which occur during or following an outage while indirect costs are those which result because an outage is expected and people take mitigating actions.

Recently Nexant Sari/Energy (2003) has undertaken a study of the economic impact of poor power quality on industries in Nepal. The study estimated the average losses suffered by the industries from unplanned outages to be around 0.49 US$/kWh, while such losses for planned outages were found to

[1] The term “power outage” refers to all electricity supply interruptions and it includes all power cuts, both planned load shedding as well as unplanned power failures, with advance notice or without. Load shedding denotes physical rationing of the electricity by the utility by forcibly reducing the demand for electricity (load) on the system, usually during periods of peak demand.

be only 0.14 US$/kWh. It is evident that Nepal has had a serious electricity reliability problem and these problems are there to stay for quite some time in the future[2].

2 Framework for Analysis

Except for study by Sari/Energy 2003 all of the studies reviewed above have been carried out for either industrialized countries or countries that are approaching this stage of development. Usually the lack of relevant data has made such studies difficult or impossible to do in the lower income countries where the incidence of such electricity outages is most acute. This study is made possible due to the availability of a rich source of industrial information on each of the power outages that affected the production at a spinning mill, a steel re-rolling mill, and an oxygen factory in Nepal. This data which covers a period of 5 years in the 1990s is accompanied by sets of detailed cost and operating data for each of these enterprises for the same five years that the power outage data is available. Because of these comprehensive sets of information we are able to measure the direct impact of electricity outages on the level of profits of the enterprises through the effect such outages have on the contribution to profits that is lost by the loss in production and increased costs[3].

2.1 Determination of the Power Outage Costs

In his paper we want to estimate the costs imposed on industrial activities by power interruptions and express these costs as a ratio of the number of kilowatt hours (kWh) of electricity not purchased due to the supply interruptions. This will give us a measure of the economic opportunity costs per kWh of electricity not supplied.

[2] Madan Kumar Dahal and Kyoko Inoue (1994) pointed out in their study that an acute electricity shortage was a fundamental problem in the context of industrial development of Nepal. Irrational planning, according to Jit Narayan Nayak (1994), caused a power deficit in Nepal that would persist for several years. The final report of National Planning Commission (1995) on the Perspective Energy Plan for Nepal admitted that the domestic power consumption was constrained by supply limitations and the development of the national economy was retarded due to load shedding. This same conclusion was reached by the report on Productivity Improvement in Infrastructure (1995) in Nepal. It recognized that power shortages adversely affected activities in industrial sectors.

[3] The complete data sets used in this paper can be downloaded from www.queensjdiexec.org/publications.

2.1.1 Classification of Costs

An enterprise would normally have two types of costs, variable costs and fixed costs. Variable costs are those that increase or decrease in proportion to the volume of production, and fixed costs are those which remain the same irrespective of the magnitude of production. In the short term and for the normal range of production capacities we are discussing here, the fixed costs remain fixed costs. So, basically, all the costs can be divided into variable or fixed costs.

2.1.2 The Contribution Method

In the literature in electricity economics, the concept of value added is generally used while estimating the cost of power outages. Value-added includes the return to fixed costs and some components of variable costs, mainly direct labor.

Contribution is a better measure of the power outage cost from the perspective of an enterprise than value-added. Contribution means the portion of the net sales proceeds which goes towards meeting the overheads and towards making the profits for the company. This is computed by subtracting all the direct or the variable costs from the net sales proceeds. A firm maximizes its profits by maximizing its contribution.

When an outage takes place, the loss in contribution gives us the true measure of the opportunity cost suffered by an enterprise. Other losses like material spoilage have to be added to obtain the total value of power outage cost. When a unit of output is not produced, all components of the variable costs are also saved and what is foregone is the opportunity cost in terms of the contribution which would have resulted and gone towards meeting the overheads and profits, had that unit been produced.

The equation for the contribution per unit of output is written as

$$b = p^{net} - \Sigma c_i^m - c^l - c^p - c^f - c^x \qquad (1)$$

Where b is the contribution per unit of output, p^{net} is net revenue, c_i^m is the cost of direct material i, per unit of output, c^l is the cost of direct labor per unit of output, c^p is the cost of direct electricity per unit of output, c^f is the cost of direct fuel per unit of output, and c^x is the other direct costs per unit of output.

p^{net} is in turn defined as,

$$p^{net} = p - d - m - x^{selling} \qquad (2)$$

Where p is the selling price per unit of output, d is the customer discounts per unit of output m is the sales commissions per unit of output, and $x^{selling}$ is direct sales expenses per unit of output.

Alternatively (2) can be expressed as,

$$p^{net} = p\,(1 - d\% - c\% - x^{selling}\,\%) \qquad (3)$$

Where d% is the customer discounts, expressed as percentage of selling price, c% is the sales commissions, expressed as percentage of selling price, and $x^{selling}$% is direct sales expenses, expressed as percentage of selling price.

In contrast, if we were to express a relationship for value-added per unit of output, *va*, it would be:

$$va = p - \Sigma c_i^m - c^p - c^f - c^x \qquad (4)$$

We can see that this does not take into consideration the savings in direct labor that might result when a unit of output is not produced, and so, it overstates the cost of an interruption in production.

2.1.3 Power Outage Costs

After calculating the value of the contribution, we will determine the impact of power outages on the production process of the enterprise, and compute the quantity of output lost. We may also need to calculate other components of the outage cost such as material wastage and idle labor. We will then calculate the total value of loss suffered due to an outage.

Under the contribution method, the expression for the power outage cost, C^{outage} becomes:

$$C^{outage} = [b * q^{output} * \{t^{outage} + t^{extra}\}] + [c^{direct\ labor} * \{t^{outage} + t^{extra}\}] + + [Q^{spoilage} * \{ c^{spoilage} + c_s^{labor} + c_s^{energy}\}] - S^{salvage} \quad (5)$$

where, in addition to the definitions given above, C^{outage} is the total financial cost of the power outage, q^{output} is the quantity of output produced per unit of time, t^{outage} is the duration of the power outage, in hours, t^{extra} is the duration of extra time lost in a) restart up, b) removing spoiled materials-in-process etc., $c^{direct\ labor}$ is the direct labor cost per hour, $Q^{spoilage}$ is the units of spoiled materials-in-process, $c^{spoilage}$ is the cost of spoiled materials-in-process per unit, c_s^{labor} is the cost of labor to remove per unit of spoiled materials-in-process, c_s^{energy} is the cost of energy to remove per unit of spoiled materials-in-process, and $S^{salvage}$ is the salvage value of spoiled materials-in-process.

If the enterprise is producing a number of products rather than a single one, the cost of the outage is the summation of the above expression across the whole range of products being produced.

In order to compare power outage costs across different enterprises, we need a numeraire which makes such comparison meaningful. The outage cost per unit of power not supplied, in Rs per unit, is a number we can use to make comparisons across different types of enterprises. The equation for the loss per unit of power not supplied is as given below:

$$L^{outage} = C^{outage} / U^{outage} \quad (6)$$

Where L^{outage} is the cost of the power outage per unit of power not supplied, and U^{outage} is the units (kWh) of power not supplied during the power outage. In turn

$$U^{outage} = \{U^{month} / H^{month}\} * t^{outage} \quad (7)$$

Where U^{month} is the number of units of power consumed in a month, and H^{month} is the hours worked during the month

3 Power Outages in Nepal

3.1 The Sources of Data

The power outage data for the five years are obtained from two sources, Himal Iron & Steel (P) Limited, Parwanipur (Himal), a steel re-rolling mill that produces a variety of steel products, and Jyoti

Spinning Mills Limited, Parwanipur (JSM), both located in the central southern part of Nepal. Himal and JSM have methodically kept records of each occurrence of power failure – the time the power went off and came back – on a daily basis. Himal receives power at the primary distribution voltage of 11 kV and pays the Nepal Electricity Authority (NEA) for the power at the tariff applicable for that voltage. In the case of JSM, power from the grid is tapped at 66 kV. JSM pays for the electricity at a lower tariff which is applicable to 66 kV supply. Similar to Himal, Himal Oxygen (P) Ltd. (Oxygen) receives power from the same government owned NEA substation. Therefore Himal data on power outages is used for both Himal and Oxygen. Nepal has its own calendar, in the Bikram Sambat era (B.S.). The actual data have been recorded for the years 2049-2053 B.S.

3.2 Analysis of Power Outages in Nepal

3.2.1 Power Failures

In carrying out this study we classify power outages into two types. The first category is power failures, and the second category is load shedding. Power failures are unscheduled outages that occur without notice. Load shedding refers to outages that are planned ahead of time by NEA, and the firms are notified the exact time that the outage will occur.

At Himal, over this five-year period, a total number of 2,001 power failures took place for total outage duration of 1,517.42 hours. On average, about 400 power failures took place each year and the average duration of these power failures was $45^{1}/_{2}$ minutes. At JSM, for the same five-year period, a total number of 430 power failures took place for a total duration of 631.88 hours. In other words, an average of 86 power failures took place annually with an average duration of 88.2 minutes.

An important feature for our analysis of power outages is made possible by the fact that Himal receives power from a government (NEA) owned substation which also supplies power to many other consumers in the area, while JSM's captive substation is fully dedicated to supplying power to its own factory. Both of these substations obtain their electricity from the same high voltage line. The power outages that are common to both the enterprises can be attributed to power system failure, i.e. a breakdown of the whole grid or a shortage of generation capacity. We find, however, that there were many power outages at Himal which did not simultaneously occur at JSM. These outages can be attributed to substation failure. This provides us with a controlled experiment where a comparison of the number and duration of power failures for Himal versus JSM enables us to evaluate the benefits of substation improvements.

(insert table 1)

By comparing the experience of JSM with Himal in Table 1 we see that the uncertainty in power supply, as measured by the frequency of power failures, is considerably more when an enterprise such as Himal is obtaining power supply from a government owned NEA substation.

3.2.2 Load Shedding

Himal and JSM also kept detailed records of every incidence of planned load shedding imposed by NEA. We find that for Himal, the duration of the individual events of load shedding generally fell between 1 ½ to 2 and 3 hours. In the case of JSM, the duration of the individual events of load shedding was exactly 1½, 2 or 3 hours. Having a captive generator to generate about half of its needs seems to have been beneficial to JSM. It could ensure that the load shedding occurred exactly at the pre-determined time. In some cases during 2049 and 2050 it could keep operating if the systems load shedding was not to fully cut off the power from the spinning mill.

(insert Table 2)

In the case of load shedding for enterprises that do not work around the clock, advance notice helps them change their production hours to reduce the effects that load shedding would have on their operations. For the enterprises which must operate twenty four hours continuously either because of the nature of their production operation or because of the large capital investment that has been made, having a captive generator is an option for overcoming some of the production stoppages caused by load shedding.

4 Calculation of the Power Outage Costs

4.1 Production Time Lost

To begin the analysis of the power outages we consider first the cost of power failures. In these cases the power cut happens unplanned and unannounced. The impact of a power failure on production time lost can be much longer than the duration of time of the power failure itself. So, as the first step, we need to establish the relationship between the duration of the power failure and the actual production time lost. Fortunately data was collected by these three enterprises so that we can separate power failures from load shedding. In addition, for all failures power information is available for both the duration of each power failure as well as the duration of the production stoppage. From this data of individual incidents, we can estimate the relationship between the two variables, the duration of the production time lost, y (dependent variable) and the duration of the power failure, x (independent variable), using regression analysis.

For JSM the following regression is fitted,

$$y = 0.03 + 0.9616\,x \qquad R^2 = 0.833 \qquad (8)$$

(19.12) (37.28) (t-values in parentheses)

280 observations

In the case of Himal, the following regression is fitted,

$$y = 0.0079 + 1.4621\,x \qquad R^2 = 0.9818 \qquad (9)$$

(15.02) (129.72) (t-values in parentheses)

314 observations

We repeat the exercise for Oxygen. From this regression, we get the following relationship:

$$y = 0.0575 + 1.6856x \qquad R^2 = 0.7576 \qquad (10)$$

(6.87) (16.30) (t-values in parentheses)

87 observations

4.2 Contribution Values

The financial statements and cost structures information on the enterprises under consideration are used to calculate the contribution values for the firm. The sales revenue, the discounts and the commissions can be obtained from the income statement of the enterprise. The quantity of the products sold in that particular year is also known. Dividing the sales revenue by the quantity sold, one can find the selling price per unit. Similarly, the per unit value of the discounts and commissions, and the net selling price are calculated.

Next, one needs to find the direct costs of production per unit of the product. The cost of production numbers for the particular year for each of the enterprises are found from their financial statements. In this case, it is the quantity of goods produced that is needed. From these numbers, one can estimate the components of direct material (raw materials), direct labor, direct energy (electricity and fuel) and other direct costs such as packing. The contribution values are obtained by subtracting the direct costs from the net selling price.

4.3 Calculating the Cost of Power Failures

4.3.1 Losses from Power Failures at JSM

For JSM, the average production value in kg per hour has been obtained from the production records for JSM for B.S. 2049 and so have been the values for man-hour rate and average power consumption in the year. The total production lost in kg, is obtained by multiplying the total production time lost by the average production rate. The total contribution loss, is the product of the total production lost, in kg, and the contribution value, expressed in Rs per kg. Similarly, the total man-hour loss[4] is arrived at by multiplying the total production time lost, by the man-hour rate. The summation of the above numbers (equation 5) gives us the value of the total loss from power failures at JSM for the year.

The next step is to calculate the loss per kWh not supplied. First, the units (kWh) of power not supplied during power failures is estimated. This is obtained by multiplying the total production time lost, in hours by the average rate of power consumption, in kWh per hour. Finally, the loss in Rs per kWh unsupplied is obtained by dividing the total loss from power failure, in Rs, by the power not supplied, in kWh.

Table 3, row 11, a total loss of Rs 820,683 due to power failures is estimated for JSM in B.S.2049 and the loss per kWh not supplied was Rs 10.31 per kWh. (row 13). In US$/kWh (2005 prices) the loss per kWh not supplied ranges from $0.11/kWh to $0.33 kWh. (Table 3 row 14). The simple average cost of power failures over the 5 years was US$0.23/kWh.

(insert Table 3)

4.3.2 Losses from Power Failures at Oxygen

The explanations for the calculations for the losses due to power failures at Oxygen are the same as in the case of JSM, so they are not repeated. However, the results are summarized in Table 4.

(insert Table 4)

For Oxygen the loss per kWh unsupplied in US$/kWh (2005 prices) ranged from US$ 0.13 to US$ 0.32, with an average of US$ 0.24/kWh.

[4] Workers cannot be sent home at a short notice or for the duration of the power failure. When we use the contribution method, we assume that the direct labor is saved but it is not. So, we need to add the cost of idle labor or the man-hours lost during the period of a power failure as a component of the cost. Idle direct labor rate is determined by dividing the total expenditure on direct labor by the total number of hours worked, in a particular year.

4.3.3 Losses from Power Failures at Himal

At Himal, the operating hours are from 6 AM to 10 PM, 6 AM to 2 PM for the first shift and from 2 PM to 10 PM for the second shift. Hence all power outages occurring between 10 PM and 6 AM are removed from the data. Furthermore, the power failures in 88 non-working days in the year are also removed. Using equation (9) to translate each power failure duration into its impact on production time lost, the total estimated production time lost from these power failures is 307.17 hours of production time (Table 5 row 4).

On the basis of average production, contribution, and man-hour rate, total production loss, total contribution loss and total man-hour loss are calculated, as in the case of JSM. At Himal, power failures also result in wastage of the materials-in-process and the fuel oil, and these have to be included. Himal kept records of the quantities of this wastage. Records are also available on the selling price of the finished products and the purchase price of furnace oil in the respective years. From these the value of the wastage is calculated. The furnace oil waste is a product of the quantity and the price. In the case of material waste (misroll), an estimated cost equal to 50% of the regular selling price of the final product gives us a reasonable approximation of the value of the input materials wasted.

The total loss from power failures at Himal is the sum of the total contribution loss, the total man-hour loss, the material waste, and the furnace oil waste. The loss per kWh unsupplied, is calculated as in the case of JSM. The calculation of the losses per kWh are presented in Table 5.

(insert Table 5)

In the case of Himal the range of costs per US$/kWh is from US$ 0.47 to 1.28/kWh with a simple average cost for these years of US$ 0.98/kWh.

Comparing the loss from power failures to the total contribution to profits of JSM we see that the loss is only 1.57% of the total contribution from production that year. This is no doubt due to the fact that JSM has its own electricity substation that has greatly reduced the incidence of power failures.

In the case of Oxygen, these numbers were higher. The power failure losses amounted to between 11.40% to a staggering 75.56% of total contribution from the annual production averaging 35.69% over the five year period. At Himal, the losses were similarly high averaging 13.16% of the total contribution from annual production over this period.

4.4 Calculation of the Cost of Load Shedding at the Three Enterprises

At JSM and Himal, the duration of the load shedding generally ranges from 1 to 3 hours, and so, the workers cannot be sent home during the period of load shedding. Therefore, we must count the cost of idle labor.

Because of the planned nature of load shedding the extra production time lost is relatively small as compared to power failures. Hence, we will not apply the regression equation in this case to move from the time of outage to the duration of lost production. From Table 2 we see that in B.S. 2049, we see that at JSM a total of 259.50 hours of load shedding took place. The total production lost on account of this was 68,523 kgs, and the contribution loss was Rs 2,343,930. Total idle labor cost of the load shedding in this year was Rs 352,575 making the total loss from load shedding as Rs 2,696,504. The quantity of power not supplied during the periods of load shedding was 261,601 units (kWh), hence, the loss per kWh not supplied was Rs 10.31 per kWh.

(insert Table 6)

(insert Table 7)

Due to the production process the situation at Oxygen is different. The interruption of electricity whether planned or unplanned has a similar effect on extending the time of production loss beyond the period of the power outage. We have, therefore, to take recourse to the regression equation (10) derived earlier. The total impact of load shedding at Oxygen in B.S. 2049 is 706.72 hours (Table 8). The remaining calculations are same as in the case of JSM and Himal.

(insert Table 8)

In Table 9 we calculate the opportunity cost of power failures and load shedding for these three enterprises. Overall we find that for these three enterprises the values for power failures and load shedding are very similar.

(insert Table 9)

5. Policy Implications

The outage data showed that the power supply in Nepal was very erratic and unreliable. Creating standby self-generation capacity is the traditional solution for power supply problems but from our analysis of outage data, another unique option has emerged – that of allowing the private ownership and/or management of electricity substations.

5.1 Opportunity Cost of Power Supply for Outage Prevention

The value of the contribution lost per kWh not supplied is a measure of the opportunity cost of marginal power supply for an enterprise. In other words, this would be the value of the willingness to pay by these enterprises for the supply of power which would prevent such outages. Himal has the highest opportunity cost of power in comparison to the other two. For the enterprise with higher opportunity cost of power, it is more essential and feasible to invest in mitigating equipment.

5.2 Opportunity Cost of Uninterrupted Power Supply

We now calculate the opportunity cost of the electricity not supplied due to all types of power outages during this period. To do this we calculate the levelized cost of the electricity lost (Table 10). The levelized cost is obtained by taking the present value of the losses borne by each of the firms over the five years and dividing this value by the present value of the quantity of the electricity supply lost during this period. This is the rate of tariff that would make the NPV of the electricity not supplied equal to the costs inflicted by the power outages. We see that this value is 0.23 US$/kWh for JSM, 0.21 US$/kWh for Oxygen and 0.95 US$/kWh for Himal!

(insert Table 10)

(insert Table 11)

(insert Table 12)

5.3 Evaluation of the Benefits and Costs of Privatizing Substation

The outages in power supply from a captive substation are considerably less than those from a government owned NEA substation. Therefore, having a captive substation emerges as an option for dealing with the power failure problem. The benefits associated with a captive substation are the savings in power outage losses and the savings in buying high voltage power at a lower tariff than the tariff charged for low voltage electric energy.

Using the data for JSM we are able to evaluate the option of having a captive substation (Table 13). The savings obtained from purchasing high voltage electricity (row 13) is found by multiplying the difference in the average tariff between purchasing low voltage versus high voltage electricity (row 12) by the amount of power consumption (row 9). We calculate the saving in power outage losses (row 8) by multiplying the levelized cost of outages (row 7) by the additional power supplied (row 6) because these power failures have not occurred. This quantity of electricity estimated by comparing the higher incidence (in hours) of power failures inflicted on Himal and those experienced by JSM. Recall Himal and JSM are getting electricity from the same high voltage service but only JSM has its own substation.

The costs associated with the captive substation are the annual capital cost and running cost. The investment cost of the substation at the time of its purchase was US$ 647,000 in 2005 prices and the operating costs have been about US$ 9,105 per year (2005 prices). Using a real (net of inflation) user cost of capital of 15%, the annual capital cost is US$ 97,008.90, and the running cost is US$ 9,105.00[5]. This means that the annualized costs of operating a new substation is US$ 106,113.90, Table 13 row 18. If we now compare this cost with the benefits it would produce through reducing the electricity shortages (row 14), the results are striking.

(insert Table 13)

On average over these five years the combined benefits to JSM of purchasing the lower voltage power plus the savings from the avoidance of the power failures covered the annual capital and operating cost of the substation 2.18 times. The differential in the tariff rates for low and high voltage electricity alone (row 13) covered the cost of the substation (row 18) in all years. In addition to this benefit, the value of the reduced power failures to JSM (row 8) would alone on average cover, cover over 70% of the annual capital and operating costs of the substation.

At the rates of levelized cost inflicted by power failures for these three enterprises it is clear that, if the volume of electricity demanded is sufficient, an investment in one's own substation is a very good investment. In cases when a single firm's consumption of electricity is not sufficient to justify the purchase of a substation then it would be advantageous for enterprises to come together collectively

[5] The capital costs of the substation and its operating costs were obtained from the financial records of JSM. The 15% user cost of capital is made up of a real opportunity cost of capital of 10% plus a 5% charge per year to reflect the depreciation of the investment of a substation with a 20 years economic life.

to purchase their own private substation. Other options might also be considered for getting private management and incentives for proper management into this sector.

The fundamental reason for lower rate of power failures in electricity supply from one's only substation is good management of the substation. The NEA employees have little or no motivation to manage the substations properly. The result is poor maintenance of the equipment and lack of proper management practices. Leasing the substations to private operators who would buy the high voltage power and sell the electricity to the private businesses might be another option for consideration.

Privatization of the substations can also result in another substantial benefit to the national economy. In Nepal, as in several other countries in the region, pilferage of electricity is a serious problem. Electricity is stolen by illegally tapping from the transmission lines and this happens only at the secondary distribution voltage (220 V, single phase or 380 V, three phase). In other words, the pilferage takes place after the substation. If the substation is privatized, NEA would collect payments for electricity drawn at the substation. The private managers would be left to deal with the pilferage. It is not difficult to identify where the pilferage is taking place, but NEA employees have no incentive for doing this. Under private management, the situation would be different with the substation managers having a very strong incentive to charge for every kWh of electricity supplied.

5.4 New Investment in Additional Capacity

If we subtract out the hours of lost electricity supply due to substation failures we have left the system losses due to insufficient electricity generation capacity and other supply breakdowns. To simplify the analysis we assume that all the rest of the power outages are caused by inadequate generation capacity. This is the case certainly during the periods of planned load shedding, but most of the other high voltage outages are likely to have risen due to a lack of generation capacity. This problem of lack of reserve capacity can be addressed by NEA investing in additional generation capacity.

We now do a similar annualized cost benefit analysis to evaluate the benefits and costs of investing in additional generation capacity. For the 5-year period, the levelized cost of power outages is US$ 0.23/kWh for JSM, US$ 0.21 /kWh for Oxygen and US$ 0.95 /kWh for Himal. From the electricity lost due to inadequate reserve capacity figures (Table 14), we found that 60% of the lost electricity consumption was from JSM, 14% by Oxygen, and 26% by Himal. Using these percentages as the weights, and taking the levelized costs for JSM, Oxygen, and Himal from tables 10, 11, and 12, respectively we find that the weighted average levelized cost of the power not supplied is calculated to be US$ 0.41/kWh.

(insert Table 14)

In 2005 prices, the cost of generation capacity suitable for supply power during peak load period is approximately US$400 per kW.[6] Assuming a 15% user cost of capital (10% opportunity cost of capital, and 5% depreciation), the required contribution to the capital costs for a $400/kW investment in a gas turbine generation would be $60/year. The running cost of such a plant are likely to be not more than US$ 0.07/kWh. Given the number of hours system power outages, Table 15 row 5, we can estimate the annual cost per year of having an additional kW of capacity. That is found by multiplying the number of outage hours by the marginal running costs and adding the capital costs. These values are reported in Table 15 rows 8, 9, 10.

The costs saved from having additional generation capacity in the system is found by multiplying the levelized opportunity cost of US$ 0.41/kWh by hours per year when the power was not being supplied (row 5). The total costs saved are reported in row 11. The benefit cost ratios for these years are presented in Table 15 row 12.

[6] The costs of such a reserve plant were obtained from Jenkins, Glenn and Andrey Klevchuk, *Feasibility study of El-KureimatCombined Cycle Power Plant*, African Development Bank, 1995 (www.queensjdiexec.org)

(insert Table 15)

From the annual benefit cost ratios we see that additional generation capacity was more than justified during the first three years of this period 2049 to 2051. At this time there was systematic planned load shedding. During 2052 and 2053 after additional generation capacity was bought into supply we find the benefit cost ratio falls below one. It would appear that at least for these firms additional generation capacity would not be justified during the two final years of observation[7].

In contrast the problem of unexpected power failure due to inadequate capacity and management of the substations would justify such investments throughout the entire five year period, Table 13 row 19.

6 Conclusion

We have seen that the uncertainties in power supply in Nepal pose serious threats to the economic well being of the enterprises in that country. The opportunity costs range to as high as US$1.28/kWh of electricity not supplied with a levelized average of US$ 0.41/kWh. In the past, installing generators has been thought of as the only solution for the consumers to alleviate the power supply problem. However, from the careful analysis of the data on power outages in Nepal, another mitigating strategy, privatization of substations, emerges.

The issue of privatization is a common and popular topic of consideration in many developing countries. In Nepal, the government and the donor agencies have been trying to motivate private entrepreneurs to build hydropower stations to alleviate the power supply problems. Privatization of the substations, however, is a complementary measure that in the short-run have much higher returns. In addition, it is relatively easy to deal with either industrial groups or skilled entrepreneurs. In the case of Nepal the return to an investor from ownership of a substation is potentially even higher than an investment in additional generators to supply additional electricity.

[7] The electricity system in Nepal is heavily dependent on electricity supplied by hydro dams. When there is a drought, load shedding is experienced. In 2005-2006 such a drought occurred causing a serious reduction in available electricity supplies and chronic load shedding. Hence, even if our results indicate that in the last two years of our study that additional electricity capacity was not justified, this situation might have only been temporary because of heavy rains in those years.

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Table1 : Frequency, Mean Duration and Cumulative Hours of Power Failure Per Year

	2049	2050	2051	2052	2053	Total	Average
JSM Power Failure Summary (hours)							
Count per year	40	125	101	107	57	***430***	***86***
Mean length of occurrence	1.31	1.14	1.43	1.25	2.79		***1.58***
Duration (hours per year)	52.20	142.12	144.60	134.13	158.83	***631.88***	***126.38***
Himal Power Failure Summary (hours)							
	2049	**2050**	**2051**	**2052**	**2053**	**Total**	**Average**
Count per year	327	549	593	230	302	***2001***	***400.2***
Mean length of occurrence	0.73	0.82	0.62	0.65	1.03		***0.8***
Duration (hours per year)	237.80	448.95	369.80	148.82	312.05	***1517.42***	***303.5***

Table 2: Frequency, Mean Duration and Cumulative Hours of Load Shedding Per Year

	2049	2050	2051	2052	2053	Total	Average
JSM Load Shedding Summary (hours)							
Count per year	108	203	92			***403***	***134.33***
Mean length of occurrence	2.40	1.98	2.00				***2.13***
Duration (hours per year)	259.50	401.00	184.00			***844.50***	***281.50***
Himal Load Shedding Summary (hours)							
	2049	**2050**	**2051**	**2052**	**2053**	**Total**	**Average**
Count per year	195	245	92			***532***	***177.33***
Mean length of occurrence	3.00	1.90	1.91				***2.27***
Duration (hours per year)	585.45	464.92	175.45			***1225.82***	***408.61***

Table 3: Calculation of Loss due to Power Failure, JSM

	year - B.S.	**2049**	**2050**	**2051**	**2052**	**2053**
1	Number of Occurrences	40	125	101	107	57
2	Total Power Failure Duration	52.20	142.12	144.60	134.13	158.83
3	Total Production Time Lost (decimal hours)	78.98	226.61	211.73	205.98	193.75
4	Av. Production, Kg per hour	264.06	225.68	339.16	479.41	525.48
5	Contribution, Rs. per Kg	34.21	34.21	44.58	13.99	41.30
6	Man-hour rate, Rs per hour	1,358.67	1,358.67	1,682.14	2,884.95	3,192.75
7	Avg power consumed, kwh per hour	1,008.10	1,215.57	1,220.75	1,915.55	2,116.09
8	Total Production Lost (kg)	20,855	51,141	71,810	98,748	101,814
9	Total Contribution Loss (Rs)	713,376	1,749,368	3,201,596	1,381,163	4,204,516
10	Total Man-hour Loss (Rs)	107,306	307,884	356,153	594,237	618,604
11	Total Loss from Power Failure	820,683	2,057,252	3,557,749	1,975,400	4,823,119
12	Power not supplied (kwh)	79,618	275,456	258,464	394,561	409,998
13	Loss per kwh unsupplied (Rs/kwh)	10.31	7.47	13.76	5.01	11.76
14	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.28	0.19	0.33	0.11	0.24

Table 4: Calculation of Loss due to Power Failure, Oxygen

	year - B.S.	2049	2050	2051	2052	2053
1	Number of Occurrences	327	549	593	230	302
2	Total Power Failure Duration	237.80	448.95	369.80	148.82	312.05
3	Total Production Time Lost (decimal hours)	852.44	1,514.95	1,442.29	568.49	943.07
4	Av. Production, CuM per hour	28.35	28.08	23.99	30.35	51.47
5	Contribution, Rs. per CuM	12.06	18.93	16.86	24.90	26.36
6	Man-hour rate, Rs per hour	120.98	87.41	81.07	91.50	103.31
7	Avg power consumed, kwh per hour	64.45	64.57	85.36	61.49	91.48
8	Total Production Lost (CuM)	24,167	42,540	34,601	17,254	48,540
9	Total Contribution Loss (Rs)	291,381	805,455	583,234	429,578	1,279,444
10	Total Man-hour Loss (Rs)	103,128	132,422	116,927	52,016	97,429
11	Total Loss from Power Failure	394,509	937,877	700,161	481,594	1,376,872
12	Power not supplied (kwh)	54,940	97,820	123,114	34,956	86,272
13	Loss per kwh unsupplied (Rs/kwh)	7.18	9.59	5.69	13.78	15.96
14	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.19	0.24	0.13	0.30	0.32

Table 5: Calculation of Loss due to Power Failure, Himal

	year -	2049	2050	2051	2052	2053
1	Number of Occurrences	301	452	471	201	259
2	Total Power Failure Duration	237.52	350.30	287.33	153.48	250.02
3	Production Time Lost	404.18	597.62	509.14	262.40	414.51
4	Estimated Production Time Lost (76%)	307.17	454.19	386.95	199.42	315.03
5	Av. Production, MT per hour	2.57	2.02	2.21	2.55	3.70
6	Contribution, Rs. per MT	4,640.44	5,571.67	7,691.55	7,592.39	3,081.12
7	Man-hour rate, Rs per hour	316.75	339.67	420.54	396.10	331.84
8	Avg power consumed, kwh per hour	384.55	306.25	349.44	384.37	541.92
9	Total Production Lost (MT)	789	917	855	509	1,166
10	Total Contribution Loss (Rs)	3,663,334	5,111,790	6,577,458	3,860,945	3,591,377
11	Total Man-hour Loss (Rs)	97,297	154,273	162,725	78,992	104,539
12	Material Waste (Misroll) (Rs)	91,156	150,933	71,758	54,893	49,691
13	Furnace Oil Waste (Rs)	221,218	479,119	509,438	91,776	201,063
14	Total Loss from Power Failure	4,073,005	5,896,115	7,321,378	4,086,606	3,946,670
15	Power not supplied (kwh)	118,124	139,095	135,215	76,652	170,721
16	Loss per kwh unsupplied (Rs/kwh)	34.48	42.39	54.15	53.31	23.12
17	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.93	1.07	1.28	1.17	0.47

Table 6: Calculation of Loss due to Load Shedding, JSM

	year -	**2049**	**2050**	**2051**
1	Total Duration of Load Shedding (in decimal hours)	259.50	401.00	184.00
2	Av. Production, Kg per hour	264.06	225.68	339.16
3	Contribution, Rs. per Kg	34.21	34.21	44.58
4	Man-hour rate, Rs per hour	1,358.67	1,358.67	1,682.14
5	Avg power consumed, kwh per hour	1,008.10	1,215.57	1,220.75
6	Total Production Lost (kg)	68,523	90,499	62,406
7	Total Contribution Loss (Rs)	2,343,930	3,095,652	2,782,340
8	Total Man-hour Loss (Rs)	352,575	544,827	309,514
9	Total Loss from Load Shedding	2,696,504	3,640,478	3,091,854
10	Power not supplied (kwh)	261,601	487,442	224,618
11	Loss per kwh unsupplied (Rs/kwh)	10.31	7.47	13.76
12	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.28	0.19	0.33

Table 7: Calculation of Loss due to Load Shedding, Himal

	year -	2049	2050	2051
1	Total Duration of Load Shedding (in decimal hours)	489.70	439.58	175.12
2	Av. Production, MT per hour	2.57	2.02	2.21
3	Contribution, Rs. per MT	4,640.44	5,571.67	7,691.55
4	Man-hour rate, Rs per hour	316.75	339.67	420.54
5	Avg power consumed, kwh per hour	384.55	306.25	349.44
6	Total Production Lost (MT)	1,259	888	387
7	Total Contribution Loss (Rs)	5,840,123	4,947,378	2,976,747
8	Total Man-hour Loss (Rs)	155,112	149,311	73,644
9	Total Loss from Load Shedding	5,995,236	5,096,689	3,050,392
10	Power not supplied (kwh)	188,314	134,621	61,194
11	Loss per kwh unsupplied (Rs/kwh)	31.84	37.86	49.85
12	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.86	0.96	1.18

Table 8: Calculation of Loss due to Load Shedding, Oxygen

	year -	2049	2050	2051
1	Number of Occurrences	195	245	92
2	Total Power Failure Duration	259.50	401.00	184.00
3	Total Impact of Load Shedding (in decimal hours)	706.72	1,014.29	437.21
4	Av. Production, CuM per hour	28.35	28.08	23.99
5	Contribution, Rs. per CuM	12.06	18.93	16.86
6	Man-hour rate, Rs per hour	120.98	87.41	81.07
7	Avg power consumed, kwh per hour	64.45	64.57	85.36
8	Total Production Lost (CuM)	20,036	28,481	10,489
9	Total Contribution Loss (Rs)	241,572	539,271	176,799
10	Total Man-hour Loss (Rs)	85,499	88,659	35,445
11	Total Loss from Load Shedding	327,072	627,930	212,244
12	Power not supplied (kwh)	45,548	65,493	37,320
13	Loss per kwh unsupplied (Rs/kwh)	7.18	9.59	5.69
14	Loss per kwh unsupplied (US$/kwh, 2005 prices)	0.19	0.24	0.13

Table 9: Opportunity Cost of Power Failures and Load Shedding, US$/kWh, 2005

year	**2049**	**2050**	**2051**	**2052**	**2053**
Power Failure					
JSM	0.28	0.19	0.33	0.11	0.24
Oxygen	0.19	0.24	0.13	0.30	0.32
Himal	0.93	1.07	1.28	1.17	0.47
Load Shedding					
JSM	0.28	0.19	0.33	--	--
Oxygen	0.19	0.24	0.13	--	--
Himal	0.93	1.07	1.28	--	--

Table 10: Levelized Cost of Power Outages, JSM

	year >	2049	2050	2051	2052	2053
1	Total Costs (2049 prices)	3,517,187	5,304,283	5,805,187	1,600,081	3,608,596
2	Quantity of kWhs not Supplied	341,219	762,898	483,082	394,561	409,998
3	Levelized cost (Rs/kWh, 2049 prices)	8.36				
4	Levelized Cost (US$/kWh, 2005 prices)	0.23				

Table 11: Levelized Cost of Power Outages, Oxygen

	year >	2049	2050	2051	2052	2053
1	Total Costs (2049 prices)	721,580.45	1,457,682.37	796,540.77	390,092.93	1,030,158.27
2	Quantity of kWhs not Supplied	100,488	163,313	160,435	34,956	86,272
3	Levelized cost (Rs/kWh, 2049 prices)	7.93				
4	Levelized Cost (US$/kWh, 2005 prices)	0.21				

Table 12: Levelized Cost of Power Outages, Himal

	year >	2049	2050	2051	2052	2053
1	Total Costs (2049 prices)	10,068,241	10,233,714	9,054,686	3,310,164	2,952,848
2	Quantity of kWhs not Supplied	306,438	273,717	196,409	76,652	170,721
3	Levelized cost (Rs/kWh, 2049 prices)	35.16				
4	Levelized Cost (US$/kWh, 2005 prices)	0.95				

Table 13: Cost/Benefit Analysis of Substation

	year >	2049	2050	2051	2052	2053
1	Duration of power outages (hrs)					
2	without substation	823.25	913.87	545.25	185.57	312.05
3	with substation	311.70	543.12	328.60	134.13	158.83
4	Difference	511.55	370.75	216.65	51.43	153.22
5	Avg power consumed, kwh per hour	1,008.10	1,215.57	1,220.75	1,915.55	2,116.09
6	Additional Power supplied (kWh)	515,691.66	450,671.36	264,475.39	98,522.98	324,220.39
7	Levelized Cost of Power Outages (US$/kWh, 2005 pri	0.23				
8	Saving in power outage losses	116,801.22	102,074.50	59,902.17	22,314.89	73,434.07
9	Power consumption (kWh)	14,050,805.00	9,123,436.00	10,345,670.00	14,412,578.00	15,545,502.00
10	Average tariff (11 kV, US$ 2005 prices)	0.05	0.06	0.07	0.06	0.07
11	Average tariff (66 kV, US$ 2005 prices)	0.04	0.05	0.06	0.05	0.05
12	Difference	0.01	0.01	0.01	0.01	0.01
13	Saving in tariff rate	123,746.60	107,133.86	149,570.66	187,062.47	212,234.72
14	Total Savings	240,547.82	209,208.35	209,472.83	209,377.37	285,668.79
15	Cost of Captive Substation					
16	Capital cost	97,008.90	97,008.90	97,008.90	97,008.90	97,008.90
17	Running cost	9,105.00	9,105.00	9,105.00	9,105.00	9,105.00
18	Total Cost of Captive Substation (US$)	106,113.90	106,113.90	106,113.90	106,113.90	106,113.90
19	Ratio of Benefits to Substation cost	**2.27**	**1.97**	**1.97**	**1.97**	**2.69**
20	Annual Average	**2.18**				

Table 14: Electricity lost kWh/year due to inadequate reserve capacity

year >	2049	2050	2051	2052	2053	Total Units	Weights
JSM	341,219.41	762,898.26	483,082.34	394,561.01	409,998.20	2,391,759.23	0.60
Oxygen	100,487.88	163,312.91	160,434.52	34,956.17	86,272.09	545,463.56	0.14
Himal	306,437.95	273,716.51	196,408.81	76,652.19	170,720.69	1,023,936.15	0.26

Table 15: Cost/Benefit Analysis of Additional Generation Capacity

1	year >	2049	2050	2051	2052	2053
2	Duration of Power Outages (hours)					
3	Power Failures	52.20	142.12	144.60	134.13	158.83
4	Load Shedding	259.50	401.00	184.00	-	-
5	Total Power Outage Duration (hours)	311.70	543.12	328.60	134.13	158.83
6	Levelized Cost of Power Outages (US$/kWh, 2005 prices)					
7	(US$/kWh, 2005 prices)	0.41	0.41	0.41	0.41	0.41
8	Running Cost of Generation	21.82	38.02	23.00	9.39	11.12
9	Capital cost	60.00	60.00	60.00	60.00	60.00
10	Total Annual Costs	81.82	98.02	83.00	69.39	71.12
11	Costs Saved	127.80	222.68	134.73	54.99	65.12
12	Ratio of outage cost to capacity cost	**1.56**	**2.27**	**1.62**	**0.79**	**0.92**
13	Annual Average	**1.43**				