

### The Theory

The theory of calculating the benefits of RE as the increase in consumer surplus is relatively straightforward. The difficulties come in applying that theory.

Electricity supply lowers the cost of energy to the user, resulting in an increase in consumer surplus, which is the difference between what the consumer is willing to pay and what they actually do pay. Assume that before electricity, energy is supplied from a single source, kerosene, at price  $P_k$  with consumption  $Q_k$  (figure H.1). Once electricity is available at lower price  $P_e$ , consumption rises to  $Q_e$ . Using these two points, the demand curve may be interpolated; exactly how this is done is one of the important issues considered below.

The amount the consumer is willing to pay for a quantity  $Q$  is the area under the demand curve from 0 to  $Q$ . Hence the consumer is willing to pay  $A + B + D$  for consumption of  $Q_k$  but actually pays  $B + D (= P_k Q_k)$ , leaving a consumer surplus of  $A$ . Once electricity becomes available, the consumer surplus is  $A + B + C$ , so the increase in consumer surplus as a result of electrification is  $B + C$ . This consumer surplus has two parts: that arising from the reduction in the price of the  $Q_k$  units already being consumed and that associated with the new consumption,  $Q_e - Q_k$ .

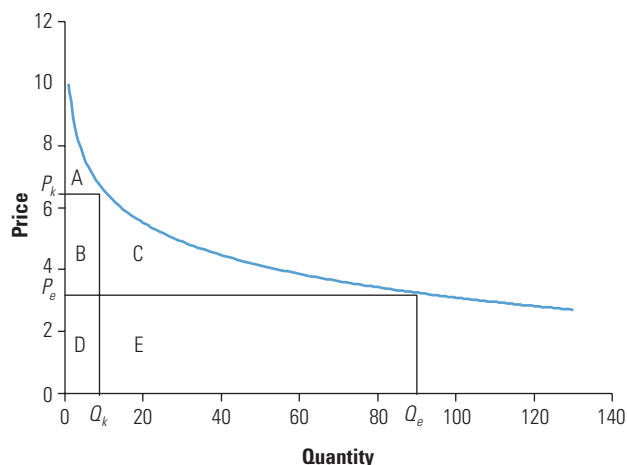
The benefit to the consumer is  $B + C$ . It is common in project analysis to also include areas  $D + E$ , sometimes referring to the whole area  $B + C + D + E$  as the willingness to pay (WTP), which is not quite correct because WTP includes area  $A$  also. It is perfectly acceptable to include areas  $D + E$ . This is the amount paid by the consumer,

which is simply a transfer payment to the utility and so a neutral flow for economic analysis.<sup>1</sup> The cost side of the analysis will capture the cost of consumption. Assuming that the average cost of supply ( $C_e$ ) is less than the tariff rate, there will be a positive producer surplus, which is being captured in this calculation (figure H.2). The alternative is to deduct the payments ( $D + E$ ) from consumers but then add them to producers, so when summing across all flows, these payments/receipts cancel out.

A complication in the above is that, in drawing the demand curve between the two observed points, it is assumed that other characteristics that affect demand are the same for those households for which  $(P_k, Q_k)$  is observed and those for which  $(P_e, Q_e)$  is observed. This is almost certainly not the case. Electrified households have higher incomes than nonelectrified, and the average income in electrified communities is higher than that in nonelectrified ones. Energy is a normal good, demand for which rises with income, so  $(P_e, Q_e)$  in fact lies on a higher demand curve than does  $(P_k, Q_k)$ .

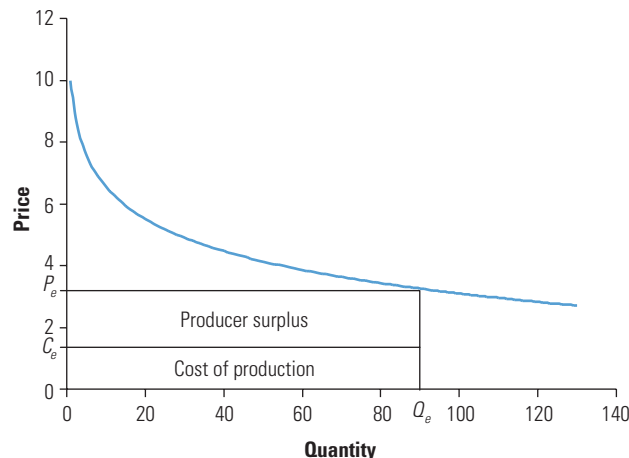
The consumer surplus for customers who are already connected is thus underestimated by this approach. But the consumer surplus for those who will become connected (if they do despite their lower income) is overestimated. In addition, when benefits are projected into the future, real income growth will shift the demand curve to the right over time so that consumer surplus is increasing. The value of this additional consumer surplus can be calculated if the income elasticity of demand for energy is known. If this elasticity is known, along with the average income of currently connected and unconnected households, then different demand curves can

**Figure H.1: Consumer Surplus**



Note:  $P_e$  = price of electricity from the grid;  $P_k$  = price of kerosene;  $Q_e$  = quantity of electricity used from the grid;  $Q_k$  = quantity of kerosene consumed.

**Figure H.2: Producer Surplus**



Note:  $C_e$  = average cost of supply;  $P_e$  = price of electricity from the grid;  $Q_e$  = quantity of electricity used from the grid.

also be drawn for these different groups to more accurately measure consumer surplus.

### Issues in Applying the Theory

There are several complications in applying this approach in practice: data availability, the common metric to be used on the horizontal axis, the shape of the demand curve, and the way in which consumer surplus is expressed.

#### Data availability

Although the analysis is based on just four pieces of information ( $P_k$ ,  $Q_k$ ,  $P_e$ , and  $Q_e$ ), these are not readily come by. A recent energy household survey (or expenditure survey with a good energy module) is necessary to estimate average prices and quantities for electrified and unelectrified households. But it is also necessary to control for income differences between these two groups. The simplest way to do this is to restrict the sample to communities whose average income is within a certain range or to take a small number of subsamples with different average incomes, which is a better approach if future RE will benefit communities with a different profile than those that have already been electrified.

#### Units for the horizontal axis

The above example puts energy on the horizontal axis. To apply the approach, a common metric is needed. Nonelectrified households rely on a variety of energy sources, often woodfuel for cooking, kerosene for lighting, and, among the better off, car batteries for TV. The mix among these varies by household. In principle, total energy consumption can be converted to a common metric such as kilowatt hour or kilograms of oil equivalent, and the average price can be calculated by dividing total consumption by energy expenditure.

There are two problems in this approach. First, the energy consumption mix varies across households, so taking a representative household might be misleading as coverage expands and different households become connected to the grid. Second, electrified households typically still use other energy sources, so the comparison is not a straightforward one between electricity and an alternative energy source. These problems might be partially sidestepped by valuing consumers separately by end use. In this case, end use-specific units can be used for the horizontal axis,

such as lumens for lighting (see below) or hours for TV watching.

**Shape of the demand curve**

The value of area C in figure H.1 clearly depends on the shape of the demand curve. The simplest assumption is to assume a linear demand curve (that is, a straight line) between the two observed points, making the calculation of area C very straightforward =  $0.5(P_k - P_e)(Q_k - Q_e)$ . But if the demand curve is convex to the origin, as theory suggests, then the linear demand curve overestimates the amount of consumer surplus. An alternative functional form is a constant elasticity (that is, log linear) demand curve. The equation for this demand function can be written as follows:

$$P = KQ^\eta,$$

where  $\eta$  is the elasticity and K a constant. The elasticity can then be calculated as

$$\eta = \frac{\ln(P_k) - \ln(P_e)}{\ln(Q_k) - \ln(Q_e)}$$

Once the parameters  $\eta$  and K are obtained, then area C may be calculated as

$$C = \int_{Q_k}^{Q_e} KQ^\eta dQ - (Q_e - Q_k)P_e = \frac{K}{\eta + 1} (Q_e^{\eta+1} - Q_k^{\eta+1}) - (Q_e - Q_k)P_e.$$

Note that the deducted amount  $(Q_e - Q_k)P_e$  (the amount paid for incremental consumption = area E in figure H.1) is usually included in project benefits (because the economic costs of production are deducted separately) so the second term need not be deducted, the first term giving C + E.

**Expressing consumer surplus**

The example given here uses either the market demand curve or that for a representative household. Assume the latter. The calculation therefore gives the value (in local currency) of the increase in consumer surplus from connecting to the grid.

To calculate total project benefits, this value can be multiplied by the cumulative number of households connected to the grid each year. The analysis can be a bit more sophisticated if there are different household types with different levels of consumer surplus, but this is quite a demand in terms of data. There is also the problem that not all consumption is residential, so these calculations need to be repeated for different end users (commercial, agricultural, and so forth).

The alternative approach is to express consumer surplus per kilowatt hour and then multiply the resulting value by total electricity sales each year. This approach does not, of course, bypass the problem of their being different types of consumer: the average consumer surplus per kilowatt hour should be a weighted average for the different end users. There are two problems here: (1) if the share of end users varies over time, the weighted average is no longer the appropriate one, although the resulting bias is unlikely to be large; and (2) the calculation of the average consumer surplus/kilowatt hour is itself biased, though again probably not by much.

Consider the case of three households shown in table H.1; consumer surplus rises with consumption but at a diminishing rate, a fact that arises from the shape of the demand curve. Average consumption is 25 kWh/month, the same as household 2, and corresponds to an average consumer surplus of Rs 2/kWh. Because total consumption is 75 kWh, applying this average suggests a total consumer surplus of 150, whereas the true figure is 145. The inaccurate result comes because the method of calculation implies a constant

**Table H.1: Consumer Surplus for Different Households**

Household	Consumption (kWh/month)	Consumer surplus (Rs)
1	20	40
2	25	50
3	30	55
Total	75	145

Note: Rs = rupees.

increase of consumer surplus with respect to consumption. The same problem arises if multiplying the number of connections by the consumer surplus per connection; such an approach also yields an estimate of a total consumer surplus of 150 in this example.

In summary, the preferred method would be to calculate consumer surplus by end user (possibly even different categories of each type of end user) and thus calculate consumer surplus based on cumulative connections for each type of end user. In practice, however, the data requirements for this approach are substantial, so a more common approach is to estimate consumer surplus per kilowatt hour (though this should be a weighted average of different end users) and multiply this amount by sales. This approach suffers from an unknown bias from the sales composition effect and an upward bias from ignoring diminishing consumer surplus as consumption rises. This bias is offset by the downward bias from ignoring growing consumer surplus as income rises. Although the balance is not known, the two cancel each other out to some extent, so the net bias will not be too great.

## Applying the Theory: Examples

### Lighting

Lighting is the main use of RE (see appendix D) and has been the focus of Bank efforts to calculate the consumer surplus from electricity. Indeed, the lighting benefits are often the only ones valued for residential consumption. In the 1990s, project documents typically compared the cost of lighting using a kerosene lamp with the cost of the same amount of lighting from electricity. But the ESMAP Philippines study (ESMAP 2003) proposed a new approach based on lumens, which is a measure of emitted light. Table H.2 shows the lumens emitted by some typical light sources.

Using these conversion factors and data from a household energy survey, it is possible to obtain estimates of  $Q_k$  and  $Q_e$  (quantity of lumens consumed for kerosene and electricity, respectively) and the corresponding prices ( $P_k$  and  $P_e$ ). This approach finds that the consumption is far higher

**Table H.2: Wattage of Common Household Appliances/Tools**

Appliance	Resistive load (watts)
Clock radio	5
Computer-PC	300
Deep fryer	1,800
Iron	1,200
TV, color	300
Fan	30–70

(by a factor of 2.5 or more) and the price far lower (by a factor of X or more) for electricity than for the next lighting source (see table H.3 for examples).

Once these data are available it is a straightforward matter to calculate the change in the consumer surplus and the WTP. Table H.3 shows the results of this calculation, assuming both a linear and a log-linear demand curve, showing that assuming a linear demand curve can overestimate increase in the consumer by a factor of up to eight times.

## Overview of Bank Approaches to Measuring Electrification Benefits

Bank project documents adopt a range of approaches to valuing electricity benefits. The focus here is on approaches based on consumer surplus. A detailed review is presented in the table of ERR calculations beginning on page 136.

As noted earlier, studies commonly estimate area B + C + D + E as the benefit, calling this WTP. The same terminology is used here, noting that WTP should in fact also include area A, but that area A is not part of the project benefits (that is, it is the terminology that is slightly wrong, rather than a conceptual error in the method of calculation). The following main approaches can be identified:

- Estimate WTP assuming a nonlinear demand curve or assuming a linear demand curve but taking only a percentage of the estimate for area C to allow for the overestimation. This approach conforms with what is considered by this review as best practice, although allowance should also be made for the different income

**Table H.3: Demand for Lumens from Different Energy Sources**

Country	Quantity (kilolumens)		Price (US\$ per lumen)		Consumer surplus		Ratio linear/log linear
	Kerosene	Grid connection	Kerosene	Grid connection	Linear curve	Log-linear	
Bolivia	7	90	0.48	0.04	21.3	8.6	2.5
Lao PDR	20	435	0.195	0.003	43.7	9.9	4.4
Peru	5	363	0.57	0.01	102.9	12.5	8.2
Philippines	4	204	0.36	0.0075	36.8	5.8	6.3

Source: Project documents.

of current and future consumers and income growth among consumers.

- Estimate WTP assuming a linear demand curve. This approach results in an overestimate of project benefits.
- Estimate WTP based on the alternative energy source, and then value the whole of expected energy consumption with electricity at that level. This approach neglects the downward sloping demand curve, resulting in a substantial overestimate of project benefits.
- Estimate benefits as the cost savings on current consumption levels (that is, area B in figure H.1). This approach underestimates project benefits, as it ignores additional consumer surplus from new consumption (area A).

Economic Rate of Return Calculations									
Country	Project	Document	Year	Method	Comment	WTP		ERR	
						Estimate	IEG revised estimate	Estimate	IEG revised
Lao PDR	Southern Provinces Rural Electrification	ICR	2004	Area under linear demand curve, using three separate curves for four data points	A single curve should be used passing through the four points, assuming constant elasticity rather than linear.	72.00	5.60	60.5	12.6
Malawi	Power V	SAR	1992	Cost of avoided diesel generation		USc33/kWh			
Indonesia	Rural Electrification Project	SAR	1990			USc15/kWh		15	
Indonesia	Rural Electrification Project	ICR	1995	Linear demand curve between two points	Should use constant elasticity demand curve, and given data they had should estimate actual $Q_k$ and $Q_e$ .	Residential: USc19/kWh Commercial: USc16/kWh			
Indonesia	Solar Home Systems Project	ICR	2004	Begins with an avoided cost estimation of CS based both on energy expenditures data and on response of TV/radio use to presence of SHS. Then computes WTP using log-linear demand curve based on average monthly energy expenditures.		\$168/million lumen hrs.	184.56	40.9	40.9
Nepal	Power Sector Efficiency Project	SAR		Takes price currently paid as WTP for all consumption (but also does lower bound based on actual tariff).				12.1	6.6
Peru	Rural Electrification Project	PAD	2006	Constant elasticity demand curve, estimated separately	Best practice PAD analysis, including Monte	TV: 2.26 S./kWh, lighting: USc11/kWh			

					Carlo simulations for sensitivity analysis.	Total USc179/kWh
Pakistan	Rural Electrification Project	SAR	1989	CS estimated separately for different end users, based on expenditure on current energy source. Benefits are CS, not WTP.	Overestimate as WTP declines as consumption rises, but underestimate as double count costs (as use CS not WTP); latter effect is larger.	USc10/kWh USc13/kWh 10.9 22.9
Bangladesh	Rural Electrification Project III	SAR				34
Bangladesh	Rural Electrification Project III	SAR	1990	They use a discounted sales-weighted average WTP based on avoided cost estimation for kerosene and the change in CS due to a switch to electricity averaged as an upper bound, and the fiscal 1990 electricity tariff rate as the lower bound.	Insufficient data to confirm that estimates are correct	Tk6.2/kWh 36.5–58
Bangladesh	Rural Electrification Project III	ICR		Similar method used as in SAR, but with benefits defined for only the first 10 kWh/month out of an average of 37 kWh/month.		95.3–102.5
Bangladesh	Rural Electrification Project II	SAR				12.7
Bangladesh	Rural Electrification Project II	PCR	1995	WTP for rural and residential consumers separately using linear demand curve	Should use constant elasticity demand curve. Limited data given to estimate this, but WTP approximately 50% that used in PCR. This lower	Residential: USc105/kWh 13.6 Residential: USc54/kWh -∞

(Table continues on next page)

Economic Rate of Return Calculations (continued)							
Country	Project	Document	Year	Method	Comment	WTP	ERR
						Estimate	IEG revised estimate
					value means net benefits are always negative (hence $-\infty$ ERR).		
Bangladesh	Rural Electrification Project	PCR	1993	WTP for rural and residential consumers separately using linear demand curve	Should use constant elasticity demand curve. Insufficient data in PCR for re-estimation.	n.a	12.6 n.a.
Bangladesh	Rural Electrification Project	SAR				11.4	
Morocco	Rural Electrification Project II	SAR	1990	Benefits are revenues plus consumer surplus. No further details given.	Insufficient information to determine method or perform re-estimation	n.a	17.8 n.a
Morocco	Rural Electrification Project II	ICR	1998	Benefits are revenues plus consumer surplus. No further details given.	Insufficient information to determine method or perform re-estimation	n.a	15.3 n.a
Senegal	Electricity Services for Rural Areas Project	SAR/PAD		WTP calculated from linear and linear in log-log scale.	Insufficient information to recalculate WTP	USc72/kWh	28.4 24
Sri Lanka	Energy Services Delivery Project	ICR	2003	Mini hydro appraisal benefits calculated using avoided cost approach, and ICR uses financial model to create financial internal rate of return to confirm ERR from PAD. Village-based hydro uses avoided cost for assessing consumer benefit, but source not given—appears to be from a	Not enough data is provided to accurately recreate net benefit stream, so leveled stream used, resulting in higher ERR.	USc57/kWh (avoided cost) for mini hydro; 0.001 Rs/lumen hour for SHS; 0.30 Rs/TV-hour for SHS, 0.70 Rs/TV-hour for SHS	0.001 Rs/lumen hour for SHS; 0.30 Rs/TV-hour for SHS

					linear demand curve. SHS component uses log-linear demand curve to derive WTP.					
Bolivia	Decentralized Infrastructure for Rural Transformation	PAD	2003	2003	Taken as one-quarter of $(P_k - P_e) * (Q_e - Q_k)$ to avoid overestimate using a linear demand curve.	n.a.	n.a.	29.1	29.1	29.1
Cape Verde	Energy and Water Sector Reform and Development Project	PAD	1999	1999	Not calculated	n.a.	n.a.	12	n.a.	n.a.
Mozambique	Energy Reform and Access Project	PAD	2003	2003	For EdM grid intensification component WTP is area under semi-log demand curve times factor of 0.8 to minimize overestimation; mini-grid components estimated similarly for North Inhambane and Mocimboa da Praia for residential and commercial users, and photovoltaic component estimates also using semi-log, but for both lighting and TV/radio consumption. WTP estimates reflect weighted averages of subgroups/components.	EdM Grid: USc13/kWh; Mini-grid: USc18/kWh (weighted avg. for residential and commercial) in N. Inhambane and also USc18/kWh in Mocimboa da Praia (estimated separately); PV: USc13/lumen-hour for TV/lighting	n.a.	23	23	23
Guinea-Bissau	Energy Project	ICR	1998	1998	WTP from linear demand curve	Data for determining WTP not provided	n.a.	n.a.	n.a.	n.a.
Malaysia	Rural Electrification Project	PCR	1990	1990	WTP not provided, but avoided cost calculated	Data for determining WTP and ERR not provided	USc58/kWh	n.a.	26	n.a.

Note: All dollar amounts are US dollars. CS = consumer surplus; ERR = economic rate of return; ICR = implementation Completion Report; kWh = kilowatt hour; PAD = project appraisal document; PCR = project completion report; PV = photovoltaic; Rs = rupees; SAR = staff appraisal report; S. = soles; SHS = solar home system; Tk = taka; USc = US cents; WTP = willingness to pay.