

Indian Power Supply Position 2010

CSTEP Working Paper No.1

August 30, 2010

Center for Study of Science, Technology and Policy (CSTEP)

Dr. Raja Ramanna Complex

Raj Bhavan Circle

High Grounds, Bangalore 560001

Tel: +91 (80) 4249-0000

Fax: +91 (80) 2237-2619

www.cstep.in

The Center for Study of Science, Technology and Policy (CSTEP) is a private, non-profit (Section 25) research corporation. CSTEP's mandate and vision is to undertake world-class research and analysis in chosen areas of science, technology and engineering and their intersection with policy and decision-making. CSTEP's studies do not necessarily reflect the opinions of its sponsors.

© 2010

Citation: R. Tongia, M. Saquib, HS Ramakrishna, "Indian Power Supply Position 2010", CSTEP Working Paper Series No.1 WP1-30.8.2010, CSTEP, Bangalore, 2010

Center for Study of Science, Technology and Policy (CSTEP)
Dr. Raja Ramanna Complex
Raj Bhavan Circle
High Grounds, Bangalore 560001
Tel: +91 (80) 4249-0000
Fax: +91 (80) 2237-2619
www.cstep.in

Indian Power Supply Position 2010

Rahul Tongia, Mohd. Saquib, H. S. Ramakrishna

CSTEP

August 30, 2010

Contact: Rahul Tongia (tongia@cstep.in)

Background on this Note

This note on India's power supply position aims to do more than capture statistics, which nowadays are often available online. CSTEP has added comments/observations (in italics) throughout this note that aim to add value and insight to the numbers. In addition, given the limits of national level statistics (which become too aggregated or averaged), we show more details and numbers from strike through Karnataka as an illustration. In addition, this exemplifies the variance across India utilities.

This note draws from ongoing research at CSTEP, including that for the Ministry. of Power, India Smart Grid Task Force and India Smart Grid Forum, and the Planning Commission; data sources are mostly official from the state or central government, unless otherwise specified. While the authors believe Smart Grids are one solution within the portfolio of solutions to India's power sector challenges, they caution that these are not a panacea, and there are many institutional, technical, regulatory, and business case challenges in the Indian context. More information on Smart Grids can be found in CSTEP's Working Paper available online at: <http://www.cstep.in/node/47>.

Abstract

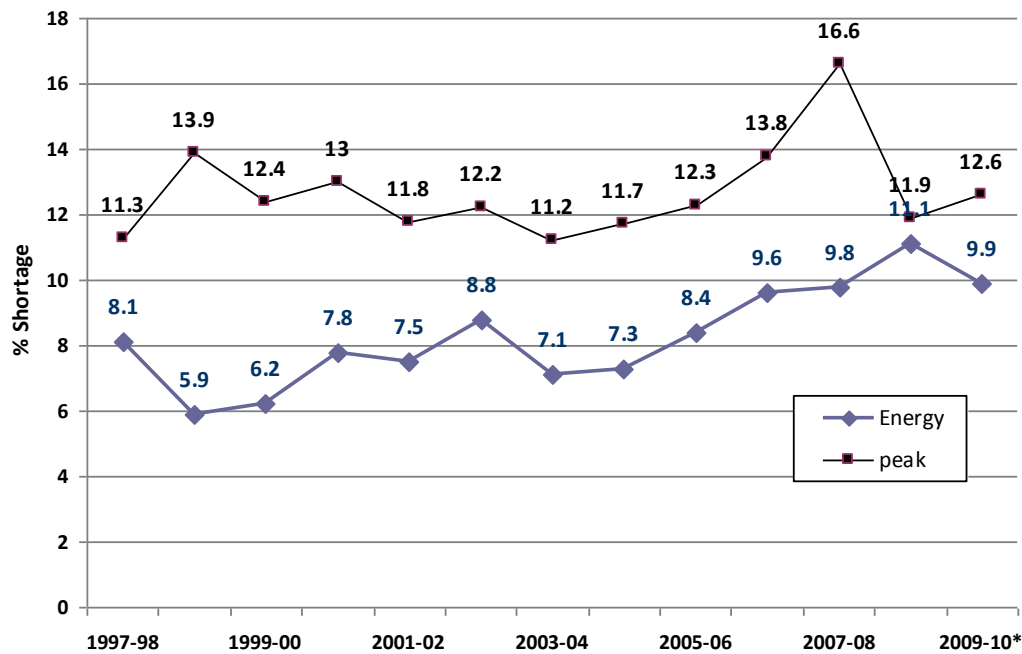
India's present installed capacity, 1,62,366.80 MW excluding captive power, allows for a modest per capita consumption of some 800 kWh/capita (CSTEP's estimate). The mix is dominated by coal, which is only 53% of the capacity but higher when it comes to generation. The generation is insufficient to meet the demand, resulting in a shortfall of both peak capacity as well as energy overall (officially 12.6% and 9.9%, respectively). There is a large push towards increasing supply, with an aim of tripling capacity in the coming 1-2 decades. Such ambitious growth has both financial implications (investments, affordability by utilities, etc.) as well as resource availability challenges.

Table of Contents

Background on this Note	3
Abstract	3
India Power Supply Overview	5
Supply Sources and Implications	7
Thermal (Coal and Gas)	7
Hydro power	8
Nuclear Power	8
Renewables	9
Wind	9
Biomass	11
Solar	11
Regulation and Reforms	12
Rethinking Load Factors, Metrics and New Services	13
Plant Load Factors	13
Meeting the Peak vs. the Load	14
New Key Performance Indicators (KPIs)	15
New Electricity Market Services	17
Growth Plans	17
Ongoing Growth Focus – Ultra Mega Power Plants	18
Discussion	18
Appendix 1: Karnataka’s Supply Position	20
Karnataka’s power purchases	21
Appendix 2: Abbreviations	24
Appendix 3: About CSTEP	25

India Power Supply Overview

India's power sector is one of the largest in the world, and the transmission system is soon to operate as a single, synchronous grid. While the capacity is large, 1,62,366.80 MW as of June 30, 2010¹ (which excludes captive power), the demand is far higher. Despite the massive capacity additions, the suppliers and Indian government are struggling to keep up with growing demand in terms of both energy and peak demand. During the period April 2010 to May 2010 we were 13.8% short of actual peak demand on the system and 12.1% deficit in terms of energy requirements (per CEA figures).



* = estimated

Source: Min. of Power Annual Report 2009-10

Figure 1: India Shortfall of electricity (peak and energy)

Comment: These actual numbers for shortfall are heavily assumption driven. It is our analysis the shortfall is higher, and even state government officials have publicly stated shortfalls as high as 30% (shortfalls are region and time of year specific). This excludes any spinning reserves plus reserve margin, typically set at 15-20% in many countries.

The IEA predicts that by 2020, 327 GW of power generation capacity will be needed, which would imply an addition of 16 GW per year. This urgent need is reflected in the target the Indian government has set in its 11th Five Year Plan (2007-2012), which envisages an addition of 78.7 GW in this period, 50.5 GW of which is coal.

Comment: The actual addition has, at best, been some 10,000 MW, and often lower. With ultra-mega power plants underway, addition may pick up somewhat, but it would not be a smooth, continuous process. Most importantly, the shortfall is not just a supply problem – China added over 100,000 MW per year recently, but still faced

¹ http://www.cea.nic.in/power_sec_reports/executive_summary/2010_06/1-2.pdf

shortages. This indicates a need for managing load and demand through both efficiency and, we believe, a smart grid.²

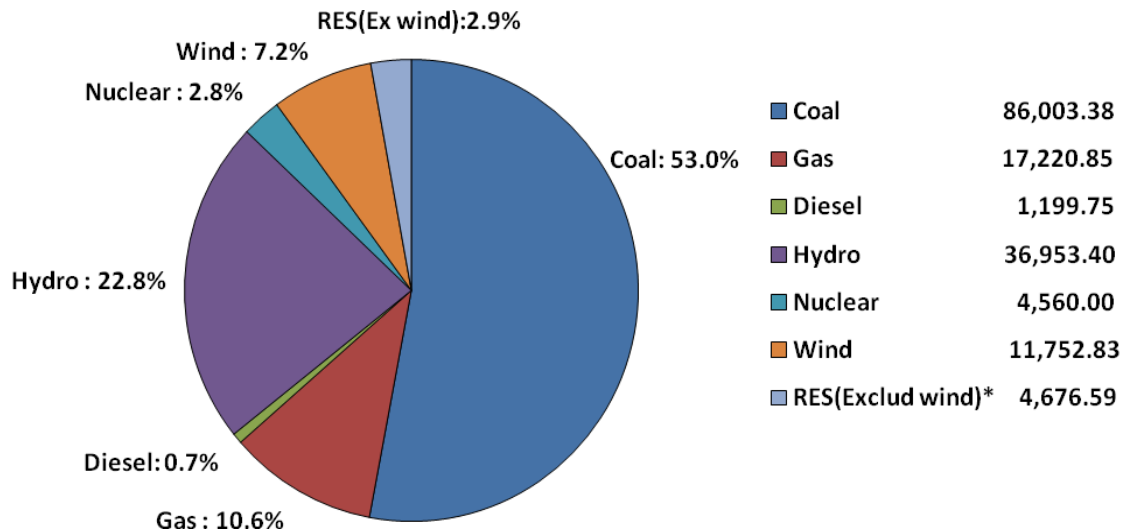
Power is a concurrent subject in the constitution, under state and central purview, but distribution utilities invariably fall under state jurisdiction. The capacity by ownership is given in

Table 1.

Sector	MW	%
State Sector	80,775.12	49.7
Central Sector	51,157.63	31.5
Private Sector	30,434.05	18.7
Total	1,62,366.80	

Source: CEA

Table 1: Total Installed Capacity (sector-wise) (June 30, 2010)



Data Sources: CEA and C-WET, as on June 30, 2010

Figure 2: Total installed generation capacity in India (1,62,366.80 MW)

² A Smart Grid is a general term for a transformation of the power system using digital communications and control to make the power system (near) real-time aware, responsive to changes, resilient to failures and attacks, robust, and amenable for renewables, both distributed and in large aggregate volume. <http://www.cstep.in/node/47>

*RES (Excluding wind) includes Small Hydro Project (SHP), Biomass Gas (BG), Biomass Power (BP), and Urban & Industrial waste Power (U&I)

Comment: It is worth emphasizing that the above capacity numbers do not paint the full picture. First of all, this is nameplate capacity, and often ignores any de-rating or curtailments of generation due to technical limits. Second, India (unlike other nations) chooses to list gross capacity of power plants, instead of what is available to the grid (i.e., after in-plant consumption, a.k.a. busbar). The so-termed auxiliary consumption can be on the order of 7-8% of thermal generation.

In addition, the plant load factors (PLFs) of different plants vary significantly. Some of this relates to the age of the plant, but much more relates to the fuel. The highest PLFs are for thermal plants, especially newer ones under NTPC. Hydro PLFs depend on water availability. The lowest PLFs are for renewables, often under 20%. Thus, the share by generation looks very different than the share by capacity.

Supply Sources and Implications

Thermal (Coal and Gas)

The mainstay of generation today is coal, which is driven by large domestic reserves. However, the Planning Commission estimates that even with India's large coal reserves of 267.210 billion tons, at projected growth levels (with electricity production being the largest consumer of coal) the supplies will only last about 4-5 decades (for power-grade, recoverable coal). The coal capacity is expected to grow to 190-200 GW by 2020 and this will require an annual coal supply of at least 1,000 million tons, or some 2.5 times the present.

Domestic coal has several issues, beyond any worries over high carbon dioxide emissions from coal combustion (see Table 2). Indian coal is typically very high in ash (~30%), and it is concentrated geographically in the center-east. This has meant a strong reliance on the railways to ship coal, and they are overburdened, or the need for very large capacity transmission lines to evacuate power, which are expensive and take time to build.

Because of these reasons, as well as the shortfalls in supply, the government has made it easier to use imported coal, which is now popular for coastal and southern power plants. There is also a push for private investment into coal fields.

The efficiency of coal plants in India is not very high, as all the present plants are based on sub-critical combustion technology. The total net generation from coal and lignite power plants was 461 billion kWh (bus-bar) in 2008-09.

Super and ultra-super critical power plants could help improve the supply position somewhat but the latter are not yet widely available. Integrated Coal Gasification Combined Cycle (IGCC) is another promising technology, which can attain higher efficiencies and lower CO₂ emissions and also produce synthetic chemical fuels such as diesel and hydrogen. However, initial estimates under Indian conditions of high ash coal show very high auxiliary power consumption and hence the overall efficiency is comparable with sub critical units at almost double the cost.

Gas based power is an attractive power generation option as the capital cost is low and the CO₂ emissions are only 0.4 kg per kWh. However, the cost of gas is usually much more than the cost of coal to generate one unit of electricity and there is

considerable uncertainty about gas availability for power given the reserves and also its alternate use in fertilizers and other sectors. It is therefore difficult for gas to contribute a large share of power sector. We have assumed that gas capacity could grow to 25,000 MW by 2020.

Region/ Country Economy	Population (million)	GDP (billion 2000 US\$)	GDP [PPP] (billion 2000 US\$)	Energy Cons. (MTOE)	CO2 emissions Mt of CO2	Per Capita Energy Cons. (kgOE)	Energy Intensity kgOE/ \$GDP ppp	Per Capita Electricity Cons. (kwh)	Per-Capita CO2 emission (tonnes)	kg CO2/ \$GDP ppp
World	6,609	39,493	61,428	12,029	28,962	1.82	0.20	2752	4.38	0.47
Brazil	192	809	1,561	236	347	1.23	0.15	2154	1.80	0.22
China	1,327	2,623	10,156	1970	6,071	1.48	0.19	2346	4.58	0.60
France	64	1,506	1,738	264	369	4.15	0.15	7573	5.81	0.21
Germany	82	2,065	2,315	331	798	4.03	0.14	7185	9.71	0.34
India	1,123	771	4,025	421	1,146	0.53	0.10	543	1.18	0.28
Japan	128	5,205	3620	513.5	1,236	4.02	0.14	8475	9.68	0.34
S. Africa	48	178	517	134	346	2.82	0.26	5013	7.27	0.67
Thailand	64	173	548	104	226	1.63	0.19	2157	3.54	0.41
Turkey	74	372	821	100	265	1.35	0.12	2210	3.59	0.32
UK	61	1,766	1,833	211	523	3.48	0.12	6142	8.60	0.29
USA	302	11,468	11,468	2,340	5,769	7.75	0.20	13616	19.10	0.50

Source: International Energy Agency 2009

Table 2: CO2 Emissions data for selected countries

Hydro power

Hydro power's share in power generation has been gradually declining because of increasing difficulty in exploiting the remaining potential, which is mainly in the north eastern regions. The July 31st, 2010 installed capacity of 37,033 MW could grow to 55,000 MW based on the ongoing and sanctioned projects. Hydropower's limitations include issues of land-use and resettlement and geography (far from load centers), though the theoretical capacity is stated as over 80,000 MW as per MoP documents.

Nuclear Power

While the present share of nuclear power is modest, some 3% of capacity, it has improved in recent years in terms of PLF. Nonetheless, its scope for growth is primarily constrained by the limited domestic fuel supply. In the past, this meant a planned move towards fast breeder reactors, but with the new international agreements, there can be an infusion of imported reactors and fuels which can increase the share of nuclear power in the coming decades to 10+%.

Examining the short to medium term, current PHWRs are expected to reach 10,000 MW by 2020. In a Moderate scenario, LWR capacity (imports) could grow to 10,000 MW. India is also building 500 MW Fast Breeder Reactors (FBR), however large scale FBR deployment is unlikely before 2020 as the technology needs to be validated and the required reprocessing capacity has to be developed. Further, thorium use in

nuclear power appears a few decades away. Overall, nuclear power could contribute about 21,000 MW by 2020 (mostly PHWRs and LWRs, balance FBRs).

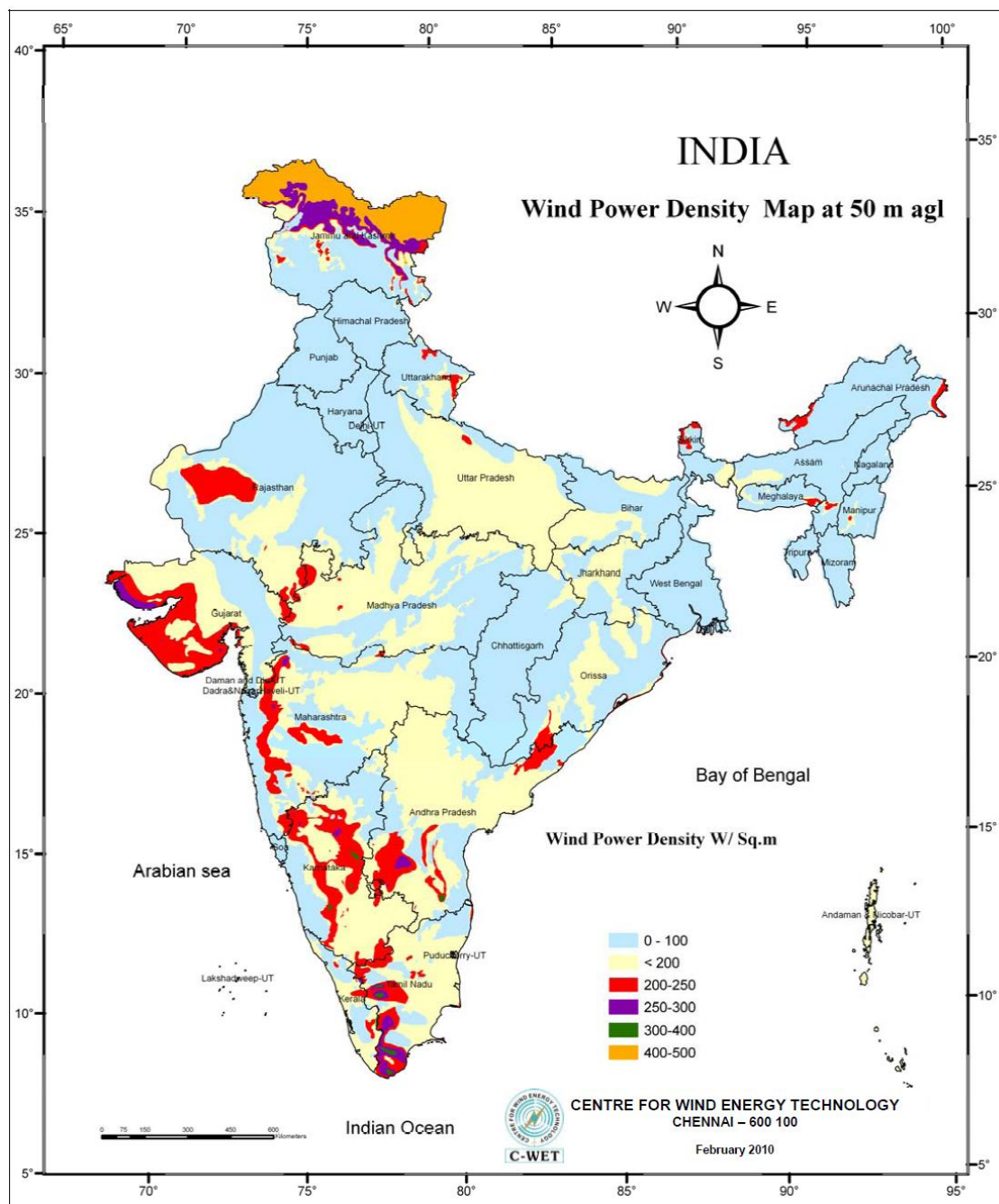
Renewables

Renewables have a modest but growing share of supply, but much of that is wind. Wind grew initially due to financial incentives (that too for capacity instead of generation) but today the picture represents a more mature industry. Most regulators in states have attractive tariffs (based on a cost-plus mechanism) for renewables, without which many systems could not compete with “regular” supplies.

Wind

The largest renewable source in India is wind power, and India is one of the largest wind users in the world (est. 4th rank). The momentum should continue and wind capacity could increase to 25,000 MW by 2020. Even though the load factor of wind plants is low (CSTEP estimates at 17-18%), it is attractive as it could be set up quickly.

Wind potential in India is estimated to be 48.5 GW by the Centre for Wind Energy Technology (C-WET). This study was based on relatively low height windspeed mapping (50m high), and with higher heights, the capacity might be 65-70 GW, and the World Institute for Sustainable Energy, India (WISE) states that with larger turbines, greater land availability and expanded resource exploration, the potential could be as high as 100 GW. This excludes off-shore windpower, which is not yet exploited in India.



Source: C-WET

Figure 3: Wind speed map of India

Figure 3 shows that the wind potential is highly concentrated in only a few regions of India. While the all-India figure for wind may be roughly 7.2% by capacity (lower by generation), for some states it is much higher.

Figure 4 shows not only the concentration of wind in selected states, but also the high fraction of windpower in these states’ portfolio of supply. In fact, this high share has started causing operational challenges in some states due to the uncertainty and variability of wind, most notably in Tamil Nadu.

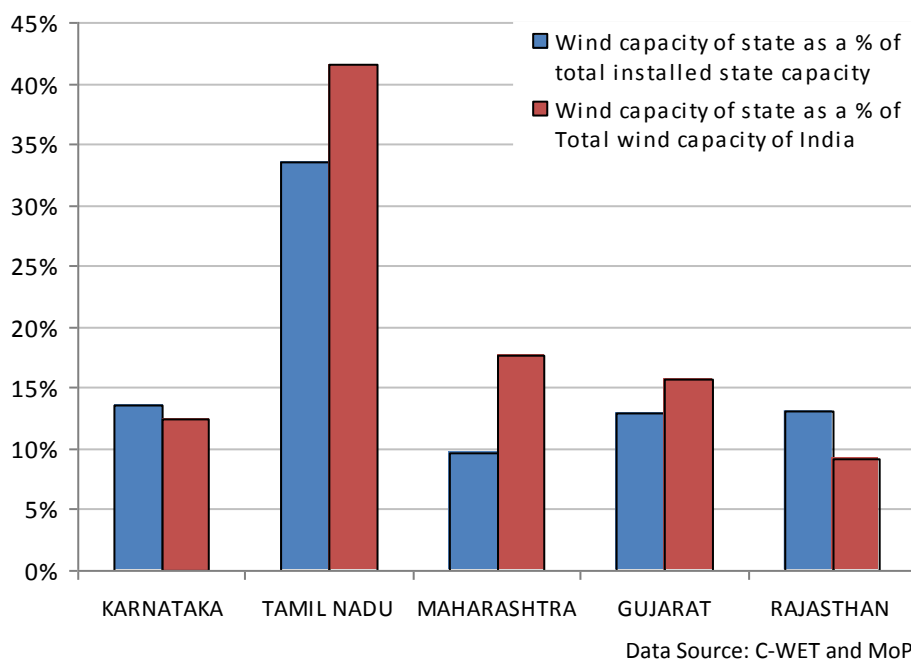


Figure 4: State-wise wind generation capacity (MW) as fraction of Indian total and state supply

Biomass

For a nation with a large agricultural base, biomass is not used much for electricity generation. The bulk of this is through co-generation, and the estimated potential in rice and sugar mills is attractive and could contribute 5,000 MW.

In theory, biomass wastes/residues could fuel power production, especially through gasifiers instead of less efficient boilers, but so-called waste actually has competing uses. In addition, land limitations and competition with food puts pressure on biomass based power. In addition, in case one thinks of energy plantations for dedicated energy crops, the financials are much more attractive for producing liquid fuels (bio-diesel or bio-ethanol) given the premium value of liquid fuels for transportation.

As a back-of-the envelope, it takes roughly 2 kg of biomass to produce one unit of power (depending on type of biomass and how dry it is). Thus, to compete with coal, biomass cannot cost much more than Rs. 0.50/kg, which becomes difficult except for certain biomass residues. Otherwise, the cost of electricity from biomass rises measurably.

Solar

India is endowed with large solar potential, with regions like Rajasthan or Ladakh having well over 6 kWh incoming insolation/square meter daily; some 15% can be converted to electricity using efficient photovoltaic (PV) modules. Such sunlight is favorable to, say, Germany, which has a large solar program but only half the sunlight. Allocating just 1% of India's land area for solar could provide for roughly 500,000 MW of capacity.

Unfortunately, economics has been the main barrier, with photovoltaic power costing at least 4-5 times coal based power, and more with the present systems. PV has made most sense for small scales and off-grid uses (remote locations).

Solar power can also be solar thermal, where the sun's heat is concentrated to heat a working fluid which then runs a regular steam turbine. This technology offers promise for several reasons, including amenability for scaling, ability to store heat to allow generation in the evening peak, and ability to use the same plant with alternative fuels as well to improve the PLF (if the regulators allow). However, there are no solar thermal plants in India, though several are proposed or under development.

The National Solar Mission has given a big thrust to solar power, but as and when support mechanisms go away, it remains to be seen as to what share solar will sustain in the portfolio mix. Industry claims that with growing manufacturing capacity in the country, short term viability gap support from government, aggressive research and development, and large scale deployment, the cost could come down to grid parity within in the coming decade.

Comment: Grid parity for solar power (especially PV) may not be compared to the average cost of supply but compared to the more expensive or peak sources.³ In that sense, solar is attractive since it somewhat coincides with load (daytime). The other advantage of utility scale solar is that no batteries are needed, which raises the off-grid use costs substantially.

Regulation and Reforms

For decades since Independence, the electricity system in India was governmental, that too mostly state level (excluding a few hydro projects or atomic energy). The utilities were classically vertically integrated, spanning generation, transmission, and distribution. In 1975, facing supply shortages, a central generation entity was established (NTPC), and this was subsequently extended to other generators.

The sweeping reforms of 1991 were meant to bring in private investment, a necessity given financing limitations, and the initial focus was on generation. Eight projects were given fast-track approvals with central govt. counter-guarantees, included the (in)famous Enron's Dabhol project. Ultimately, only a few of the projects under this scheme began generation.

By the late 1990s, the focus of reform shifted from generation to the distribution utilities. The State Electricity Boards began the process of unbundling, and, in the case of Orissa, also privatization. Most important was the creation of independent regulators, through state level and then the Central Regulatory Act, creating regulators who were meant to set tariffs in a fair, transparent, and viable manner.

Most states unbundled but left distribution companies as government companies, with only Delhi thus far privatizing after Orissa. At the generation level, most generation remains within the state, but there is an increasing level of non-state-generator purchases that distribution utilities undertake. If these are from trans-state supplier,

³ Cost-effective depends on alternatives, which is why off-grid has always been an attractive market for PV. If one compares to diesel generators, those can cost multiple times the "average cost of power" making solar attractive in just a few year.

the power comes via PowerGrid Corporation, and there are now several power exchanges (and a Power Trading Corporation) in the country. However, given that most power is contracted for through long-term power purchase agreements (PPAs) or is in-state, the volume of trades on the power exchange is relatively low.

Comment: The prices on the exchanges in 2010 appear lower than in 2009. People believe the demand for the power was higher in 2009 because this was an election year, and so there were policy directives to reduce power cuts.

There are now Letters of Intent if not MoUs for well over 130,000 MW of power generation capacity to be added via private players. It remains to be seen how many will materialize, how soon, and at what price.

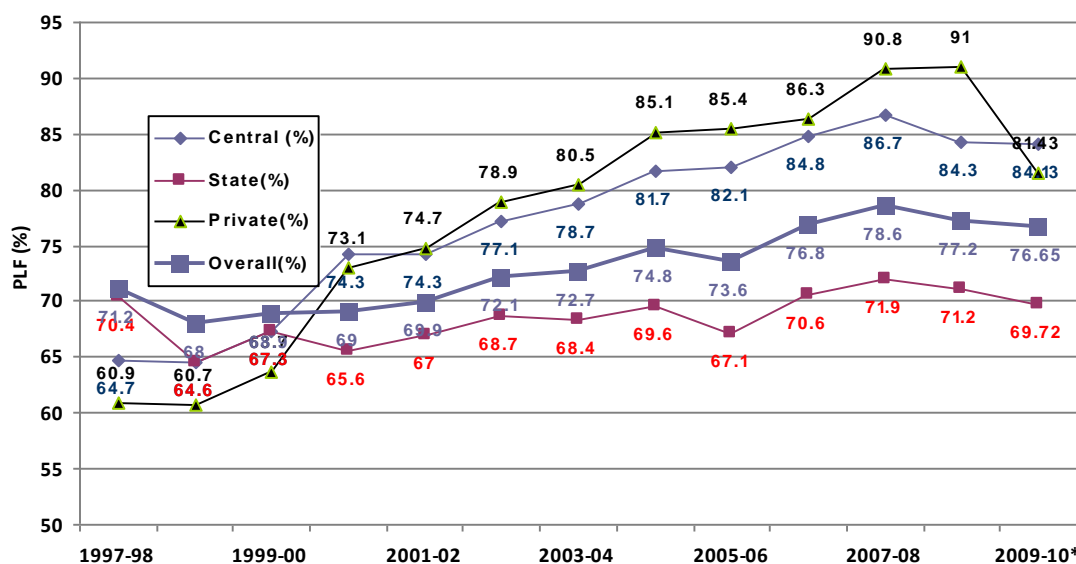
Comment: While there are now norms for bidding for power purchase agreements, one major challenge is the specifications. E.g., at what load factor (PLF) will the generator make their money (equity returns for fixed costs). Shifting to availability as a metric is a useful step but not sufficient since all new plants typically have high availabilities.

What is required is a re-think of matching suppliers and demand, something a smart grid can spur. In the absence of utility scale storage (for which many countries deploy pumped hydro), the only means to meet the peak is to have peaking supply, which is both expensive and, often, environmentally damaging. In a smart system, not only could pricing reflect the peak, encouraging shifts in consumption patterns, one could envisage active load controls to curtail demand during the peak in a non-disruptive, efficient, and fair manner.

Rethinking Load Factors, Metrics and New Services

Given electricity cannot easily be stored, it requires a balance between supply and demand (inclusive of losses). This actually needs to be dynamic since demand changes over time, both night and day as well as seasonally.

Plant Load Factors



Data Source: CEA

Figure 5: PLF of Thermal plants

Plant Load Factors (PLF) indicate energy (kilowatt-hours, kWh) that can be produced from a generator. There has been a steady improvement in plant load factors, but there has been a recent plateau in the improvement.

It turns out that the “higher the PLF the better” is not necessarily true, especially if this is the model per plant. This is because during off-peak periods, some generation will have to back down, and this choice is one dictated by not just costs (and contractual obligations) but also the technical limitations of different fuels. Coal plants cannot be turned on/off easily, and take hours to go from cold start to full power. Renewables are not only variable but unpredictable. Thus, these are not suitable for peak loads.

The entire concept of peak pricing is missing from generation in India. Other than Availability Based Tariff (ABT) applicable for central generation stations, which has a surcharge for overdrawals based on frequency (a proxy for supply-demand mismatch), most power (except exchanges) is not dynamically priced even for the utilities buying the power. Thus, they don't pay more for 6 PM power than 6 AM.

Comment: In fact, in states like Karnataka, which are heavily hydropower based which are cheaper (older), the peak power is less costly than off-peak since all costs to the utility are calculated on an average cost basis (end of month). What is required is for a separation of energy from capacity so that different technology supplies can be fairly valued. In fact, this lowers the value of some renewables since they are not only NOT peak-load coincident (wind has a negative correlation), but they are highly uncertain. This is also an area where a more dynamic (smart) system can play a role.

Meeting the Peak vs. the Load

If peak electricity only operates for a few hundred hours per year, then its electricity will inherently be more expensive. Lacking peaker units (which can only be hydro, simple gas turbine, or some types of diesel), the alternative is load-shedding. Estimates for peak electricity come in at some 4+ times more expensive than new “regular” (i.e., baseload) power, if not more.

One option would be for a smart grid to manage the peak through demand response (DR), lowering peak demand; DR is a more dynamic form of today's demand side management (DSM). In addition, a smart grid could allow for minimum consumptions even during shortfall periods, with load control not at the feeder level like today but consumer if not appliance level. This sort of a guaranteed consumption need not entail enormous capacity if the loads are controlled to 100-300 watts per home during the peak (today's load-shed) periods.

Comment (Meeting the rural unserved load): A parallel calculation is how much capacity would be required to serve all the rural and unserved loads. Estimating the households lacking electricity today, say, 50% overall, giving each of them 100 watts consumption and then applying a small diversity factor, we find that centralized supply, including technical losses, would only be between 9-11 GW of capacity. This is a small amount given that the annual increase is of this order. Thus, the challenge is not supply per se but distribution (last mile) and ensuring adequate control over the supplied power (e.g., it is not overused or diverted for pumping water).

Gujarat, through its Feeder Separation program (“JyotiGram”), has already achieved 100% reported household electrification, with virtually 24/7 household supply. This indicates supply shortfall per se is not the bottleneck, and may have implications for off-grid plans, except for remote or distant villages which are entirely disconnected. Short of per household supply options, like Rooftop PV, other renewables/distributed generation systems also require last-mile connections, which may make deepening household penetration of the grid a good option.

Financially, meeting the peak could be done through several options, regardless of fuel choice and supply. One option is how developed countries manage, which is to have (expensive) peaker units (and standby, etc.) and then average out the cost across the total consumption. This would, perhaps, raise today’s average costs of Rs. 3.5 or 3.8/kWh by 50 ps to 1 rupee, perhaps. The other alternative is to separate peak (costly) power from today’s supply position, and charge accordingly. This may require time of use (a.k.a. interval) metering, as well as modifications to tariffs. Such pricing would incentive demand response, which is a dynamic form of demand side management.

Is there an ability or willingness to pay? At least with some segments of the population, we know there is, evidenced by the widespread use of diesel generators and batteries+inverters. These can cost some Rs. 12 or 8/kWh, respectively. One unknown is the true impact of lack of power on economic growth and human well-being. Estimates claim several percent of the GDP. A more subtle unknown is the cost implication of poor quality power, which adds unnecessary cost and inefficiency due to stabilizers and UPS, not to mention reduced lifespans of equipment, including blown appliances, burnt-out pumpsets, etc.

New Key Performance Indicators (KPIs)

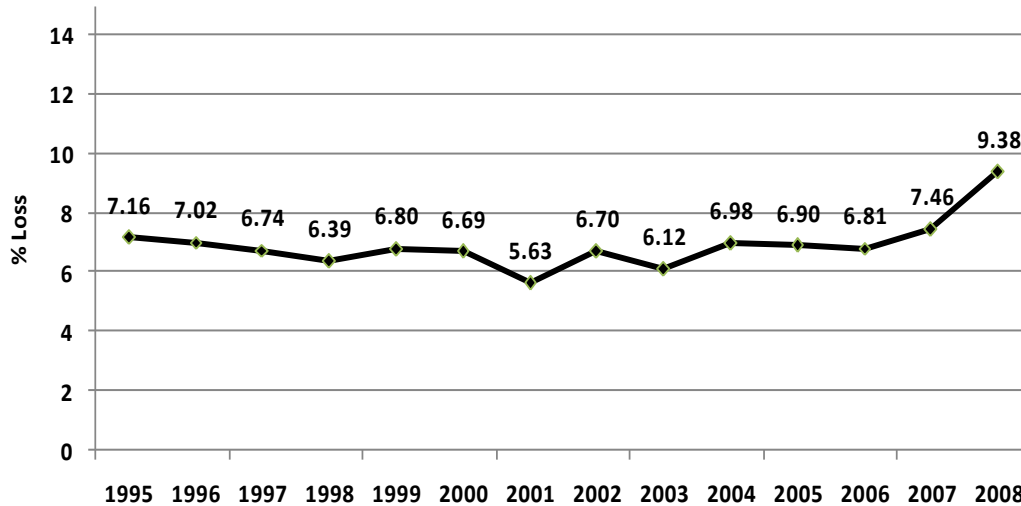
Probably the most talked about metric is losses, today calculated via aggregate technical and commercial (AT&C) losses. This number is *estimated* at around 30% with high variance across utilities. The exact number is unknown since agricultural irrigation pumpsets (IP) are mostly unmetered. Thus, there are assumptions made as to their size and usage giving the load.

Comment: The load for IP usage may be higher or lower depending on the region. West Bengal (and Gujarat) have begun metering pumpsets (approaching 100%), which has nothing to do with pricing or subsidies. They find the load is lower than officially calculated. On the other hand, in BESCO (rural Bangalore) the sanctioned load for pumpsets was under 5 horsepower (HP) (3.7 kW). A detailed survey showed the actual average size as over 12 HP!

What should AT&C losses be? Clearly, as low as possible. How low is realistic?

Comment: We believe that while AT&C is a useful metric for cross comparisons, it needs disaggregation. Technical losses should be separated from “commercial” (theft) losses, and non-collection of bills should also be separate. Each type of loss reduction would require a different approach. NOTE: AT&C is today calculated for a distribution utility or company (Discom), and so does not factor in transmission losses at certain levels.

One of the lowest losses in the world is in Korea, with some 4% or lower. Technical losses in the US have varied between 5.63 and 9.38% over the last few years (Figure 6), which includes transmission and distribution (T&D) both. China reports about 8%. The estimates are 1/3 as T losses, and 2/3 are D losses. R-APDRP has a target of 15% AT&C losses for the discom. This covers only the urban and semi-urban areas, which are likely to have lower technical losses than rural areas which have longer feeders.



Source: EIA Annual Energy Review 2008

* The large jump in T&D losses for 2008 needs further examination

Figure 6: US T&D Losses (Total Generation 2008: 4119.35 BU, net)

Comment: The target of R-APDRP is a start, but may not be sufficient. Ignoring collection for now, the technical losses in an urban area (D only) should not be more than 5% ideally. This is because rural areas will have higher losses, and this ignores T losses. T losses today are over 5% within the state (using Karnataka data), and then PGCIL has its own losses for inter-state. Aggregating these by weighted loads, the T today is likely some 6-7%.

While utilities measure and proclaim KPIs like System Average Interruption Frequency Index (SAIFI), CAIFI (for consumers), etc., these numbers are limited because of several reasons. For starters, they ignore momentary disruptions (perhaps under 3 minutes). Adding MAIFI (momentary interruptions) will be helpful (and something a smart grid is meant to help with). Second, they are calculated only on the basis of feeder inputs, and miss sub-feed (e.g., distribution transformer or low tension distribution) failures.

Most importantly, they don't factor in load-shedding since that is not termed a fault. However, to a consumer, lack of power is lack of power. The KPIs should be updated to two sets, with and without load shedding. Given load shedding is very local-specific, the KPIs should then be presented with finer granularity than utility-wide. In fact, each consumer should see their own KPI in their bill, and a public website could even list KPI by neighborhood. Appendix 1 gives some more details and insights into shortfall of supply.

New Electricity Market Services

In addition to energy (kWh), there are other services that are required to keep a power grid in balance. In some nations, there are capacity markets separate from energy markets. There are also frequency support (“regulation”) markets, markets for reactive power, markets for standby and spinning reserve capacity, transmission congestion charges, etc.

While today’s power grid faces acute shortfalls, any transformation including through smart grids must facilitate appropriate non kWh contracting (whether via markets or bilaterals) to improve the reliability of service in a predictably affordable manner. Else, the only solution is over-engineering, which is unaffordable.

Growth Plans

Simple extrapolations from today’s generation supply paint a somber picture of required growth. Even assuming the elasticity of electricity to GDP growth is as low as 0.9 (through increasing efficiency and rise of services), the requirements for supply over the coming decades are enormous. Given the present annual per capita consumption is somewhere near 800 kWh [CSTEP’s estimate, including captive power], even meeting the global average implies a 3 fold increase in capacity.

	6%	7%	8%	9%	10%
2020	269	295	324	355	389
2030	481	580	699	841	1,009

Table 3: Extrapolated Capacity (Gigawatts) for Various Annual Growth Rates
(this assumes a 150 GW base for 2010)

As Table 3 shows, the likely capacity in 2020 or 2030 depends heavily on the assumed annual growth rate, compounded. In reality, a steady percentage growth rate is unlikely since over time, the same rate of growth implies much larger capacity additions per year. We expect the growth rate to increase from today’s maximum of approximately 7% but then come back down over time. In linear terms, 7% is roughly 10 GW today, but would be 20 GW in 2020.

Probably the cheapest and best option for managing growth is *efficiency*. Consider a 6% annual energy growth rate versus a 9% growth rate (this means a 33% reduction through efficiency and conservation means, such that we don’t harm our GDP). In just 20 years, this makes a difference between a 3.2 times growth from today versus 5.6 times, and in 30 years, 5.7 times versus 13.3 (the benefit of compounding).

Can India achieve such an improvement in efficiency? Energy usage usually grows faster than GDP in the initial period, with energy efficiency improving as the GDP rises. Examining US energy intensity (energy input per unit GDP output) from 1919-1973, it fell by only 1.6% per annum, but this improved to 2.1% annually over 1973-2006. In contrast, China saw enormous efficiency gains between 1980 and 2002, but from 2002-2005, the energy growth spiraled out-of-control. It was only when the government recognized the seriousness of the problem and took proactive steps towards efficiency and new technologies did this improve again (by almost 5% in just one year).

Comment: Given the Indian GDP growth target (9% estimated), we cannot fuel this entirely by efficiency, but we can make an enormous dent in the energy growth rates!

Japan and Denmark are twice as energy efficient as the US. Half the difference comes from lifestyle (e.g., smaller homes, shorter distances) but half comes from efficiency. It is such energy efficiency that India should promote if not mandate.

Ongoing Growth Focus – Ultra Mega Power Plants

One recent thrust has been towards Ultra Mega Power Plants (UMPPs), which can add large quantities of baseload power (typically 4,000 MW per location, at an estimate of 16,000 crore each). Policies for these were enacted with the expectation that economies of scale would lead to lower costs. The government has identified 9 sites for these across India, and 3 projects are already underway.

As per MoP's Annual Report 2009-10:

“Mundra in Gujarat : The project was handed over to the Successful Bidder i.e., Tata Power Company Ltd., on 23.04.2007 at the evaluated levelised tariff of Rs. 2.26367/ kWh As per available information, two units of 800 MW each are expected to be commissioned in the XI Plan.

Sasan in Madhya Pradesh : The project was handed over to the Successful Bidder i.e., M/s Reliance Power Ltd., on 07.08.2007 at the evaluated levelised tariff of Rs. 1.19616/ kWh. Financial closure has been achieved and order for main plant equipment has been placed by developer.

Krishnapatnam in Andhra Pradesh : The project was handed over to Reliance Power Ltd., on 29.01.2008 at the levelised tariff of Rs. 2.33/kWh. The development work is being undertaken by the developer.”

Tilaiya in Jharkhand : The project was handed over to Reliance Power Ltd. on 7.8.09, at a levelised tariff of Rs.1.770/kWh. First stage forest clearance has been received on 3.2.2010.”

We notice there is substantial variation in the tariffs, and this needs further examination.

Comment: Given the very large requirements in supply, UMPPs have the benefit that as and when projects go online, the quantum of power they supply will be large. But there is a dichotomy. If paperwork and the time for approvals is similar to traditional power projects, this is an expedient model, but if the ability to absorb such plants (both from a technical, i.e., transmission, point of view and financial risk management perspective), then there are downsides to such models.

Discussion

The large gap between supply and demand implies that any and all sources of generation will be required, within the bounds of price, supply security, and environmental constraints. In fact, no one can know what the true demand is since it has never been met – load-shedding data are just an estimate of curtailment.

If supply is \ll demand, then a market-based system would signal this through an increase in prices, incentivizing more generation. Given utilities lose some Rs. 1/kWh sold, on average, we are far from price equilibrium. However, from a supply portfolio point of view, pricing per se is not the only issue. For starters, comparing prices across fuels is more than examining the Rs./kWh – that figure is typically the levelized cost of energy, and assumptions such as amortization lifespan (as opposed to physical lifespan), cost of capital, performance, load factors, etc. all matter enormously.

More fundamentally, we believe the Indian power system needs to evolve to more than a kWh (energy) “market” (here meant to convey transactions regardless of whether bilateral contracts, power exchange markets, etc.) One step would be separation of energy (kWh) from capacity (kW), with proper reference to despatchability for capacity and load following capabilities (peak vs. off-peak). This can negatively impact renewables due to their variability and uncertainty, not to mention non-coincidence with the peak, especially in the case of wind. In fact, proper equilibrium needs the creation of markets or at least signaling and payments for ancillary services including the regulation market (which in the US operates on a timescale of a minute or so).

Another “market” would be for environmental characteristics, such as the proposed Renewable Energy Certificates (RECs). While a detailed examination of renewables pricing and policy is beyond the scope of this paper, it is clear that renewables are important, growing, and inevitable. Like with other forms of supply, the fundamental question of risk vs. returns remains.

Appendix 1: Karnataka's Supply Position

Karnataka is a medium-large state in terms of power in India, and overall a medium-large state with a population of over 50 million. Its installed capacity was 11,423 MWs as of August 2010, including its share of central generation and available IPPs.



Figure 7: Karnataka, India
(map courtesy: "Incredible India")

	Capacity (MW)
Thermal (incl. IPPs)	3,918
Hydel	3,641
Non-conventional	2,330
Central allocation	1,534
<i>total</i>	11,423

Table 4: Karnataka Installed Capacity (August 2010)

Compared to the nominal capacity of over 11,400 MW (Table 4), the peak load that has been served is just over half of this amount.

Using April 3, 2009 data as an example, we see that the power purchased for the Discoms via the state intermediary was 126.4 million units (MU). Assuming 5% in-state technical transmission losses (a precisely calculable number because of a state-wide transmission level SCADA system), and 10% technical distribution losses as a minimum (estimate), this implies the served load was only 107.4 million units. Using a base of just 11,000 MW (for 2009), this implies an average loading of only 40.7%.

In an equilibrium system like the US, this may be correct but in the Indian system, this reflects unavailability of much of the theoretical supply, and extensive peak clipping (load shedding).

We know that some fraction of the supply is unavailable due to auxiliary consumption (for thermal units). Other amounts are regularly if not invariably unavailable due to a combination of:

1. T&D losses – technical – perhaps 15+%
2. Limited water availability for hydropower (which is often reserved for peak loads due to its quick ramp up/down times)
3. Variability of renewables and non-conventional energy, which are sizeable in Karnataka (20.4% of capacity, for just 5% of generation but 10% of power purchase costs)
4. Down-times and poor production from existing units, e.g., repairs.

Put together, the peak load served was just about half the theoretical (nameplate) capacity. In fact, there is heavy load-shedding regularly. On August 8, 2010, there was scheduled load-shedding of 1,500 MW, and unscheduled of 700 MWs between 0600-1900hrs, 900 MWs between 1900-2200 hrs & 300 MWs between 2200-2400 hrs (as per KPTCL official statistics online).

Scheduled load-shedding is known well in advance, and announced to the public. Rural areas receive only 6 hours 3-phase supply (for pumping) and half the day single phase supply in some places. Urban areas have rostered (rotating) load-shedding to reach to goal of peak load shedding of 1,500 (scheduled). Unscheduled is because of unplanned unavailability of supply.

The Karnataka load-shedding touches as high as 2,400 MW (scheduled plus unscheduled, assuming that overlaps in the evening peak). If one uses the nominal installed capacity of 11,000 MW or so, then the shortfall comes to close to 22% only. But, if one instead uses the delivered load (consumption) as the base (denominator for calculations) the shortfall is much higher, about 40%!

Which base is better to use? Increasing the nominal capacity by 22 percent would not suffice since we still have the similar mechanisms for shortfall as listed in the bullets above. Thus, a more realistic loss calculation schema may be required. This excludes the desirability of spinning reserves and standby margins (15%).

To meet such shortfalls, the State government has announced plans for creating additional capacity of 12,000 MW within 3 years, which appears ambitious.

Karnataka's power purchases

Error! Reference source not found. Error! Reference source not found. shows the impact of different sources on the power used by a state Discom (BESCOM, within Karnataka). We notice several important trends.

Total: 126.4 Million Units (MU)

Average Price: Rs. 2.025 Rs./unit (gross)

Total purchase cost (excl. transmission and losses): Rs. 25.601 crore

1. Hydropower is by far the cheapest source – especially as these are older (amortized) sources (suppliers no. 11-25)
2. The average price is Rs. 2.025/kWh as purchased by the state (via an intermediary state company in this case, PCKL). This is the gross price, plus Transmission costs (about Rs. 0.21/kWh) plus losses.
3. The most expensive power is that from an IPP and then in-state diesel generator, Yelahanka DG, which cost some Rs. 6.6 and 6.4/kWh, respectively. In fact, for 2010, the regulator approved *variable* cost for this generator is Rs. 7.5/kWh, plus fixed costs.
4. Non-conventional energy is a sizeable fraction (5.0%) of the supply (mainly wind) but a disproportionate fraction of the cost (10.4%); ostensibly, at a capacity level, it just over 20%.

The implications are that

1. New power is likely to be closer to the higher end of the scale
2. Renewables place a burden on the utility from a financial perspective. Operationally, the capacity is listed as much higher than the generation share – it has a low PLF as expected.
3. A smart system should, in theory, avoid the most expensive power (average cost number is not meaningful). BUT, there are limits since some power cannot be turned off (or on) quickly, due to ramp-up time requirements.

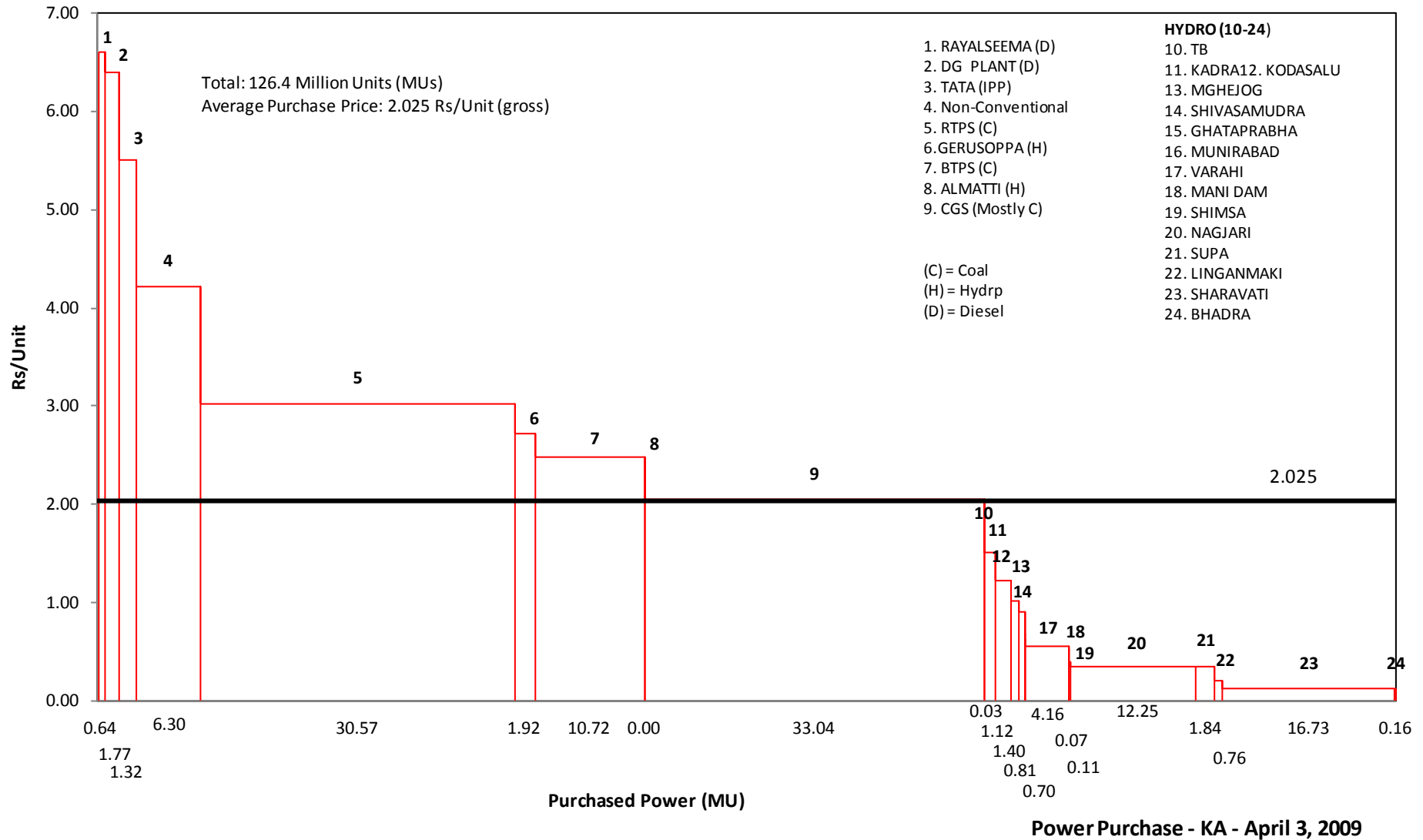


Figure 8: Karnataka power daily power purchase (April 3, 2009)

Appendix 2: Abbreviations

CEA	Central Electricity Authority
ABT	Availability Based Tariff
AT&C	Aggregate Technical and Commercial (losses)
CAIFI	Consumer Average Interruption Frequency Index
CWET	Centre for Wind Energy Technology
Discom	Distribution Company (aka ESCOM, or Electricity Supply Company)
DR	Demand Response
DSM	Demand Side Management
FBR	Fast Breeder Reactor
IEA	International Energy Agency
IPP	Independent Power Producer
KPI	Key Performance Indicator
KPTCL	Karnataka Power Transmission Company Limited
LWR	Light Water Reactor
MAIFI	Momentary Average Interruption Frequency Index
MoP	Ministry of Power
NTPC	National Thermal Power Corporation
PGCIL	Power Grid Corporation of India Limited
PHWR	Pressurised Heavy Water Reactor
PLF	Plant Load Factor
R-APDRP	Restructured Accelerated Power Development and Reform Programme
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
T&D	Transmission and Distribution
UMPP	Ultra Mega Power Plant
UPS	Uninterruptible Power Supply
WISE	World Institute for Sustainable Energy

Appendix 3: About CSTEP

The Center for Study of Science Technology and Policy (CSTEP), Bangalore is a private, not-for-profit Research Corporation (known as Section 25 Company in Indian Company Laws) established in July 2005. Founded by some of the leading scientists and researchers in India, its vision is to pursue scholarly, quantitatively rigorous and objective research on issues interfacing science, technology and policy in subjects such as national security, energy, information, communications and infrastructure. India has few such institutions for inter-disciplinary studies and thus CSTEP is uniquely positioned to undertake technology and policy analyses.

CSTEP maintains academic rigor and neutrality in its analysis. CSTEP has raised several endowments from industry here in India – notably the SSN Educational and Charitable Trust and the Sir Dorabji Tata Trust. CSTEP also has received government grants for specific projects. Recently, CSTEP was invited to give a presentation to the Prime Minister and several Cabinet Ministers on issues in science and technology. CSTEP was also invited to participate in the Prime Minister's National Solar Mission. CSTEP completed a major study of India's nuclear power prospects and also contributed newspaper articles during the Parliament debate on the recent international nuclear agreement. The Ministry of Power appointed CSTEP and Infosys to look at the role of information technologies in power distribution; the report was released in October 2008. Recently, CSTEP has been appointed Knowledge Partner and Advisor to the India Smart Grid Forum, and Advisor to the Smart Grid Task Force.

Members of CSTEP regularly publish op-ed pieces in India's leading and global newspapers and magazines. Their opinions are sought frequently by the Press and other agencies. A list of such publications is given in CSTEP's home page (www.cstep.in).

CSTEP's Chairman, Dr. V. S. Arunachalam, was former Scientific Advisor to the Defence and Prime Ministers of India, and CSTEP's Board has a number of distinguished scientists, management specialists and the Chairman of a leading industry. Prof. M. G. K. Menon was the Scientific Advisor to the Prime Minister, Chairman of the Science Advisory Committee to the Cabinet and Minister for Science & Technology, Government of India. Dr. P. Rama Rao was Secretary, Department of Science and Technology, and Chairman, Atomic Energy Regulatory Board, and Member of the Atomic Energy Commission. CSTEP's Scientific Advisory committee is headed by Dr. M. Vijayan, President of Indian National Science Academy (INSA) and also includes Dr. Kirit Parikh, former Member in charge of Energy and interstate cooperation, Planning Commission, Government of India. Please see the CSTEP web site (www.cstep.in) for further information.