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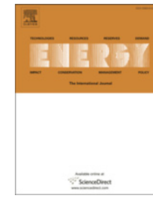

Research highlights

► With 8% GDP growth rate, import dependence for energy in 2030 will be 29% to 59%. ► By 2031 due to better energy efficiency and renewable use, CO_2 emissions fall by 35%. ► Improved efficiency and mass transport use will reduce oil demand by 25% in 2030. ► Energy efficiency and conservation will ease coal demand by 38% in 2030. ► Energy intensity can be reduced by 20% with commercially viable technologies.

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India's energy needs and low carbon options

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ABSTRACT

India's aspiration for economic growth has consequences for energy growth and CO_2 emissions. This paper examines India's need for energy with 20 year perspectives. From an earlier paper by K. Parikh et al. (2009), demand scenario are examined from the supply perspectives ranging from coal, hydrocarbon, nuclear, hydrogen, hydro and other renewable etc. None of these are substantial and India will have to rely on imports. The need for energy has to be reduced by drive for energy efficiency and renewable energy. Government programmes for the above are also commented upon. Though India's CO_2 emissions are unlikely to grow very much due to energy scarcity and energy mix the article examines the potential to reduce CO_2 emissions and the associated costs involved in various options. It finds that 30% reduction in CO_2 emissions by 2030 is feasible but would involve additional costs. The most promising option is to reduce energy demand by various measures to increase energy use efficiency in production and consumption.

1. India's energy challenge

India faces formidable challenges in meeting its energy needs and providing adequate and diverse forms of energy of desired quality to users in a sustainable manner and at reasonable costs. With nearly 40% of the households classified as below the poverty line in the latest estimate [1], India needs economic growth for human development, which in turn requires access to clean, convenient and reliable energy for all. As India aspires to attain 8–10% growth rate, the quantity & quality of energy needed would increase substantially. The nature and dimension of the energy challenge becomes clear when we look at the energy scene in the country today. In a special issue of this journal edited by J Parikh and N. Lior [2] a number of papers have addressed various issues of energy and its sustainable development in India. In that issue J. Parikh and N. Lior summarise India's energy scene briefly but do not link it with carbon emissions and energy supply issues arising from scarce resources compared to the demand and new technologies needed. On the other hand J. Parikh et al. [3] give a detailed assessment of CO_2 emissions by sectors for the Indian economy for 2003; but do not reflect on future emissions and strategies.

1.1. The energy scene

Per capita consumption of energy in India is one of the lowest in the world. India consumed 530 kg of oil equivalent (kgoe) per person of primary energy in 2007 compared to 1480 in China, 7750 in the U.S. and the world average of 1820 [4]. India's energy use intensity for generating a dollar worth of Gross Domestic Product (GDP) measured in terms of Purchasing Power Parity (PPP) that compares what it would cost in a country to buy a basket of goods that costs 1$ in US at 2000 prices (GDP_PPP_$2000) at 0.15 kgoe is better than the world average of 0.20, China's 0.20 and US's 0.20. However, it is 25% higher than UK. Clearly, significant reduction in the energy intensity of growth can be achieved based on existing technologies. India's CO_2 intensity is also one of the lowest at 0.22 kg of CO_2 per dollar of GDP PPP_$2000. This compares with 0.61 for China, 0.50 for US and 0.47 as global average.

This low use of energy is unevenly distributed and millions of households do not have access to modern energy. As per the National Sample Survey of 2004–05 [5], 84% of the 160 million rural households, 84% cook with biomass based solid fuels such as firewood, agricultural waste and animal dung. Even in Urban areas 23% of the 72 million households use firewood for cooking. Some 70 million households did not have electricity in 2004–05 in the country. See Table 1. The burden of use of such traditional dirty fuels is enormous especially on women and children. A study based on an integrated survey covering 15,293 rural households from 148 villages in three states of rural North India and one state in South India show the importance of clean fuels [6]. The study estimated that

- 85 million households spend 30 billion hours annually for fuel wood gathering.
- Respiratory symptoms are prevalent among 24 million adults of which 17 million have serious symptoms.

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Table 1
Source of energy for cooking and lighting (Percent of rural and urban households).

	Cooking		Lighting	
	Rural	Urban	Rural	Urban
Firewood and Dung	84	23		
LPG	9	57		
Electricity			55	92
Kerosene	1	10	44	7
Total Households (millions)	160	72		

- 5% of adults suffer from Bronchial asthma, 16% from Bronchitis, 8.2% from Pulmonary TB and 7% from Chest infection.
- Risk of contracting respiratory diseases and eye diseases increases with longer duration of use of biofuels.

Using a then prevailing minimum wage rate of Rs.60 per day, total economic burden of dirty biomass fuels was estimated to be Rs.300 billion comprising of opportunity cost of gathering fuels, working days lost due to eye infections and respiratory diseases, and the cost of medicines.

The details of primary energy supply by fuels are given in Table 2. The dominance of coal is seen. Indian coal has a high ash content and hence a low specific energy of 17.17 Mj/kg. Even so 42% of the energy is provided by coal. The table also shows large import dependence for oil.

For converting electricity to peta joules (PJ), the IEA conversion factors are used. These conversion coefficients distort the contribution of hydro and wind energy compared to electricity obtained from say coal. One KWhr of electricity from coal is assigned a primary energy value which is more than thrice that from one KWhr of hydro electricity. As a result the contribution of hydro electricity appears to be only 2.3%. This is even more starkly seen in Table 3 which provides the form in which energy is consumed. Electricity constitutes only 14.2% of energy consumption, even though much of the coal goes into power generation.

Table 4 shows the installed capacity and gross electricity generation by source of energy (i.e including auxiliary consumption by power plants). Coal and lignite provide nearly 60% of electricity and hydel provides 16%.

Given the very low level of energy consumption, India's energy use needs to grow. This paper attempts to discuss how much energy is needed, how this can be met, what is the role of renewable resources and other low carbon options and what is India planning to do to reduce emissions. In Section 2, a brief review of India's energy needs over the next two decades is given. Section 3 looks at India's low carbon options in the context of its energy resources and Section 4 looks at what is India doing to pursue low carbon development. Section 5 concludes.

Table 2
Primary energy supply in 2007.[a]

Energy source	Units	Quantity domestic	Net imports	Energy PJ	Percent share in total PJ
Coal	Mt	457	29	8343	41.9
Lignite	Mt	34	0	408	2.0
Crude oil	Mt	34.1	121.7		
Petroleum products	Mt	34.1	121.7	6523	32.7
Natural gas	Bcm	32.4	0	1221	6.1
LNG	Mt	0	8.3	427	2.1
Hydro energy	TWh	120.9	5.3	454	2.3
Nuclear Energy	TWh	17	0	186	0.9
Renewable including wind	TWh	25.2	0	91	0.5
Fuel wood + Animal Dung[b]	Mtoe	155	0	2271	11.4
Total energy Supply				19924	100.0

[a] Refers to financial year from april 1, 2007 to march 31, 2008.
[b] Projected based on IEP.

Table 3
Energy consumption by fuels and forms.

Form of Energy	Units	Quantity	Energy PJ	Share in PJ
Coal	Mt	123	2111	14.4
Petroleum products	Mt	131.6	6523	44.6
Natural gas	Bcm	27	1221	8.3
LNG	Mt	8.2	427	2.9
Electricity	TWh	578	2081	14.2
Fuel Wood + animal dung	Mtoe	155	2271	15.5
Total	PJ		14634	100

2. Estimation of energy needs

The Expert Group on Integrated Energy Policy chaired by one of the authors (K Parikh), projected [7] total primary commercial energy requirement on the basis of elasticities of total primary commercial energy (PCE) and electricity generation w.r.t. GDP. These elasticities give percentage change in commercial energy requirement or electricity generation for one percent change in GDP. The elasticities obtained from time series data of India's commercial energy use were also compared with estimates from cross country regressions [7].

Elasticity of total primary commercial energy supply (TPCES) w.r.t. GDP estimated from time series data of India is falling. That is, India is using less and less energy for generating a $ of additional GDP at constant prices – adjusted for inflation. The elasticity based on data from 1990–2004 was estimated to be 0.80. Other countries with per capita GDP in the range of 2000–8000 measured in US$ PPP_$2000 have estimated elasticity of 0.78. The estimate of elasticity of electricity generation w.r.t GDP based on data for 1980–2004 was 1.30 and based on data from 1990–2004 was 1.06 for India whereas the estimate from cross country data was 1.25 for the GDP range of 2000–8000 PPP_$2000 and was 1.09 for countries with GDP exceeding 8000 PPP_$2000. Based on these estimates, elasticity for projections of electricity requirement was assumed to fall from 0.95 for 2004 to 2010 to 0.85 for 2011 to 2020 and to 0.78 for 2021 to 2031. The requirement of electricity was projected for GDP growth rates of 8%. These were described in detail in an earlier article [8]. Hence we only summarize the results for GDP growth rate of 8% in Table 5. Since electricity generation is the major user of primary fuels, the TPCES depends on the fuels used for electricity generation and the fuel efficiency of power plants. Alternatives for electricity supply are assessed in an optimization model using the projected electricity requirements.

Table 4
Installed capacity and gross electricity generation by sources 2007. Q4

Source	Installed capacity on 31.03.08 GW	Gross generation TWh	Load factor	Percent TWh
(i) Utilities				
Hydro	35.9	120.4	0.38	14.8
Coal lignite	76	487	0.73	59.9
Nuclear	4.1	17	0.47	2.1
Gas	14.7	69.7	0.54	8.6
Renewables	11.1	25.2	0.26	3.1
Diesel	1.2	3.4	0.32	0.4
(ii) Total Utilities	143.1	722.6	0.58	88.9
(iii) Captive (1 MW and above)				
Hydro	0.1	0.2	0.38	0.02
Steam	11.8	53.6	0.52	6.6
Gas	4.2	17.0	0.46	2.1
Diesel and Wind	9.0	9.7	0.12	1.2
(iv) Total captives	25.0	90.5	0.41	11.1
(v) Total	168.0	813.1	0.55	100.0

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Table 5
Projections for India's electricity requirements.

	Unit	2006[a]	2020	2030
Population	Millions	1114	1329	1454
GDP	Rs. in Billion @ 1993–94 prices	17839	51398	110964
Total electricity requirement (GDP Growth Rate 8%)	GWhr	761	1951	3597
Electricity required at bus bar (GDP Growth rate 8%)	GWhr	712	1825	3365
Projected peak demand (GDP growth rate 8%)	Giga Watts	107	298	592
Installed capacity (GDP growth rate 8%)	Giga Watts	153	408	778

[a] Financial year 2006–07.

Another major energy using sector is transportation. Elasticities w.r.t GDP were estimated using data from 1980–2004 for passenger kilometres and freight tonne kilometres. The modal split between rail and road were prescribed exogenously. The requirements of other uses of fuels were projected using time trends.

2.1. Energy scenarios

To explore the consequences of different alternatives and their quantitative significance a multi-sectoral, multi period optimising linear programming model described in detail in Parikh K et al. [8] was used. The model is driven mainly by the projected requirements of electricity and transport. The model minimizes the present discounted value of costs involved to meet the projected requirements of electricity, transport and other fuel needs. The base scenario relies mainly on coal and is called the coal dominant scenario. For the year 2030, it projects, see Table 6, 1553 Mtoe of TPCE. Of this in Mtoe terms, 453 is from crude oil, 93 from natural gas, 923 from coal, 13 from hydro electricity, 68 from nuclear and 1 from renewables.

The modelled scenario suggests India's likely dependence on energy imports. Given India's energy resources, domestic production of oil and gas will depend critically on new finds. In the absence of major new discoveries, production can increase only marginally.

Therefore, it is assumed that India can produce by 2030 only 35 Mtoe of oil per year and up to100 Mtoe of natural gas including coal bed methane. Production of coal is constrained by the ability to successfully use ample domestic resources. The main hurdles can be an inability to expand production at the needed pace, environmental constraints due to associated deforestation and the social problems of resettlement of project affected people. At a modest growth rate of production of 5.5 percent per year – a rate slightly higher than what has been achieved over the previous 25 years – the production of coal and lignite by 2030 will be around 1400 Mt of Indian coal. Based on these assumptions, import needs for the base scenario will be as shown in Table 6 amounting to 781 Mtoe. Thus, with an 8% GDP growth rate, import dependence for energy in 2030 could be 50 percent. This projected large dependence on imported energy raises serious concerns about energy security. It is therefore critical for India to explore other options to improve its energy security and at the same time reduce CO_2 emissions.

The CO_2 emissions for the year 2030 from the energy use in the coal dominant scenario are 5.23 billion tonnes. A McKinsey study [9] has estimated emissions of 5.7 billion tonnes (BT) of CO_2 equivalent by 2030 assuming a growth rate of 7.5% over 2005 to 2030. Similarly a World Bank study [10] which covers only five sectors which together emit 75% of India's total emissions, project emissions of 4.5 BT of CO_2 for the year 2031 assuming a GDP growth rate of 7.6% over 2007 to 2031.

3. India's low carbon options and energy resources

Strategies to meet energy requirements are constrained by India's energy resources and import possibilities. Unfortunately, India is not well endowed with natural energy resources. Resources of oil, gas and Uranium are meagre though it has large resources of thorium. While coal is abundant, it is regionally concentrated and is of low calorie and high ash content, though it has the advantage of low sulphur content. The extractable reserves, based on current extraction technology, remain limited. Concerns for climate change will also put an additional constraint on use of coal. Hydro electricity potential is significant, but small compared to the needs and its contribution in terms of energy is likely to remain small. Further, the need to mitigate environmental and social impact of hydropower with storage, often delays hydro development thereby causing huge cost overruns. We discuss below the potential of each available energy resource.

3.1. Hydrocarbon resources

India's hydrocarbon energy resources and reserves are summarised in Table 7. These are grossly inadequate to meet India's need estimated in Section 2.1.

3.2. Nuclear resources

India is poorly endowed with Uranium. Available Uranium supply can fuel only 10,000 MW of the Pressurised Heavy Water Reactors (PHWR) for their lifetimes of about 30 years. Further, India extracts Uranium from extremely low grade ores (as low as 0.1% Uranium) compared to ores with up to 12–14% Uranium in some countries. This makes Indian nuclear fuel 2–3 times costlier than international supplies. The substantial Thorium reserves can

Table 6
Commercial energy requirement, domestic production and imports for 8 percent growth: base scenario.

Fuel	Commercial energy requirement 2020	Commercial energy requirement 2030	Assumed domestic production capacity 2030	Imports 2030	Import 2030 (Percent)
		(R)	(P)	(I)	(I/R)
Oil (Mt)	259	453	35	418	93
Natural gas (Mtoe) including CBM	52	93	100		0
Coal (Mtoe)	511	923	560	363	39
Others (Mtoe)	41	82	–	0	0
TPCES	1553	1553	–	781	50

TPCES: Total primary commercial energy supply.

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Table 7
India's hydrocarbon resources and reserves.[c]

Resources	Unit	Proved	Inferred	Indicated	Total reserve	Production in april 2007–march 2008	Net imports during april 2007–march 2008	Reserve/ production ratio.	
		P	F	I	R = P + F + I	Q	M	P/Q	R/Q
Coal resource[a]	Mt	105820	37920	123470	267210				
Extractable coal reserves[b]	Mt	37451	5965	33987	77403	457	48.8	81.9	169.4
Lignite resource	Mt				35600				
Extractable lignite reserves	Mt	1220				34		35.9	35.9
Oil reserves	Mt	769				34.12	121.67	22.5	22.5
Gas reserves	Bcm	1050				32.42	8.32 (LNG)	32.4	32.4
Coal bed methane (CBM) resource	Bcm	1374							

[a] As of 1.4.2009 with a depth o f 1200 m.
[b] 90% of proved, 70% of indicated and 40% of inferred with a production to reserve ratio of 2.543.
[c] Extractable at today's technology. With new technology such as in situ gasification of coal, deeper coal can be mined and a greater fraction can be recovered but this is not an economical technology today.

be used but that requires that the fertile Thorium be converted to fissile material. In this context, a three-stage nuclear power programme is envisaged. This programme consists of setting up of Pressurised Heavy Water Reactors (PHWRs) in the first stage, Fast Breeder Reactors (FBRs) in the second stage and reactors based on the Uranium 233-Thorium 232 cycle in the third stage.

As PHWR generates electricity a part of the Uranium fuel gets converted into plutonium. With enough Plutonium and depleted Uranium coming out from PHWR a fast breeder reactor can be operated. An FBR generates electricity and accumulates more Plutonium than what is put in. So after 8–10 years enough Plutonium accumulates to start another FBR. Moreover when an FBR's reactor core is covered with a Thorium blanket it converts Thorium into Uranium 233, a fissile material. However this slows down the rate at which Plutonium is bred and so there is an optimal time phasing of introducing thorium based plants. This three-stage programme has the potential to provide significant amount of energy as shown in Table 8

The pace of development of nuclear power is constrained by the rate at which plutonium can be produced in the first generation plants or FBRs and Thorium converted to fissile material. If India is able to import nuclear fuel, the process can be accelerated. Import of first generation power plants with uranium for their lifetimes and a right to reprocess fuel can substantially accelerate nuclear power. As the first generation plants produce Plutonium, a number of FBRs can be started earlier if plants are imported in near future. While India has the technology to build nuclear plants, the capacity to build many plants at a time is limited. Imports of nuclear plants can help overcome that capacity constraint as well. Three possible growth paths of nuclear power are summarised in Table 9 based on Ref. [11]. A nuclear plant is primarily a base load plant and adequate balancing and flexible plants such as hydro electric or gas based ones are needed. Over the next two three decades this is not likely to be a problem as the installed nuclear capacity would be limited. There is also a concern for safety primarily from terrorism. If nuclear is the only option one will have to deal with that risk.

Nuclear electricity from PHWR is competitive with coal at distances exceeding 1000 km from coal mines [12]. The cost of fast breeder reactors are not known as the first 500 MW commercial plant is under construction.

Table 8
The approximate potential available from nuclear energy (with domestic resources).

Particulars	Amount	Thermal energy		Electricity	
		TWh	GW-yr.	GWe-Yr.	GWe
Uranium-metal	61,000-t				
In PHWR		7992	913	330	10[a]
In FBR		1,027,616	117,308	42,230	500[b]
Thorium-metal	2,25,000-t				
In breeders		3,783,886	431,950	1,55,500	Very large

[a] Installed capacity based on a plant life of 40 years and load factor of 0.8.
[b] Installed capacity that can be supported for 100 years at a load factor of 0.85
Source: Grover R.B. and Subhash Chandra (2006), "Scenario for growth of electricity in India", Energy Policy 3A(2006) 2834–2847.

3.3. Renewable energy resources

Given the limited amount of domestic fossil and nuclear energy resources, renewable energy resources gain significance in the Indian context [7]. India's renewable energy resources are summarised in Table 10. It may be noted that many renewables require land. India is a land scarce country. The net cultivated area has remained more or less constant for the last 15 years as there is no possibility to expand it. Also, the estimated 60 million hectares of "wasteland" is often used by people for a variety of purposes ranging from pasture to access roads to fallow lands and is not available and not all of it may be suitable or have required water for growing wood or Jatropha or other biofuel plantations. The potential energy generated is assessed independently for each option. If all such options are developed together the combined potential may be less than the sum due to a paucity of available land for energy generation as other competing land uses may dominate. The various resources are discussed below.

3.3.1. Hydroelectricity

India's hydro electric resources are estimated to be 440 TWh annually. In 2007,the utility based installed capacity was 35.9 GW and the generation was 120.4 TWh giving a load factor of 39%. Because of environmental concerns and social cost of uprooting people in future fewer storage schemes may be taken up. The load factor may be lower with run of the river schemes. At a load factor of 0.33 an installed capacity of 150 GW including some 15 GW of small hydel plants (size <25 MW) may be possible given the available potential hydro electric energy. In addition there are

Table 9
Possible development of nuclear power installed capacity in MW.

Year	Unit	Import by 2020		
		40 GW	8 GW	No import
2030	GWe	90	63	48
2050	GWe	650	275	208

Table 10
Renewable energy resources.

Resources	Unit	Present	Potential	Basis of accessing potential
Hydro-power	MW	32,326	1,50,000	Total potential assessed is 84,000 MW[b] at 60% load factor or 1,50,000 MW at lower load factors
Wind Energy	Mtoe/year	<1	10	Onshore potential of 65,000 MWe at 20 percent load factor
Small Hydro-power	Mtoe/year	<1	5	
Biomass				
Wood	Mtoe/year	140	620[a]	Using 60 million Ha wasteland yielding (20) MT/Ha/year
Biogas	Mtoe/year	0.6[b]	4	In 12 million family sized plants
		0.1	15	In community based plants if most of the dung is put through them.
Bio-Fuels				
Bio-diesel	Mtoe/year	–	20[a]	Through plantation of 20[a] million hectares of wasteland or 7[a] million hectares of intensive cultivation
Ethanol	Mtoe/year	<1	10	From 1.2 million hectares of intensive cultivation with required inputs.
Solar				
Photovoltaic	Mtoe/year	–	1200	Expected by utilising 5 million hectares wasteland at an efficiency level of 15 percent for solar photovoltaic cells
Thermal	Mtoe/year		1200	MWe scale power plants using 5 million hectares

[a] The availability of land and inputs for getting projected yields is a critical constraint.
[b] Based on 50 percent plants under use.

possibilities of importing hydropower from Nepal and Bhutan whose combined economically feasible potentials is estimated to be in excess of 290 GWh.

The costs of hydropower plants depend on the site and what proportion of the cost is allocated to irrigation a, co-benefit of many hydropower schemes. A 30 percent higher capital cost per MW and a lower operating cost per kW compared to coal based plant and zero fuel cost have been taken in our scenario.

3.3.2. *Wind resources*

Onshore wind energy potential is estimated to be around 67 TWh by the Ministry of New and Renewable Energy (MNRE) [14]. Current technology and India's wind speeds give a plant factor of about 17 percent. Even when one assumes that technological innovations will raise the capacity factors to 20% from the present 17% and the total contribution of wind energy to India's electricity needs by 2030 could be about 80 TWh which would be less than 3 percent. Nevertheless wind power should be pursued as it can be set up quickly and it is a renewable resource with no emissions. The capital cost per MW of an onshore wind power plant is 10%–30% higher than a coal based plant. The very low load factor however makes cost of wind power higher than that from coal based plant.

Cost of generation of electricity from wind has been estimated by Pillai and Banerjee [15] at Rs.5.60/Kwhr at a capacity utilization factor (CUF) of 14% and Rs.2.62 at a CUF of 30% using a discount rate of 10%.

3.3.3. *Traditional biomass, biogas and biofuels*

Biomass is used for cooking, and consists mainly of agricultural by-products and gathered wood. Domestic biomass use in 2000 was 80 Mtoe. Along with dung cakes which provided 30 Mtoe, biomass based fuels provide 81% of domestic energy [7]. Biomass is also used as industrial fuel by small industries in the unorganised sector and by cottage industries. Though falling in its share of the total energy mix, biomass dependence shall continue to rise in absolute terms, and biomass will remain a part of India's energy supply scene till 2031 and beyond. Enhanced efficiency of use of biomass/biofuels is highly desirable.

India has a 40 year old biogas programme based on cattle dung. The total number of family size biogas plants installed is 3.7 million, though evaluation studies show that only half of these are in use. Community based plants can process dung from households with less than the 3–5 animals that are required for a family size plant and can also use any excess gas available from family size plants. Managing a community size plant in an incentive compatible way that ensures voluntary cooperation of all stakeholders is admittedly challenging but is very much possible and worth pursuing [16].

Biomass could become a major sustainable energy source if fuel wood plantations at village level are developed. This requires land, which may have other competing uses. In fact, biomass, biofuels (vegetable, edible and non-edible oils and ethanol) and solar energy on sizeable scale all require large amounts of land. The potential energy that can be generated is shown in Table 10. At appropriate relative prices of agricultural products and energy, farmers may themselves decide to use their land for producing energy. This would take away land from growing food. Unless India is able to substantially increase land productivity of food or unless it is willing to import food sparing land for it, biofuel production may increase energy security but will reduce food security. The trade off will have to be carefully balanced through appropriate policy instrument. Clearly, Table 10 shows that wood plantations offer the best option for biomass based supply sources along with possessing a huge employment generation potential. Wood gasification or direct combustion is possible options for power generation based on such biomass. The economics would depend on actual yields from the wood plantations [17].

Bio-diesel on the other hand seemed to offer use of wasteland on which non-edible tree-borne oil seeds could be grown. Bio-diesel is a natural diesel substitute. Bio-diesel from non-edible oils such as Jatropha, Karanj, Mahua etc., has attracted lot of attention recently. The Planning Commission brought out a strategy document in 2003 to promote bio diesel. Cultivation of these non-edible oil seeds was expected to generate rural employment as well [18]. Subsequently a National Policy on Biofuels was announced by the Ministry of New and Renewable Energy of the Government of India. The economic feasibility of bio diesel depends largely on the yields one can get from wasteland and/or the returns one can get from good quality land with irrigation and fertiliser use compared to returns from growing other crops. The benefits of employment generation should be factored in while assessing the desirability of bio-diesel [7]. Even when bio diesel is found economical, its availability will remain constrained by land.

Ethanol is used extensively in Brazil as a fuel for cars. Brazil produced some 25 billion litres of ethanol in 2009 [20]. Ethanol blending has been mandatory and in 2007, ethanol constituted in terms of energy equivalence, 17.6% of total energy consumption by the transport sector. While it has been described as 'Lean and green but not mean' [21], concerns have been raised about its ecological consequences due to rainforest destruction either to cultivate sugarcane or to cultivate soybeans displaced by sugarcane. In the Indian situation of scarcity of land and water, the available quantities of ethanol, when used as feedstock for production of chemicals and potable alcohol, offer higher economic returns compared to its use as an admixture with gasoline.

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A promising new technology that is potentially attractive is cellulosic ethanol. The agricultural waste in India can provide raw material to produce 200 Mt of ethanol per year without competing with food production. Two commercial plants have been announced by Danish companies promising ethanol at $2 per gallon [22]. Since this uses agricultural waste, no additional emissions of N_2O is involved in production. India should watch the development of this technology and also carry out research to make it economically viable. If technology can be developed to economically collect and convert crop residues such as rice straws (which are currently burnt) or if intensive cultivation of land for crops to produce cellulosic ethanol constitutes an attractive option to farmers, adequate quantity of ethanol could then be available to blend petrol. At present ethanol as a transport fuel can make some contribution but is not likely to constitute a major option. An expert group set up by the Ministry of Science and Technology estimates [23] positive net energy balance in terms of output/input ratio to be between 3.32 and 7.06 depending on the feedstock used. It also estimates carbon reduction compared to the use of petroleum product substituted to vary from 68% to 86%.

The saving of GHG emissions through use of bio diesel or ethanol has been questioned. Crutzen et al. [24] have argued that the warming effect of N_2O released while producing oil seeds for bio diesel or corn for ethanol has a higher warming effect than CO_2 saved by replacing fossil fuels by biofuels.

3.3.4. Solar energy

The one significant option that stands out in Table 10 is solar energy. Solar energy has a large potential in the country. The average solar insolation in the country is 6 kWh/meter^2/day. This can be exploited by many direct thermal applications such as for cooking, heating, solar thermal power plants or in photovoltaic cells that directly convert sunlight to electricity. The present conversion efficiency of commercially available photovoltaic (PV) cells is less than 15 percent. With this efficiency the potential of covering just 5 million hectares of land with photovoltaic cells is 1200 Mtoe/year. With only 10 million hectares of land it can provide all the needed energy projected for 2030 [7]. Also the land need not be cultivable land. It could be in deserts or on roof tops in urban areas or road dividers on highways. With increase in efficiency of PV cells, land requirement will go down. Photovoltaic technology is proven but expensive and the cost of electricity exceeds Rs.15/kWh at present compared to Rs.2 for pithead coal plants and Rs.4 at coal plants near consumption centres. Potential to reduce costs and increase efficiency of solar power exists; India has launched a national solar mission [25] as part of its National Action Plan for Climate Change (NAPCC). The mission's main goal is to make solar power cost competitive to coal power by 2020. It envisages setting up 20 GW of solar capacity by 2020 and 100 GW by 2030 through decreasing over time feed in tariff to stimulate innovations and to reap economies of scale.

Apart from cost, solar energy poses other challenges. It needs to be integrated into grids and balanced through other electricity sources available on demand such as hydro electricity or gas. This will call for smarter grids. A high powered committee has been set up by the Prime Minister to chalk out a road map to develop smart grid [26].

Solar thermal generation is already economic for water heating for households as well as industrial use. Concentrated solar power with heat storage is an option that may have large potential. Storing heat and operating solar plants for longer hours can provide more reliable energy but its costs are not yet known. Similarly hybrid solar thermal plants using supplementary fuels will involve higher costs. The supplementary fuel can be a renewable source such as fuel wood from plantations.

3.3.5. Hydrogen

Hydrogen is seen as the new energy carrier [7]. Development of Hydrogen technology is being pursued in many countries. India has also set up a Hydrogen Development Board to promote development of technologies for producing, transporting, storing and distributing hydrogen as well as to explore the field of fuel cells for efficient end-use of hydrogen. A hydrogen road map was announced by the Government in 2007 [27]. Hydrogen can be produced from hydrocarbons and biomass, by splitting water with the use of solar, hydro, wind or nuclear energy, and through certain microbial processes. The overall efficiency of the hydrogen cycle, however, remains in doubt. Hydrogen production, liquefaction or compression, transportation, storage and final dispensation, all entail huge amount of energy consumption and loss. Manish and Banerjee [28] compare hydrogen fuel chain with that of gasoline in terms of life cycle cost (Rs/Km), green house gas emissions (gms/km) and non-renewable energy consumption (Mj/km). They find that hydrogen based on natural gas to be sustainable on the GHG and non-renewable energy use criteria but has a significantly higher cost. Hydrogen based on biomass performs better on all these criteria but availability of land for biomass production pose a constraint for widespread adoption of it in India. Significant barriers relating to financial and technological viability remain in the widespread use of hydrogen in automotive or stationary applications. Metal hydrides that store hydrogen and release it for direct combustion have been developed for powering two/three-wheelers in the country but the technology has not yet been commercialised. Stationary applications or automotive applications using fuel cells are still relatively uncompetitive.

3.3.6. Emerging technologies

Among new energy resources that have yet to be proven are gas hydrates and nuclear fusion. India has large deposits of gas hydrates (methane gas trapped inside ice) off her coasts [29]. The technology to exploit it is yet to be developed. Fusion power which requires fuels that can be obtained from sea water offers virtually unlimited power. The technology of controlled fusion with positive energy gain in an economic way is also yet to be developed. These two energy sources are not likely to be available commercially in the next 25 years.

3.4. Energy use efficiency in production and consumption

Increasing energy use efficiency and reducing requirements are the most important virtual energy supply sources that India can pursue. A unit of energy saved by a user is greater than a unit produced as it saves on production, transport, transmission and distribution losses. A "Negawatt" (a negative Megawatt) produced by reducing energy need saves more than a Megawatt generated. Cross country comparisons do show that energy intensity can be brought down by 20% in India with commercially viable technologies currently available and already in use in the developed countries. The major areas where efficiency in energy use can make a substantial impact are mining, electricity generation, electricity transmission, electricity distribution, pumping water, industrial production and processes, transport equipment, mass transport, building design, construction, heating ventilation and air conditioning, lighting and household appliances. Among specific opportunities are the following:

(a) Efficiency of coal power plants themselves can be improved substantially. The average gross efficiency of generation from coal power plants is 30.5%. The newer plants being installed have an efficiency of 34%. The best plants in the world operate with super critical boilers and get gross efficiency of 42%.

Germany is even claiming gross conversion efficiency of 46%. It should be possible to get gross efficiency of 38–40% at an economically attractive cost for all new coal-based plants. This alone can reduce coal requirement. With ultra super critical boilers efficiency can exceed 50%. Table 11 compares the costs of different coal plants.

(b) In the 1990s, several studies have estimated the potential and cost effectiveness of energy efficiency and demand side management (DSM) in India (Nadel, S., V. Kothari, and S. Gopinath [30], Banerjee R., Parikh J.K. [31], Parikh J.K., Reddy B.S., Banerjee R. [32], Parikh J.K., Reddy B.S., Banerjee R. & Koundinya S. [33]). A study prepared for the Asian Development Bank (ADB, 2003) estimated an immediate market potential for energy saving of 54,500 million units and peak saving of 9240 MW. Though there is some uncertainty in any aggregate estimates, it is clear that cost effective saving potential is at least 15% of total generation through DSM. If electricity demand is reduced by 15% by 2031–32, a reduction of 115 Mtoe in coal requirement takes place. Additional savings are possible on the supply side through reduction in auxiliary consumption at generating plants and lowering technical losses in transmission and distribution. At present an estimate of the total volume of the energy efficiency consulting business (audit, performance contracting, engineering, technical assistance and consultancy) is less than 1% of its potential [34]. Energy efficiency and DSM should have a very high priority in India's strategy.

(c) Urban mass transport is much more fuel efficient per passenger kilometre compared to private vehicles. Mass transport also reduces road congestion and air pollution. Thus development of urban mass transport systems of quality and convenience that can attract passengers will contribute significantly to energy conservation [35]. Also increasing energy efficiency of vehicles and use of mass transport have to have high priority.

3.5. Cost involved in reducing energy needs and CO_2 emissions

The optimizing model referred to earlier and described in Ref. [8] was used to generate scenarios to assess the implications for energy use and CO_2 emissions as well as the costs involved. Some of the promising options described above were mandated in the different scenarios. In the extreme scenario aggressive development of renewables, nuclear, hydro electricity, gas and increased energy use efficiency and transport efficiency were stipulated.

It stipulated full development of hydro and nuclear potential, 16% of generation by natural gas, coal use efficiency of new power plants increased to 38%, railway freight share increased from 32 percent to 50 percent, demand side management reduces electricity demand by 15 percent, fuel efficiency of all motorized vehicles increased by 50 percent, 30000 MW of wind power, 10000 MW of Solar power, 50000 MW of biomass power, 10 Mt of bio diesel and 5 Mt of ethanol.

Based on these scenarios, the total commercial energy requirement for India in 2030 comes down to 1258 Mtoe from 1553 Mtoe in the base scenario. The required annual rate of growth of commercial energy over the level in 2003–04 to sustain an 8% growth rate of GDP comes down to 5.2% in this scenario compared with 6.1% in the base scenario.

The impacts of specific options assessed in different scenarios are summarized in Table 12. The CO_2 emissions fall by 30% to 3.65 billion tonnes in the scenario where all the measures are pursued, renewables are pushed and where energy use efficiencies improve in production and consumption.

This however has an additional cost. The present discounted value at 4% discount rate is about 91 billion US dollars over 25 years in terms of constant dollar. The most important option is seen to be measures to reduce energy use efficiency. Reduction in CO_2 emission of 8.6% is obtained along with cost reduction of 120 billion dollars which is nearly 5.2% of the total cost. It is assumed that 15% reduction in electricity demand can be realised at negligible cost. Larger use of natural gas in power generation, assuming that gas is available, leads to a 7% reduction in CO_2 emissions but at a cost of some 29 billion dollars. If the energy efficiency of all motorised transport vehicles is increased by 50%, (an efficiency level that is already achieved in the world today) oil requirements can go down by some 86 Mt by 2030. If on the other hand railways are able to win back the freight traffic they have lost to trucks and manage to carry 50 percent of freight billion tonne kilometre (Bt-km), then oil requirement can go down by 38 Mt. These two initiatives in the transport sector can, together, reduce our oil requirement by over 25% from the most oil intensive scenario in 2030 [35].

Improvement in efficiency of motorised vehicles lead to a reduction of 4.3% and aggressive introduction of renewable lead to 6.5% reduction in CO_2 emissions. While vehicle efficiency improvement reduces costs by 43 billion dollars, renewables increase it by 57.5 billion dollars. The projected reduction in emissions is comparable to 30% projected by McKinsey [9] and 18% projected by the World Bank [10].

The message is clear. While in the long term India must pursue development of cheaper renewables, in the medium term improvement in energy use efficiency in production and consumption is the best option with substantial potential to reduce emissions of CO_2.

4. Actions taken by India for low carbon development

India's energy reserves of hydrocarbons are limited and it must develop all available and economic alternatives such as nuclear, solar and renewables. Simultaneously, a major stress must be laid on improving energy use efficiency in production and consumption [6]. This has been recognised and a number of initiatives are underway.

4.1. Nuclear power

The agreement with the nuclear suppliers group that permits India to import Uranium and nuclear power plants has greatly enlarged the potential role of nuclear power in India's energy strategy.

4.2. New and renewable energy

India was one of the first countries in the world to set up a special department for non conventional energy in the early

Table 11
Cost of coal based electricity.

	Capital cost Mn $/MW	O&M Cost Cents/kWh	Raw material cost $/ton	Specific cons kg/kWh	Cost of electricity at bus bar cents/kWh
Coal conventional domestic	1	1.3	15	0.721	3.3
Load centre 1000 km from mines	1	1.3	33	0.7	4.5
Load centre 1500 km from mines	1	1.3	37	0.7	4.8
Coal super critical domestic	1.1	1.3	15	0.66	3.3
Coal super critical imported	1.1	1.3	45	0.41	4.1

Table 12
Impact on primary commercial energy requirement and emissions.

Option	Absolute values for base scenario and change from it					
	Change in primary commercial energy requirement		Change in CO_2 emissions		Change in cost	
	Mtoe	Percent	Billion tonnes	Percent	Billion US $ of 2005	Percent
Base scenario	1553		5.23		2323.6	
Maximize nuclear	1.3	0.1	−76.1	−1.5	4.2	0.2
Maximize hydro	−40.9	−2.6	−238.9	−4.6	5.0	0.2
Higher coal plant efficiency	−22.1	−1.4	−76.0	−1.5	−10.6	−0.5
Railway freight share increased	−31.4	−2.0	−95.3	−1.8	167.1	7.2
Natural gas generation	9.3	0.6	−94.0	−1.8	29.0	1.2
Electricity demand reduced	−122.7	−7.9	−450.0	−8.6	−119.9	−5.2
Higher vehicle efficiency	−73.5	−4.7	−224.3	−4.3	−42.8	−1.8
Accelerated renewables	−17.7	−1.1	−342.5	−6.5	57.5	2.5
All together	−294.3	−19.0	−1588.5	−30.3	91.3	3.9

eighties, which is now a full fledged ministry and called Ministry of New and Renewable Energy (MNRE). Its latest annual report summarizes the achievement over the years in promoting new and renewable energy sources [36]. Table 12 shows this.

These initiatives are accelerating. However the most important initiative is the launch of the National Solar Mission under the NAPCC [37]. Many state governments have set up their own targets and the Mission has generated lots of interest among entrepreneurs and technologists.

In another initiative, MNRE is promoting solar cities where plans are being prepared for a number of cities for maximizing use of renewable energy and energy efficiency.

Though promoting renewable energy is a goal, India recognizes that households who use biofuels, which are renewables, have to be supplied modern energy. Thus there is a programme to electrify all villages and provide free connections to all households below the poverty line.

Also kerosene and LPG or natural gas are to be provided to all households as clean cooking fuels and with subsidy to poor households as they are considered as merit goods. It is even proposed that fuel wood plantations be set up within 1 km of households so that poor women who cannot even afford the subsidized fuel have to carry the burden over a short distance.

4.3. Energy efficiency

A Bureau of Energy Efficiency (BEE) has been established to give thrust to energy efficiency. The BEE has launched a number of programmes [38]:

a A lighting programme called Bachat Lamp Yojana to replace incandescent lamps with CFLs, where a consumer can exchange it free of cost.
b A star rating labelling programme for energy using household appliances.
c A benchmarking programme for industries which are required by law to have energy audit.
d Established a code for energy conservation building code (ECBC) which is voluntary at present.

These will get further boost when a National Mission on Energy Efficiency is launched under the NAPCC. A scheme for trading of energy saving certificate is also underway.

Since Energy Efficiency (EE)/DSM schemes are often cost effective, is it necessary to have policy interventions? In actual practice there are several barriers that constrain the adoption of EE/DSM schemes including high transaction costs, lack of incentives to utilities who perceive DSM as a loss of market base, inadequate awareness, skills and training, lack of access to capital, perceived uncertainty in energy savings, a high private discount rate, limited testing infrastructure with which to ascertain savings and an absence of a reliable measurement and verification regime. Policy interventions are required to address these barriers. The national mission will explore fiscal incentives to promote energy efficiency.

The Government (Central/State), Railways, Defence and public sector units constitute a large market segment for energy intensive products. The basis for selecting a vendor is usually only the lowest initial cost. If the procurement process is modified based on the minimum annualised life cycle cost (see Table 13) it can give a big

Table 13
Progress in new and renewable energy use. Q5

		Addition over April 08–march 09	Cumulative (million) (till March 31, 2009)
a. Biogas plant		101529	4.12
b. Solar photovoltaic			
	i. Home lighting system	50,900	1.4
	ii. Street lighting	7391	
	iii. Solar lantern	41,397	
	iv. Solar generation	300 KWp	
c. Solar thermal	Solar cookers	20,590	0.657
d. Remote village electrification (RVE)			
	RVE	269	4237 (~~remote~~ villages) 1142 (hamlets)
e. Solar water heaters		500,000 Sq Metre	2,700,000 Sq Metre
f. Wind power		1485 MW	10,382 MW
g. Biomass power		345 MW	1752 MW (703 MW biomass + 1049 MW Cogen)

Table 14
Comparison of initial cost and annualised life cycle cost (ALCC).[a]

Sl. No.	Equipment	Rating	Initial cost (Rs)	Annual electricity use (KWhr)	Equipment life years	ALCC (Rs)	Cost of electricity as % of ALCC
1.	Motor	20 hp	45,000	101,267	20 years	513,382	98.6
2.	EE motor	20 hp	60,000	97,304	20 years	495,684	98.2
3.	Incandescent lamp	100 W	10	300	1000 h	1530	98.0
4.	CFL	11 W	110	42	8000 h	259	81.0

[a] With discount rate of 10%.Source: Planning Commission (2006) updated ~~[16].~~

boost to energy efficient appliances and equipment. A manual should be prepared establishing the methodology for annualised life cycle costing with a simple spreadsheet package to enable easy implementation. Though life cycle costing seems particularly relevant for appliance purchase since appliances are often bought without consideration of operating costs, it should be used for all decision-making and alternatives should be compared in terms of expected present discounted values of life cycle cost (Table 14).

5. Concluding comments

India's economy needs to grow if it is to deal with poverty and human development. Thus its requirement for energy will grow significantly over the next two decades. However, it is short of hydrocarbon resources. Though it has potential for hydro electricity and other renewable energies, it is limited compared to India's need for electricity. India has to develop all its resources. However, its main options lie with nuclear, solar and energy efficiency and conservation. India recognizes this and is pursuing these options. Much of this will result in lower carbon intensity.

Uncited references

[13,19].

References

[1] Tendulkar Committee report. Planning Commission, Government of India, http://planningcommission.nic.in/reports; 2010.
[2] Parikh J, Lior N. Special issue "Energy and its sustainable development for India". Energy; 2009. Elsevier.
[3] Parikh J, Panda M, Ganesh Kumar A, Singh V. Co_2 emission structure of Indian economy, Energy 34(8), Elseviers.
[4] International Energy Agency (IEA), Key Energy Statistics 2007, http://www.iea.org/textbase/nppdf/free/2007/Key_Stats_2007.pdf.
[5] National Sample Survey of 2004–05; http://planningcommission.nic.in/news/prmar07.pdf.
[6] Parikh Jyoti K, et al. Lack of energy, water and sanitation and its impact on rural India. In: Parikh Kirit S, Radhakrishna R, editors. India Development Report 2004–2005. New Delhi: Oxford University Press.
[7] Integrated Energy Policy, Planning Commission, 2006, http://planningcommission.nic.in/reports/genrep/rep_intengy.pdf.
[8] Parikh KS, Karandikar V, Rana A, Dani P. Projecting India's energy requirement for policy formulation. ~~Energy August~~ 2009;34(8).
[9] Rajat Gupta, Shirish Sankhe, Sahana Sarma. Environmental and energy sustainability: an approach for India. McKinsey and Company; August 2009.
[10] Bank World. India: options for low carbon development. South Asia Sustainable Development Department, World Bank; December 2009.
[11] Grover RB, Chandra Subhash. Scenario for growth of electricity in India. In: Energy Policy, 3A; 2006. 2834–2847.
[12] Nema AK, Pathak BK, Grover RB. India—nuclear power for GHG mitigation and sustainable energy development. Nuclear Power for Greenhouse Gas Mitigation. International Atomic Energy Agency Publication; November 2000.
[13] Hydro power potential of India, Basin-Wise of Hydroelectric Potential of Indian River System assessed by Central Electricity Authority (CEA) in 1980 available on web site of national institute of hydrology, Roorke. http://www.nih.ernet.in/nih_rbis/india_information/hydropower.htm.
[14] Wind power potential in India, http://mnre.gov.in/wpp.htm.
[15] Pillai IR, Rangan Banerjee. Renewable energy in India: status and potential. Energy August 2009;34(8):970–80. Elsevier.
[16] Parikh Jyoti K, Parikh KS. Mobilisation and impacts of biogas technologies. Energy 1977;2:441–5.
[17] Parikh J, Walia A. Techno-economic assessment of bio-energy in India. Vishwakarma Bhawan, New Delhi: TIFAC Publication; 2007.
[18] Planning Commission, Government of India. Report of the committee on development of biofuel; 16 April 2003.
[19] National Policy on Biofuels, from MNRE website. http://www.mnre.gov.in/policy/biofuel-policy.pdf.
[20] Renewable Fuels Association. 2010 industry outlook; 2010. Washington, D.C.
[21] Biofuels in Brazil: lean, green and not mean". The Economist. 26.06.08. http://www.economist.com/world/la/displaystory.cfm?story_id=11632886. Retrieved 28.11.08.
[22] Danish company cellulosic ethanol plant, http://domesticfuel.com/2010/07/09/danish-company-claims-worlds-largest-cellulosic-ethanol-plant/ http://bioenergy.checkbiotech.org/news/race_build_first_commercial_cellulosic_ethanol_plant.
[23] Ministry of science and technology. Estimation of energy & carbon balance of biofuel in India. Government of India; February 2010.
[24] Crutzen PJ, Mosier AR, Smith KA, Winiwarter W. N_2O release from agro-biofuel replacing fossil fuels. Atmospheric Chemistry and Physics 2008;8:389–95.
[25] National Action Plan on Climate Change, http://pmindia.nic.in/climate_change.htm.
[26] Committee on Smart Grid, http://ias100.in/news_details.php?id=112, http://www.egovonline.net/news-list/34-news/8282-sam-pitroda-to-head-smart-grid-taskforce.html.
[27] Ministry of New and renewable energy, Hydrogen Road Maps, http://mnre.gov.in/prog-hydrogen.htm.
[28] Manish S, Rangan Banerjee. The techno economic assessment of the hydrogen fuel chain. International Journal of Nuclear Hydrogen Production and Applications (IJNHPA) 2008;1(4):309–23.
[29] National Gas Hydrate Programmes (NGHP), http://www.oidb.gov.in/index3.asp?sslid=257&;subsublinkid=69.
[30] Nadel S, Kothari V, Gopinath S. Opportunities for improving end-use electricity efficiency in India. Washington, DC: American Council for an Energy-Efficient Economy; 1991.
[31] Banerjee R, Parikh JK. Demand side management in power planning – an exercise for H.T. industries in Maharashtra. Economic and Political Weekly; 7–14, August 1993:1659–70.
[32] Parikh JK, Reddy BS, Banerjee R. Planning for demand side management in electricity sector. New Delhi: Tata Mc-Graw Hill Company Ltd.; 1994.
[33] Parikh JK, Reddy BS, Banerjee R, Koundinya S. DSM survey in India: awareness, barriers and implementability. Energy 1996;21(10):955–66.
[34] DSCL. Catalysing markets through innovative financing and competitive procurement for energy efficiency, www.bee-india.nic.in; 2004. G.C. Datta Roy Presentation available from:.
[35] Report of the expert group (Kirit Parikh committee) on a viable and sustainable system of pricing petroleum products. Government of India, http://petroleum.nic.in/reportprice.pdf; Feb 2010.
[36] Annual Report 2008–09, Ministry of New and Renewable Energy; http://www.mnre.gov.in/.
[37] Jawaharlal Nehru National solar mission, http://www.mnre.gov.in/http://mnre.gov.in/pdf/mission-document-JNNSM.pdf.
[38] Bureau of Energy Efficiency, Energy Saving Initiatives, http://www.bee-india.nic.in/useful_downloads.php.

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