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Sustaining India's Economic Growth

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Abstract

Depleting fossil fuel reserves and the tangible impact of climate change have mandated nations to review national energy-mix policies. The Government of India's target of 7% GDP growth rate will require 1,476 GW installed power capacity by 2052. But historical constraints since 1951 on growth of power capacity (like land acquisition, water, fuel supply chains and silting of dams) have limited power capacity growth in India to a maximum 4GW/year. Should these historical constraints continue into the future as "business-as-usual" scenarios, just 472 GW would have been realized by 2052, effectively slowing India's GDP growth rate to 3.5% per annum. Assuming those constraints affect only coal-based thermal power plants and that there will be no constraints to realizing Government targets for nuclear, hydroelectric, wind and solar power capacities, 932 GW might be realizable by 2052, yielding 5.5% GDP growth rate. Even with 5.5% GDP growth, the nation will have to increase annual power capacity from a historical peak of about 4 GW/year to unprecedented levels of 18 GW/year in 2032 and 28 GW/year by 2052.

India's emphasis is now on terrestrial solar power. This type of energy is clean and perennial, although its availability is limited to an average 5.6 hours per day. Solar energy harvested in space is recognized as an always available 24x7 source. For a sustained 7% GDP growth rate targeting 1,476 GW in 2052, and as an "insurance policy" for shortfalls in achieving power capacity growth using terrestrial sources, this paper presents a Space Solar Power profile that increases from 17 GW in 2017 to 544 GW in 2052. This added SSP capacity almost doubles India's per capita GDP, delivering a net GDP benefit to the nation estimated to be worth over $100 trillion. The net carbon avoided by SSP substitution would be about 66 million tonnes, in addition to 9 million tonnes of carbon avoided by the National (200 GW Terrestrial) Solar Power Mission. The technology for building and orbiting space solar power stations is complex and politically sensitive. Some 10-15 years may be required to implement a working system in space. So, the outline of an advanced space transportation system based on two decades of design work on affordable space solar power for India is also briefly described.

Strategic Goals and Policies

India's population exceeds 1 billion. Its per capita GDP is among the lowest in the world. India stands 134th in the Human Development Index among nations. Climate change is expected to have an adverse impact on economic growth among developing countries, especially in South Asia. Energy is widely thought to be the principal engine for economic growth. Access to energy can multiply human labour and increase productivity in agriculture, in industry and in services. To sustain economic growth, energy supplies have to grow in tandem.

The Planning Commission of India in its Integrated Energy Policy Report of August 2006 advocated that an 8% GDP growth rate be sustained for the next 25 years.[1] In June 2008, the Prime Minister of India announced a National Solar Mission recommending a massive build-up of terrestrially distributed solar power plants for rural areas.[2] This mission has the potential to directly accelerate human development and reduce poverty levels in a manner that could not be achieved in centuries gone by. In May 2009, the Government of India announced a targeted GDP growth rate of 7% per annum. In June 2009, the Prime Minister addressing Parliament urged the nation to target for 9% GDP growth rate.

Energy Elasticity: Historical Growth Projections

The relationship between GDP growth rate and growth rate of electric power capacity is called "elasticity." This is an important metric that determines whether socio-economic growth is sustainable. Energy elasticity in India has been falling over time with increasing GDP.[1] A constant energy elasticity of 0.775 for the future period 2010-2052 has been assumed as one of the basic premises for the analysis presented in this paper.[3] The installed power capacity now in India is 176 GW out of which 148 GW is from utilities only (not including biomass).[4] Values from 1951 to 2009 for each power source are shown in Table 1.[4]

Year	Total Thermal Power (GW)	Total RE (Non-Solar) Power (GW)	Total Non-Utilities Power (GW)	Total Nuclear Power (GW)	Total Hydro Power (GW)	Total Power (All Sources) (GW)	Total Power (Utilities Only) (GW)
1951	1.1	0	0.6	0	0.6	2.3	1.7
1961	2	0	1	0	1.9	4.9	3.9
1971	7.9	0	1.6	0.4	6.4	16.3	14.7
1981	17.6	0	3.1	0.9	11.5	33.1	30.0
1991	45.8	0	8.6	1.5	18.8	74.7	66.1
2001	73.6	0.2	16.2	2.9	24.9	117.8	101.6
2006	88.3	4.5	21.3	3.4	28.1	145.6	124.3
2007	93.3	6.4	22.3	3.9	28.7	154.6	132.3
2008	101.5	8	25	4.1	28.3	166.9	141.9
2009	104	13.2	27	4.1	26.7	175.0	148.0

Table 1. Baseline Historical Data of Installed Power Capacity in India from Economic Survey, July 2009.[4] (click image for larger view)

Year	Total Thermal Power (GW)	Total RE (Non-Solar) Power (GW)	Total Non-Utilities Power (GW)	Total Nuclear Power (GW)	Total Hydro Power (GW)	Total Power All (Sources) (GW)	Total Power (Utilities Only) (GW)
2010	108.6	15.8	28.5	4.7	26.7	184.3	155.8
2011	113.2	18.5	30.1	5.2	26.8	193.8	163.7
2012	118.0	21.2	31.7	5.8	26.8	203.5	171.8
2017	143.1	24.3	33.5	6.4	26.8	234.0	200.6
2022	170.3	27.6	35.4	7.1	26.8	267.2	231.8
2027	199.8	31.2	37.5	7.8	26.7	303.0	265.6
2032	231.5	35.1	39.7	8.5	26.6	341.5	301.8
2037	265.4	39.4	42.1	9.3	26.5	382.7	340.5
2042	301.5	43.9	44.7	10.0	26.4	426.5	381.8
2047	339.7	48.7	47.4	10.9	26.2	472.9	425.5
2052	380.2	53.7	50.3	11.7	26.0	522.0	471.7

Table 2. "Business-as-Usual" Power Capacity projection 2009-2052, Logarathimic Series Extrapolation of 1951-2009 Trend. (click image for larger view)

Reading from Table 2, the rate of growth of total power from all sources over 42 years is 2.6% per annum; while growth rate of utilities power alone is 2.8%. It may thus be assumed that the "Business-as-Usual" 1951-2009 power growth scenarios extrapolated to 2052 would result in a mere 2.7% energy growth rate. This, in turn, would yield a GDP Growth Rate of only 3.48% assuming energy elasticity is 0.775.

Integrated Energy Policy Report

In 2006, the Government of India's Planning Commission set up a special Policy Committee to suggest new energy-mix options to achieve a growth rate of 8-9%. Taking into account perceived constraints, the Committee issued in August 2006 an Integrated Energy Policy Report recommending an aggressive energy growth policy up to year 2052 for all energy sources with the exception of thermal (coal) power where projections were made to 2032 for 294 GW installed capacity.[1]

Since no projection for coal was available to 2052, and considering various acknowledged constraints in respect to mineable coal capacities, coal quality, land acquisition and water availability, the "Business-As-Usual" trendline methodology was used to project thermal (coal) power capacity in 2052. This approach indicated an installed thermal power capacity of 231.5GW in 2032, just 21% lower than the 294 GW recommendation of the Planning Commission. Similar 2052 projections were made for such non-utility power sources as biomass.

In 2008, the Government of India announced the addition of Terrestrial Solar Power to its energy growth plan, with 200 GW targets for 2052.[2] These numbers have also been factored into Table 3 below that sets out the energy-mix and growth profile as projected up to 2052, including historical growth constraints placed on thermal (coal) and non-utilities power sources.

Total Power (Utilities Only) (with Solar Peak Power-to-Baseload Ratio=5.6/24) (GW)	Year	Total Thermal Power Log-Trendline (GW)	Total RE (Non-Solar) Power GoI Target (GW)	Total Non-Utilities Power Log-Trendline (GW)	Total Nuclear Power GoI Targets (GW)	Total Hydro Power GoI Target to 2032 (GW)	National (Terrestrial) Solar Mission Targets Day Time Peak Power (GW)	Total Power All Sources (with Solar Peak Power-to-Baseload Ratio = 5.6/24) (GW)
160.7	2010	108.6	13.8	28.5	9.0	28.8	2	189.2
171.3	2011	113.2	14.4	30.1	12.0	31.1	2.5	201.4
181.3	2012	118.0	15.0	31.7	14.0	33.6	3.1	213.0
218.1	2017	143.1	18.6	33.5	18.0	36.3	9.0	251.6
293.4	2022	170.3	23.1	35.4	22.0	72.6	22.9	328.8
379.7	2027	199.8	28.6	37.5	33.5	106.7	47.1	417.1
480.8	2032	231.5	35.5	39.7	51.1	150	54.4	520.5
564.9	2037	265.4	44.0	42.1	78.0	150	117.9	607.0
658.4	2042	301.5	54.6	44.7	118.9	150	143.4	703.1
779.3	2047	339.7	67.7	47.4	181.2	150	174.5	826.8
931.	2052	380.2	80.0	50.3	275.0	150	200	982.1

Table 3. Power Capacity Projection [2009-2052] with Integrated Energy policy Report & National Solar Mission Targets (Thermal & Non-Utilities by 1951-2009 tren Extrapolation). (click image for larger view)

Reading from Table 3, the rate of growth of total power from all sources over 42 years is 4.2% per annum; while growth rate of utilities power alone is 4.4%. It may thus be assumed that the "Business-as-Usual" scenario modified for Government growth targets as set out in the Integrated Energy Policy Report with power growth scenarios extrapolated to 2052 would result in 4.3% energy growth rate. This in turn would yield a GDP Growth Rate of 5.55% assuming energy elasticity is 0.775.

However, the Government targeted 7% GDP growth rate with Energy Elasticity at 0.775 would call for power capacity growth at 5.42% every year from 2010 onwards on a base of 160.7 GW. By 2052 the installed power capacity should be about 1,476 GW for sustained 7% GDP growth.

The Integrated Energy Policy Report Targets, with historical constraints placed on coal, would result in only 932 GW in 2052. How, then, is this gap of 554 GW to be filled? This paper advocates India's power capacity shortfall gap be filled by access to a non-constrained, non-terrestrial source of energy, namely Space Solar Power.

Constraints on Installed Power Capacity in India

Foremost among the reasons for growth-limiting constraints on Power Capacity in India are: 1) Political turmoil and serious breakdown of law and order in the land acquisition process, especially when diverting scarce agricultural land for industrial purposes; 2) Tendering tangles, delayed statutory clearances even when acquiring non-arable land; 3) Disjointed fuel supply chains and a severe shortage in facilities to manufacture power equipment (Note that India has entered a phase where its industrial capabilities appear inadequate to expand electric power plants, a hen-and-egg situation); and 4) Severe shortages in water supplies for these power plants, due to drying and silting up of rivers and other water sources associated with climate change.[5]

Rapid capacity expansion is important for ambitious rural electrification. Power-for-all programmes and shortfall in power capacity build-up is compelling states to give away thousands of crores (billions of dollars) worth of electricity free to the farming community for agricultural operations. The adjacent Figure 1 illustrates that for just for 5.5% GDP growth, the nation has to gear up for annual power capacity additions from the historical peak of about 4 GW/year to unprecedented levels of 18 GW/year in 2032 to 28 GW/year by 2052. This growth must be achieved in the face of severe economic, environmental and other constraints.

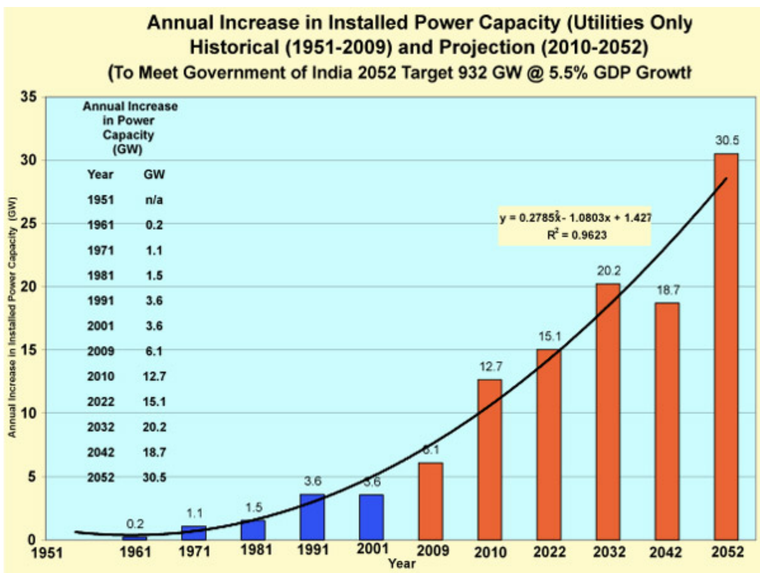

Figure 1. (click image for larger view)

Problem to be addressed

In 2008-09, against a target of 11.06 GW only 3.6 GW capacities were added. The loss to businesses across the country was reported to be Rs 43,000 crores (about $ 9 billion) in 2008 alone.[5] For 5.5% energy growth rate, India would have needed a minimum of 6-8 GW to be added in 2009. To meet these targets, annual power capacity additions will have to increase dramatically from a historical peak of 3.6GW/ year to 18-20 GW/year in 2032 and 28-31GW/year in 2052.

These are formidable and unprecedented levels of annual power capacity additions. For several reasons, capacity addition for thermal, nuclear and hydroelectric power plants has lagged during the last five years and the installed capacity for hydroelectric power is reported to be actually falling. Hence, the Indian Government proposes to force the pace of hydroelectric power development, a difficult goal to achieve in a democracy sustained by the majority rural agricultural population. The Indo-US Nuclear Agreement serves to accelerate the acquisition of new nuclear power plants and the import of uranium supplies. India's indigenous Fast Breeder R&D programme based on thorium fuel is expected to enter commercialization stage by 2020.

Addressing the Strategic Power Capacity Shortfall

Table 4 sets out India's total power capacity profile for 2010-2052, without and with space solar power. It is seen that a SSP capacity build-up profile increasing from 17 GW in 2017 to 544 GW in 2052 is adequate to ensure a sustainable 7% GDP growth rate from 2010 to 2052. SSP can provide an "insurance policy" for shortfalls in required power capacity growth.

These results were presented at the IAA-SSP Toronto Conference 08-10 September 2009.[7]

Year	Total Power (Utilities Only) (with Solar Peak Power-to-Baseload Ratio = 5.6/24) (GW)	Installed Power Capacity Required to Sustain 7% GDP Growth (@0.775 Energy Elasticity (Utilities only) from 2010 (GW)	Installed Capacity Requirement for Space Based Solar Power System (GW)
2010	160.7	160.7	
2011	171.3	169.4	
2012	181.3	178.6	
2017	218.1	232.6	14.5
2022	293.4	302.8	9.4
2027	379.7	394.3	14.7
2032	480.8	513.5	32.6
2037	564.9	668.6	103.7
2042	658.4	870.6	212.2
2047	779.3	1133.6	354.3
2052	931.8	1476.1	544.3

Table 4. Requirement for Space Solar Power.[7]. (click image for larger view)

Economic and Carbon Sequestration Benefits of SSP

The net benefit to India's economy will be a near-doubling of its GDP per capita when 554 GW of SSP are added to the national grid. The actual increase in GDP would be $103 trillion. For greater accuracy and completeness, the reader should note that the GDP comparison is based on electricity consumption source-wise and not installed (nameplate) capacity alone.[7]

Assuming 1.256 Kgs/Kwh CO_2 avoided by use of solar power, the net carbon sequestered by the Space Solar Power profile by years 2017 (17 GW) and 2052 (554 GW) would be 66 million tonnes. This is in addition to 9 million tonnes of carbon avoided by the implementation of the National (Terrestrial) Solar Power scheme that is expected to deliver 200 GW by 2052.

Progress towards Low Cost Space Transportation

India is among the few spacefaring nations of the world who have the capability to effectively participate in global missions for space solar power and related space transportation systems. Throughout the 1990's, advocacy for SSP increased in India and the US. At an International Conference on High Speed Air & Space Transportation in Hyderabad in June 2007 organized by the Aeronautical and Astronautical Societies of India, leaders from D-R-D-O- and I-S-R-O advocated a global aerospace and energy mission. They placed on record their recommendation that "there is a need to generate a national consensus for the Global Aerospace & Energy Initiative, determine the sources and uses of funding, and evolve a suitable management structure and system to plan and implement the mission." With the same population density and hence land availability constraints as India, Japan also has made quiet, highly impressive studies advancing the technological base for space solar power implementation.

Cost of Access to Space

It is estimated that the cost of transportation delivering space solar power plants into low earth orbit, and then subsequently transferring them to their parking orbits accounts for more than 50% of the SSP capital cost. In September 2000, former NASA space engineer John Mankins testified before the U.S. Congress that that recurring launching costs in the range of $100-$200 per kilogram of payload to low-Earth orbit is needed if SPS are to be economically viable.[6] Until current date, no nation has developed and tested space launch vehicles that will meet those cost targets.

India's interest in SSP originated in 1987, with the conceptual design of a Single Stage to Orbit fully reusable aerospace vehicle called Hyperplane. Over 22 reusable aerospace launch vehicles have since been designed world over. None have been made operational so far. ISRO has taken up a programme to develop a RLV (reusable launch vehicle) Technology Demonstrator somewhat on the lines of Japan's Hope concept. The cost of access to space depends on a host of factors, principally, the reusability of the vehicle and its hydrogen fuel fraction. Above all, if R&D investments are to be amortized in commercial service, the cost of access will depend on the size of the market for space applications, as measured in tonnes of mass flowing every year into space. Currently the cost of access to space is $25,000 for the "Shuttle" that has a hydrogen fraction of 10%, a payload fraction of 1.5% and is reusable about 10 times. To achieve a cost of $100 to $200 per kg in LEO, a SSP transportation system has to be reusable at least 100 times, and have a payload fraction at least 10 times that of Shuttle, namely, 15%.

It has been scientifically established independently in India and abroad such high payload fractions are attainable only when the vehicle carries no liquid oxygen on board at take-off, but collects and liquefies oxygen while climbing to orbit in hypersonic flight regime. A study by scientists in the Applied Physics Laboratory of John Hopkins University in 1964 reported payload fractions as high as 30% when air is collected, liquefied oxygen separated and stored as the hypersonic vehicle accelerates from Mach 5 to 7 in atmospheric flight. India's reusable launch vehicle design studies in 1987-1996 independently reported 4-12% payload fraction, depending on the take-off weight of the vehicle. A regression law is determined for several RLV design concepts from the US, Europe, Japan and India. This is the "Design-to-Cost Curve for low cost space transportation for SSP missions .

An Integrated Design Approach Needed

The next step recommended is for India to prepare a Detailed Feasibility Study on Space Solar Power and Reusable Space Transportation System as an integrated mission and systems design effort with assistance from other interested nations. This would include advanced, reliable space transportation systems that have high payload efficiency [>10%] and payload delivery costs < $200 per kg specifically for the SSP payload as well as Space Solar Power satellites and orbital assembly technologies. The funding for this Detailed Feasibility Study and critical technology demonstration could be around $100-200 millions over 2-3 years.

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