Introduction

RAHUL TONGIA

Since the 1970s, if not earlier, renewables were touted as the energy of the future, but remained so for decades. However, that future has now arrived, and renewables are not merely a niche, but a mainstay of electricity supply, and growing in importance. What has changed? On the supply side, technologies have improved, most notably for solar and wind power. On the demand side, a Business As Usual model based on fossil fuels has proven limited in its ability to feed a growing appetite for electricity. Add to this is the pressure for sustainability, with environmental pressures ranging from local pollution (air and water) to global (carbon and climate change). Ultimately, the supply and demand have intersected moving renewable power towards viability.

While there is much enthusiasm and support for renewables in India, especially at the central government level, there are reasons for caution and improved policies when we consider the long-term plans for renewable energy. More than just the economics, there are issues of scalability, grid integration, consumer acceptance if not participation, etc., in addition to worrying about the broader transformation of the grid that renewables will entail.

The scope of this volume is broad, as demonstrated by the topics covered in the chapters (sole or lead authors listed below). While the focus is Renewable Energy, a sub-text of this work is the broader transformation the power system needs, not just from an economics or regulation point of view but also grid design, operations, and architecture. In the West, utilities and governments have already started grappling with the "utility death spiral" driven by renewables and technology, where small-scale renewable generation by end-customers (plus storage, smart grids, etc.) prompts them to reduce if not eliminate supply from the broader grid, raising the utility's costs (which still needs to serve "expensive" customers and also keep the grid stable), which further prompts others to exit the grid, and so on.

India isn't quite there yet, but broader changes are inevitable, in part driven by an unsustainable system of cross-subsidies which sparks its own exit strategies of captive power, renewable power, and even theft. Renewables have thus far mostly been grid-scale, feeding into utilities, but more and more, end-users will opt for renewable power, either distributed (small-scale) or even larger. The fundamental question this will raise is how will this impact the utilities, who must still be a provider of last resort, and keep the grid stable? Will this transition be gradual and managed, or will this be the straw that breaks the camel's back? This is the important conversation that must be started, on the future of the grid.

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This volume goes beyond targets and vision. Building on the expertise and analysis of the authors, the chapters offer insights for making renewable power sustainable in India, balancing challenges with opportunities and policy needs. Importantly, there remain a number of issues on which not only is there no answer offered (easy or otherwise), but the various authors themselves have differing points of view, all with valid points and counter-points. Ultimately, it is the need for dialogue, enunciation of tradeoffs, focused analysis, and transparent choices that will best serve the sustainable growth of sustainable energy in India.

PUTTING RENEWABLES IN CONTEXT

Aren't renewables sustainable by definition? Environment is only one of the pillars of sustainability, which must also cover economics and equity. Making renewable power viable for generators is easy – raise the price – but long-term sustainability requires buyer sustainability as well, which is sometimes more than just a utility (or even direct end-user), we have the state as a stakeholder, both financially and otherwise.

Potential - From Paper To Practical

Renewable power is doing exceptionally well in India. From Table 1, we can see that it is already 12% of the capacity in India, and a disproportionate fraction of the capacity being added presently. In fact, the share by capacity is expected to grow to roughly 18% within just 5 years. A less well publicized aspect of renewables is the low plant load factor (PLF, also called capacity utilization factor). While coal plants often cross 70%, the PLF of wind and solar is often just over 20%. While one could say the economics can work that out, the implications for the grid, especially because of variability, need special attention. At a national level, renewable generation is only about 5-6% of the total, and that too varying heavily by time including by season.

TABLE 1: Installed Electricity Capacity in India as of July 31, 2014

	CAPACITY (MW)
Renewable Energy (RE)	31,692.14
Total Capacity	250,256.99

SOURCE: CEA

A number of publications have talked about the enormously high theoretical capacity for renewables in India. While the capabilities for solar are easy to understand based on surface area (and several of our authors offer ranges for these), the potential for wind was more complicated and for many years used to be in the ballpark of 50,000 MW. Increasing the height at which measurements were made to 80 meters and further extrapolations have increased the official potential (as per the National Institute of Wind Energy, formerly known as C-WET) to the range of 100,000 megawatts. However, a number of other publications[1] indicate 600,000 – 800,000 MW of capacity potential for wind, if not more.

While there are limitations if not flaws of some of the studies (e.g., limited granularity), most scientists and analysts would agree that the potential is dramatically higher than the actual rollout. This prompts the more important question of why aren't we realizing a greater fraction of the potential? The answer is not because of the limitation of technology or inherent potential, but of policy, regulation, and business model issues. For starters, the wind-speeds in India are lower, often class 2 or 3 (on a scale of 1-5, with very few class 5 sites). Many of the best wind sites are already used, but their utilization some time back was often with less capable wind turbines – revamping existing sites has complex business implications. Second, there is the issue of logistics, starting with land acquisition, to construction (with poor roads and connectivity to increasingly remote sites), to interconnecting with the grid (termed power evacuation). Ultimately, these issues collide in economics, which is exacerbated by the high interest rates that impact all renewables (which are capital cost heavy). Economic concerns also extends to state utility finances, which raise risks, further raising costs of RE.

Solar power has grown tremendously in the last few years, spurred by state and national level support, notably the Jawaharlal Nehru National Solar Mission (JNNSM). The resource potential in India is very high by global standards, unlike wind, and projects are ramping up, though mostly at the grid (megawatt) scale, and not per-user through a solar panel on every roof. Grid scale solar inherently serves the broader grid, and doesn't require a battery, which an individual household system would if it were the primary source of power. Such a system, of small, household level solar panels has thus-far remained niche or for areas where the grid is absent or functionally absent (very poor supply), but this is changing very rapidly. As seen in Germany, which has a strong and stable grid, the rapid growth of solar PV (photovoltaic) systems was for grid-interactive (feed-in capable) ones, which are expected to grow in India as well, especially when pricing and operational norms for feeding-in become clear. Per the National Institute of Solar Energy (NISE)'s study of February 2014, the PV potential in India is 749 GW. [2]

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The other major forms of renewable power, micro-hydro and biomass based, haven't yet captured the imagination of most stakeholders (per MNRE, micro/mini-hydel have a potential of 19.75 GW, estimated for March 2014,[3] and biomass-based electricity has a potential of 18 GW from bio-residues and 5 GW for bagasse-based cogen[4]). Hydro is naturally very location-specific, and biomass has challenges of land use competition, reliability of the technology, and feedstock availability. In addition, if one were to compare rupees per unit energy, the greatest bang for buck from biomass is for liquid fuels for transportation, and not pow-

[1] *An early reassessment was by Lawrence Berkeley Labs; Phadke, A., Bharvirkar, R., & Khangura, J. (2011). "Reassessing Wind Potential Estimates for India: Economic and Policy Implications." Retrieved from http://ies.lbl.gov/sites/all/files/lbnl-5077e_1.pdf*

[2] *http://mnre.gov.in/file-manager/UserFiles/Statewise-Solar-Potential-NISE.pdf*

[3] *http://mnre.gov.in/file-manager/UserFiles/SHP-potential.pdf*

[4] *http://mnre.gov.in/schemes/grid-connected/biomass-powercogen/*

er generation. Nonetheless, there is enormous potential for using so-called waste biomass, especially in a co-generation mode where heat/steam are used for different processes such as sugar production, or even co-firing a tiny fraction within conventional coal power plants, which can be done with little if any modification.

THE ELEPHANT IN THE ROOM: ECONOMICS

The most often quoted figure of merit for electricity is a "simple" price in Rupees per kilowatt hour. The catch is a comparison of "x" rupees per kilowatt-hour versus "y" is misleading since power plants rarely cost a fixed amount at any given point in time. For traditional plants, fuel costs vary (grow) over time, while for capital intensive plants like renewables, the up-front costs are high. These are all brought into a single number for comparison based on levelizing, a technique that factors in the time value (discounting) for future money as well as future power production. The problem is this is assumption driven, and even value-laden. Market prices are only available for interest rates (debt), and, to a lesser extent, equity returns.

Even if one had 100% accuracy in predicting the output of renewables, which removes the uncertainty (stochasticity), there remains variability to contend with

Beyond this uncertainty, from a utility or grid operator perspective, the when, where, and other characteristics like predictability also matter enormously. Renewables like wind and solar are use-it-or-lose-it (from a grid dispatch operator's perspective, not only would these score high in terms of merit-order despatch with the lowest marginal costs, these are treated as "must-run" generators). These also vary over time both with some reasonable predictability as well as randomness (stochasticity). On the other hand, while a coal plant is despatchable (can be summoned or controlled), it cannot ramp production up or down very quickly. So-called peaking plants, capable of rapid ramp-ups or ramp-downs (like hydropower or open-cycle gas turbines), are needed to handle variability (not just of supply but even consumer demand).

Unfortunately, power procurement by Indian utilities has predominantly focused on unit costs, without factoring in such characteristics, which are worth not just signaling for but even paying for, as is done in many countries. Unfortunately, India is yet to develop markets (or non-market systems) for ancillary services (like frequency regulation, ramp-up/ramp-down, etc.). While the exact number varies based on grid conditions and alternative supply options, per several US studies, e.g., by the utility Xcel Energy, the increased variability of renewables above 20% or 30% penetration leads to approximately half a US cent/kWh in increased ancillary services costs and wear and tear implications of cycling alternative plants more due to renewables' variability.[5]

Even if one had 100% accuracy in predicting the output of renewables, which removes the uncertainty (stochasticity), there remains variability to contend with. The Indian grid mostly faces peak demand around 7 PM (based on examining 6 years data available from the National Load Despatch Center). Solar power is mostly unavailable at 7 PM, and even wind power isn't at its peak most often. Thus, for every kW of solar power added, one would still need 1 kW of some other despatchable power source to meet the evening peak, at least for the foreseeable future with a pronounced evening peak.

Considering this factor, IEEE (the major global electrical and electronics engineers Society) suggests treating the output of renewable power not as helping capacity,

[5] *Different grids have different costs based on alternatives, as seen in an IEA multi-country (International Energy Agency's Task 25 "Design and Operation of Power Systems with Large Amounts of Wind Power"), the summary of which is available at http://www.ieawind.org/task_25/PDF/W1W/WIW13_Task25_Summarypaper_final.pdf (October 2013).*

but rather as negative demand (at a capacity level, they suggest equating it to the maximum additional load that can be added reliably with that form of renewable power, which would approach zero for both solar (daily variations) and wind (seasonal variations)). Of course, this depends on the definition of "reliably" is, and there are studies indicating a capacity value of renewables in India in the range of 20-30 percent. If we treat renewable energy as negative demand, then its marginal value only equals the savings of displaced fuel. In theory one could consider avoiding diesel, but in practice the displacement is often coal (at the utility level). A more sophisticated analysis is recommended to truly understand the grid implications of RE variability in India, one that factors in not just supply and demand as declared but shortfalls (load-shedding), peak/off-peak, transmission limitations, etc.

If we consider a simple model for the economics of coal versus solar (not to claim the two are directly comparable), any assessment clearly depends on not only standard power plant variables like plant load factors, installed capital costs, interest rates, etc., but also case-specific decisions. Is one displacing imported (expensive) coal or domestic coal? Is one only considering fuel costs (from the negative demand perspective) or all the capital costs for coal as well? Analytic choices on these points can change the cost ratio for coal versus solar by a factor of 2 or 3. We dig into this more in the chapter on renewables economics.

MANY OPTIONS, MANY CHOICES

The history of renewable energy, worldwide, has involved support mechanisms, ranging from tax breaks to up-front support (e.g., the accelerated depreciation norms used for wind power in India), to feed-in-tariffs that offer a higher price than other generation sources. Such "subsidies" aren't necessarily inefficient, since renewables are still improving along the price-performance curve at a healthy clip (a learning curve effect, estimated on the order of 20% for solar, or even 40% in recent years). However, which support mechanism(s) work best, and what do they achieve are important questions that need reflective analysis.

One critical aspect of renewables is their concentration in favorable locations, notably in just 5 states (Table 2), which have over 85% percent of the country's Renewable Energy (RE) deployments. This obviously impacts grid integration and balancing, but it also impacts finances when we consider both utility ability (and willingness) to pay as well as state obligations and targets. Isn't coal also concentrated in just a handful of

TABLE 2: Concentration Of Renewable Energy (Re) In Select States (July 31, 2013)

STATE	CONVENTIONAL GENERATION	WIND	SOLAR (ABOVE 1 MW)	BIOMASS	BAGASSE	SMALL HYDRO	TOTAL RE (MW)	RE CAPACITY SHARE
Rajasthan	9,588	2,683	553	106		24	3,366	26.0%
Gujarat	18,479	3,164	857	31		6	4,058	18.0%
Maharashtra	27,137	3,008	206	127	996	332	4,669	14.7%
Karnataka	10,247	2,142	14	106	1,147	701	4,110	28.6%
Tamil Nadu	11,974	7,179	20	204	659		8,062	40.2%
Total (5 States)	**77,425**	**18,176**	**1,650**	**574**	**2,802**	**1,063**	**24,265**	**23.9%**

SOURCE: Central Electricity Authority (2013)[10]

[10] *Central Electricity Authority. (2013). Large Scale Grid Integration of Renewable Energy Source - Way Forward. CEA, New Delhi. Retrieved from http://www.cea.nic.in/reports/powersystems/large_scale_grid_integ.pdf*

states? Yes, and there are bottlenecks and costs associated with transporting coal. The takeaway for RE should be that concentration of capacity isn't a fundamental bottleneck, but one that requires investment and effort to manage.

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Resource availability mostly drives concentration of renewables, but policy support helps, so the next question comes to state level Renewable Portfolio Obligations – to what extent can or should these reflect the in-state realities of Renewable Energy potential? Just to list a few of the choices, (a) Set a uniform target everywhere. This makes some states "importers" and others "exporters" (which could be via credits/RECs (Renewable Energy Certificates), instead of actual power delivery across state borders); (b) Set up a small range of targets of Hi/Med/Lo based on resource potential; (c) Set up a precise target per state based on the respective potential, e.g., whatever the state potential may be, they should achieve, say, 25% of that to start with; (d) Let states decide on their own, through whatever mechanism they wish.

Most analysts do not recommend a one-size fits all approach, since variances are inherent and inevitable. This extends to more than target deployments but also any tariffs to be offered (feed-in). Do we want a regular determined RE tariff, e.g., state Commissions or CERC, or the market? One number never suffices, since wind speeds (or solar radiation) vary by location, in addition to other variables impacting costs. Even if we get a reasonable number for a state, it may not be appropriate across the entire state – even small variations as allowed by Maharashtra may not be sufficient to reach the ultimate potential. Instead, one could do the reverse – consider a market-based system for determining takers for a given site (ideally, where resources assessment is done, and there are single-window clearances for developers). In theory, a market is a good mechanism for price discovery, but there are a number of caveats to making markets work well.

It's worth pointing out that already a number of states are over 20% of capacity by RE, an oft-reported threshold for where renewables integration poses externality costs on the rest of the grid. That western number is for a stable grid – the Indian grid today has virtually zero reserve margins (unlike the 15-20% target in the west). The fact that the entire National Grid is interconnected is a start but not sufficient. At a national level we are still well below 20% RE, but at the level of both financial and despatch control (the state), the RE share is only going to grow for RE-heavy states. The point isn't to ask up to what point can the grid handle increased RE? There isn't a fixed limit. It can handle more and more, just at higher and higher costs of transmission and variability management.

How renewables policy unfolds will be a work in progress, with lots of choices, and tradeoffs. The fact that distinguished authors, and analysts can come up with divergent recommendations, (e.g., whether we need state-by-state renewables targets or a national targets) is a reflection of not only the challenging nature of sound policy but the fact that there are trade-offs for any policy. What we believe to be important in this process is transparency and a dialogue amongst stakeholders to ensure the top-down and bottom-up come together. A classic example of where this fell short was in wind power, where policies promoting wind power led to a rush of developments. In contrast, the transmission grid, especially at a state level, often failed to keep up, resulting in numerous cases where wind power evacuation became the bottleneck, and not wind capacity. In Texas, Germany, and other places, high renewables output has periodically resulted in negative prices for electricity! Without such mechanisms and with transmission bottlenecks, we end up wasting (backing down) a small but measurable share of renewable power.

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FROM OPPORTUNISTIC RENEWABLES TO THE FUTURE GRID

At the highest level, electricity sustainability cannot be viewed in isolation from broader transformations of the electricity grid, and all sustainability (including energy efficiency) should be coordinated, if not brought under an integrated National Electricity (or even Energy) Sustainability Mission.

Much of renewable power in India added in the last few years has been what could be described as opportunistic. This term is used without any negative connotation – when the wind blows or the sun shines, power is generated, without significant storage of electricity. This is the cheapest RE possible. However, as and when the scale of RE grows, opportunistic growth, that too without holistic planning (operational or financial), will lead to distortions in the rest of the grid.

For an end-user, while RE may be attractive, his or her benchmark is traditional supply, which is often expensive through cross-subsidy designs (for select classes of end-users) or simply unreliable. However, just like large users exiting traditional utility supply through Open Access never took off as planned (due in part to subtle if not overt hostility by state utilities), continued state-level utility support for RE cannot be taken for granted indefinitely. This is especially true if we consider economics from a utility and despatch choice perspective. Fundamentally, renewables shouldn't be considered only a generation issue – these have enormous operational impacts on the grid. With holistic planning, we can move from opportunistic and perhaps limited RE to what some observers have called the Future Grid, one that is robust, flexible, and capable of a very large share of RE.

A subtle policy recommendation for thinking of the economics and operations of renewables worth re-iterating is to think dynamics, and at the margin, i.e., adding (or removing) one unit of power at a particular location, what does it do to the rest of my system. The variability of renewables actually results in unplanned environmental impacts, something the use of average numbers cannot capture (fast-acting fossil fuel plants like gas turbines or diesel, used to offset renewables' variability, have higher fuel consumption and pollution emissions when operated in a cycling mode, which, per one study, measurably reduced some of the environmental benefits of renewable power). Thinking dynamics could improve everything from grid operations (variability) to finance (time of day pricing) to innovation (storage technologies and Smart Grids).

Renewables have a bright future, and must play a leading role in India's energy security and growth. They aren't a panacea, but a vital tool in the broader spectrum of India's electricity future. For sustainability, renewables cannot be viewed in isolation, but rather as part of a transition if not transformation of the grid, which includes variable and dynamic pricing, distributed generation, storage technologies, smart grids, etc. Of course, no discussion of the future of the grid in India can ignore the other elephant in the room, agriculture (pumpset) supply, which itself cannot be solved as an energy problem but a broader challenge spanning land, subsidies, crop-choices, water tables and availability, fertilizers, support prices, etc.

The highest level takeaway we hope to convey is that sustainable growth of renewable energy isn't a rushed dash for more capacity, but a longer term endeavour that has to factor in economics, grid integration, consumer and utility demand, and innovation. Broader transformations of the power grid are anyways viewed as inevitable, given the current system is both loss-making and has failed to deliver on its social contract (with many users lacking supply). The recent announcement by the government increasing the target for solar power by 5 times to 100,000 MW by 2022 is a useful and ambitious target, but such a target should be there to guide stakeholders and the enabling environment, and not a hard-and-fast obligation. In that vein, not reaching the target (if that happens) should be viewed not as a failure but simply a reflection that the time and ecosystem wasn't right. Any target can be met, with heroic or disproportionate effort, or unintended consequences. The goal is to meet the target sustainably.

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We hope this volume provides a few insights and recommendations that engender a deeper dialogue on the issues and trade-offs, leading to policies that accelerate the deployment and enhance the sustainability of renewable energy in India.