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1. Objective

Ensure that the poorest sections of population have access to clean and modern energy sources.

2. Introduction

There are estimates that more than 2 Billion people lack access to clean and modern energy sources. In China, 423 Million people rely on conventional biomass for cooking applications. The corresponding number in India and Africa is 855 and 657 Million respectivelyⁱ. Similarly, almost 400 million Indians lack access to electricity. The per capita electricity consumption of India is a measly 600 kWh as against over 12,000 for the USⁱⁱ. Providing clean and cheap energy access is a major challenge, especially in the developing countries.

The question arises, how much energy is essential? If India were to achieve a reasonable level of economic prosperity, a simple calculation suggests that India's electricity generation would have to increase from the present 700 Billion kWh to 5,000 Billion kWh. Or, the installed generation capacity will have to increase to almost 925,000 MW! At that point, India and China combined would be emitting in excess of 10,000 Million Tons of CO₂ per annum from coal alone. Likewise, there would be a large replacement of biomass by alternate cooking fuels such as natural gas, kerosene or LPG. On the other hand, with aggressive energy efficiency like Denmark or Japan (which are relatively compact nations, of course), the energy requirements for comparable economic prosperity would be much lower. Even this requires enormous growth in the energy supply.

Nobel Laureate Richard Smalley coined the phrase "The Terawatt challenge" to refer to the global objective of ensuring equitable access to clean energy supply, especially to the 2 – 3 Billion population which presently lacks accessⁱⁱⁱ.

Some of the key questions that emerge are:

- Can this be accomplished in an inclusive sustainable manner?
- What are the fuel and technology options?
- What is the impact on green house gas emissions, in particular CO₂?
- What are the required investments and mechanisms for financing these?
- And, what regulatory framework is required for this transition to occur?

This report will examine the implications of "universal energy access" at the global level. We also periodically provide some illustrations from Indian scenario.

3. Global Energy Resource Availability

We first ask the question: Are there enough energy resources in the world to cater to large scale increase in energy demand, in particular in developing countries?

The table below shows the global resources of various energy resources. The present global energy supply is about 14 Terawatt hours per year. Keeping this in mind, the world has enough energy resources to last for centuries. Coal and nuclear can sustain the world energy for over four centuries. Therefore, there is no global energy crisis.

Figure 1: Availability of global energy resources ^{iv}

| Energy Resource | Energy Potential (Tera Watt year) |
|-------------------------------|-----------------------------------|
| Oil and gas (Conventional) | 1,000 |
| Oil and gas (Un conventional) | 2,000 |
| Coal | 5,000 |
| Methane Clatherates | 20,000 |
| Oil shale | 30,000 |
| Uranium (Conventional) | 370 |
| Uranium (Breeder) | 7,400 |
| Sunlight on land | 30,000 per year |
| Wind | 2,000 per year |
| Fusion (if successful) | 250,000,000,000!! |

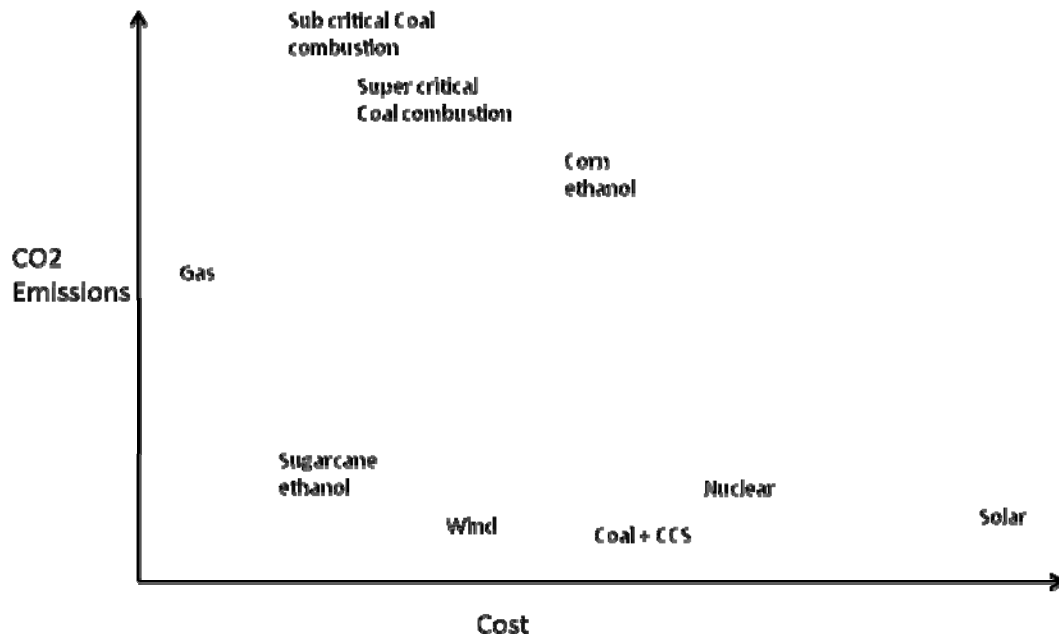
The main issue is of harnessing these resources in an efficient and environmentally friendly manner and distributing these with the appropriate regulatory framework to all sections of the society. The table below shows the lifetime CO₂ emissions (grams per kWh) from different energy resources.

Figure 2: Lifetime CO₂ emissions associated with various energy resources ^{iv}

| Energy Resource | Life Cycle CO ₂ Emissions (kg per kWh) |
|---------------------|---|
| Sub Critical Coal | 0.95 |
| Super critical coal | 0.84 |
| Oil | 0.80 |
| Natural Gas | 0.45 |
| Solar | 0.01 – 0.73 |
| Wind | 0.07 – 0.12 |
| Nuclear | 0.02 – 0.06 |

Clearly, we are attempting to satisfy three simultaneous criteria: energy security, economics and environmental compatibility. At the moment, there are few options which satisfy all the three. Coal, for instance, is presently the cheapest energy option and there is abundant supply. However, it is severely damaging the environment. If India and China decide to go with building large coal power plants, it would have a disastrous impact on the environment, both from global warming as well as local air pollution perspectives. Nuclear is a proven source of clean energy. However, the recent incident in Japan has once again brought back the issue of safety of reactors to the forefront. It is likely to delay if not stop the building of new reactors till this concern is adequately addressed. Solar is abundant and can sustain the world indefinitely. However, the cost is prohibitively high and its integration with grid increases the overall energy cost and that further increases the vulnerability of poorer sections. Biomass and biofuels are in theory “net zero” carbon options. However, in most developing countries, biomass is used for various applications such as cooking, heating and in agricultural processing. It is not clear how much biomass is available for energy generation and the opportunity cost would be high. Moreover, using land for making fuels is fraught with danger given the concerns about food security.

Figure 3: Cost and environmental tradeoffs between several energy generation options. The relative positions on the scales is only representative.



4. Low Carbon Options: Centralized Generation

We first discuss the potential of several low carbon fuel and technology options.

Advanced Coal Combustion

Coal presently accounts for majority of the global primary energy supply. The developing countries including India and China rely on cheap coal reserves for meeting their energy aspirations. It is therefore reasonable to assume that coal will continue to remain a major part of the world energy mix under any scenarios in the near future. Therefore, it is important to consider technology options which could reduce CO₂ emissions.

Most sub critical power plants operate at about 35% efficiency and generate 0.93 to 1 kg CO₂ per kWh of electricity (net). The efficiency of coal power plants increases with the increase in combustion temperature. In super critical coal power plants, the steam is generated under super critical conditions and these can operate at almost 40% efficiency. As a result, the CO₂ emissions reduce to about 0.85 kg per kWh. It is possible to increase the temperature further (Ultra super critical combustion); however that places stringent material challenges.

Government of India has already taken a lead in this regard by constituting the mission on Clean Coal (Carbon) Technologies as one of the National Mission under the National Action Plan on Climate Change. As part of this, it has been decided that most of the new coal power plants in the coming decade will be super critical technology. Further, the government has placed high priority on the development of Advanced Ultra Supercritical (Adv-USC) Technology for Power Plants as part of the above proposed National Mission. The government recently came up with a document titled “Mission 2017 - Advanced Ultra Super Critical Technology Demonstration”, which envisages the implementation of indigenously developed advanced ultra super critical technology in an 800MWe Adv-USC plant, which would have steam cycle pressure of 300 kg/cm² and 700 degree C steam temperature. So far, the existing power plants have achieved peak pressure and temperatures of 247 kg/cm² and 565 degree C / 593 degree C. With these parameters, the efficiency of the proposed indigenous Adv – USC plant is expected to be over 45%. It will therefore, emit much lower CO₂ than a typical sub critical power plant.

It is important to note that this is entirely an indigenous effort and the parameters targeted have not been adopted and commercialized anywhere in the world so far.

Coal gasification is also considered an attractive option for high efficiency coal utilization. It generates a partially combustible gas, which can be utilized for power generation and also for production of synthetic transportation fuels and also hydrogen. Coal gasification is also more amenable for CO₂ capture as compared with conventional coal combustion. However, technical and commercial viability of coal gasification is yet to be proven, especially for high ash Indian coals. For the moment, super critical and ultra super critical coal combustion appear to be more cost effective than coal gasification.

Underground coal gasification (UCG) is yet another promising technology option, which could be used to recover coal reserves that cannot be economically mined and are located in ecologically fragile regions. UCG also provides the opportunity for in situ carbon capture in the existing mine. However, UCG is site specific, and depends on several geological variables UCG could be an important technology to consider for developing countries given that coal mining comes into direct conflict with environmental degradation.

Given that coal will continue to be an important source of energy in the near future, it is vital that all new coal power plants are of the efficient super critical technology. There should be close coordination of global research in coal technologies to achieve this objective.

Nuclear Power

Nuclear power is an important component of any future low carbon energy mix. Nuclear power is poised for expansion with several countries including India and China announcing plans to build several reactors in the coming years. The recent earthquake and tsunami in Japan leading to the nuclear accident in Fukushima has raised concerns about the safety of nuclear reactors. It is premature to speculate on its impact on the nuclear power programs. It could possibly slow down the capacity addition plans until public concerns on safety are adequately addressed. However, it is unlikely to stall the nuclear programs.

Nuclear power reactors of most countries, including US, France and Japan are based on the once – through cycle, in which the spent fuel is permanently stored

after sufficient cooling. However, the spent fuel contains small quantities of plutonium, which is a fissile material, and could be used for starting new nuclear reactors. India is the only country pursuing this option and is building a 500 MW Fast Breeder reactor. There is considerable debate on the economics of reprocessing spent fuel vs. direct disposal. The international evidence seems to suggest that direct disposal is cheaper^v. However, we believe that plutonium is too precious an energy resource to be disposed along with the nuclear waste. This is particularly true in case of India, which relies on thorium for its long term energy security. However, thorium is not a fissile material and has to be converted to a fissile isotope of Uranium (233) in a reactor using plutonium. Therefore, harnessing the country's large thorium reserves requires a sufficient stock of plutonium fuel.

India has indigenous research programs for both Fast Breeder and Thorium reactor technologies. However, it could immensely benefit from international cooperation in technology, and nuclear material. This will help accelerate the nuclear power program in the country. At present, nuclear fuel, technology and equipment are tightly controlled by a select group of countries (the Nuclear Suppliers Group) and under the International Atomic Energy Agency (IAEA). Most of these regulations were framed in the cold war era and were guided by restricting access of nuclear material to other countries. However, now that many countries such as India and China have large nuclear power programs, it is opportune to revisit these provisions. We propose to discuss a new international regulatory framework which facilitates development of nuclear power as a safe, and low carbon source of power while addressing the concerns of proliferation.

Solar

In theory, solar provides limitless potential for meeting global energy needs. One hour of sunshine falling on the Earth's surface could potentially meet the entire world's energy needs for an entire year (around 14 TW·year). Nevertheless, solar energy currently provides less than 0.1% of the world's energy supply.

Unfortunately, the flux of solar radiation is low (less than 1000 W/ m² at the noon peak) and intermittent, and conversion technologies are inefficient and expensive as compared to conventional fossil fuels.

India has recently announced a major initiative "National Solar Mission", which targets 20,000 MW of solar capacity by 2022. The government provided

attractive feed in tariffs to incentivize solar projects. The initial signs are encouraging as many solar plants are being commissioned. The next few years would therefore provide an opportunity for considerable learning from these projects. It will also help India develop an indigenous base for manufacturing of solar technologies.

However, building several utility scale grid connected solar farms requires large tracks of land and water (in case of solar thermal technologies). This may not be easy, particularly in densely populated country like India. Hence decentralized generation options should be closely pursued. For village or community level energy needs, a combination of wind, mini-hydel, solar and biomass can provide a solution. However, for the household level, perhaps solar is unique; as it can be scaled down even to light a single bulb. The challenges of decentralized generation are discussed in a subsequent section.

5. Universal Energy Access

Millions in India do not have access to clean energy for the most basic needs - lighting and cooking. 16% of the 600,000 villages in India are not electrified and due to last mile connectivity challenges, roughly around 60 million rural households depend on kerosene that is polluting and has several ill-effects and remains subsidized. Around 75% of the rural households and 18% of the urban households use traditional biomass for cooking and heating. Modern energy for lighting, health care needs and cooking can provide substantial socio-economic and health benefits to the community overall and to individual households. However, this has proven to be an enduring challenge, given the vast terrain and geographical diversity of the country and economic disparity among the citizens.

In the case of cooking, the fuel choice is often based on availability of modern alternatives, culinary habits, and affordability. The number of households using modern fuel sources such as kerosene and LPG in rural India constitute less than 10%. Given that biomass will continue to remain the mainstay for cooking in the near term, the design and increased dissemination of efficient cook stoves can help in reducing indoor smoke as well as reduce the dependence on traditional biomass which has several ill-effects.

In the case of electrification, given the demand-supply gap and high transmission and distribution losses in the country it is unclear that just extending the grid to remote areas alone can usher in good quality reliable electricity to the remote

villages. Even with significant capacity addition, the availability of quality and reliable power supply will be a challenge in the near future. Hence it is important to look into decentralized generation options which are affordable, economically and environmentally sustainable. Alongside, innovative financing, and institutional mechanisms have to be in place to increase the adoption in a sustainable manner.

6. Decentralized Generation

Decentralized power generation using locally available resources is thus considered an attractive option. The optimal solution is very location specific depending on the availability of local resources and demand. Solar, wind, mini-hydel and biomass could provide interesting possibilities for local energy supply. Decentralized generation can be at the individual level or at the community level (micro-grid).

There is considerable experience in the country in decentralized generation, particularly, biomass and solar. Several pilot projects have been attempted; however, these experiences have not scaled up. The learning from the initial global experiences highlights the following challenges:

- Institutional mechanisms
 - Ownership and operations
 - Price and availability of resources, particularly in the case of biomass as the opportunity cost of biomass is high as it is used for cattle feeding, cooking, heating, hut making etc.
 - Revenue model for pricing of energy given the subsidized tariffs in rural areas, particularly for irrigation. The energy tariff policies in India provide virtually free power supply to the irrigation sector. This is a disincentive for the decentralized generation model and also encourages inefficient water usage.
- Lack of adequate service and maintenance.
- Upfront capital cost particularly in the case of solar and lack of adequate financing mechanisms.

Among the decentralized options, solar energy has played an important role in the country. Globally, a large range of applications and institutional mechanisms

have evolved in the dissemination of solar technologies. This has made solar based applications flexible to meet the rural household's need. As a source of distributed energy, solar photovoltaic technologies can be used to electrify all the way from individual homes to communities. The significant penetration of solar home lighting systems requires the presence of a well-functioning market of suppliers, maintenance service providers and of course competitive pricing.

Solar home lighting systems have seen a wide adoption across the developing world and several different service models have been used. For example, while Sri Lanka and Bangladesh relied on microfinance^{vi}, Latin America (Honduras and Nicaragua)^{vii}, and in certain regions in Africa^{viii}, the leasing or micro-leasing approach was prominent. In Argentina franchisees are chosen based on competitive bidding and are given the responsibility of service providers. There are several merits and demerits with each of these models.

However, India is unique in having an extensive banking network, and rural regional banks have played an important role in the solar technology dissemination. A UNEP solar loan program in 2003 was one of the first instances of the Indian mainstream banks financing solar lighting systems^{ix}. In this case, the UNEP extended an interest rate subsidy. Market based dissemination models with interest subsidies, orchestrated by rural regional banks in India is likely to help increased adoption. This is an integral part of the national solar mission.

To support broader development needs of rural India, a comprehensive rural electrification program that takes into account a range of technologies, financial solutions and institutional mechanisms need to be planned. Low interest loans are a must to ease the periodic cash requirement to pay back the loan. However, the upfront down payment requirement by the banks from the customers is often the major barrier faced by end-users and hence innovative financing schemes keeping in mind the end-users' cash flow is critical.

To increase the penetration of solar energy solutions India's extensive network of banking institutions can be utilized. While it is unclear CDM benefits alone could help with large scale adoptions, earmarking funds towards subsidized loans targeting decentralized generation from renewable sources could prove to be beneficial. In addition, help with capacity building, policy and regulatory framework and affordable financing mechanisms are some of the other critical

factors to increase the uptake of decentralized generation from renewable sources.

7. Biomass and Bio – Fuels

Biofuels have come into increasing prominence because of the perceived scarcity (and distributional concentration in selected areas) of petroleum resources and the volatility in their price and supply. As oil prices reached record highs in recent years, several countries announced biofuels targets. For example, the US has an ambitious target of producing 36 billion gal (1.4×10^{11} l = 1.4×10^8 m³) of biofuels per year by 2020.

However, the benefit of bio – fuels to energy security and environment should be examined on a life cycle basis. For instance, corn ethanol has a net energy balance of around 1.34, which implies that the energy contained in a liter of corn based ethanol is only marginally (34%) more than the fossil fuel energy consumed in the process^x. As a result, corn ethanol doesn't provide either energy security or environmental benefits. In contrast, ethanol from sugarcane molasses has a net energy balance of 8 – 10.

Large scale bio – fuel production often comes in direct conflict with food production. A recent World Bank study reported that large-scale production of biofuels in the US and Europe and the related consequences of low grain stocks, speculative activity, and export bans accounted for almost 75% of the total food price rise^{xi}. The report also mentioned that Brazil's sugarcane-based ethanol did not have an appreciable impact on food prices. It also argued that the presence of subsidies and tariffs on imports added to the price rise and that, without such policies, the price increase would have been much lower. Another study determined that the current biofuel support policies in the European Union and United States would reduce greenhouse gas emissions from transport fuel by no more than 0.8% by 2015, but that Brazilian ethanol from sugarcane would reduce greenhouse gas emissions by at least 80% compared to fossil fuels^{xii}.

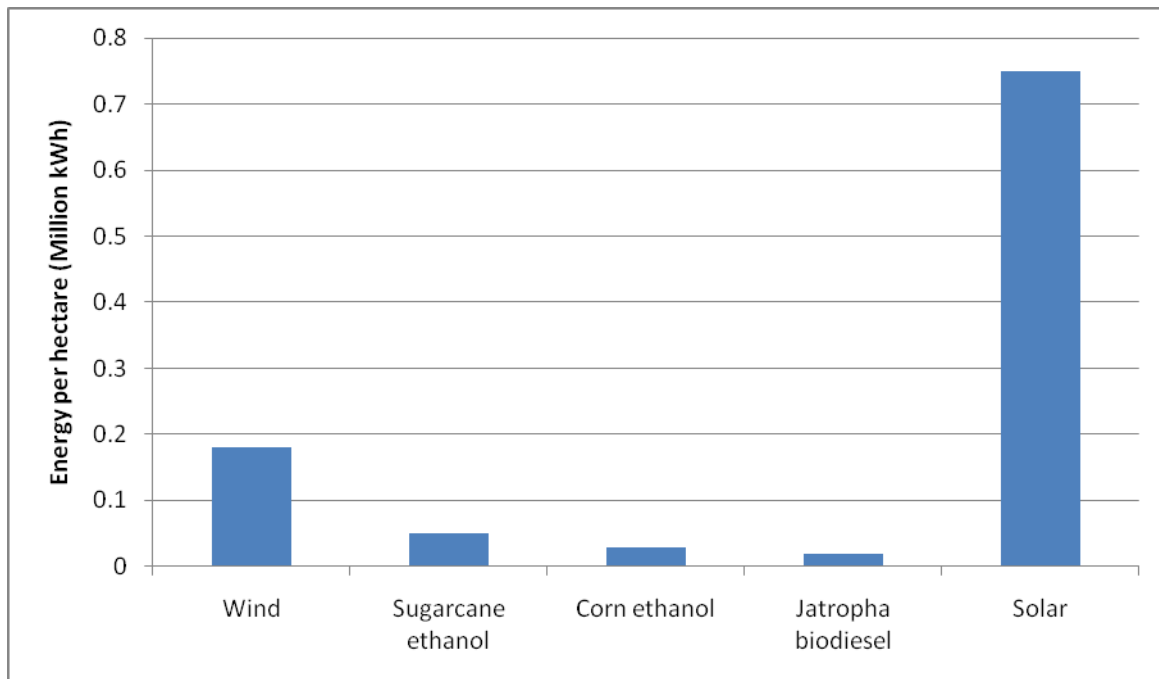
Another unanticipated impact of biofuels policy is the indirect land use change. Specifically, the bio – fuel targets announced in the European Union led to the large-scale clearing of forest and peat lands in Indonesia and Malaysia for cultivation of biofuel crops. Land clearing results in a large initial release of CO₂ to the atmosphere and it could take a few decades for this to be recovered by the

annual biofuel cycle^{xiii}. In fact, deforestation significantly increased Indonesia's CO₂ emissions and made the country among the world's leading emitters.

Therefore, bio – fuels should be pursued with caution. There are interesting options with Next Generation bio – fuels, in particular cellulosic ethanol and algae based ethanol. These do not conflict with the food chain. However, these technologies have to be technically and economically proven.

However, this is a model that should be pursued with appropriate financial and regulatory support as this alone will ensure development of the villages in short to medium run. There is also the issue that any energy option requires land. The figure shows that solar is the most efficient option for producing energy from an acre of land as compared to bio – fuels and even wind. This is because efficiency of photosynthesis is less than 1%.

Figure 4: Energy generation from various sources per hectare of land.



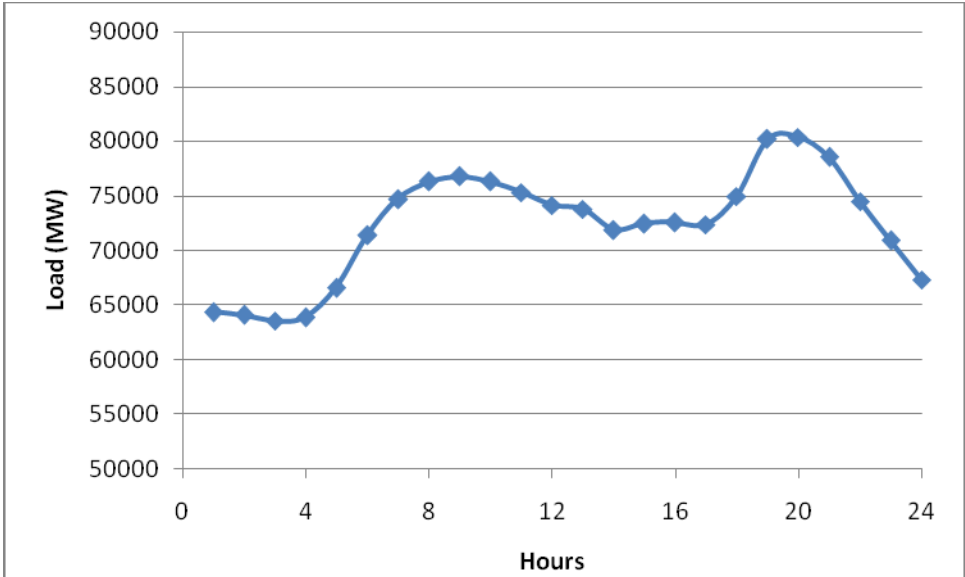
8. Smart Electricity Distribution Options

Any large – scale transition to a renewable based power generation is contingent on a parallel revamp of the transmission and distribution grid. The power grid of today looks essentially the same as that built a century ago and cannot handle the

integration of intermittent renewable sources. However, recent advances in telecommunication technologies has led to an exciting new paradigm in what is called the “Smart Grid”, which aims to use digital communications and control technologies to make the electricity supply system more robust, efficient, cost-effective, and amenable to renewables.

In the envisioned smart system, one would know exactly what power was going where and when and be able to act in response to conditions, either through direct control mechanisms or through economic signaling (changing the price). For example, today’s retail consumers have mostly enjoyed flat-rate tariffs for electricity, even though power at 5 PM is typically more expensive to supply than that at 5 AM. Figure 5 shows India’s load curve on a typical summer day. As the load reaches the peak, the utilities resort to large – scale load shedding to meet the peak power demand. The utilities are driven by commercial concerns and try to ensure supply to large cities, which have paying customers. The villages get hit as a result. Smart metering provides the opportunity for better peak management to ensure near uninterrupted supply.

Figure 5: India’s load curve on a typical summer day^{xiv}



At base, it would mean that consumers would be paying for the electricity they use, ideally at prices that directly reflect costs. It is just such microeconomic efficiency that has proponents excited. Conversely, fears have been raised about the complexity of such a system, about the undue financial burden it could place

on those least prepared to respond to dynamic prices (e.g., senior citizens), and about the potential it could pose for invasion of privacy and risk to consumer data. Government of India has embarked on a major program for reform of the electricity power transmission and distribution network with an outlay exceeding \$ 10 Billion. As part of this program, it is undertaking the deployment of a few pilot smart grid projects in various parts of the country.

9. Next Steps: International Policy and regulatory framework

The above sections highlight the global challenge of ensuring universal energy access to the 2 – 3 Billion which presently lack access to modern energy. This is a daunting task in its own right and it is further complicated by the constraint of reducing global CO₂ emissions. We have discussed the potential of a few select fuel and technology options, which is by no means exhaustive. However, a global transition to a radically different energy mix requires a concerted international effort covering three key aspects: Innovation and technology transfer, Funding and Policy and regulatory framework. We briefly flag these issues in this interim report. The final report will discuss these in more detail and also come up with clear policy recommendations.

Innovation and Technology transfer

It is clear that we need to pursue innovation and research and development of a portfolio of low carbon technologies. However, technology alone is not sufficient. Its success or failure depends on the over arching context of the country or region under consideration. For instance, India is pursuing research in the Fast Breeder and Thorium reactor technologies. China and India have undertaken major research programs in advanced coal technologies. Solar technology is presently tightly controlled by a few leading manufacturers in the US and Europe. Even the raw materials such as Silicon are available only in a few select countries thus providing them with an economic advantage in the cell manufacturing process.

Innovation and technology development should be undertaken in countries/regions which have a comparative advantage in the specific sector. Further, there should be significantly higher collaboration and mechanisms required for technology transfer. We will examine a few such illustrations in the final version of this paper.

Funding

Global transition to low carbon technologies is inherently an expensive option. For instance, most renewable sources are expensive as compared with conventional technologies. Wind is now almost cost competitive, but solar power is very expensive; almost four times that of coal based power generation. Developing countries would be unable to undertake such a transition in the absence of a global funding initiative to incentivize a large – scale deployment of renewable power. The present mechanisms such as CDM and World Bank/GEF funded projects have only gone so far and are not adequate for large scale adoption of renewable sources in developing countries.

We have to think out of the box for innovative options. One option is a Global support (such as Feed in Tariff). The underlying principle is to subsidize renewable sources using a tax imposed on very high energy consumers in the developed countries. The key questions to examine are:

- Is such a system workable?
- How much funding could it generate?
- And what is the international regulatory environment required?
- Else, what are the other funding mechanisms?

We will examine the viability of such possibility in the final version of the paper.

Policy and regulation

The international policy and regulatory framework should facilitate the global adoption of low carbon technologies. For instance, the nuclear regulatory framework was constituted in the backdrop of the cold war era. This may require a change as nuclear power is poised for expansion in countries such as India and China and they would require access to nuclear technology, material and equipment. Similar analogies can be drawn in other cases also such as solar power. The report will articulate clear policy recommendations which could be enacted under an international framework.

10. Authors

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11. Appendix: About C-STEP

CSTEP is a private, non-profit organization with a vision to undertake research in engineering, science, and technology where it is relevant to India's economic and human development. We work in subjects such as energy, infrastructure, materials science, information and communications technologies, and security.

Energy

India faces tremendous challenges generating sufficient energy to propel its growth in an environmentally and economically sustainable manner. CSTEP is working on projects related to energy efficiency, smart electricity grids, solar thermal, batteries and energy and climate policy.

Information & Communications Technology

Information and communication technologies present great opportunities for countries such as India that are in the process of rapid economic development to create the groundwork for shared growth. CSTEP has worked on both general and specific issues related to ICT for development in an Indian and international context.

Infrastructure

CSTEP is building a Next Generation Infrastructure Laboratory (NGIL) to study design and policy-related infrastructure questions with both innovative and conventional tools. The lab's main project is to create simulation-based games for policy analysis.

Security

India faces security challenges of all types: internal, external, economic, political, social, and environmental; CSTEP performs evidence-based analysis, some classified, of these challenges.

New Materials

New materials are key to improvements in human welfare. Our focus is on new material development in the energy area, with an emphasis on batteries. This has implications for energy conservation and efficiency, disposal of waste and environmental sustainability, and innovations for new methods of energy use.

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