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Abstract

Given the low levels of electricity access in rural India, the poor quality of supply post electrification (electricity connection) is an often-neglected issue. The definition of electrification has traditionally focused on physical wire to the home, but not delivery of service. Frequent supply outages have a significant impact on the quality of life of rural households and on the economic development of rural areas. Using a rich dataset of the Bangalore Electricity Supply Company (BESCOM) utilizing the state-level SCADA system (from KPTCL, the TransCo), this paper analyzes supply rostering ('load shedding') in metropolitan, small town and rural feeders in and around Bangalore, the capital city of Karnataka in south India using multiple days of data across 3 seasons during 2012-13. The inequity in load shedding is analyzed through calculated transfers due to differential tariffs between the urban and rural residential consumers, and the financial (supply-side) relief provided to BESCOM through avoided procurement of additional supply from generators, because rural and small town feeders are load shed higher than Bangalore city. This factors in the higher costs of supply and losses in rural areas, but avoids calculations for *value* of lost power or opportunity costs. The estimates of the net transfers are in the range of Rs. 120-380/consumer-year from the rural consumers (varying based on the actual load-shedding), and Rs. 220-370/consumer-year from the small town consumers (in aggregate, Rs. 200-640 million/year and Rs, 120-200 million/year, respectively). The metropolitan consumers are found to be net beneficiaries. Recognizing the revenue shortfalls of the utility (BESCOM) and lack of generation supply procurement options, we end with an examination of alternatives to the status quo and demonstrate the viability of current limited supply using smart meters as a solution.

1. Introduction – Electricity and Electrification

Electrification planning in India has been urban-centric, beginning with the provision of access. Rural electrification was largely neglected till the mid-80's, with the principal focus (if at all) being energizing irrigation pump-sets. A useful indicator of the importance given to village electrification is provided by how 'village electrification' has been defined over time. Until 1997, a village was deemed to have been electrified if electricity was used for any reason whatsoever; this definition was revised to one where electricity was used in inhabited areas (Gokak report, 2002). Even today, the official definition for an electrified village only requires the existence of the distribution infrastructure, supply to public facilities and 10% of households being electrified (Ministry of Power, 2003). As per the 2011 Census, 45% of rural households (76 million) remain unelectrified, compared to 7% of the urban households (6 million). The problem of rural electrification is particularly acute in the northern states of Bihar and Uttar Pradesh – with rural household electrification levels of 11% and 24% respectively (Census 2011).

This paper explores the more neglected issue of reliability of supply once a village or home has been electrified. The gains due to electrification are intimately associated with the reliability of grid supply – its availability, predictability and quality. Rao (2013) demonstrates that the availability of supply has a robust positive effect on the income of household enterprises, in addition to the effects due to access. Khandker et al. (2012) also show that supply availability has a significant effect on household electricity access and consumption levels. The poor availability of supply and the voltage fluctuations also impose significant costs on to the agricultural consumers, through days of lost income, the costs of backup source of power or through damage to equipment (World Bank, 2001).

1.1. Why the power goes out periodically

Electricity has a fundamental technical characteristic of real-time dynamics—the modern electricity grid operates on Alternating Current (AC), which cannot easily be stored. Hence, the grid operates in a mode of real-time balancing, with supply and demand always in synch (net of losses along the wire). When the hourly demand exceeds the available supply, the utilities have to ration the available supply. While the institutional regulation of electricity supply varies across and even within countries, regardless of ownership or structure (e.g., public versus private), one has assets for generation, transmission, and distribution. The latter is what is used for retail supply of electricity, whether in a competitive market set-up or (as is the norm in India) a regulated costs-plus geographic monopoly. Distributions companies such as BESCOM (Bangalore Electricity Supply COMpany) must purchase power from generators, and then deliver (and get paid for) power to end-users.

When faced with a shortfall in supply (through either low supply or higher than anticipated demand, or both), Indian utilities regularly resort to cutting off an entire feeder (11 kV voltage level) of approximately a few thousand consumers – this is dubbed "load shedding." This can be one or more 11 kV feeders in an area, and sometimes even the entire substation. Utilities develop rostering schedules on a monthly or seasonal basis and target achieving them. If deficits remain despite these "scheduled" outages, there are additional unscheduled outages. As Dreze and Sen (2013) described it bluntly, load shedding is the expression given to "managing the outages, instead of doing something about them".

1.2. Who gets load shed? An analysis

Using a rich dataset (at a minute-level resolution for each feeder) for the Bangalore Electricity Supply Company (BESCOM), the study looks at the distribution of supply in metropolitan, small town and rural feeders. Karnataka is the only state in India with distribution feeder level SCADA (Supervisory Control and Data Acquisition), offering extremely granular data. BESCOM serves eight districts in the state of Karnataka, including Bangalore city and the surrounding areas. The population of this region is 20.7 million (Census 2011), of whom 46% live in Bangalore city (hereafter, Bangalore will refer to the city unless specified otherwise). Besides being the capital city of Karnataka, Bangalore is also a major economic hub, known especially for the Information Technology industry.

The principal hypothesis tested in this study is that the rural residential consumers are load shed enough for the resultant supply procurement relief to the utility to overcompensate for any tariff subsidy extended to these consumers relative to their counterparts in urban areas. We therefore quantify two kinds of transfers based on tariffs and load shedding. Both these transfers are framed in a somewhat narrow accounting sense, and do not consider factors such as the economic value of the unsupplied power (opportunity costs) or the consumer interruption costs. Section 3.1 will elaborate on the problem formulation.

Even a preliminary analysis of the data suggests that rural (R) feeders, and surprisingly non-Bangalore urban (NBU) feeders as well, receive supply that is worse than in Bangalore city (Bangalore Urban, or BU). However, there are high variances – and due to data constraints we cannot be sure whether some feeders receive especially poor or good supply all the time or whether some kind of time-specific rotation process is being used.

Finally, we assess measures to reduce the load shedding in rural feeders. We demonstrate that providing uninterrupted but current limited supply, using smart metering technology, instead of outright blackouts is a feasible compromise solution. Compared to the additional installed system costs of approximately Rs. 4000 per meter, the total willingness to pay among the stakeholders—through avoided interruption costs to the consumers, rerouted kerosene subsidies from the central government, and net transfers due to inequitable load shedding—is in the range of Rs. 2,900 - 9,500.

We begin this paper with a broad overview of the power sector institutions, and the supply deficits that necessitate load shedding. Agricultural consumption plays an important role in the utility's finances and as a result, the electricity supply provided to villages. This is described in section 2.3. The rest of the background section directly sets the stage for the analytical framework used in this paper – the tariff setting process and the resultant subsidies, and load shedding. Section 3 covers the methods and data used for the analysis, and outlines three major research questions of interest here. Section 4 summarizes the results – providing estimates of load shedding for the three consumer categories, and the net transfers. We conclude the results section with an engineering economic analysis of the viability of supplying limited electricity instead of zero during shortfalls (technologically, using smart meters) as one solution to blackouts. Section 5 discusses policy implications of the study.

2. Background: Electricity Policies and Ground Realities

2.1. Institutions

Up until the nineties, most of India's states had vertically integrated State Electricity Boards (SEBs) that looked after transmission, distribution, and much of the generation. These boards were for all practical purposes an arm of the state government. The SEB's finances were thus treated as secondary to the state's social and political goals. At the same time, the accounting methods were weak, and the utilities' operations were kept afloat by 'soft' transfers from the government (Tongia, 2007). By the end of the 80s, the Indian power sector was in crisis. Power shortages were constantly increasing and had become chronic. Theft ("commercial losses") was growing, as were technical losses because the infrastructure was in urgent need of an overhaul. In parallel with the onset of liberalization in 1991, a range of measures was introduced – these included private sector participation (especially with an eye on foreign investments) in power generation, corporatization and unbundling of the utilities, and the establishment of independent regulatory commissions. For more on the reforms process and the 2003 Electricity Act, see Thakur et al. (2005), Singh (2006), Tongia (2007). We will briefly discuss the significance of the reforms and the Electricity Act of 2003 on rural electrification in the country. We then highlight salient features of the reforms process in Karnataka and BESCOM.

As implemented, village electrification comes with a set of challenges and disincentives for the utilities. The loads are typically remote and dispersed, increasing the capital costs which cannot be recovered completely through the consumers because of their low ability to pay. Subsequent to electrification, residential demand is low (compared to the urban consumers) and there are few non-agriculture productive loads. As elaborated below, agricultural loads represent a particularly problematic category, which are highly subsidized. Given this context, utilities do not find electrifying village attractive, unless there are high government subsidies. Multiple central government programs have tried to push village electrification aggressively. The most recent and ambitious of these is the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), launched in 2006, under which 90% of the capital costs are subsidized by the central government. Karnataka is among the better electrified states in India, and household and village electrification rates have been among the highest (87% of rural households, and almost 100% of villages).

BESCOM was unbundled from the former Karnataka Electricity Board (KEB) as an independent (government owned) distribution utility in 2002, to service eight districts including and around Bangalore city. In parallel, Mangalore, Hubli and Gulbarga ESCOMs were created. Unlike many of the other states, Karnataka has historically had separate entities for power generation (Karnataka Power Corporation Limited), and transmission and distribution (KEB). The restructuring of the electricity sector started with the Karnataka Electricity Regulatory Act in 1999, and the creation of the Karnataka Electricity Regulatory Commission (KERC). Besides setting up the regulatory body, one of the objectives of the Act was to encourage private sector investment in generation, transmission and distribution (KERC, 2000).

2.2. Supply deficits

India's gross generation capacity has increased from 1.4 GW in 1950 to about 230 GW in 2013.[1] Over the last decade, the capacity has almost doubled with an average addition of 12 GW per year (Central Statistics Office, 2013). Despite this substantial growth, per capita electricity consumption was 684 kWh/year in 2011 (for the sake of comparison, China was at 3300, Brazil 2440, and OECD 8160) (IEA database, 2011). Demand has consistently outstripped supply and deficits remain a concern. For the year 2012-13, the Central Electricity Authority (CEA) estimated a peak deficit (in GW) of 9% and an energy deficit (in billion kWh) of 8.7% (CEA, 2013). Due to methodological and data reasons, the actual shortfall is likely to be substantially higher.

The distinction between generation capacity and energy produced is important. Electricity demand at any moment will be in the units of power (watts, or W). When aggregated over time, the demand is expressed in watt-hours (Wh). In the power system network, supply should meet demand exactly at

[1] This excludes standalone "captive" power used by commercial or industrial users bypassing the grid, or back-up power capacity which in total could be 50% of the total in India.

any instant. Typically, the demand at a particular time of day is usually well known, and power from the generating plants is dispatched accordingly. Demand varies over time, and additional demand is is met using peaking power plants (some of which may be in reserve). These plants, usually hydropower or natural gas fired thermal generators, should be able to ramp up quickly. Coal fired thermal plants, which account for almost 58% of the generating capacity, cannot ramp quickly and so cannot serve as peaking plants. They are used to meet the base load.

Of the approximately 120 GW added over the last 10 years, 70% has been through coal plants (Central Statistics Office, 2013). While India does have large reserves, the domestic coal has high ash content. Another major constraint has been access to coal mines due to environmental, and relocation concerns. Similar concerns have also affected capacity addition through large hydropower and nuclear plants. With natural gas, fuel availability has been a concern. As a result, the problem of deficits is not likely to be resolved quickly. While it is only a partial solution, there is considerable potential in India for improved energy efficiency and demand side management. Although, there have been programs like *Bachat Lamp Yojana* to encourage the uptake of Compact Fluorescent Lamps, there remains significant potential for progress through interventions.

State owned power generation in Karnataka was primarily based on hydropower until 1985 when the Raichur thermal plants became operational. The state has long term Power Purchase agreements for a capacity of about 13 GW – this includes shares of Central Generating Stations (about 1.8 GW) that are allocated to the state, as well as power purchased from Independent Power Producers (1.1 GW) and captive generation plants (0.4 GW) (CSTEP, 2013). Karnataka is also ahead of the curve for renewables, with renewable energy equal to 29% of notional capacity (CEA, 2013). In addition, the utilities in the state have been depending increasingly on expensive short term power purchase to make up for deficits in supply – in 2012-13, this was about 11 Billion kWh of the total 57.2 Billion kWh purchased (about 19%) (CSTEP, 2013). Much, if not all, of this power obtained with short term contracts is purchased during the hours of peak demand. Despite this, Karnataka's energy deficit for 2012-13 was approximately 14% and the "peak" deficit was about 14% as well (CEA, 2013).[2]

2.3. Agriculture – lots of consumption, and not paid for

Power for irrigation pump-sets is an important factor affecting the operations and finances of Indian utilities and is intimately connected to the availability and quality of electricity supply in rural areas, as we shall describe shortly.

With the advent of the Green Revolution, irrigation pump-set use was encouraged in many states of the country, especially those where agriculture had previously been mostly rain-fed. While before, the pump-sets and wells were public-owned, individually owned pump-sets started becoming popular during the 1980s (Dubash and Rajan, 2002). Their use mushroomed over the next two decades. With little oversight or groundwater planning, and negligible (if not zero) tariffs being charged for the electricity consumed by these pump-sets, the water tables in many states of the country have dropped dramatically, necessitating ever deeper wells and increasing the risk of well failure. The farmer lobby has been resisting tariff rationalization motivated in part by the high costs and risks of operating pumpsets (Narendranath et al, 2005). Another complaint is about the poor quality of supply, which leads to motor burnouts due to low voltage and fluctuations (World Bank report, 2001).

Starting in the early eighties, the KEB, or perhaps more accurately, the state government, consciously prioritized agriculture over industry. Agricultural use was "aggressively" encouraged with de-metering of all pump-sets less than 10 HP and the introduction of capacity (in horsepower) based flat tariffs in 1981 (KERC, 2000). In parallel, in 1983-84, the KEB introduced a cap on sales to large, energy intensive industrial consumers, necessitating some of their demand to be borne by captive generation (Reddy and Sumithra, 1997). The power supply to agricultural consumers was heavily subsidized, eventually becoming free. The costs of the subsidies were borne by the larger consumers, most notably the industrial and commercial consumers, who also began increasingly relying on captive generation. The power sector in Karnataka thus got locked in to an

[2] The implausible similarity between average shortfall (energy) and peak (capacity) is a marker for the poor measurements of shortfall in India.

unsustainable cross-subsidy mechanism. It is important to note that the subsidies to agriculture were not borne by the state for many years. The state government only partly meets the costs of the subsidies.[3]

Since the de-metering of small pump-sets that began in the 1980s, even metering the consumption has been stoutly opposed by the farmers. One fear could be that the metering may be followed by tariffs. As a result, agricultural consumption is not reliably monitored by the utilities. In fact, the utilities tended to overstate the agricultural consumption to cover for the very high technical losses and theft (Ranganthan, 2005). Given this context, the only way for the utilities to limit consumption by the agricultural consumers is to provide restricted hours of supply. One common practice in many utilities is to provide a target number of hours of three-phase supply in the mornings or late in the night, and provide single-phase supply for households in the evenings. Most pump-sets cannot be run with single-phase supply, unless phase converters are used. These are widespread, although the extent of their use is unknown. However, because of this, there is a disincentive to provide single-phase supply to rural areas as well.

Recognizing this problem, the Andhra Pradesh state government introduced a physical segregation of rural feeders into agriculture and non-agriculture (primarily, residential) feeders in the early 2000s (ESMAP, 2013). A similar program in Gujarat has been especially acclaimed. While the agriculture feeders continued to receive restricted (but predictable) hours of supply, the non-agriculture feeders were to receive uninterrupted three-phase supply (Shah and Verma, 2008). Based on the success of this program, other states including Karnataka have since sought to replicate it, and the segregation process is still underway.

[3] The state government pays (Regulatory) Commission Determined Tariffs on behalf of the subsidized agriculture consumers. These tariffs seem to be back-calculated from the total quantum of subsidy that the state government is willing to allocate, the gap in revenues for the utility, and the total estimated consumption by the agricultural consumers. For the year 2012-13, the CDTs were Rs. 1.3/kWh; in comparison, the average cost of supply was Rs.5/kWh

2.4. Utility finances and tariffs

One of the principal difficulties in discussing "true" costs of supply in the Indian context is that accounting in the power sector has been generally weak or opaque. Ideally, the tariff design must balance multiple objectives: efficiently allocate the finite resources among the consumers, be sustainable for the utilities and other 'producers', and be equitable – a very subjective notion, especially in light of both subsidies (overall) and cross-subsidies, both across consumer categories, and within consumer categories, through the use of tiered tariffs by consumption level ("slabs"). In practice, electricity prices could, and, as is the case here, do become politicized. The role of the regulatory body would then be, among other things, to balance these objectives and limit the influence of the government in setting tariffs. With the setting up of independent regulatory commissions to regulate state-owned entities, the Indian power sector entered "unchartered territory" (Dubash and Rao, 2008). In its early days, KERC had to contend for authority with the state government that was "regulating in parallel" and continuing to impose its own political agenda on the tariffs (Dubash and Rao, 2008).

The Karnataka Electricity Regulatory Act requires KERC to lay out the methodology in setting tariffs. In the 2000-01 tariff order, the regulators stated that one of the objectives was to progressively phase out subsidies, and base the tariffs on the costs to serve a given category of consumers. Ideally, from an economic standpoint, the tariffs should be equal to the long run marginal costs of supply. The KERC opted to use the more conventional Rate of Return (or "cost-plus") accounting approach instead, citing lack of sufficient data to compute the marginal costs. Even with such an approach, assets and expenditures must be separated between generation, transmission and distribution, and then used to compute demand (i.e. capacity) related, energy related and customer related charges for each consumer group. The fixed tariffs, that are capacity (kW) driven and unrelated to energy consumption (kWh), should ideally reflect the customer service *and* demand related charges. The demand related charges would account for the burden placed on "the system" by a given consumer especially at times of peak demand when the marginal costs of power are likely to be significantly higher than on average, due to the need for peaking power. Currently, fixed charges in the tariffs are limited to service costs like employee salaries, administrative costs, and costs of maintenance and repair, and are normalized using the consumers' connected load. Demand related charges have not been included due to insufficient data- this is an important omission and is especially relevant in the context of this study.

KERC also discusses its approach in balancing the paying capacity of the consumers (and hence, the need for subsidies) with efficient pricing, and the significance of quality of supply. The regulators clarify that the constraints in paying capacity must be considered only for "lifeline" consumption (a basic minimum usage in households) and that the tariffs in general should be at least at average costs of supply. In 2002, the KERC approved a rural rebate of 25% in the *fixed charges* for residential and industrial consumers in rural feeders owing to the poorer quality of supply[4]. In 2005, stakeholder consultations instead resulted in a three tier pricing mechanism for metropolitan, small town and rural consumers to account for the difference in quality of supply. The measure was also designed to increase revenues from urban centers (especially Bangalore) that could then be reinvested to improve supply in rural areas. In 2010, the three-tier pricing was changed to two-tier (rural and urban).

The tariff setting process and tracing the changes in the pricing structure are important because many got locked in. In years that followed, the tariffs have been largely changed on an incremental basis and been set by the utilities while petitioning KERC. The distribution utility estimates the likely demand and the costs of supply and operations for the upcoming year, and the revenue shortfalls with the existing tariffs in order to earn a particular level of returns. New tariffs are proposed for each of the consumer categories in order to meet these shortfalls. KERC decides, based partly on stakeholder inputs, whether these proposed increases in tariffs are reasonable.

For the fiscal year 2012-13, the consumption and average revenues received from different consumer categories are summarized in Table 1. The average revenues received per unit consumed – KERC's estimate of 'actual cost of

[4] Quoting from KERC 2005: "Many rural consumers have strongly represented that there should not be any discrimination between rural and urban consumers in the quality of supply and it should be the same across the state and as such, grant of rural rebate would defeat its purpose of giving scope for the ESCOMs to further neglect the rural areas. A few consumers have also stated that the rural rebate should be so fixed that it would act as a disincentive so that better supply is provided to the rural areas".

supply' – was 5 Rs./kWh. The magnitude of the cross-subsidization is clear from the weighted average tariffs from the low voltage (residential, agriculture, and some commercial consumers among others) and high voltage (predominantly industrial and commercial) consumers- Rs.3.9/kWh and Rs. 6.6/kWh, respectively. Note that there is an increasingly tiered tariff structure for many of these consumer categories. The details for residential consumers are elaborated in Section 4.2.

Table 1: Consumption and revenues from important consumer categories in BESCOM for 2012-13 (BESCOM average revenue is Rs. 5/kWh)

Consumer category	Number of consumers	Total cons. (MU)	Average monthly cons. (kWh)	Revenue/ month/ consumer (Rs.)	Revenue per unit (Rs./kWh)
Rural- poorest *Bhagyajyothi*	0.7 million	110	13[#]	65*	5*
Irrigation pump-sets (<10HP)	0.7 million	4300	530[#]	700*	1.3 *
Rural residential	1.6 million	550	28	92	3.4
Urban residential	4.2 million	5600	110	470	4.3
LT Commercial	0.8 million	1800 (urban) 100 (rural)	210 (urban) 90 (rural)	1,600 (urban) 660 (rural)	7.6 (urban) 7.3 (rural)
HT Industrial	4866	5800	100 ,000	600 ,000	6
HT Commercial	4777	3900	68 ,000	540 ,000	8

[#]- Not always metered, and hence presumptive
*- Subsidized by Government of Karnataka
MU = Million Units (kWh)
Data source: Estimated consumption and tariff levels from 2012-13 Tariff order, and number of consumers from 2013-14 Tariff order

Table 1 demonstrates that both urban and rural residential consumers (as aggregate categories) are cross-subsidized by the larger (bulk) consumers. The poorest of poor consumers are completely subsidized by the state. The agricultural consumers have an interesting arrangement: although the state does pay the commission-determined tariff of Rs. 1.3/kWh on their behalf, this tariff is, even without specific calculations, noticeably lower than the cost of supply. The remaining costs are once again recovered through the cross-subsidies from the larger consumers.

To be clear, the tariff-based transfers studied in this paper are based on the differential tariffs between the rural and urban residential consumers only. We do not model transfers both within and across categories of consumers.

2.5. Load shedding

Electricity outages come in different forms – scheduled and unscheduled outages due to supply shortfalls, unanticipated faults, and burnouts. While the scheduled supply availability targets (or conversely, the scheduled load shedding arrangement) are decided in advance, the methods and often even the precise timing of the outages are not always transparent. Unscheduled outages are any that occur above and beyond the schedule, and are done if there is a deficit between available supply and the restricted (curtailed) demand. The smallest area that can be load shed is that served by a single 11kV feeder. In addition to load shedding, the first level of load management is rostered supply to agriculture, by switching off 1 or 2 phases out of 3 phases. This leaves supply to rural homes and other smaller users (3 phase supply is meant for loads typically over 5 kW).

Maharashtra has a systematic load shedding arrangement. Feeders are classified into different categories based on losses and collection efficiency. The list of feeders in each category is updated every month, but this list is not explicitly declared. The load shedding arrangement is managed by the state load dispatch centre (SLDC), essentially working backwards from the worst feeders upwards until the supply and demand are balanced. While systematic, this raises concerns of fairness since all the consumers on a feeder are treated equally. Of course, the same problem remains for all load-shedding.

Load shedding in Karnataka is not as transparent. In the event of a deficit, the Karnataka SLDC rations the load to be shed among the five ESCOMs based on extent to which they are overdrawing compared to the allotted supply for that hour. Within the ESCOM's, the load shedding appears to be rationed among the 220 kV substations. Beyond that stage, there does not seem to be a consistent process in place. The actual load shed amounts are not published in Karnataka or most states.

The load duration curve for Karnataka (not just BESCOM, which is almost half the state load) for one year (spanning May 2012- April 2013) is shown in Figure 1. Load duration curves show the fraction of hours in the year corresponding to a given load level or higher. Considering the restricted supply, we distinguish between the estimated "unrestricted" demand (given the present tariff structure) and the loads served. Note this gap is only based on the published load-shedding (both scheduled and unscheduled), and is the top-down official figure for the deficit. The ground reality of outages may differ as our data finds. The peak deficit estimates mentioned previously are normally computed as the difference between peak demand and peak load served.[5] More et al (2007) argue that given the uncertainties in estimating load shedding, a more reasonable estimate could be derived from the load duration curves corresponding to demand and load at 15% of the year level. Based on this method, the peak deficit is computed to be 744 MW (or 9 %), which is more conservative compared to the official peak deficit estimates of 1295 MW (or 13%).

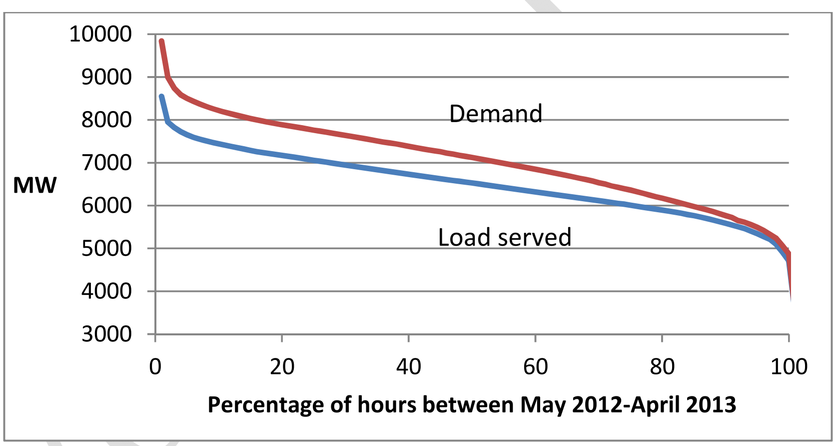

Figure 1: Load duration curve for May 2012- April 2013 for Karnataka. Compiled using state load profiles from KPTCL website

While making an allowance for the imperfect demand estimates, it is worth considering the hourly demands and loads as well. The load duration curves are a little misleading as they may suggest a time coincidence along the vertical. On the contrary, for the same level of demand, the load shedding varies by time of day, month, and season. Similarly, peak deficit estimates present a partial picture, as shown by Table 2 that compares hourly deficits (also computed by the KPTCL, the TransCo) with the official peak deficit estimate for the year.

[5] Karnataka is able to compute such a difference in near real-time due to its SCADA system. For national figures, the deficit is based on the gap at 7 PM, the notional peak.

The deficit percentage was higher than "peak" about 12% of the time! Besides raising questions about the metrics used in reporting reliability, this also has implications on electricity planning and energy dispatch.

Table 2: Hourly deficits compared to peak deficit estimates and the timing of these instances for May '12- April '13 (Analysis based on state daily load profiles from KPTCL website)

		No load shedding	Hourly deficit % is greater than "peak deficit" of 13%	Hourly deficit is greater than "peak deficit" of 1300 MW
Number of hours in the year* (% of total)		2720 (31%)	1012 (12%)	468 (5%)
Time of day	6am-6pm	1%	19%	8%
	6- 9pm	4%	11%	8%
	9pm- 6am	80%	2%	0%
Months	August-September	25%	31%	16%
	March-April	30%	14%	7%
	Rest of the year	33%	6%	2%

* Out of 8688 hours (363 days) – data for two days were missing on the KPTCL website

3. Analysis Methods

3.1. Framing the problem

Table 1 and the subsequent discussion highlight the many kinds of subsidy transfers among BESCOM's consumers. This paper will restrict the analysis to rural and urban residential consumers. The industrial and commercial consumers not only pay much higher tariffs, they also form a very distinct group compared to the residential users in terms of the nature and times of electricity use and its economic value. Given the data constraints, much of the analysis is restricted to the consumer groups at the aggregate level. We do, however, distinguish between Bangalore urban (or metropolitan) and non-Bangalore urban (or small town) residential consumers, although there are no longer differential tariffs between these two groups.

The focus of the paper is residential consumers across geographies between the peak periods of 6-10 PM for several reasons. First, this is defined as the peak period, and the regulator asks utilities to supply power for 11 hours out of the 12 hour period from 6 PM to 6 AM to homes (when lighting is important). Second, utilities are not required (and rarely) supply power to agriculture (via 3-

phase power) during this peak period. Third, this is truly the peak demand period for rural homes, and from a citizen perspective, load-shedding is the most disruptive due to the implications on lighting. While the majority of residential consumption in rural areas is likely to be in this period (due not only to lighting needs but also because people are likely to be out of the house in the day), there is load-shedding during other periods which, if calculated, would increase the inequity between rural and urban (rather, metropolitan urban) areas.

The hypothesis in this analysis is that because the rural consumers are load shed "more than they ought to be", at a time of day the utility's cost of procuring additional power from generators is more expensive than on average, they provide a net "relief" to the utility in terms of their procurement costs. While procurement costs ultimately pass through to consumers, increased load-shedding decreases the average cost, but the benefits accrue disproportionately to those who receive the power, i.e., urban (rather, metro) consumers. Those who are subject to increased load-shedding are getting more of an interruptible supply, without the commensurate tariff discount for the same. We also explore the flip side, how much more reliable supply the urban consumers are entitled to because of the higher tariffs that they pay.

There are two aspects to the problem – the tariff-based transfer and the load shedding based transfer. The tariff-based transfer will be related to the difference between the average actual tariffs and "uniform" tariffs, defined in some manner. The load shedding based transfer will be related to the difference between "equitable" and actual levels of load shedding. There are several ways one could define these "uniform" tariffs and "equitable" levels of load shedding.

3.2. Tariffs and Tariff Subsidies

As shown in Table 1, the urban tariffs are slightly higher than rural tariffs for all the consumption slabs. Typically, the average costs of supply are higher in the rural areas than urban. On a per consumer basis, the fixed costs of setting up the infrastructure will very likely be higher in the rural areas, especially as the villages get more remote and sparse; but as already discussed, there is no differentiation made between actual costs to serve consumers during the utility's calculation of fixed charges. The difference in fixed charges (the rural rebate) was instituted to reflect the poorer quality in rural areas. The technical losses may be higher in rural areas because of the longer feeder lines required (again, normalized per consumer or per unit delivered)[6]. Similarly, with not all consumers metered, commercial losses may be higher. This is especially the concern with agricultural consumers as described in the background section. Assuming that the technical losses are higher, the "uniform" tariffs must be such that rural consumers pay slightly more than the urban consumers should, reflecting the slightly higher costs of supplying each kWh to the consumer. The calculations are based on BESCOM's filings (called D-21) to the KERC while proposing tariffs.

To estimate the tariff-based transfers, we consider the loads served in the urban and rural residential feeders, and remove the fraction of loads from non-residential sources. For the urban feeders, these are principally the commercial consumers. For the rural feeders, non-residential consumption with single-phase supply includes irrigation pump-sets running on phase converters and poorest of poor consumers who receive subsidized supply. Commercial sales from rural areas are small enough to be neglected for the analysis. Using the National Sample Survey (NSS) data, we can estimate the fraction of rural and urban consumers fall in different slabs. This is used to calculate the weighted average actual and "uniform" tariff for each of the feeder types. For the purposes of this analysis, only the energy (kWh) charges are considered. These can be used to obtain the normalized tariff-based transfers on a Rs./consumer-day basis as shown in Equation 1.

$$Tariff\ transfers = \frac{Load_{served}\left(tariff_{uniform}^{avg} - tariff_{actual}^{avg}\right)(1 - loss_{dist}) \prod (1 - frac_{non-residential})}{Number\ of\ consumers\ in\ the\ category}$$

[6] The higher distribution losses and the subsequent higher marginal costs of supply merit additional discussion. The technical (or I^2R = current squared times resistance) losses depend on the power consumption in these feeders, which in turn depends on time of day. When irrigation pump-sets are used, the average power consumption in rural feeders is very similar to that in the urban feeders around the same time (2-3 MW). In the evenings, with single-phase supply, the predominantly domestic consumption in the rural feeders is about a third of that in the urban feeders, and hence, for equivalent technical losses, the feeder lines could be a factor of 3 longer. It appears that the conventional wisdom of higher technical losses in rural areas might be true on average, but during the evening peak, when supply is meant for households and not pump-sets, this may not be the case.

- Eq.1

To estimate the load shedding based transfers, we need to compare the actual load shedding levels with an equitable level. The most straightforward choice of such an equitable level is one where all feeders get load shed to the same extent, say, by cutting supply for the same fraction of time. The relief could then be estimated based on the avoided unrecovered costs. However, the transfers obtained from this calculation do not have a very intuitive interpretation, and furthermore, don't sum to zero because the costs of supply and the marginal tariffs differ across consumer categories. One could also make equitable based on kWh, or fraction of kWh, but each would lead to a different result, with systematic biases. To be less regressive, we use an alternative method wherein we estimate the unrecovered costs of power supply if the rural and non-Bangalore urban residential consumers (the "contributors") are load shed at the Bangalore urban level (the "beneficiaries").

3.3. Load-shed welfare transfers (or subsidies)

To estimate these load shed transfers, we use weighted average marginal tariffs, calculated in a manner similar to the weighted average tariffs – using NSS data on household consumption. To avoid double counting we use the greater among the uniform and actual tariffs to compute the avoided unrecovered costs. Only residential loads and demands are considered, by deflating for the fraction of non-residential loads. When normalized by the number of consumers in the rural and non-Bangalore urban categories, we have the load shedding transfers in Rs./ consumer-day. The load shedding transfer *to* the Bangalore urban consumers is calculated by normalizing the sum of rural and non-Bangalore urban load shedding transfers by the number of Bangalore urban residential consumers.

For rural and non-Bangalore urban consumers:

$$Load\ shed\ transfers = \frac{(Load_{at\ BU\ level} - Load_{served})(1 - loss_{dist})\left\{Cost_{peak}^{supply} - tariff_{marg}\right)frac_{residential}}{Number\ of\ consumers}$$

-Eq.2

For rural consumers, the unsubsidized $tariff_{marg}$ should be used (to avoid double counting), and for non-Bangalore urban, the actual marginal tariffs are used. For Bangalore urban consumers,

$$Load\ shed\ transfers\ to\ BU\ consumers = \frac{Load\ shed\ transfers_{R}^{agg} + Load\ shed\ transfers_{NBU}^{agg}}{Number\ of\ BU\ consumers}$$

- Eq.3

Instead of this juxtaposition of tariff and load shed based transfers, other approaches could be considered too. One option is to consider the economic value of electricity in different parts of the grid. If load shedding is inevitable, it should be done in such a way that the economic loss is minimized. Alternatively, if different consumers have different interruption costs, load shedding should be done such that the aggregate interruption costs are minimized. The difficulty with either way of framing the problem is that there are likely to be significant income effects—consumers with higher incomes will have higher interruption costs—or there is a strong causal link between the reliability and economic output. One reason for the poor development of industry in rural areas is the poor infrastructure, including electricity access and reliability. Hence, arguing for a preferential treatment towards the urban areas due to the higher economic output becomes circular.

3.4. Data

Karnataka is the only state in the country that has implemented Supervisory Control and Data Acquisition (SCADA) systems for all the substations. The SCADA allows for real time centralized monitoring of the power supply and consumption in all the 11kV feeders at the substation level. Very briefly, the state transmission infrastructure consists of 66kV or 110kV lines (and a few few higher voltage ones) that are stepped down to 11kV by the substation transformers. The 11kV feeders, which can be kilometers long, dubbed medium voltage, are then stepped down to the Low Voltage level where the power can be used by regular appliances (at the notional 220 V supply for single phase, or 400V for 3-phase). While faults can occur at the low-voltage level, all the load shedding decisions are implemented for entire 11kV feeders. The SCADA dataset provides information on the supply and the consumption on a minute-by-minute basis. Hence, we can calculate the demand and the load shed at a very granular level, for the first time in India.

The dataset used in this study has been obtained from Karnataka Power Transmission Corporation Ltd. (KPTCL) for some or all of BESCOM region for the dates listed in Table 3. The dates were chosen by KPTCL as representative of the three seasons. As KPTCL is responsible for transmission and not distribution, we do not believe there to be any biases. Later, we use other estimates on loads served and shed at the state level, to weight the results from each of these nine days based on how representative they are.

Table 3: Dates and feeder types of SCADA data obtained from KPTCL[7]

Zone	Dates	Number of feeders
Chitradurga Tumkur	Sep 25-27, 2012 Dec 25-27, 2012 Apr 13-15, 2013	Rural feeders: 600-637 Urban feeders: 46
Bangalore Rural	Sep 25 and 26, 2012 Dec 26, 2012 April 15, 2013	Rural feeders: 405-481 Urban feeders: 49-54
Bangalore urban	Sep 25 and 26, 2012 Dec 26, 2012 April 15, 2013 (NRS Substation- all 9 days)	Rural feeders: 82-92 Urban feeders: 955-966

Besides rural and urban feeders (that is, those which primarily serve residential consumers), the dataset includes commercial, industrial, waterworks and auxiliary feeders. High Voltage industrial and commercial consumers are not part of this dataset. BESCOM's feeder list was used to classify the feeders in the dataset into their types[8]. We do not have the consumer make-up of each of these feeders, and hence restrict ourselves to the aggregate feeder analysis. Both the rural and urban feeders likely include commercial consumers. While the commercial consumption in rural areas is low enough to be neglected (about 100 million kWh in 2012-13), the urban commercial consumption is high (about 1800

[7] Mixed urban and rural feeders were classified as one or the other based on BESCOM naming and other criteria.

[8] If the feeders in the dataset were not part of the list, they were manually classified into one of the types using the following criteria: 1) based on keywords within the feeder names like "town", "waterworks", etc. and 2) based on whether periods of single-phase and three phase supply were provided, this happens only for rural feeders

million kWh). We do not know how much of this is through the commercial feeders alone and how much through the regular feeders.

Examples of a rural and an urban feeder from the SCADA dataset have been provided in Figures 2 and 3. The figures show the loads served in these feeders as a function of time of day. The rural supply consists of times of single (in red) and three (in green) phase supply, as already discussed. Three phase supply is typically limited to 4-6 hours at not necessarily specified times during the day. Evening supply is usually restricted to single-phase[9]. The blank spaces within the figures correspond to times of no supply. Very short gaps (few minutes) are likely to be faults and not load-shedding, which is typically in hourly batches, but sometimes half hour.

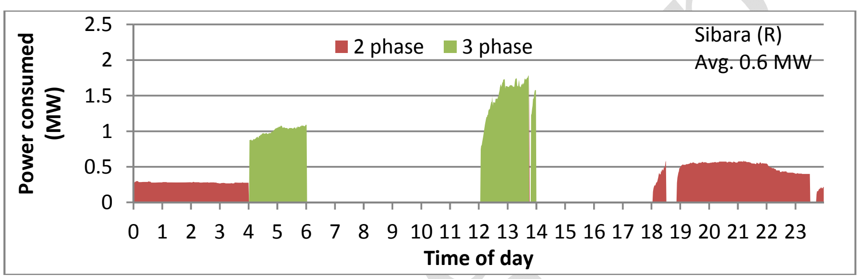

Figure 2: Loads with single and three phase supply for an example rural feeder in Chitradurga substation from September 26 2012

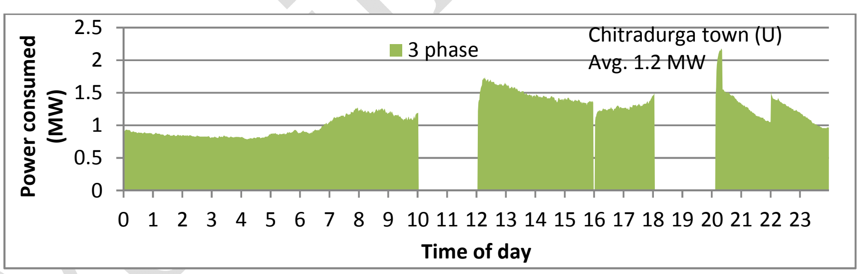

Figure 3: Loads with single and three phase supply for an example urban feeder in Chitradurga substation from September 26 2012[10]

The distribution of hours of supply availability for three days from each of rural (R), non-Bangalore urban (NBU) and Bangalore urban (BU) zones are shown in Table 4. From this table and Table 5, the motivation for this study is clear. The rural areas received significantly poorer supply than Bangalore urban;

[9] More correctly, evening supply to the feeder could be one phase, or two phases (for load balancing purposes) with an individual consumer receiving only one phase. Hence, this is still termed as single-phase.

[10] It is interesting to note the temporary spike in demand after the evening load-shed, representing latent deferrable demand. While some load is lighting (use it or lose it), other loads like heating/cooling or even charging back-up power batteries, cause spikes and represent additional sources of grid inefficiency.

and among the urban feeders, non-Bangalore consumers receive worse supply. Rather surprisingly, the non-Bangalore urban consumers receive supply that is not significantly different from the rural feeders in the evenings.

Table 4: Summary statistics on supply in the three types of feeders

	26 September '12		26 December '12		15 April '13	
	Mean (St.Dev.)	Median	Mean (St.Dev.)	Median	Mean (St.Dev.)	Median
Rural						
24 hours	10.9 (3.9)	11.2	13.2 (3.9)	12.0	13.6 (4.3)	13.8
Three-phase all day	5.3 (3.8)	4.4	5.0 (4.0)	4.0	7.3 (5.5)	5.6
6pm-10pm	2.3 (1.1)	2.4	3.7 (0.7)	4.0	3.2 (1.1)	3.6
Non-Bangalore urban						
24 hours	15.8 (3.7)	15.8	20.8 (3.1)	21.0	19.3 (6.3)	21.9
6pm-10pm	2.6 (0.9)	2.4	3.7 (0.7)	3.9	3.2 (1.2)	3.7
Bangalore urban						
24 hours	22.3 (3.8)	23.9	22.6 (3.5)	24.0	22.1 (1.2)	3.7
6pm-10pm	3.8 (0.7)	4.0	3.8 (0.6)	4.0	3.4 (1.0)	4.0

Table 5: Results of two sample t-tests (with unknown variance) for evening supply in the three categories of feeders- absolute value of t statistics with null hypothesis as equal means (- p<0.01, *- p<0.05)**

	Sep 26 '12	**Dec 26 '12**	**Apr 15 '13**
Rural and Non-Bangalore Urban	2.9**	0.4	0.5
Rural and Bangalore Urban	38.3**	4.5**	4.1**
Non-Bangalore and Bangalore Urban	15.7**	2.6*	1.4

With rural areas, one factor affecting the availability statistics is the restricted hours of three-phase supply in the mornings. One difficulty with discussing load shedding for pump-set use is that the schedule itself is not hour-specific. The utility targets a certain number of hours spread over the day. Hence, the load shedding estimates are also not hour specific. Given the research questions in this study, the analysis is restricted to evening hours alone and all demand and load shedding estimates in rural areas are restricted to consumption with single-phase alone, in order to avoid pump-set consumption.

3.5. Research questions

How does the load shedding compare?

The first piece of the analysis is to prepare a thorough set of estimates for the load shedding. Within the bounds of our problem framing (chiefly, non-commercial feeders, evening demand, non-agricultural rural consumption), we estimate the absolute and percentage load shedding in each of the feeders. The first set of comparisons in our analysis will be based on the load shedding levels.

Load shedding estimates are made by interpolating across times with no supply. The interpolations are made within 15 minute blocks for each feeder, if possible. If there was no supply over a given 15 minute block, the average demand (in MW) between 6-10PM for a given month is used to interpolate. To avoid three-phase pump-set usage, we use a multiplier if the supply provided in the feeders is of three-phase. The multipliers are feeder and season specific if there is any information available for loads served with single and three phase supply in the evenings. Otherwise, representative multipliers are used. On average, single-phase consumption was 20-30% of the consumption with three-phase. In other words, the three- phase specific loads, primarily due to pump-sets, were 3-4 times that of the single-phase loads.

Is the tariff subsidy an adequate explanation for the load shedding disparity?

The next question is about the equity in such a load shedding arrangement. We compare tariff-based transfers with load shedding transfers, from or to each of the three residential categories (R, NBU, BU). The directions of the net transfers are of primary interest. The magnitudes of the net transfers could have additional policy implications in terms of tariff setting, and in assessing the economic argument for solutions to reduce such an inequity in load shedding.

Using the uniform tariffs, the tariff-based transfers are computed for each of the consumer categories for the evenings of the nine days. Similarly, based on the load shedding estimates and benchmarking to the Bangalore-urban load shedding level, the load shedding based transfers are estimated for the nine days.

The net transfers are just the sum of these two, and are computed for the three consumer categories for the nine days. We then use KPTCL estimates for demand and load shedding for the months May 2012- April 2013 to determine how representative each of these nine days is and use the resulting multipliers to make annual estimates via extrapolations.

How viable are the solutions?

Finally, we explore the alternatives available to reduce load shedding. There are two straightforward interventions: uniform percentage load shedding for all feeders, and additional procurement of peak power (through short term purchases, for instance) to avoid load shedding entirely. Several intermediate approaches exist in the continuum between these two extremes.

One way of facilitating such an intermediate approach is providing current limited supply as opposed to outright blackouts. Using certain kinds of smart meters, the utility could restrict the current drawn and hence, restrict the usage by the consumer. The smart meters would hence allow for uninterrupted (but occasionally limited) supply, which would remove the need for backup energy or battery storage. The installed costs are higher than for conventional static meters, but if stakeholders besides the end-users these pick up these costs, the cumulative willingness to pay for it may make it a viable option. The stakeholders include consumer categories that benefit from the load shedding arrangement (making the quantities of the net transfers relevant), and the central government's Ministry of Petroleum and Natural Gas (that subsidizes kerosene used for back-up lighting)..

3.6. Analysis Limitations

The analysis is in aggregate for entire consumer categories, and hence multiple points of heterogeneity at the feeder level are ignored. For instance, among both rural and urban feeders, some feeders will likely be load shed much more than others systematically. We are unable to differentiate between these due to the limited number of days of data. We also do not have the consumer mix at the feeder level. With the consumer data, we could have investigated whether feeders with consumers with low demand levels were load shed more (the utility maximizing revenues) or less (the utility minimizing number of consumers impacted) than those with high demand consumers.

On a related note, this analysis creates a dichotomy between urban and rural consumers. At the aggregate level, and even in terms of BESCOM's load shedding schedules that make a similar distinction, these are reasonable. However, it is likely that there is a continuum and that there will be pockets in urban areas (possibly, low income) that are load shed much more than others, and pockets in rural areas (with administrative capitals of local governments or with powerful local commercial/industrial or political lobbies) that receive better supply.

When we monetize the transfers, non-residential loads are ignored because of the framing of the problem in this analysis. However, the supply to commercial or agricultural consumers will certainly impact the utility's finances, and this dimension is not included. This limitation is mitigated by the focus only on the 6-10 PM period.

While we do attempt to understand the representativeness of the nine days of data, the discrepancies in the load shedding numbers demonstrate the difficulty in this exercise. To some extent, the direction of net transfers is of principal interest and the robustness of our results along that dimension can be verified more easily than the magnitudes themselves. It also becomes self-explanatory that the greater the load-shedding, the greater the inequity can be.

Another concern is about the representative of the BESCOM region itself. It is possible that the load shedding patterns will be very different in regions lacking a large metropolitan city like Bangalore. To help answer this question, we investigate supply availability for another part of Karnataka served by the Hubli ESCOM, with somewhat more limited data. The results are expounded in Appendix 1, but the differentiation remains between cities (now much smaller) and rural areas.

Finally, while computing the load shed transfers, we are implicitly assuming that there is power supply that is available which must only be procured at a certain higher than average cost. This is not always true.

4. Results

4.1. Load shedding estimates

Based on the steps outlined already in Section 3, the load shedding estimates for the three categories of feeders are summarized in Table 6. Briefly, the true demand is estimated using interpolations within 15-minute blocks between 6-10 pm. In the rural feeders, the demand is restricted to what it would be with single-phase supply, after removing (most of) the agricultural load. The estimates are in terms of energy consumption (in MWh).

Table 6 Estimated aggregate demand and load shed in rural, small town and metro feeders from the 9 days

		25 Sep '12	26 Sep '12	27 Sep '12	25 Dec '12	26 Dec '12	27 Dec '12	14 Apr '13	15 Apr '13	16 Apr '13
Karnataka (full-state) evening load shed % (KPTCL estimate)		16%	18%	17%	6%	7%	9%	5%	5%	5%
Rural	Demand (MWh)	3500	3600	2900	3200	3200	3300	2200	2000	2100
	Load shed (MWh)	1640	1540	1090	240	270	270	290	440	390
	Load shed %	46%	42%	38%	7%	8%	8%	13%	21%	18%
Non-Bangalore urban	Demand (MWh)	900	900	900	800	800	800	700	800	800
	Load shed (MWh)	340	330	190	60	100	90	120	160	150
	Load shed %	38%	36%	21%	8%	13%	11%	16%	21%	19%
Bangalore urban	Demand (MWh)	4300	4400	4200	3700	3700	3700	4000	4200	4300
	Load shed (MWh)	200	200	110	30	60	50	390	550	510
	Load shed %	5%	5%	3%	1%	1%	1%	10%	13%	12%
Estimated average BESCOM Load Shed % (rural and urban 11kV feeders only)		25%	23%	17%	4%	6%	5%	11%	16%	14%

In general, rural feeders face a higher percentage of load shedding than the urban feeders. Non-Bangalore urban feeders, however, are significantly worse off than Bangalore urban, and surprisingly, can be load shed more than even rural feeders in the evenings. Also worth noting is how the absolute load shed amounts from the rural feeders exceeded that from Bangalore urban on six of the nine days. When we factor in the fact that the number of residential consumers in rural areas is far lower than in urban (especially Bangalore Urban) areas, this is a surprising result. In terms of load shed per consumer (in kWh), the rural areas are higher on all 9 days.

The differences day to day (weekdays) are low, while seasonal variations are much higher. This is partly due to not just seasonal demand, but also seasonal supply variations. Importantly, April 2013 was just before an election, and it's possible that there was a political directive to reduce the load shedding in rural areas, and hence the higher load shed from Bangalore.

Interestingly, the estimates do not seem to be highly correlated (correlation coefficient of about 0.68) with the reported total state-level load shedding in the evening of the nine days. A clear one-to-one correlation is not necessary because the load shedding in BESCOM depends on whether it was over-drawing or under-drawing relative to its allocated shares of the state supply. Also, the entire demand for the state includes high voltage (especially industrial) feeders, which are not part of the data set. It is unknown how these are shed vis-à-vis residential feeders.

4.2. Fair tariffs

The first objective for this analysis is to estimate the uniform or fair tariff structure. Assuming, for now, that the technical losses are higher, the uniform tariff structure (and hence, the tariff-based transfers) can be derived using the following steps. First, we assume that the rural consumers are charged identically to their urban counterparts. This would imply higher revenues to the utility and hence, the next step would be to deflate the tariffs to ensure that the aggregate revenues to BESCOM remain unaffected. We ensure that the aggregate revenues from each of the fixed and the variable components remain unaffected. Next, we account for the higher marginal costs of supply in rural areas due to the higher *technical* losses using a cost-plus approach. Hence, the "uniform" tariffs obtained in this manner will be such that the urban consumers actually pay lower than their rural counterparts do in any given consumption slab (tier). This is the only difference needed between rural and urban consumers since our calculations for load shedding will be at the margin (during the evening peak), and higher fixed costs of rural supply are treated as sunk costs.

Table 7 outlines the steps and the results of the calculation. KERC approved tariffs for 2012-13 are used along with slab-wise consumption data from the following year (2013-14) from BESCOM's tariff order filing to KERC (BESCOM's D21 filing in 2013 to KERC).

Table 7 Calculating 'uniform' tariffs

		Tariffs charged 2012-13		Step 1: If rural consumers paid urban tariffs	Step 2: Keeping aggregate fixed and variable charge revenues unchanged*		Step 3: Adjusting for higher marginal costs of supply in rural feeders (but keeping aggregate variable) **	
		Rural	Urban	Rural	Rural	Urban	Rural	Urban
Fixed charges	1st kW	15	25	25	23	23	23	23
	Additional kW	25	35	35	33	33	33	33
Energy charges	0-30	2.2	2.3	2.3	2.3	2.3	2.4	2.3
	30-100	3.2	3.5	3.5	3.5	3.5	3.6	3.4
	100-200	4.3	4.6	4.6	4.5	4.5	4.7	4.5
	>200	5.1	5.6	5.6	5.5	5.5	5.7	5.5
Average revenue per unit from fixed charges (Rs./kWh)		0.5	0.4	0.9	0.8	0.4	0.8	0.4
Average revenue per unit from variable charges (Rs./kWh)		3.0	3.8	3.2	3.2	3.7	3.4	3.7

Assumptions:
Data on consumptions within each slab are from the D21 filings by BESCOM for 2013
*- The deflating factor to keep the revenues unchanged is applied uniformly to all the slabs
** Inputs – Average cost of power purchase: Rs. 2.5/kWh, Transmission loss- 5%, Distribution loss- 10% (Urban), 15% (Rural)

The subsidies are computed as the difference between the actual tariffs and the fair tariffs. Based on this approach, the rural consumers are estimated to receive subsidies of Rs.0.3/kWh through fixed charges, and Rs.0.4/kWh through energy charges. In comparison, the urban consumers (no distinction made between metro and small town) provide negligible subsidies on fixed charges and less than Rs.0.1/kWh on energy charges per kWh. Factoring in the average household consumption in urban areas being more than a factor of 4 than in rural areas, the average rural consumer receives a subsidy of about Rs.18/month, and the average urban consumer provides a subsidy of about Rs.7/month based on tariffs. (These net to zero because there are about 2.5 times more urban consumers than rural)

4.3. Net transfers- tariff and load shedding based

Our estimates of both kinds of transfers are summarized in Table 8. For all nine days, non-Bangalore urban consumers are net contributors, and Bangalore urban consumers are net beneficiaries. For the rural consumers, the direction of the net transfer depends on the load shedding level – as the outages become worse, the load shedding transfers increasingly dominate the tariff-based transfers.

Table 8 Tariff and load shedding based transfers (Negative sign indicates that the transfer is to the category, and positive sign implies the transfer is from the category. Color coding of green indicates the net transfer is from the category, and red that the net transfer is to the category.)

	25 Sep ‘12	26 Sep ‘12	27 Sep ‘12	25 Dec ‘12	26 Dec ‘12	27 Dec ‘12	14 Apr ‘13	15 Apr ‘13	16 Apr ‘13
Rural									
Subsidies on variable charges (Rs./day/consumer)	-0.3	-0.3	-0.2	-0.4	-0.4	-0.4	-0.3	-0.2	-0.2
Subsidies due to avoided costs (Rs./day/consumer)	3.8	3.5	2.6	0.5	0.6	0.6	0.2	0.4	0.4
Non-Bangalore urban									
Subsidies on variable charges (Rs./day/consumer)	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05
Subsidies due to avoided costs (Rs./day/consumer)	2.30	2.23	1.23	0.43	0.72	0.59	0.33	0.47	0.43
Bangalore urban									
Subsidies on variable charges (Rs./day/consumer)	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.05
Subsidies due to avoided costs (Rs./day/consumer)	-2.06	-1.93	-1.37	-0.31	-0.37	-0.36	-0.13	-0.27	-0.23

These results will be sensitive to some of the inputs and assumptions, and we will elaborate in the next section, along with sensitivity analysis.[11]

[11] One of the sensitive assumptions could be the fraction of single-phase load that is due to irrigation pump-sets using phase converters. Triangulating from the aggregate rural load served, we find that if pump-sets on phase converters account for 10% of the rural load between 6-10PM the average residential consumption is in the range of 23-35kWh/month (assuming 80% of the rural residential demand is in the evenings and 15% incremental technical distribution loss); if the pump-set use is about 20%, this number goes down to 18-26kWh/month. As the tariff order pegs this number at 28kWh/month, it would seem that the non-residential rural single-phase

KPTCL publishes its estimates on the aggregate state level load served and scheduled and unscheduled load shed. These are available online as daily datasets, which were extracted and compiled for the year spanning May 2012-April 2013. Figures 4 and 5 summarize KPTCL's estimates of demand and load shedding. The 9 days from our data set have been highlighted in the two graphs. The last week of September 2012 seems to have been atypical[12] in terms of load shedding, but the December and April data seem to be broadly representative.

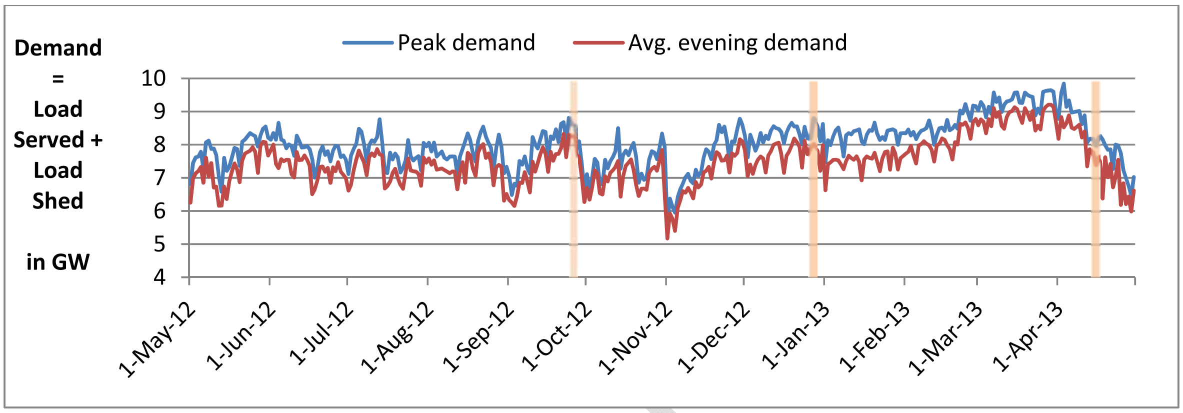

Figure 4: Variation of Karnataka state demand over the course of the year (Evening defined as 6-10PM)

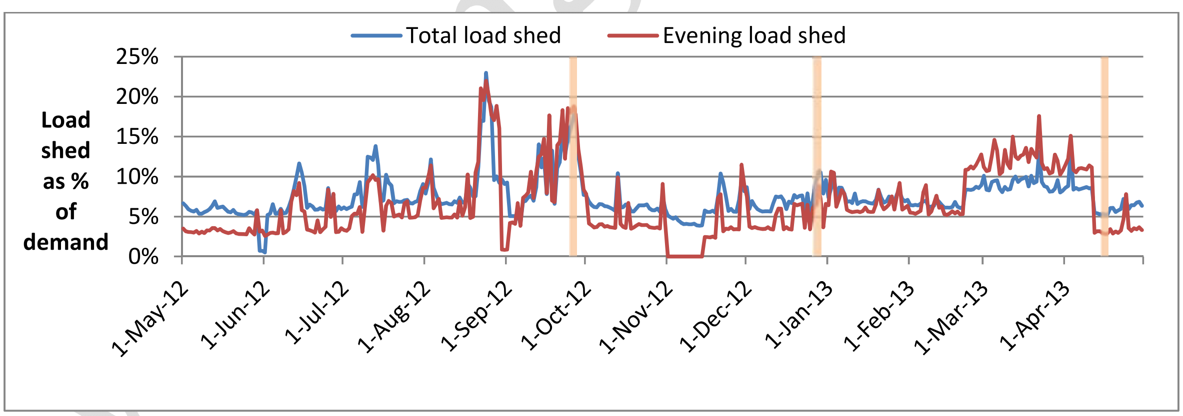

Figure 5: Variation in load shedding over the course of the year (Evening defined as 6-10PM)

In order to weight our estimates, each of the 365 days are classified into one of the 9 day-types, based on which of these 9 days is the most similar in

load, which is likely to be mostly pump-sets, is likely to be within 20% of the overall rural single-phase load.

[12] Newspaper reports from the last week of September 2012 cite multiple reasons for the power shortages including coal shortages, maintenance shutdowns of the Raichur thermal power plant, and unanticipated low wind power generation (Indian Express, Sep 27 2012; Deccan Herald Sep 29 2012; Times of India Sep 30 2012)

terms of factors that could affect the load shedding schedule. The aggregate load shedding levels are likely to be highly correlated with the overall levels of load shedding in the BESCOM area, as well as the skew towards R and NBU feeders. Also, we may want to distinguish between scheduled and unscheduled load shedding (although we have been unable from doing so in the analysis of the SCADA dataset). Another factor that could affect the load shedding pattern is the evening or peak demand. The classification method should be able to combine multiple factors. We use a method wherein the day that has the smallest normalized squared distance in the n-dimensional space is found. That is, if the classification criteria belong to the set C, for each day i in the year, we find the day j from our dataset that minimizes

$$\sum_{c\in C}\frac{(x_{i,c}-x_{j,c})^2}{(x_{i,c}-X_c)^2}$$

where, X_C is the mean of $x_{j,C}$.

The results will depend on the classification criteria used. Table 9 summarizes the results from this classification procedure.

Table 9: Results of the classification process

	Number of similar days								
Classification criteria	25 Sep ‘12	26 Sep ‘12	27 Sep ‘12	25 Dec ‘12	26 Dec ‘12	27 Dec ‘12	14 Apr ‘13	15 Apr ‘13	16 Apr ‘13
A. Unscheduled and scheduled load shed in the evening	4	10	14	134	41	24	36	21	78
B. Unscheduled and scheduled load shed, and demand in the evening	9	2	11	98	43	18	14	143	24
C. Unscheduled and scheduled load shed in 24 hours	36	3	5	140	61	73	30	11	3
D. Total load shed and demand in the evening	36	17	67	14	60	165	3	0	0

Based on multipliers derived from the results in Table 9, the annual load shedding and net transfers are provided in Tables 10 (normalized to consumer-year) and 11 (aggregate). These four criteria provide a range for likely annual reality, and we do not aim to average these numbers.

Table 10 Normalized estimates for load shed and net transfers (Rs./consumer-year)

Classification criteria	Annual load shed transfer			Annual net (load shed + tariff) transfer		
	R	NBU	BU	R	NBU	BU
A. Unscheduled and scheduled load shed in the evening	240	200	-140	120	220	-120
B. Unscheduled and scheduled load shed, and demand in the evening	230	200	-140	120	220	-120
C. Unscheduled and scheduled load shed in 24 hours	320	260	-190	190	280	-170
D. Total evening load shed and demand	510	350	-290	380	370	-270

Table 11 Aggregate estimates for load shed and net transfers in BESCOM (Rs. Crore*)

Classification criteria	Annual load shed transfer Aggregate			Annual net transfers Aggregate		
	R	NBU	BU	R	NBU	BU
A. Unscheduled and scheduled load shed in the evening	40	11	-51	20	12	-45
B. Unscheduled and scheduled load shed, and demand	38	11	-49	20	12	-44
C. Unscheduled and scheduled load shed in 24 hours	54	14	-68	32	15	-62
D. Total evening load shed and demand	85	19	-104	64	21	-98

(* 1 crore = 10 million)

Irrespective of the classification criteria used, rural consumers are consistently found to be net contributors to the system. Not surprisingly, the non-Bangalore urban consumers are net contributors too, and Bangalore urban net beneficiaries. Since there are positive transfers from the non-Bangalore urban consumers based on both tariffs and load shedding, the net transfers from them are higher than from the rural consumers. The magnitude of the net transfers will be sensitive to some of the inputs as shown in Figure 6. The results are reasonably consistent with distribution losses. As would be expected, the (avoided) procurement costs at peak demand are a sensitive input. The net transfers are positive from rural consumers, only if the peak procurement costs are greater than Rs.5/kWh (which are then subject to technical losses not only at the distribution level but also transmission level). The results are not sensitive to the distribution losses in rural areas.

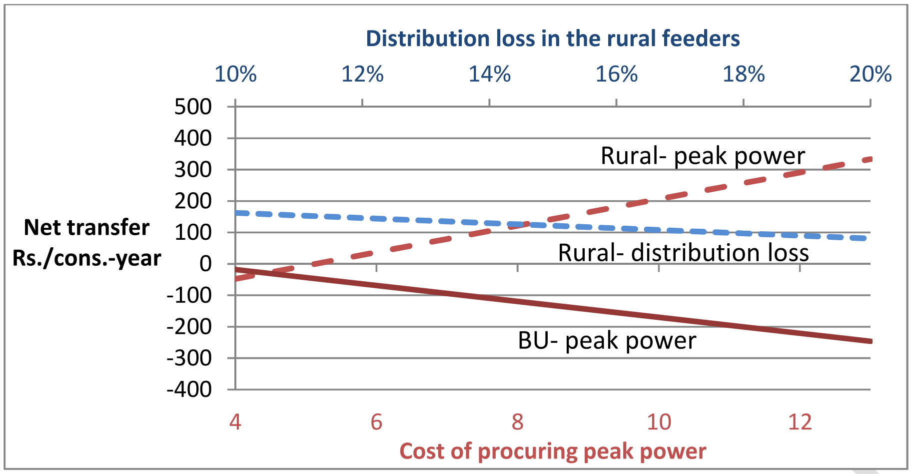

Figure 6: Sensitivity analysis of normalized net transfers (using scheduled and unscheduled load shedding, and demand in the evening). The base assumptions are 15% for rural losses and Rs. 8/kWh for cost of procuring additional (peak) power.

Using state peak deficits, total rural residential consumption, and the rural residential demand as a fraction of peak demand, we can make rough estimates of state level and national multipliers to extrapolate the transfers from BESCOM level. Appendix 2 elaborates on the assumptions and the estimates. Based on these methods, the national multipliers are found to be in the range of 30x- 50x. Using the results with classification criteria B in Table 11, the national load shed transfers from rural residential consumers are in the range Rs. 1,200-2,000 crores/year, and the net transfers are estimated to be between Rs. 600-1,000 crores/ year, or higher depending on assumptions and actual quantums of load-shedding.

How significant are these numbers? The annual expenditure on electricity for rural consumers in the BESCOM region is on average Rs. 1150. The total cross-subsidy that the rural consumers receive, now examining beyond the residential category, in comparison to the average cost of supply (as assumed by the KERC in the absence of better data) is about Rs. 450/ year. A load shed transfer of Rs. 240-510/ rural consumer-year is a non-trivial amount— on average, accounting for 20-44% of consumer electricity expenditure.

There is another equity concern among rural consumers that merits analysis. An extrapolation of an economic preference towards urban feeders would be a preference towards rural feeders serving relatively more affluent regions with higher consumption levels and better commercial operations. Conservatively, we could assume similar load shedding levels across incomes and compare net transfers as proportions of electricity expenditure. Appendix 3 discusses this in some more detail. On the lower end of our estimates, net transfers are of the order of 20% of electricity expenditure for the poorest deciles; and for the richest deciles, it is about 10%. In the higher range of our estimates, these go up to 60% and 30-40% respectively. These are partly because the tariff transfers between urban and rural consumers is greater in the higher consumption slabs, and partly because electricity expenditures increase with income. Hence, not only is the load shedding arrangement inequitable to the rural consumers, the poorest households are most vulnerable.

Note that these transfers do not include the inconvenience costs due to outages and the costs of very inefficient backup lighting (through kerosene lamps typically) for the consumer. We will take this up further in the next section when discussing the economics of alternatives and solutions.

4.4. One possible solution – Current limited supply

The analysis in the preceding sections demonstrates that the supply in the rural feeders is not only poorer than in the city feeders, but is inequitable even within a restricted economic profitability sense. The question then is about how the supply could be improved, while keeping the utility's finances in mind. This section is written with a focus on rural feeders. However, as we have seen, the non-Bangalore urban feeders perhaps have a stronger case in their favor for better supply. It is expected that any policy approaches that are viable for rural feeders will be even more applicable in the non-Bangalore urban feeders.

Two extreme approaches that are available are to load shed all feeders uniformly or to eliminate load shedding altogether by procuring additional power. There is, of course, a continuum between these. For instance, the load shedding could be lower and predictable. Instead of days with 2-3 hour outages during the evening followed by days with close to uninterrupted supply, schedules that are consistent through the week, well-advertised, and at predictable times, would be preferable. Here, we explore the economics of the relatively novel notion of current limited supply as opposed to outright blackouts.

That is, provided uninterrupted supply but with occasional restrictions on power (that is, in kW) consumption. Replacing conventional single-phase meters with smart metering technology can facilitate this. Where new digital ("static") meters cost about Rs.800-1100, smart meters in the market today cost about Rs. 2,000-3,000, or slightly more depending on features, plus a little more for network equipment and the back-end. Hence, we would need to work out the viability of not only the incremental power procurement, but the installed costs of smart meters themselves. These costs have to be compared with the cumulative willingness or obligation to pay from the multiple stakeholders.

For the rural residential consumer, the willingness to pay will be a combination of two factors: avoided interruption costs and savings in expenditure on backup. Backups including kerosene lighting are not only more expensive per unit service delivered (say, on a light output-time in klm-h), but are also more expensive even per unit time used. Hence, there are net savings with even limited electricity supply. Kerosene lighting is the default choice for backups during outages, and the kerosene is subsidized by the central government. A reduction in kerosene consumption would be welcome to the central government too. Over the short term, this could represent a more effective channeling of subsidies for lighting fuel. Table 12 gives a sense of the costs of using electricity vis-à-vis conventional backup sources.

Table 12: Costs of lighting with and without electricity

	Cost of 1 hour of usage (Rs.)	Lamp output (lumens)	Cost per unit service delivered (Rs./klumen-h)
60 W incandescent - with grid power	0.18	720	0.25
15 W CFL - with grid power	0.05	750	0.06
Two Kerosene lamps	0.4 (+0.6 subsidy)	20-200#	2-20
Candle	5	10-15	330-500

#- Light output from kerosene lamps can vary within a large range depending on quality of lamps and factors like the wetness of the wick, and soot accumulation (Apte et al., 2007; Mills, 2003)

The interruption costs present a trickier problem for the following reasons. One, it is difficult to monetize the inconvenience to the consumers. Two, an abstractly defined interruption cost may not get translated into willingness to pay for the smart meter or other alternative. Three, there is the question of whether all these interruption costs should get reflected in the charges to the consumer, or whether there should be a smaller, more equitable amount.

The interruption costs are estimated as loss in consumer surplus using the approach developed in Harish et al. (2014). Briefly, the method involves estimating the monthly demand curve for an "average" rural household in the country, and makes a series of assumptions regarding the household's electricity usage patterns. The principal assumptions are that lighting is the only end use for which there is significant willingness to pay, that much of the value of the electricity is derived in a few hours of high demand, and that within these few hours there is a certain flexibility in rescheduling activities that require electricity (and more specifically, lighting) in the order of their priority. The interruption costs are derived from known willingness to pay based on price elasticity of electricity consumption and the amortized costs of solar lanterns and lighting systems. That this willingness to pay will get reflected in the smart meters is a non-trivial assumption.

How much of this willingness to pay for reliable electricity ought to get reflected as the consumer's share of the smart meter's installed costs? The load shedding that the consumer faces could be divided into two components – an equitable level up to which the consumer could be reasonably expected to pay, and an additional unfair amount for which the compensation must come from the beneficiaries of the current arrangement. The rural household's interruption costs for the load shedding level could be used as a benchmark for their willingness to pay for the smart meter. And the net transfer from this consumer could be recovered in some manner from the urban residential consumers.

With the help of smart meters, the utility could schedule current limited supply in multiple ways. The approach we consider is to keep the schedule identical to what it is currently, and procure incremental power to provide current limited supply instead of outright blackouts to the rural feeders in the evenings. The costs of procurement and supply will exceed the marginal tariffs from the rural residential consumers. Hence, this component will reduce the cumulative willingness to pay for the meters.

In sum, the cumulative willingness to pay for the meter is the sum of:

1. The net savings due to substitution of kerosene (backup) lighting and a portion of the avoided interruption costs for the rural households,
2. The subsidies provided by the central government for kerosene lighting (i.e. an alternative routing of existing support)
3. The net transfers (tariff and load shedding) from the rural residential consumers, recompensed by the utility perhaps through incrementally higher tariffs for the Bangalore urban consumers
4. Less the unrecovered costs of incremental power procurement for the utility

Table 13 provides a range of estimates for the annual willingness to pay for the meter through these stakeholders. The total discounted willingness to pay for the meters are also estimated, if these are spread over 10 years at a discount rate of 10%. This calculation assumes for simplification that the load shedding schedules will remain unchanged over time, as will the real costs of procurement.

Table 13: Economics of the current limiter

	Low	Likely	High
Assumptions/ inputs			
Annual evening load shedding %	14%	16%	19%
Number of kerosene lamps used	2	3	3
Fuel consumption (in liter/h)	0.01	0.01	0.02
Cost of peak power (Rs./kWh)	12	8	6
Kerosene consumed for backup lighting (l/ year)	4	7	17
(R. Cons.) Savings in kerosene expenditure (Rs./year)	80	140	330
(Central Govt.) Savings in kerosene subsidies (Rs./year)	120	210	500
(U. Cons.) Net transfers (Rs./year)	120	120	390
(R. Cons.) Avoided interruption costs (Rs./year)	290	340	420
Current limited load – 100 W			
(BESCOM (Less) Unrecovered costs (Rs./year)	220	150	110
(R. Cons.) (Less) Increase in electricity expenditure (Rs./year)	60	70	80
Cumulative stakeholder willingness to pay/ year (Rs.)	330	590	1450
Willingness to pay for the smart meter (Rs.)	2,000	3,600	8,900
Current limited load – 50 W			
(BESCOM) (Less) Unrecovered costs (Rs./year)	110	75	60
(R.Cons.) (Less) Increase in electricity expenditure (Rs./year)	30	35	40
Cumulative stakeholder willingness to pay/ year (Rs.)	470	700	1,500
Willingness to pay for the smart meter (Rs.)	2,900	4,300	9,500

Given that smart meters in the range of Rs. 4,000 (total system costs) are already available in the market, the analysis suggests that we are already in the ballpark in terms of viability. It is to be noted that some of the estimates used here are very conservative. The kerosene consumption estimated bottom up here is in the range of 4 to 17 l/ year, while the subsidized amounts usually (based on NSS 2011-12) purchased is in the range of 24 to 36 l/year (10^{th} and 90^{th} percentiles). Also, this analysis is being done based on *average* levels of load shedding. A solution like current limited supply, implemented at the consumer level, is probably ideal for feeders that receive particularly poor supply. Here, the kerosene expenditure as well as the net transfers will be significantly higher than on average, as would probably the consumer's true willingness to pay for the solutions. In addition, this viability is only based on one benefit of such smart meters. Other benefits such as theft reduction, improved outage detection, load management/profiling, etc. could even outweigh these benefits.

The current limited supply case also seems to be preferable to the other alternatives of uniformly load shedding to rural and urban feeders, or providing uninterrupted supply if we consider all three principal stakeholders – the rural and urban residential consumers, and the utility. Using the inputs for the likely case from table 13 and 50 W supply, the unrecovered costs for the utility if uninterrupted supply (full-load) is to be provided to rural areas by procuring additional power are of the order of about Rs 400/ rural residential consumer-year in comparison to the about Rs. 70/ rural residential consumer-year with current limited supply (in all cases, again, focusing on the evening peak from 6-10 pm as a starting point for policy). The rural residential consumers themselves are better off, but the very high unrecovered costs may leave all the consumers in the BESCOM areas ultimately worse off. With uniform load shedding, the unrecovered costs for the utility are very similar to the current limited case (Rs. 60/ rural residential consumer-year with uniform load shedding to the Rs. 70 with current-limited supply). However, urban residential consumers, whose welfare is unaffected with the current limited supply, are worse off. The inconvenience costs of rural consumers are equal by design with their share of the smart meter costs.

5. Discussion – the status quo appears both inefficient and inequitable

This study highlights firstly the importance of using the data we have at our disposal in making better estimates of load shedding, and in developing more appropriate metrics to monitor supply reliability (not to mentions policies for improved or optimized shortfall management). Due to constraints in data available to us, we are unable to determine whether some feeders are always load shed much more than others. However, we do know though that on any given day many feeders are load shed more than on average, in a systematic manner based on geography.[13] This is almost certainly sub-optimal planning and/or operational practices as the inconvenience to the consumer due to outages over the course of a week is not likely to be linearly additive.

The study chooses one possible framing of the problem where there is a tradeoff between the subsidies (or the viability of the utility) and supply reliability. This tradeoff is based on the rationale provided by KERC for charging differential tariffs to rural and urban consumers. Such a formulation may not entirely reflect the utility's planning, however. Load shedding schedules, especially at the substation level, are largely ad hoc. Hence, systematization of the scheduling processes and the chain of command are essential prerequisites. While recognizing the problem of the supply deficits, load shedding needs to be better planned, communicated, monitored and recognized as a short term solution.

Any discussion about the inequity in electricity services to rural and urban households in India is incomplete without noting the very poor levels of access in rural India. It could be argued that the net transfers estimated here represent a very conservative lower bound, given that costs of providing access to unelectrified rural households (on a wire basis) has been omitted from the analysis. There is a massive transfer through fixed costs because the overall system today is artificially cheaper by not serving the (mostly rural) unelectrified consumers.

[13] This is above and beyond the fact that the load-shedding is far higher than the officially designated norm, e.g., the KERC directive to supply power for 11 out of 12 hours to homes during 6 PM – 6 AM.

One of the important results from this study is the neglect of the smaller town and cities in this region. Unlike in the villages, the partial defense of having instituted tariff differentials does not exist either. The neglect of smaller towns represents a broader skew of the State's investment and policies towards the metropolitan areas, which has led to a lopsided and increasingly unsustainable urbanization. The scale of migration to large cities which offer better economic opportunities and public services has resulted in dangerous levels of air pollution, congested roads and living areas, deteriorating law and order, and unchecked exploitation of groundwater resources.

The poor quality of electricity supply in non-Bangalore urban feeders also presents a red flag to the success of the feeder separation program that is ongoing in Karnataka along with a few other states (World Bank, 2012). As discussed in Section 2.3, this program only deals with the problem of the unviable but locked-in free, unmetered power supply to irrigation pump-sets. However, the problem of supply deficits remains, and it is unclear how this very capital-intensive program[14] will meet its stated goal of provided uninterrupted supply to villages when the towns do not receive such supply currently. Fundamentally, any such program must answer the question of how do energy savings due to isolation of pumpset loads compare to unmet other loads? If we only look at the 6-10 PM (evening lighting) period, it is not clear there is actually enough savings since pumpset supply is mostly rostered.

5.1. Policy Implications

One way of interpreting the results is that the tariff differentials as they exist do not sufficiently account for the load shedding arrangement and as such, the *tariffs* need to be revisited and that (all else equal), the Bangalore urban consumers should pay more to reflect the better quality of service they receive. In our opinion, this must not be the solution or the take-away. Outages of the order that exist in rural India are indefensible, and while the constraints in supply must be acknowledged, alternative routes to reduce the impact of these should be considered urgently. These include at the most basic level, higher predictability in the outages – through more transparent schedules, that are well advertised in

[14] In 2011, the project was estimated to cost more about Rs. 2,100 crores. It is likely that these estimates have been revised upwards over time. http://gokenergy.gov.in/schemes.html Accessed on August 26, 2014

advance such that the consumers can plan for them. These could also include incentivizing the use of backup lighting like solar lighting systems that use an alternative, consumer owned source of generation to charge the batteries for use when needed. And alternatively, as explored in some detail here, we could explore new technology like smart meters to facilitate uninterrupted, but occasionally current limited supply.

While exploring the economics of the smart meters, our analysis is at the average levels of load shedding. A policy intervention on the other hand could instead start by identifying feeders that are especially vulnerable to frequent outages. The threshold of 'vulnerability' could be identified in a manner similar to our approach here and factor in the consumer willingness to pay and the subsidies available from the central and state governments. Once again, we stress on the need to putting the SCADA data (and other monitoring mechanisms) to good use in monitoring the feeders, developing better metrics for reliability and actively intervening in underserved regions. Importantly, the goal of this paper is not to claim any specific transfer number, since it depends heavily not only on assumptions but the actual load-shedding pattern, which varies by supply and demand conditions. A bad monsoon means a much higher gap. Instead, the generalized findings and indicative range are robust and warrant changes in policy.

A final generalized policy implication tests the basic premise of regulated utilities who do not equitably serve all consumers. For any utility ostensibly meant to serve all consumers in a geography (especially those with a regulated rate-of-return monopoly), by not serving all the consumers, one could estimate a social welfare transfer from those not served to those served (be in in terms of access or actual delivery of service). Such inequities have been observed in supply of water in Bangalore by income areas for sub-city geographic granularities (Mehta et al., 2013). This problem is made worse when we examine alternatives. While the value of not receiving service is invariably linked to income (which is higher in urban areas than rural), the alternatives may, in fact, be more expensive in rural and poorer areas. For water, the alternatives are tanker-supplied water or underground borewells/tubewells, but alternatives in rural areas are shallow wells, dirtier water, and distant sources demanding hours of time for fetching water. For electricity, if lighting is the primary basic service, while urban households may have battery-based backups, the use of kerosene is especially expensive, both to households and the exchequer. Whatever may be the method and assumptions for equitable supply, proper monitoring and transparency are key to improved societal outcomes.

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The authors remain responsible for the content.

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8. Appendices

8.1. Appendix 1 – Rural-urban differences with no metropolitan city

It is possible that BESCOM is a relatively special case due to the distortionary effect of having a large metropolitan city like Bangalore. To verify that the general rural-urban trend is valid, we used data from the distribution utility serving 8 districts in northwestern Karnataka in the Hubli-Dharwad region. Hubli ESCOM (HESCOM) has about 1 million each of rural and urban residential consumers. Tariff structures are very similar to those in BESCOM. We have data for 167-184 urban and 625-700 rural feeders from the 172 substations (the files for another 137 substations had entry errors with no valid data). Supply availability statistics for rural and urban feeders in our sample are given in Table A1.1.

Table A1.1: Mean (St. Dev) for supply availability in the Hubli (HESCOM) region. Absolute value of t-statistics from a two sample t-test with unknown variance with null hypothesis as equal means (- p<0.01)**

	25 Sep '12	26 Sep '12	27 Sep '12	26 Dec '12	27 Dec '12
Rural					
24 hours	9.7 (4.0)	9.6 (4.2)	10.2 (4.6)	12.3 (4.3)	12.7 (4.5)
Three-phase all day	6.1(4.4)	6.1 (4.5)	6.6 (4.9)	7.7 (5.5)	8.2 (5.6)
6pm-10pm	2.5 (0.9)	2.4 (1.0)	3.3 (1.0)	3.1 (0.7)	3.1(1.0)
Urban					
24 hours	19.8 (3.2)	20.7 (3.7)	20.8 (3.7)	22.2 (4.2)	22.5 (3.7)
6pm-10pm	3.5 (0.7)	3.4 (0.8)	3.3 (1.0)	3.8 (0.5)	3.9 (0.4)
t-statistic	15.2**	14.3**	10.9**	13.6**	16.8**

Supply availability in the rural and urban feeders are significantly different during the evenings. The only caveat is potential errors or biases due to the substations with no data.

8.2. Appendix 2 – National estimates for load-shedding transfer

To make order of magnitude estimates of the transfers at the national level, we need to estimate multipliers that reflect the factors that lead to the inequity in load shedding.

$$\textit{Load shed transfer from rural households nationally (Rs. per day)}$$

$$= \sum_{States} \{\textit{Avoided costs of procurement by discriminatory load shedding}\}$$

$$= \sum_{States} \left\{ \begin{matrix} \textit{State rural} \\ \textit{residential demand} \end{matrix} \begin{matrix} X\,(\textit{Actual rural load shed\%} - \textit{Actual urban load shed\%}) \\ X(\textit{Cost of rural supply at peak} - \textit{Marginal tariff}) \end{matrix} \right\}$$

A simplifying assumption is that gap between 'true' marginal costs of supply at peak hours to rural areas and the marginal tariffs are broadly similar across the country. Hence, we need to consider only the effect of supply deficits on the differences between urban and rural load shedding in each state, and weight these by the size of the rural demand. The differences in urban and rural load shedding will probably be closely related to the overall load shedding percentages, and in turn, to the state peak deficits for which we have official estimates. Hence, we could assume,

$$(\textit{Actual rural load shed\%} - \textit{Actual urban load shed\%}) \propto \textit{Actual overall load shed\%}$$
$$\propto \textit{State peak deficit\%}$$

In addition, states where the rural residential demand makes up a higher fraction of the overall peak may have lower disparities (with fewer consumers to treat preferentially). We could use this to derive a lower bound of the national multipliers.

$$\textit{National multiplier}$$
$$= \sum_{States} \left(\begin{matrix} \dfrac{\textit{State rural residential demand}}{\textit{BESCOM rural residential demand}} X \dfrac{\textit{State peak deficit\%}}{\textit{Karnataka peak deficit\%}} \\ \left\{ X \dfrac{\textit{Fraction of BESCOM peak from rural}}{\textit{Fraction of state peak from rural}} \right\} \end{matrix} \right)$$

The rural residential demand numbers were estimated based on National Sample Survey data (2011-12) for electricity consumption and Census 2011 data for number of rural households. Data on peak deficit percentages and the peak loads were from the Central Electricity Authority for the year 2012-13.

Based on this we obtain multipliers provided in Table A2.1 giving a national multiplier of 30- 50, which are rounded estimates to help give an order of magnitude calculation.

Table A2.1: Estimating multipliers for the transfers

State	Upper bound-peak deficits	Lower bound-peak deficits/ rural as fraction of state peak
Andhra Pradesh	13	5
Punjab	7	5
Tamil Nadu	6	3
Uttar Pradesh	4	4
Karnataka	3	3
Maharashtra	3	2
Himachal Pradesh	3	1
Jammu & Kashmir	2	1
Kerala	2	1
Haryana	2	1
Orissa	1	1
Madhya Pradesh	1	1
Bihar	1	1
Rajasthan	1	1
Chhattisgarh	1	0
All India	**50**	**30**

8.4. Appendix 3 – Inter-decile distribution of transfers

While the paper focuses on households as a group by geography, there are implications for social welfare and transfers within the groups by income level. Our analysis didn't directly factor this in given we don't have data on incomes by feeder level, but some estimates can be made for transfers by decile.

We use household expenditure data from the 68th round of National Sample Surveys (NSS), administered in 2011-12, to compare the transfers among different expenditure (as a proxy for income) deciles. Besides overall expenditures, used here to sort the households into deciles, the NSS data also includes reported electricity consumption (kWh/month) and expenditure. These are used to back-calculate expenditures with the uniform tariffs from Section 4.2, and subsequently the tariff transfers for each of the sampled households. This analysis uses data only from households in the BESCOM region (a stratified sample of 384 households with multipliers provided by NSS based on their representativeness). It is possible that load shedding is lower in relatively affluent villages because revenues per unit delivered here may be higher due to higher residential consumption levels, the presence of commercial loads, and possibly access to political leverage. However, in the absence of data to validate these hypotheses, we assume that there is no differentiation by income while load shedding, only per geography as per the overall study. Figure A3.1 shows the average net transfers for households in different income deciles as a proportion of their electricity expenditure.

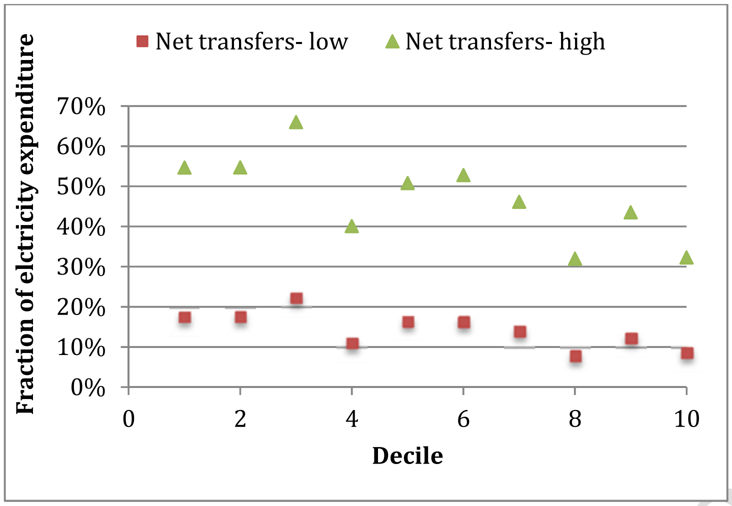

Figure A3.1- Net transfers as proportions of electricity expenditure for rural households by expenditure (income) deciles. Net combines tariff subsidies received and above average load-shedding. The range of high-low corresponds to the estimated range of net transfers.

The broad trends show that the proportions are clearly decreasing and suggest that the load shedding regime among rural households is regressive. However, these trends are not secular. This is probably because income (or more correctly, total household expenditure) is not the only determinant of electricity consumption behavior and we are not controlling for other factors here. The tariff transfers are also found to be regressive— that is, higher income groups benefit more than lower income. However, note once again that the tariff transfers are being computed between rural and urban households, and these transfers are not the same as tariff subsidies.

The costs of backup energy are not considered while computing the net transfers. However, studying kerosene expenditure in rural households is useful given that kerosene lighting is the most prevalent backup in villages. There are limitations though. Kerosene is rationed and Above Poverty Line houses are allocated less kerosene, if at all. Further, richer households may use other, more sophisticated backups for which data are unavailable. Within these limits, using NSSO data, in the first three deciles in rural Karnataka, kerosene expenditure is on average 85% of the electricity expenditure, and in the richest three deciles, this proportion is 55%. This substantiates the point that load shedding is regressive and disproportionately impacts the poorest households.