MODULE -1

ENERGY:

It is great word, which is defined as the ability or capacity to do work. We use energy to do work and make all movements. When we eat, our body's transform the food into energy to do work. When we run or walk or do some work, we ―burn" energy in our bodies. Cars, planes, boats machinery etc. also transform energy into work. Work means moving or lifting something, warming or lifting something, warming or lighting something. There are many sources of energy that help to run the various machines invented by man.

Energy is measured in BLU (British Thermal Unit) or Joule (Named after the English Physicist type of energy). One Joule after the amount of energy required to lift 1 pound (approx 400g) about 9 inches (23cm). It takes 1000 Joules to equal a Btu. It would take 2 million Joules to make a pot of coffee. A price of buttered tarts contains 315 kilo Joules of energy.

Kinds of energy

Kinetic energy: it is the energy of motion

Potential energy: It is the energy due to position or energy stored.

Types of energy

Light, chemical. Mechanical, heat, electric, atomic, sound.

All these forms of energy can be broken down either into kinetic or potential energy.

Sources of energy

Primary Energy Sources:

Energy resources are mined or otherwise obtained from the environment.

Ex. a. Fossil fuels: coal, lignite, crude oil, Natural gas etc.

b. nuclear fuels: Uranium, Thorium, other nuclear used in friction reaction.

c. Hydro energy: It is energy of falling water, used to turn a turbine.

d. Geo thermal: The heat from the underground stream.

e. Solar energy: Electromagnetic radiation from the Sun.

f. Wind energy: The energy from moving air used by wind mills.

g. Tidal energy: The energy associated with the rise and fall of the tidal waters.

Global energy consumption patterns

Transportation consumes about 24% of the energy, 40% for industry, 30% for domestic and commercial purposes and remaining 6% for other uses including agriculture. The top 20 richest countries of the world consume 80 of the natural gas 65% of the oil and 50 of the coal produced every year while these countries have only one fifth of the world's population. One third of the world"s population is about two billion people, lack access to adequate energy supplies, they mainly depend on fuel wood, dung, coal, charcoal and kerosene for cooking and heating. U.S.A is the largest energy consumer in the world.

Table 1: **Different Sources of Energy**

Energy Source	**Percentage of total energy**	**Subtotal percentage**
Non- renewable Source		
Oil	32	
Coal	21	
Natural gas	23	
Nuclear	6	82
Renewable Sources		
Bio mass (mainly wood)	11	
Solar, wind, hydro and Geothermal power	7	18
Total		100

Energy Status of India

India"s energy status is not promising. Presently, the country consumes about 100 million tones of coal and 32,5 million tons of oil annually. Official estimate report that 40 billion tones of coal are available but only one half this is recoverable which means it is less than the projected demand of 23 billion tons of coal till the year 2020. n the other hand the projected demand for hydroelectric power by 2020 is 12 times more than the present installed capacity of nearly 15, 000 MW.

India's oil deposits Is about 400 million tonnes as against the world oil reserve of 750,000 million tonnes. Gas reserves of our country are about 100 million cubic meters, as against world's reserves of 63,000 million cubic meters. Here, one can conclude that the energy Scenario of India is blank.

Renewable and Non- Renewable Energy Sources

Renewable or inexhaustible energy sources:

These are the resources that can be generated continuously. These are mostly biomass based which are renewed over relatively short period of time and then available in unlimited amount in nature. These include conventional energy sources like: firewood, petrol plants, plant biomass, animal dung, water energy etc.

Non-conventional energy sources like solar energy, wind energy, tidal energy, geothermal energy and dendro thermal energy etc. These can reproduce themselves in nature and can be harvested continuously through a sustained planning and proper management.

Non- renewable or exhaustible energy sources:

These are available in limited amount and develop over a longer period of time. Hence, they cannot be replenished in the quantities they are being consumed in a given period of time. Non-Conventional energy sources like nuclear energy etc. Development of modern technological civilizations is chiefly based on the non-renewable sources. These reserves are fast depleting and within a few decades they will get exhausted. The unwise and exploitative use of renewable energy sources have forced these resources in the category of non- renewable energy sources as the rate of production of these sources become much less than the rate of their utilization.

ELECTROMAGNETIC RADIATION

An electromagnetic radiation is energy in the form of a wave due to changing electric and magnetic fields. There are different forms of electromagnetic radiation, each with different wavelengths (i.e., Distance between successive peaks or troughs in the wave) and energy content. Such radiation travels through space at the speed of light, which is about 3, 00 000 kilometers/sec. Cosmic rays, gamma rays, x-rays and ultra violet radiation are known as Ionizing radiation because they have energy to knock electrons from atoms and change them to positively charged ions. The resulting highly reactive electrons and ions can disrupt living cells, interfere with body processes and cause many types of sickness, including various cancers. The other forms of electromagnetic radiation do not contain enough energy to form ions and are known as non-ionizing radiation.

The visible light that can be detected by our eyes is a form of non- ionizing radiation that occupies only a small portion of full range or spectrum of different types of electromagnetic radiation.

HYDRO ELECTRICAL ENERGY

Electricity produces from waterpower is known as hydroelectric energy. The potential energy of falling water captured and converted to mechanical energy by water wheel powered the start of industrial revolution. Wherever head or change in elevation could be found, river and stream were dammed and mills were built.

Large Scale Hydro power: in this case a high dam is built across a large river to create a reservoir, water is allowed to flow to through huge pipes laid along the steep hill slopes (falling) at controlled rates, thus spinning turbines (prime movers) and in turn generators producing electricity.

Small hydropower: In this case a low dam with no reservoir (or only a small one) is built across a small stream and the water used to spin turbine to produce electricity.

Pumped Storage hydropower: In this case the surplus electricity conventional power plant is used to lift water from a lake or tail race to another reservoir at a higher elevator, water in the upper reservoir is released to spin the turbine for generating electricity.

In 2001, hydro power supplied about 7% of the world"s total commercial energy, 20% of the world"s electricity. It supplies 99% of the electricity in Norway, 75% in New Zealand and 50% in developing countries and 25% in China.

In India the generation of hydroelectricity has been emphasized right from the beginning of the First Five Year plan. By the end of Fourth plan, India was able to generate 6.9 thousand MW of hydroelectricity, contributing 42% of the total power generation capacity. But due to increase in demand, by the end of Eighth plan it fell down to 25% only. The hydropower potential of India is estimated to be 4 X 10 11k w –hours. Till now we have utilized only a little move than 11% of this potential. Because of increasing concern about the harmful environment and social consequences of large dams, there has been growing pressure on the World Bank and other development agencies to stop funding new large scale hydro power projects.

According to a study by world commission on Dams, hydropower in tropical countries is a major emitter of greenhouse gases. This occurs because reservoirs that power the dams can trap rotting vegetation, which can emit greenhouse gases such as Carbon dioxide and Methane. Small-scale hydropower projects eliminate most of the harmful environmental effects of large-scale projects. However, their power output can vary with seasonal changes in the stream flow.

Advantages	**Disadvantages**
Moderate to high net energy.	High construction cost
High efficiency (80%)	High environmental impact
Low cost electricity emission from biomass decay in shallow tropical reservoirs	High carbon dioxide
Long life span	Floods natural areas.
No carbon dioxide emission during operation	Coverts land habitat to lake habitat.
May provide flood control below dam.	Danger of collapse
Provides water for year-round Irrigation.	Uproots People
Reservoir is useful for fishing and recreation	Decreases fish harvest Below dam

Above are the advantages of and disadvantages of using large-scale hydropower plants to generate electricity

According to the United Nations, only about 13% of the World"s exploitable potential for hydropower has been developed. Much its un trapped potential is in South Asia, (China), South America and parts of Russia.

FOSSILS FUELS

Fossils fuels (oil, coal, natural gas) are energy rich substances that have formed from the remains of organisms that lived 200 to 500 million years ago. During the stage of the Earth's evolution, large amount of dead organic matter had collected. Over million of years, this matter was buried under layers of sediment and converted by heat and pressure into coal, oil and natural gas.

Chemically, fossil fuels largely consist of hydrocarbons, which are compounds of hydrogen and carbon. Some fossils fuel also contains smaller quantities of other compounds. After the accumulating sediments exerted increasing heat and pressure for millions of years on the ancient organisms' hydrocarbons were formed. Most common among them are petroleum, coal and natural gas. However, Geologists have identified other types of hydrocarbon rich deposits, which can serve as fuels. Such deposits are: oil shale, tar sands and gas hydrates. However, they are not widely used due to the fact that they are very costly to extract and refine. Majority of fossil fuels are being used in transportation, industries heating and generation of electricity.

Crude petroleum is refined into gasoline; diesel and jet fuel that power the world's transportation system. Coal is mostly used in the generation of electricity (thermal power). Natural gas is used for commercial and domestic purposes like heating, air conditioning and as fuels for stoves and for other heating appliances.

Once we discovered the fossil fuel, we began consuming them at an increasing rate. From 1859 to 1969, total oil production was227 billion barrels (1 barrel=159 lts). 50% of this total was extracted during the first 100 years, while the next 50% was extracted in next 10 years. Today, fossil fuels are considered to be non-renewable for the reason that their consumption rate is far in excess of the rate of their formation.

Coal:

About 250 to 350 million years ago coal was formed on earth in hot, damped regions. Almost 27350 billion metric tons of known coal deposits occur on our planet. Out of which about 56% are located in Russia, 28% in USA and Canada. India has about 5% of world's coal reserve and that too not of vary good quality in term of heat capacity. West Bengal, Jharkhand, Orissa, Andhra Pradesh, Madya Pradesh and Maharastra are the major coal producing states of India. Mainly, there are three types of coal: Anthracite or hard coal (90% carbon content) Bituminous or soft coal (85% carbon content) Lignite or brown coal (70% carbon content). The present annual extraction rate of coal is about 3000 million metric tons, at this rate coal reserves may last for about 200 hundred years and if its use is increased by 2% per year then it will last for another 65 years.

Petroleum:

Convenience of petroleum or mineral oil and its greater energy content as compared to coal on weight basis has made it the lifeline of global economy. Petroleum is cleaner fuel when compared to wood or coal as it burns completely and leaves no residue. Petroleum is unevenly distributed like any other mineral. There are 13 countries in the world having 67% of the petroleum reserves which together form the OPEC (Organization of petroleum exporting countries). Six regions in the world are rich in petroleum – USA, Mexico, Russia and West Asian countries. Saudi Arabia oil producing has one fourth of the world oil reserves. The total oil reserves of our planet is about 356.2 billion metric tonnes out of this annually we are exporting about 28% million metric tonnes. Hence the existing reserves would last for about 40 – 50 years. About 40% of the total energy consumed in the entire world is now contributed by oil.

The oil-bearing potential of India is estimated to be above one million square kilometers is about one third of the total geographic area. Northern plains in the Ganga-Brahmaputra valley, the coastal strips together with their off-shore continental shelf (Bobay Hihgh), the plains of Gujarat, the Thar Desert and the area around Andaman and Nicobar Islands.

Natural gas:

Natural gas mainly consists of Methane (CH4) along with other inflammable gases like Ethane and propane. Natural gas is least polluting due to its low Sulphur content and hence is clearest source of energy. It is used both for domestic and industrial purposes. Natural gas is used as a fuel in thermal plants for generating electricity as a source of hydrogen gas in fertilizing industry and as a source of carbon in tyre industry.

The total natural gas reserves of the world is about 600 000 billion meters, out of this Russia has 34%, Middle East 18%, North America 17%, Africa and Europe 9% each and Asia 6%. Annual production of natural gas is about 1250 billion cubic meters and hence it is expected to last for about 50-100 years. In India gas reserves are found in Tripura, Jaisalmer, off shore areas of Bombay and Krishna-Godavari Delta.

Environmental effects of Using Fossil Fuels:

Acid rain: When fossil fuels are buried, Sulphur, Nitrogen and Carbon combine with oxygen to form compounds known as oxide. These oxides when released into the atmosphere, they react with water form and result in the formation of Sulhuric acid, Nitric acid and Carbonic acid. These acids can harm biological quality of forests, soils, lakes and streams.

Ash particles: Ash particles are the un burnt fuel particles. However with strict imposition of Government regulations, perubben are provided to trap these particles. Petro and natural gas generate less ash particles than coal, diesel or gasoline.

Global warming: Carbon dioxide is a major by product of fossil combustion and this gas is known as green hour gas. Green hour gas absorbs solar heat reflected off the earth"s surface and retains this heat, keeping the Earth warm and habitat for living organisms. Rapid industrialization between 19th and 20th centuries however has resulted in increasing fossils fuel emissions, raining the percentage of carbon dioxide by about 28%. This drastic increase has led to global warming that could cause environmental problems, including disrupted weather patterns and polar ice cap melting. Metal hydra rides, charcoal powders, graphite nanofibers and glass micro spheres containing hydrogen will not explode or burn of a vehicle"s tank is ruptured in an accident. Such tanks would be much safer than current gasoline tanks.

Advantages and Disadvantages of various fossil fuels

a. Conventional oil

Advantages	Disadvantages
Amply supply for 40-90years	Need to find substitute within 50 years
Low cost (with huge substitute)	Artificially low price encourages waste and discourages search for alternative
High net energy yield	Air pollution when burnt
Easily transported within and between countries	Released carbon dioxide when burnt
Low land use	Moderate water pollution
Technology is well developed	
Efficient distribution system	

b. Heavy oils from oil shale and Tar sand

Advantages	Disadvantages
Moderate existing supplies	High costs
Large potential supplies	Low net energy yield
Easily transport within and between countries	Large amount of water needed to process
Efficient distribution system in place	Severe land disruption
Technology is well developed	Water pollution from mining residues
Air pollution when burnt	
Carbon dioxide emissions when burnt	

c. Conventional Natural gas

Advantages	Disadvantages
Ample supplies (125 years)	Non-renewable resources
High net energy yield	Releases carbon dioxide when burnt
Low cost (with huge subsidies) can leak from pipelines	Methane (a greenhouse gas)
Less air pollution than other fossil fuels	Shipped across ocean as highly explosive LNG

Moderate environmental import at wells because of low prices	Sometimes burnt off and wasted
Easily transported by pipelines	Requires pipelines
Low land use turbines	

Coal

Advantages	**Disadvantages**
Ample supplies (225-900 years)	Very high environmental impact
Air pollution can be reduced with	Several land disturbance air
High net energy yield pollution and water pollution	High land use (including mining)
Low cost (with huge substitutes)	Severe threat to human health
Mining and combustion technology well developed	High carbon dioxide emissions developed when burnt
Releases radio-active particles and mercury into air.	

NUCLEAR ENERGY

Nuclear energy is non- renewable source of energy, which is released during fission (disintegration) or fusion (union) of selected radioactive materials. Nuclear power appears to be the only hope for large scale energy requirements when fossil fuels are exhausted. The reserves of nuclear fuels is about ten times more than fossil fuels and its major advantage is that even small quantities can produce enormous amounts of energy. For example, a ton of uranium –235 can produce an energy equivalent 3 million tons of coal or 12 million barrels of oil. Nuclear energy has been successfully used in the generation of electricity in spaceships, marine vessels, chemical and food-processing industry.

Nuclear fission: nuclear fission reaction are based on the fission of U235 nuclei by thermal neutrons 92 U235 The energy from these nuclear reactions is used to heat water in the reactor and generates steam to drive a stream turbine. High temperature gas-cooled reactors and Fast Breeder reactors convert non fissionable Pu 239 and U233 Nuclear fusion It is based on deuterium-deuterium and deuterium-tritium reaction. The deuterium-deuterium re actions promise an unlimited source of energy will take several more years due to the technical problem. Nuclear fusion is also known as thermo nuclear reaction.

Environmental impact: nuclear fission power reactor generates large quantities of radioactive fission waste products, which may remain dangerous for thousands of years. In addition, these are no safe disposal methods.

SOLAR ENERGY

The solar energy originates from the thermonuclear fusion reaction taking place in the Sun. It is one of the potential non-conventional energy sources. The earth continuously receives energy from the Sun, part of which is absorbed while the remaining is emitted back into space. Out of the solar radiations reaching the earth 92% consists radiations in the range of 315 to 1400 mm. 45% of this is in the visible range and emits radiations in the infra-red region (2u to 40u). The heat equivalent of the solar radiation reaching the earth is estimated to be about 2,68x 10 Joules per year.

Solar energy being non- polluting and non-depletes is considered as renewable energy and thus fills into the principle of sustainability. But only 0,25 to 0.5 % of the solar energy reaching the earth is utilized for photosynthesis. Utilisation of solar energy is to gain popularity among the masses due to expensive nature. In India, solar photovoltaic systems are being installed by Department of Non- Conventional energy resources for lighting, running of TV sets, water pumping etc. In India, there has been steady rise in demand for solar photovoltaic system.

Solar cells are used to convert the impinging solar radiation directly of this method is that no mechanical movement of parts is need. The reliability of the operation is extraordinarily high. Even under severe space conditions a maintenance free life span of ten or more years has been achieved. Only disadvantage is that, its cost is very high for a solar power station with a capacity of 1000 Mw, a land of surface of about 12 km2 is required.

Advantages of solar energy

Solar energy is free and it is available locally in abundance. Solar energy is pollution free. Systems are easy to install, generate and maintain. System can be specifically designed according to individual requirements. Supply of hot water is instant and un interrupted Recurring fuel costs are zero Heating 100 liters of water to 60o c by solar system results in an energy saving of 1200-1500 units (kilowatts hours) of electricity per year.

BIOMASS

Biomass is the term used to describe the organic matter produced by photo synthesis that exists on the Earth's surface. The source of all energy in biomass is the Sun, the biomass acting as a kind of chemical energy store. Traditionally the extraction of energy from biomass is split into three distinct categories:

Solid biomass: The use of trees, crop residues animal and human waste, house hold or industrial residues for direct combustion to provide heat.

Biogas: it is obtained an aerobically (without air) digesting the organic material to produce ethane. Animal waste and municipal waste are two common feed stocks for anaerobic digestion.

Liquid bio-fuels: They are obtained by subjecting organic materials to one of the various chemical or physical processes to produce a usable, combustible liquid fuel. Bio fuels such as vegetable oils or ethanol are often processed from industrial or commercial residues such as biogas or from energy crops grown specially for these purposes.

Biomass use in the development world

More than two billion people in the developing world use biomass for the majority of their household energy needs. Biomass is also used widely used for non-domestic appliances. Biomass is available in varying quantities throughout the developing world. In recent decades, with the threat of global deforestation much focus has been given to the efficient use of biomass.

Biomass resources: They are renewable energy recourses**.** Natural Biomass resources vary in type and content depending upon the geographical location. World's biomass producing areas are classifieds into three distinctive regions.

Temperate regions: Produce wood, crop residues like straw, vegetable leaves, human and animal waste. Arid and Semi-arid regions: Produce very little excess vegetation for fuel. People living in these areas are often the most affected by desertification and have differently in finding sufficient wood fuel. Humid tropical regions: Produce abundant wood supplies, crop produces, animal and human

wastes, commercial industrial agro and food processing residues. Many of the world's poorer countries are found in these regions and hence there is a high incidence of domestic biomass use. Tropical areas are currently the most seriously affected by deforestation, logging and land clearance for agriculture.

Activities including Commercial utilization of Biomass- Biomass can be used for a variety of commercial tobacco curing praising direct heat for brick burning, for lime burning and cement kilns.

In India, sugar mills are rapidly turning to bagasse, the leftover of cane after it is crushed and its juice extracted to generate electricity. This is mainly done to clean up the environment, cut down power cost and additional revenue. According to current estimates, about 3500 MW of power can be generated from bagasse in the existing 430 sugar mills of the country. Around 270 MW of power has already been commissioned and more are under construction. The advantages of biomass are that it can be locally sourced.

Biomass **energy and environment:** Concern for the environment was one of the major inspirations for early research and development work on improved stoves. Initially, one environment concern dominated the improved stove work, saving trees. Today, this is considerably downplayed. At the same time, other environmental issues have become dominant. Large scale combustion of biomass is only environmentally feasible if carried out on a sustainable basis. For obvious continual large-scale exploitation of biomass resources without care for its replacement and regeneration will cause environmental damage and also Jeopardize the fuel source itself.

Benefits of Biomass energy:

* Renewable or recyclable energy source (Stored solar energy)
* Less waste directed to landfills.
* Decrease reliance on imported energy sources.
* Potential rural development and job creation.
* Can generate renewable electricity when the Sun is not shining and the wind is not blowing.

BIOGAS

Biogas is obtained by an aerobically (without air) digesting organic material to produce a combustible gas known as methane. Animal waste and municipal waste are two common feed stocks for an aerobic digestion. At present biogas technology provides an alternative source of energy in rural India for cooking. It is particularly useful for village households that have their own cattle. Through a simple process cattle dung is used to provide the gas. The residual dung is used as manure. India has world's largest cattle population - 400 million, thus offering tremendous potential for biogas plants. Biogas production has the capacity to provide us with about half of our energy needs either burned for electricity production or piped into current gas lines for use. It just has to be done and made a priority. Though about 3.71 million biogas plants in India up to March 2003 are successfully in operation but still it is utilizing only 31% of the total estimated potential of 12 million plants. The payback period of the biogas plant is only 2 to 3 years. Rather in the case of community and industrial Biogas plants is even less. Therefore, biogas electrification at Community Panchayat level is required to be implemented. Sixty cubic feet approx. 2 m3 biogas plant can serve the needs of one average family.

The charge for the biogas generation consists f dung and waste in the form of slurry. The fermentation is carried out between 35 to 500C. About 160 liters of gas is produced per kg of cow dung and heating value of the gas is 490 kilocalories on 160 liters basis. The average composition of biogas is methane 55%. Hydrogen 7.4%, Carbon dioxide 39%, Nitrogen 2.6%, Waster- traces. The average gross calorific value of the gas is 5300 kilo cals /cubic meters.

HYDROGEN AS AN ALTERNATIVE FUTURE SOURCE OF ENERGY

Alternative energy sources

Other alternative source of energy for future is the nuclear energy derived from nuclear fission or nuclear fusion processes. The use of nuclear energy mainly requires its conversion into electrical energy. Out of the world's total energy requirement only 20% constitutes electrical energy. The rest of the 80% requirement is energy in the form of heat. Conversion of nuclear energy into chemical energy for storage and transportation and disposal of nuclear waste are the problems of this technique.

Hydrogen as fuel

Hydrogen is an important alternative energy source. Some advantages of hydrogen are:

Hydrogen is abundantly available in the combined form as water.

• Use of hydrogen as fuel provides pollution free atmosphere because its combustion product is water. Time required for regeneration of hydrogen is short. Automobile's engine burning hydrogen is about 25 to 50% more efficient than an automobile engine burning gasoline (petrol). Heat of combustion per gram of hydrogen is more than twice that of jet fuel. Hydrogen-oxygen fuel cells provide other possibilities of powering motor vehicles. Hydrogen is excellent reducing agent and produces less atmospheric pollution than carbon. So it can replace coal in many industrial processes.

The changes in our way of life by adopting widespread uses of hydrogen are referred to as 'hydrogen economy'.

Hydrogen economy

Although hydrogen looks as very good future fuel, the problems associated with its economy are:

Availability

Hydrogen is not available as such. It does not occur in a free state in nature. The cheap production of hydrogen is a basic requirement of hydrogen economy. The source of hydrogen is water and using nuclear energy or solar energy might generate it.

Transportation

Hydrogen gas has explosive flammability and so is difficult to handle. This causes problem to its storage and transportation. A solution for this is the use of Fe-Ti alloy, which absorbs hydrogen and results in the formation of fine silvery powder. Heating the powder safely releases hydrogen gas. Such storage system is safer than storage of hydrogen as gas or liquid.

Platinum scarcity

Platinum is required as catalyst in oxygen-hydrogen fuel cells. The demand of platinum exceeds the supply. This will cause problems for fuel cells, which are highly promising energy source for automobiles.

Cost

Hydrogen is an expensive fuel because its cost of production is high.

Use of liquid hydrogen as fuel

Liquid hydrogen is used as an important rocket fuel because of its low mass and high enthalpy of combustion. The chemical reaction involved is:

$$H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_I + 286\ KJ$$

Both reactants H2 and O2 are stored as liquids in separate tanks. The advantage of using hydrogen as a rocket fuel is: The product of combustion is water.

There is no emission of environmental pollutants such as CO, SO2, oxides of nitrogen, hydrocarbons, etc. Although during the 'lift off operations, these propellants power shuttle's main engine for about 8.5 min, liquid hydrogen cannot be used much because the extraction of it from water is an expensive procedure

Advantages and disadvantages of hydrogen

Advantages

- Can be produced from water.
- Low environmental impact.
- No carbon dioxide emissions if produced from water.
- Good substance for oil.
- Competitive price if environmental and social costs are included in cost comparisons.

 Easier to store than electricity.

 Safer than gasoline a natural gasoline.

 High efficiency 65-95% in full cells.

Disadvantages

 Not found in nature.

 Energy is needed to produce fuel

 Negative net energy.

 Carbon dioxide emission if produced from carbon containing compounds.

 Non- renewable if generates by fossil fuels or nuclear power.

 High costs.

 Short driving range for current fuel cells cars.

 No fuel distribution system in place

 Excessive hydrogen leaks may deplete ozone.

Key energy trends in India

Demand

- India has been responsible for almost 10% of the increase in global energy demand since 2000. Its energy demand in this period has almost doubled, pushing the country's share in global demand up to 5.7% in 2013 from 4.4% at the beginning of the century. While impressive, this proportion is still well below India's near 18% current share of global population, a strong indicator of the potential for further growth.
- Expressed on a per-capita basis, energy demand in India has grown by a more modest 46% since 2000 and remains only around one-third of the world average, slightly lower than the average for the African continent (refer fig.1).
- One reason is that a significant part of the Indian population remains without modern and reliable energy: despite a rapid extension of the reach of the power system in recent years, around 240 million people in India lack access to electricity.

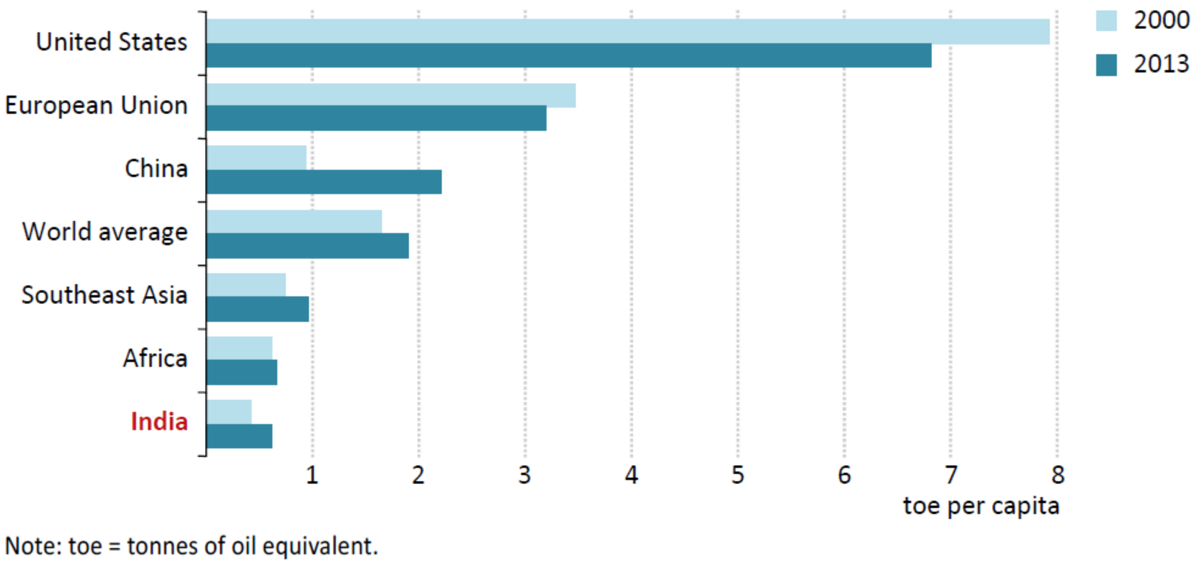


Fig. 1: Per-capita energy consumption in India and selected regions

The widespread differences between regions and states within India necessitate looking beyond national figures to fully understand the country's energy dynamics. This is true of all countries, but it is particularly important in India, both because of its size and heterogeneity, in terms of demographics, income levels and resource endowments, and also because of a federal structure that leaves many important responsibilities for energy with individual states.

Energy demand has almost doubled since 2000, but this is slower than the rate of economic growth over the same period (fig.2). This is due in part to the shift away from bioenergy3 consumption in the residential sector, the rising importance of the services sector in the Indian economy and increased policy efforts directed at end-use energy efficiency.

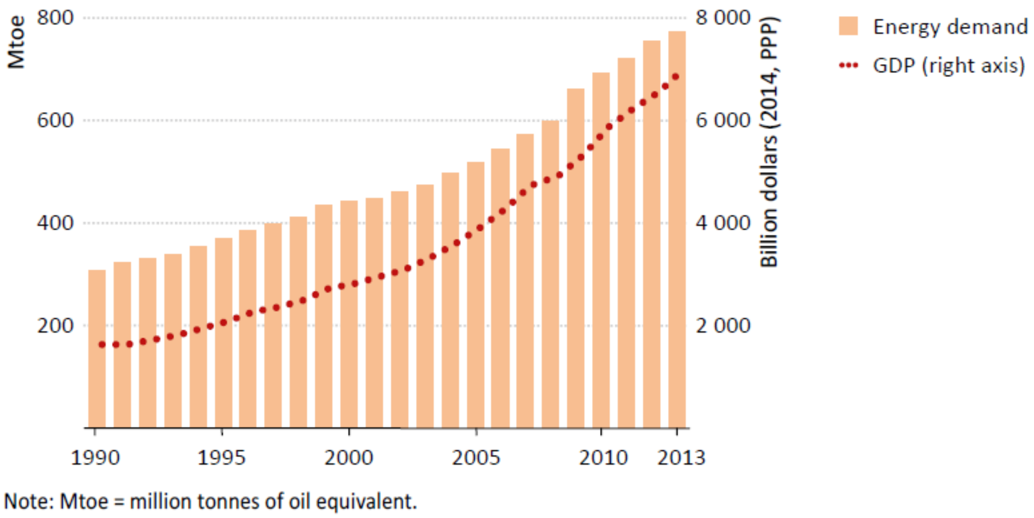


Fig.2: Primary energy demand and GDP in India

Almost three-quarters of Indian energy demand is met by fossil fuels, a share that has increased since 2000 because of a rapid rise in coal consumption and a decreasing role for bioenergy, as households move away from the traditional use of solid biomass for cooking (Fig.3). Coal now accounts for 44% of the primary energy mix (compared with under a third globally) – mainly because of the expansion of the coal-fired power generation fleet, although increased use of coking coal in India's steel industry has also played a part. The availability and affordability of coal relative to other fossil fuels has contributed to its rise, especially in the power sector. Demand for bioenergy (consisting overwhelmingly of solid biomass, i.e., fuelwood, straw, charcoal or dung) has grown in absolute terms, but its share in the primary energy mix has declined by almost ten percentage points since 2000, as households moved to other fuels for cooking, notably liquefied petroleum gas (LPG).

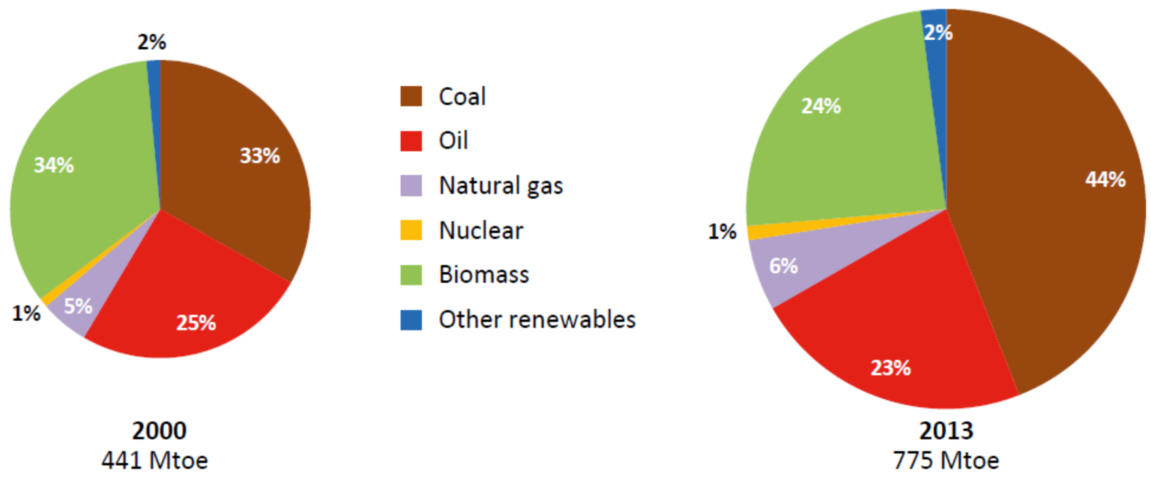
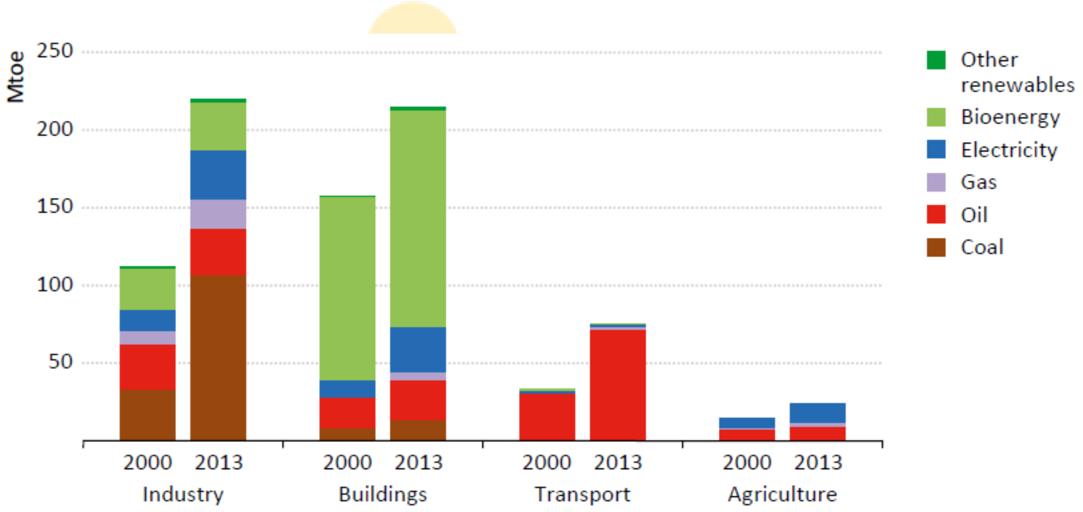


Fig.3: Primary energy demand in India by fuel

Oil consumption in 2014 stood at 3.8 million barrels per day (mb/d), 40% of which is used in the transportation sector. Demand for diesel has been particularly strong, now accounting for some 70% of road transport fuel use. This is due to the high share of road freight traffic, which tends to be diesel-powered, in the total transport use and also to government subsidies that kept the price of diesel relatively low (this diesel subsidy was removed at the end of 2014; gasoline prices were deregulated in 2010). LPG use has increased rapidly since 2000, reaching over 0.5 mb/d in 2013 (LPG is second only to diesel among the oil products, pushing gasoline down into an unusually low third place). The rise in LPG consumption also reflects growing urbanisation, as well as continued subsidies. Natural gas makes up a relatively small share of the energy mix (6% in 2013 compared with 21% globally). It is used mainly for power generation and as a feedstock and fuel for the production of fertilisers, although it also has a small, but growing role in the residential sector and as a transportation fuel. Hydropower, nuclear and modern renewables (solar, wind and geothermal) are used predominantly in the power sector but play a relatively small role in the total energy mix.

Energy demand had traditionally been dominated by the buildings sector (which includes residential and services) (Fig.4), although demand in industry has grown more rapidly since 2000, overtaking buildings as the main energy user in 2013. In the buildings sector, a key driver of consumption in both rural and urban areas has been rising levels of appliance ownership, especially of fans and televisions, and an increase in refrigerators and air conditioners in urban areas over the latter part of the 2000s. As a result, electricity demand in the buildings sector grew at an average rate of 8% per year over 2000-2013. The share of bioenergy in the buildings sector (mostly the traditional use of biomass for cooking and heating) has declined from 75% of the sector's total consumption in 2000 to two-thirds in 2013, as electricity and oil products have gained ground.



Notes: Other renewables includes solar photovoltaics (PV) and wind. Industry includes energy demand from blast furnaces, coke ovens and petrochemical feedstocks.

Fig.4: Energy demand by fuel in selected end-use sectors in India

Industrial energy demand has almost doubled over the 2000-2013 period, with strong growth from coal and electricity. Large expansion in the energy-intensive sectors, including a tripling in steel production, is one component. Nonetheless, consumption levels of cement and steel are still relatively low for a country of India's size and income levels: consumption of cement is around 220 kilograms (kg) per capita, well behind the levels seen in other fast-growing economies and a long way behind the elevated levels seen in China in recent years (up to 1 770 kg per capita). The agricultural sector, though a small part of energy demand, is a key source of employment and since 2000 has accounted for roughly 15% of the increase in total final electricity demand as more farmers obtained electric pumps for irrigation purposes.

Over 90% of energy demand in the transport sector in India is from road transport. The country's passenger light-duty vehicle (PLDVs) stock has increased by an average of 19% per year since 2000, rising to an estimated 22.5 million in 2013, with an additional 95 million motorbikes and scooters (two/three-wheelers). Yet ownership levels per capita are still very low compared with other emerging economies and well below ownership levels of developed countries (Fig.5). Poor road infrastructure is a major constraint to broader vehicle ownership; according to the World Bank, one-third of the rural population lacks access to an all-weather road, making car ownership impractical – even in cases where it is affordable (World Bank, 2014).

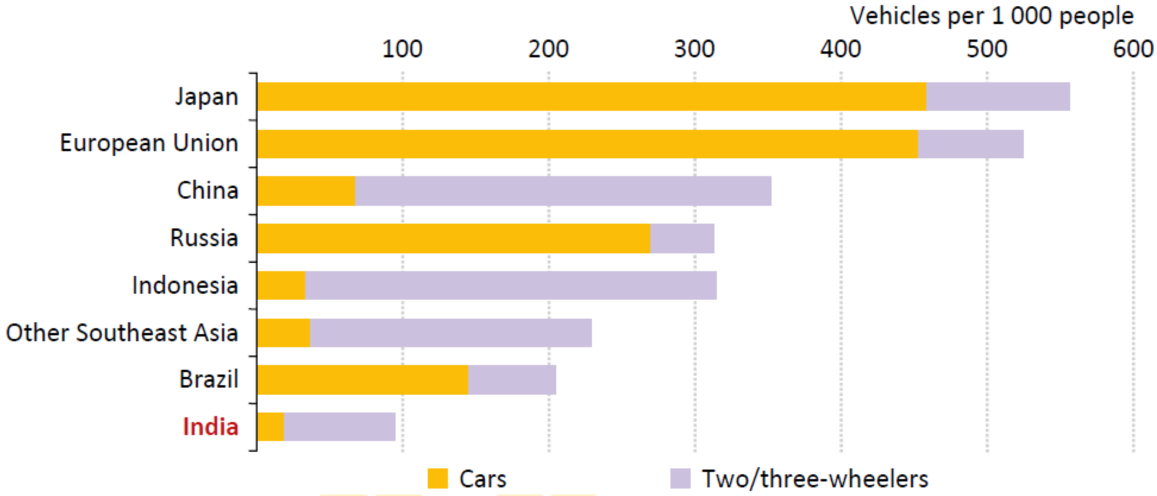


Fig.5: Vehicle ownership in India and selected regions, 2013

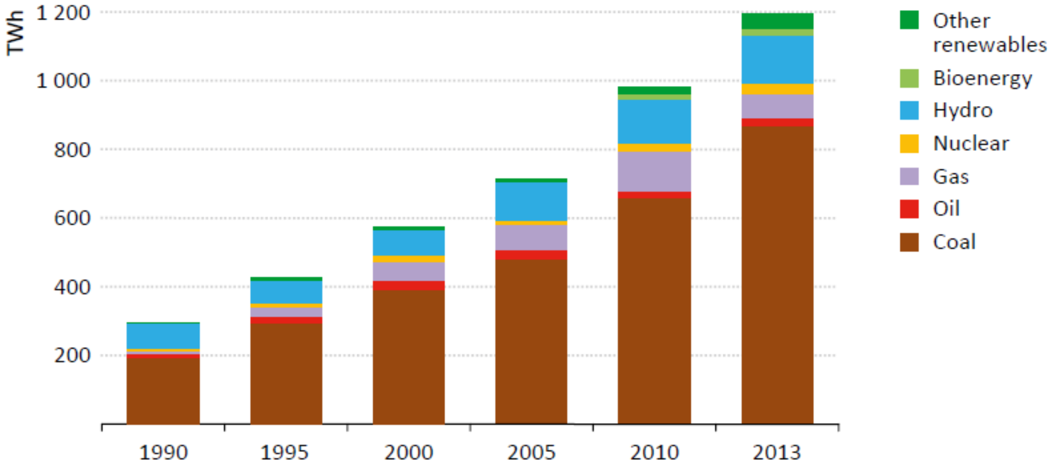
Electricity

The provision of electricity is critical to India's energy and economic outlook and is a major area of uncertainty for the future. The country's electricity demand in 2013 was 897 terawatt-hours (TWh), up from 376 TWh in 2000, having risen over this period at an average annual rate of 6.9%. Electricity now constitutes some 15% of final energy consumption, an increase of around four percentage points since 2000. As with all other demand sectors, further rapid growth is to be expected: around one-sixth of the world's population in India consumes about one-twentieth of global power output. With continued economic expansion, expanding access to electricity, urbanisation, an ever-larger stock of electrical appliances and a rising share of electricity in final consumption, pressures on the power system will persist and increase.

The situation varies from state to state, but higher tariffs paid by commercial and industrial consumers are typically not enough to offset the losses arising from subsidies to residential and agricultural consumers, despite efforts to raise retail rates in recent years (see section on energy prices below). The consequent financial problems faced by local distribution companies are often exacerbated by shortfalls in subsidy compensation payments due from state governments and by poor metering and inefficient billing and collection, creating a spiral of poor performance, inadequate investment, high transmission and distribution losses and regular power outages. This is a key structural weakness for the energy sector as a whole.

On the supply side, India has some 290 gigawatts (GW) of power generation capacity, of which coal (60%) makes up by far the largest share, followed by hydropower (15%) and natural gas (8%). The mix has become gradually more diverse: since 2000, almost 40% of the change in installed capacity was non-coal. This is reflected also in the figures for generation, which show how renewables are playing an increasingly important role (Fig.6). But, despite the increase in generation, India faces a structural shortage of power. For residential consumers, this constraint is most evident during periods of peak demand, typically in the early evenings as demand for lighting, cooling and other appliances surges (with the result that, where they can afford it, households often invest in small diesel generators or batteries and inverters as back-up).

Industrial consumers are also affected by unreliable and unpredictable power supply: around half of the industrial firms in India have experienced power cuts of more than five hours each week (FICCI, 2012). Elevated end-use industrial tariffs, allied to unreliable supply, lead many industrial and commercial consumers to produce their own electricity, using back-up diesel generators or larger plants (albeit not utility-scale). Energy-intensive industries, such as steel, cement, chemicals, sugar, fertilisers and textiles are key auto-producers, with cement producers, for example, estimated to produce around 60% of the electricity that they consume. This capacity has been growing steadily and is often coal-fired, relatively inefficient compared with utility-scale generation units and under-utilised (many companies need less electricity than their captive plants can produce, but there are obstacles to feeding this excess power into the grid). The increased use of captive generators, both at household and industrial levels, often worsens local air pollution.



Note: Other renewables includes solar PV and wind.

Fig.6: Total electricity generation in India by fuel

Access to modern energy

India has made great strides in improving access to modern energy in recent years. Since 2000, India has more than halved the number of people without access to electricity and doubled rural electrification rates. Nonetheless, around 240 million people, or 20% of the population, remain without access to electricity (Table 1). The population without access is concentrated in a relatively small number of states: almost two-thirds are in two populous northern and north-eastern states, Uttar Pradesh and Bihar. In large swathes of India, including the majority of southern states, electrification rates are already well above 90%. Of the total without access, the large majority – some 220 million people – live in rural areas where extending access is a greater technical and economic challenge. In urban areas, electrification rates are much higher, but the quality of service remains very uneven, especially in India's large peri-urban slum areas that are home to around 8.8 million households (National Sample Survey Office, 2014b). India's rural electrification programme, the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), was launched in 2005 and aimed to provide electricity to villages of 100 inhabitants or more and free electricity to people below the poverty line. The effective implementation of RGGVY has faced several challenges and there are strong variations in outcomes between states, as well as questions over the definition of access.

In July 2015, RGGVY was subsumed within a new scheme, the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY). The main components of this scheme are the separation of distribution networks between agricultural and non-agricultural consumers to reduce load shedding, strengthening local transmission and distribution infrastructure, and metering. Among the issues that have held up progress with electrification is the need to find local solutions adapted to the specific circumstances of the remote settlements without access, and a variety of problems in securing authorisation for the necessary projects (e.g., land acquisition and rights-of-way for transmission lines and roads).

Table 2: Number and share of people without access to electricity by state in India, 2013

	Population without access (million)			Share of population without access		
	Rural	Urban	Total	Rural	Urban	Total
Uttar Pradesh	80	5	85	54%	10%	44%
Bihar	62	2	64	69%	19%	64%
West Bengal	17	2	19	30%	7%	22%
Assam	11	0	12	45%	9%	40%

Rajasthan	10	0	11	22%	2%	17%
Odisha	10	0	11	32%	4%	27%
Jharkhand	8	1	9	35%	4%	27%
Madhya Pradesh	7	1	8	16%	3%	12%
Maharashtra	6	2	6	11%	2%	7%
Gujarat	2	0	3	7%	6%	6%
Chattisgarh	2	0	3	14%	6%	12%
Karnataka	1	2	1	5%	1%	3%
Other states	3	16	6	2%	2%	2%
Total	221	16	237	26%	4%	19%

Source: National Sample Survey Office, (2014); Central Electricity Authority, (2014a); IEA analysis.

Aside from those without electricity, India also has the largest population in the world relying on the traditional use of solid biomass for cooking: an estimated 840 million people – more than the populations of the United States and the European Union combined. There is a host of issues associated with the traditional use of solid biomass for cooking, including the release of harmful indoor air pollutants that are a major cause of premature death, as well as environmental degradation as a result of deforestation and biodiversity loss. The government has made a major effort to address these issues, primarily through the subsidised availability of LPG as an alternative cooking fuel (see section below on energy prices).

Energy production and trade

Fossil fuels supply around three-quarters of India's primary energy demand and, in the absence of a very strong policy push in favour of alternative fuels, this share will tend to increase over time as households move away from the traditional use of biomass. This high – and potentially growing – reliance on fossil fuels comes with two major drawbacks. India's domestic production of fossil fuels, considered on a per-capita basis, is by far the lowest among the major emerging economies (Fig.7), meaning that India has a structural dependence on imported supply. In addition, combustion of coal and oil products contributes to pressing air quality problems in many areas, as well as to global greenhouse gas (GHG) emissions.

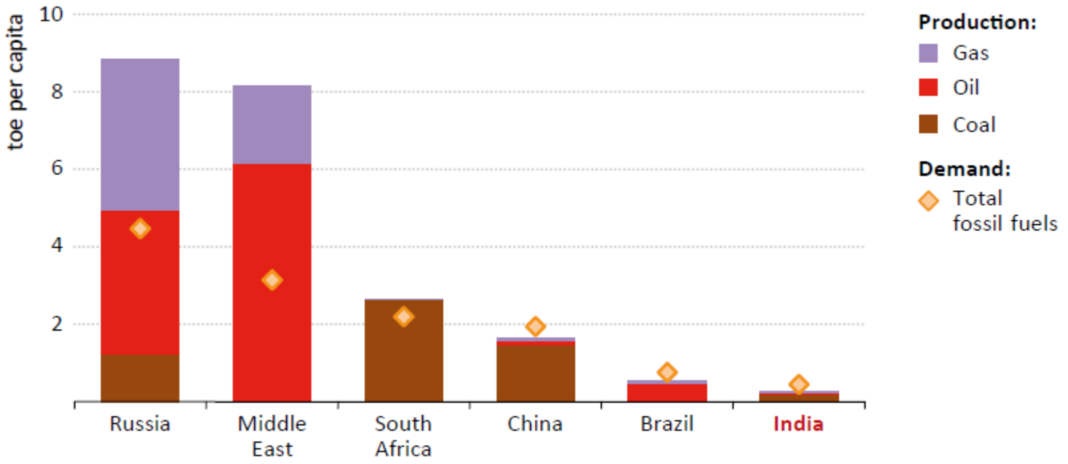


Fig.7: Fossil-fuel production and demand per capita by selected countries, 2013

Coal

India has the third-largest hard coal reserves in the world (roughly 12% of the world total), as well as significant deposits of lignite. Yet the deposits are generally of low quality and India faces major obstacles to the development of its coal resources in a way that keeps pace with burgeoning domestic needs. In 2013, India produced almost 340 million tonnes of coal equivalent (Mtce), but it also imported some 140 Mtce – roughly 12% of world coal imports (61% from Indonesia, 21% from Australia, 13% from South Africa). With a view to limiting reliance on imports, the government announced plans in early 2015 to more than double the country's coal production by 2020.

The coal sector in India is dominated by big state-owned companies, of which Coal India Limited (CIL) is the largest, accounting for 80% of India's output. CIL has an unwieldy structure and is characterised by poor availability of modern equipment and infrastructure, an over-reliance on surface mining and very low productivity from a very large workforce. Around 7% of national production comes from captive mining, i.e. large coal-consuming companies that mine for their own use; private companies are not at present allowed to mine and market coal freely, though there are now some moves to open the coal market. At present, more than 90% of coal in India is produced by open cast mining. This method has relatively low production costs and is less dangerous than deep mining, but has a large, adverse environmental footprint in the form of land degradation, deforestation, erosion and acid water runoff.

Among the other problems facing the Indian coal sector is a mismatch between the location of hard coal reserves and mines, which are concentrated in eastern and central India, and the high-demand centres of the northwest, west and south. A tonne of coal must travel on average more than 500 kilometres (km) before it is converted to electricity, straining the country's rail network. There are also challenges related to the quality of the coal reserves. Most of the hard coal has low to medium calorific values and high ash content. The low heat value means that more coal must be burned per unit of electrical output, leading to higher local emissions. The ash content increases the cost of transporting coal, is corrosive and lowers the efficiency and load factor of coal-fired power plants. In addition, most power plants are designed for a specific coal quality; if not available, operators may choose to blend different coal types, which can adversely impact the performance of the power plant, as the properties of blends can vary widely.

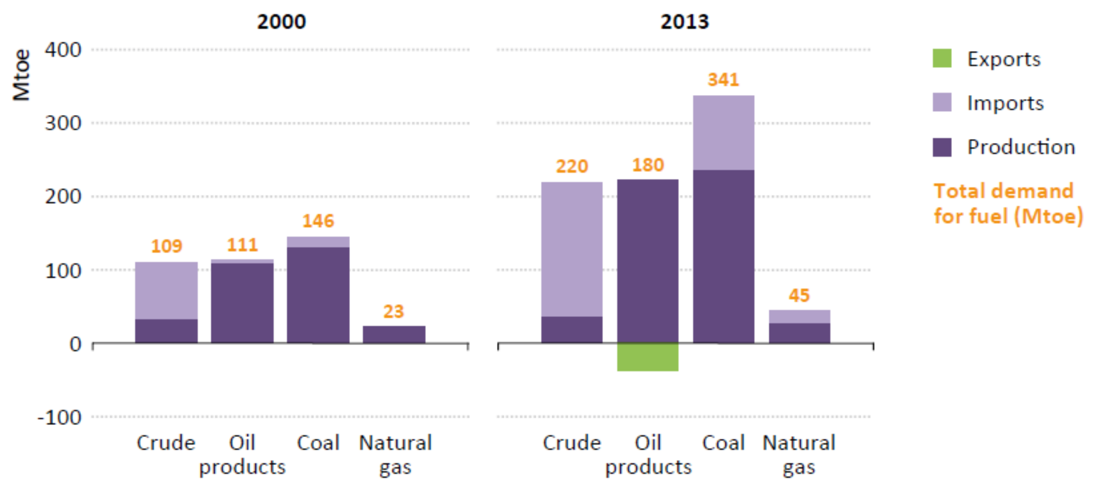
The difficulty in expanding coal production in recent years has been related to a number of factors, including delays in obtaining environmental permits, land acquisition and rehabilitation and resettlement issues, infrastructure constraints (limited transport capacity to connect mines, dispatch centres and end-use destinations), insufficient coal-washing facilities to remove the ash and technological limitations (notably for underground mining). Other questions concerning future supply have arisen as a result of a Supreme Court decision in 2014 to annul the award of almost all of the coal blocks allocated since 2003 on the grounds that these awards had not been made on a transparent and competitive basis, although this has also opened an unexpected opportunity for the government to reform the coal sector in order to comply with the judgement. Two successful rounds of bidding have already been held to re-allocate some blocks and there is a possibility that private companies may be invited to participate in future rounds.

Oil and oil products

India is one of the few countries in the world (alongside the United States and Korea) that rely on imports of crude oil while also being significant net exporters of refined products (Fig.8). Domestic crude oil production of just over 900 thousand barrels per day (kb/d) is far from enough to satisfy the needs of 4.4 mb/d of refinery capacity. The output from the refinery sector, in turn, is more than enough to meet India’s current consumption of oil products, at around 3.8 mb/d (with the exception of LPG, for which India imports about half of domestic consumption).

India has relatively modest oil resources and most of the proven reserves (around 5.7 billion barrels) are located in the western part of the country, notably in Rajasthan and in offshore areas near Gujarat and Maharashtra. The Assam-Arakan basin in the northeast is also an oil-producing basin and contains nearly a quarter of total reserves. Despite efforts to bolster oil production, including the opening of India’s upstream sector to non-state investors, the sector has underperformed. Key impediments to investment include the complex regulatory environment (including uncertainty over contract terms and pricing arrangements), and a resource base that is still not well-explored and appraised. The upstream is still dominated by a few state-owned companies: about two-thirds of crude oil is produced by the Oil and Natural Gas Corporation Limited (ONGC) and Oil India Limited (OIL) under a pre-liberalisation nomination regime. Most of the remaining production comes from joint ventures with the national oil and gas companies and from blocks awarded under successive licensing rounds held under the New Exploration Licensing Policy introduced in 1999.

By contrast, the refining sector continues to strengthen. India has almost doubled its refining capacity in the last ten years and has added more than 2 mb/d of new capacity since 2005, with strong private sector participation from companies such as Reliance and Essar (India is now fourth in the world in terms of total refining capacity, behind only the United States, China and Russia). India's refinery assets include the largest refinery in the world, Reliance's Jamnagar complex, with over 1.2 mb/d of throughput capacity (more than India's domestic crude production). These capacity additions have given India a surplus of refined products, as the growth in oil product demand growth, even at an impressive 4.2% average annual rate, has been slower than the capacity boom.



Note: Demand for crude oil shows refinery intake.

Fig.8: Fossil-fuel balance in India

The refining capacity expansion, along with stagnant domestic crude oil output, means that India has become the third-largest crude oil importing country, behind the United States and China, with about 3.7 mb/d of import requirements (overall, India must import feedstock to meet 80% of its refinery needs for crude oil). The majority of ports that handle imported crude oil are located on the western side of India to accommodate oil tankers from the Middle East (the largest source of imports), Latin America and Africa. India has sought to diversify its sources of supply, especially as disruptions have plagued several of its suppliers such as Iran, Libya and Nigeria. The government announced in March 2015 a strategic aim to reduce reliance on imported crude by as much as 10% by 2022. The fall in the price of crude oil has also offered a cost-effective opportunity to build up emergency stockpiles of crude. With the expected completion of additional storage facilities for the strategic petroleum reserve expected in late 2015, India will have a combined storage capacity of about 37 million barrels, or roughly ten days' worth of crude imports. With refinery output exceeding total demand by roughly 1 mb/d, India is a net exporter of all refined products except LPG. India has been an important supplier of diesel to Europe and a regular supplier of transport fuel to Asia-Pacific and Middle Eastern countries. Its exports come mainly from the private sector refiners Reliance and Essar, while the public sector refiners supply the domestic market. Growing product exports from India have contributed to refinery capacity rationalisation in both European and Asia-Pacific markets, as India's more modern, privately owned refineries, which are capable of efficiently processing Middle Eastern oil into high quality products, were able to gain market share from less complex refineries in Europe and Japan.

Natural gas

Natural gas has a relatively small share (6%) of the domestic energy mix. Optimism about the pace of expansion, fueled by some large discoveries in the early 2000s, has been dashed by lower-than-expected output from offshore domestic fields. The main onshore producing fields are in the states of Assam in the northeast, Gujarat in the west and Tamil Nadu and Andhra Pradesh in the south. Some of the most promising areas are offshore, including the Krishna Godavari basin off the east coast. The production record in recent years has been strongly affected first by the start of production at the much-awaited KG-D6 offshore field in 2009, and then by its faster than expected decline because of reported subsurface complexity. This has contributed to an overall decrease in Indian gas output since 2011. Production of conventional gas reached 34 bcm in 2013 and was supplemented by LNG imports via four regasification terminals. The majority state-owned gas company, GAIL, is the largest player in the midstream and downstream gas market.

In addition to conventional gas resources, India also has large unconventional potential, both from coalbed methane (CBM) and shale gas. Commercial production at scale is still some way off, although CBM activity is starting to gain momentum, with a number of private companies, including Reliance and Essar, stepping up their involvement. In the case of shale gas, the government approved in 2013 an exploration policy that allows the two national companies – ONGC and OIL – to drill for shale resources in their existing blocks. However, upstream gas development in India continues to face a number of significant hurdles: a key issue is the price available to domestic producers.

Hydropower

India has significant scope to expand its use of hydropower: its current 45 GW of installed capacity (of which over 90% is large hydro) represents a little under a third of the assessed resource. Much of the remaining potential is in the north and northeast. A further 14 GW are under construction, although some of these plants have been delayed by technical or environmental problems and public opposition. If developed prudently, hydropower can bring multiple benefits as a flexible source of clean electricity, and also as a means of water management for flood control, irrigation and domestic uses. It can also enable variable renewables to make a greater contribution to the grid. However, its development has lagged well behind thermal generation capacity, leading to a consistent decline in its share of total electricity output. Capacity additions and generation have routinely fallen short of the targets set in successive government programmes, while the objective of bringing in private investors has likewise proved difficult to realise.

High upfront costs, the need for long-term debt (which is quite limited in India's capital markets) and consequent difficulties with financing have been a major impediment to realising India's hydropower potential. Much of the potential is in remote areas, necessitating new long-distance transmission lines to bring power to consumers. Adequate and efficient project planning and supervision is another hurdle, notably the challenge of evaluating and monitoring environmental impacts (including long-term water availability and potential seismic risks), ensuring adequate public involvement and acceptance, and assessing the effect of multiple projects (often in different states) on individual river systems. Some hydropower projects have faced very long environmental clearance and approval procedures, as well as significant public opposition arising largely from resettlement issues and concern over the impact on other water users. Some of these concerns can be reduced by undertaking small-scale projects: India has an estimated potential 20 GW of small hydro projects (up to 25 megawatt [MW] capacity) (MNRE, 2015). As of 2014, 2.8 GW of small hydro (less than 10 MW) had been developed.12 Such projects are particularly well-suited to meet power requirements in remote areas.

Bioenergy

Bioenergy accounts for roughly a quarter of India's energy consumption, by far the largest share of which is the traditional use of biomass for cooking in households. This reliance gives rise to a number of problems, notably the adverse health effects of indoor air pollution. India is also deploying a range of more modern bioenergy applications, relying mainly on residues from its large agricultural sector. There was around 7 GW of power generation capacity fuelled by biomass in

2014, the largest share is based on bagasse (a by-product of sugarcane processing) and a smaller share is cogeneration based on other agricultural residues. The remainder produce electricity via a range of gasification technologies that use biomass to produce syngas, including small-scale thermal gasifiers that often support rural small businesses. Although modern bioenergy constitutes only a small share of energy use at present, Indian policy has recognised – with the launch of a National Bioenergy Mission – the potential for modern bioenergy to become a much larger part of the energy picture especially in rural areas, where it can provide a valuable additional source of income to farmers, as well as power and process heat for consumers.

Biofuels are another area of bioenergy development in India, supported by an ambitious blending mandate, dating back to 2009, that anticipates a progressive increase to a 20% share for bioethanol and biodiesel by 2017. Implementation has thus far been slower than planned: the present share of bioethanol – mostly derived from sugarcane – remains well under 5% and progress with biodiesel has been even more constrained. The main concern over biofuels – and some other forms of bioenergy – is the adequacy of supply: land for biofuels cultivation can compete with other uses, as well as requiring water and fertilisers that may be limited and is required in other sectors.

Wind and solar

From a low base, modern renewable energy (excluding hydropower) is rapidly gaining ground in India's energy mix as the government has put increasing emphasis on renewable energy, including grid-connected and off-grid systems. Wind power has made the fastest progress and provides the largest share of modern non-hydro renewable energy in power generation to date. India has the fifth-largest amount of installed wind power capacity in the world, with 23 GW in 2014, although investment has fluctuated with changes in subsidy policies at national and state level. Key supporting measures have included a generation-based financial incentive (a payment per unit of output, up to certain limits) and an accelerated depreciation provision. A scheme of renewable purchase obligations also exists, requiring that a certain percentage of all electricity should be sourced from wind, solar and other renewables, but the operation of this scheme has been undercut (and not enforced in some cases) by the financial state of many distribution companies.

Solar power has played only a limited role in power generation thus far, with installed capacity reaching 3.7 GW in 2014, much of this added in the last five years. However, India began to put a much stronger emphasis on solar development with the launch in 2010 of the Jawaharlal Nehru National Solar Mission, the target of which was dramatically upgraded in 2014 to 100 GW of solar installations by 2022, 40 GW of rooftop solar photovoltaics (PV) and 60 GW of large- and medium-scale grid-connected PV projects (as part of a broader 175 GW target of installed renewable power capacity by 2022, excluding large hydropower). The dependence of national targets on supportive actions taken at state level is underlined by the fact that four states (Gujarat, Rajasthan, Madhya Pradesh and Maharashtra) account for over three-quarters of today's installed capacity. Rooftop solar also has the potential to become a more important part of India's solar portfolio, particularly where it can minimise or displace expensive diesel-powered back-up generation.

While the promise is undeniable, renewable energy faces, like other energy source, structural, governance and institutional challenges. Though costs for solar and wind are declining, in most cases the technologies do not yet warrant investment in India (as in most other countries) without some form of subsidy. Fiscal incentives and policy support are strong at the moment, but this is a source of uncertainty, especially when juxtaposed with the financial difficulties faced by local distribution companies that are often obliged to absorb the extra cost. The need for land and additional transmission and distribution infrastructure (which India is trying to address via the concept of "green energy corridors") could likewise constrain progress. Given the priority in Indian policy to develop the domestic manufacturing sector, the outlook is also contingent to a degree on the local availability of equipment, such as solar panels and wind turbines, where India has lost ground to lower cost producers. In China, for example, the cost of locally produced solar modules and cells is 25-50% lower than in India.

Nuclear power

India has twenty-one operating nuclear reactors at seven sites, with a total installed capacity close to 6 GW. Another six nuclear power plants are under construction, which will add around 4 GW to the total. The operation of the existing nuclear fleet has been constrained in the past by chronic fuel shortages, in 2008 the average load factor was as low as 40%. This constraint was eased after India became a party to the Nuclear Suppliers' Group agreement in 2008, allowing access not only to technology and expertise but also reactor parts and uranium. The average plant load factor rose to over 80% in 2013 (DAE, 2015).

Though the current share of nuclear power in the generation mix is relatively small at 3%, India has ambitious plans to expand its future role, including a long-term plan to develop more complex reactors that utilise thorium – a potential alternative source of fuel for nuclear reactors. India has limited low-grade uranium reserves, but it has the world's largest reserves of thorium: developing a thorium fuel cycle will though require a range of tough economic, technical and regulatory challenges to be overcome.

The nuclear industry in India is also subject to the broader challenges that are facing the worldwide nuclear industry, including project economics, difficulties with financing and the implications of the Fukushima Daiichi accident in Japan for public acceptance of new projects. India has struggled to attract the necessary investment and to gain access to reactor technology and expertise, with the Civil Liability Nuclear Damage Act of 2010 widely seen as deterring potential suppliers (especially Japanese and US companies). However, the United States and India reached an understanding on nuclear liability issues early in 2015 that may facilitate US investment in Indian nuclear projects.

Factors affecting India's energy development

Economy and demographics

The pace of economic and demographic change is a vitally important driver of India's energy sector. Since 1990, India's economy has grown at an average rate of 6.5% a year, second only to China among the large emerging economies, and two-and-a-half-times the global average (if both these countries are excluded). This propelled India beyond Japan in 2008, to become the third-largest economy in the world, measured on a PPP basis. India alone has accounted for over 9% of the increase in global economic output since 1990.

In the period since the early 1990s, the poverty rate (measured as the proportion of the population making less than $1.25/day in PPP terms14) fell by more than half, from almost 50% to less than 25%. In the eight years 2004-2011, more than 180 million people in India were lifted out of extreme poverty. Despite this progress, income per capita is still low and a gap has emerged between India and its counterparts among the BRICS (Brazil, Russia, India, China and South Africa). Though starting off at similar levels in the early 1990s (in PPP terms), average income per capita in China is now more than double that in India (Fig.9). Furthermore, although extreme poverty has been reduced, income inequality has increased in India, with the poorest quartile of society earning a smaller share of total income than they did in 1990.

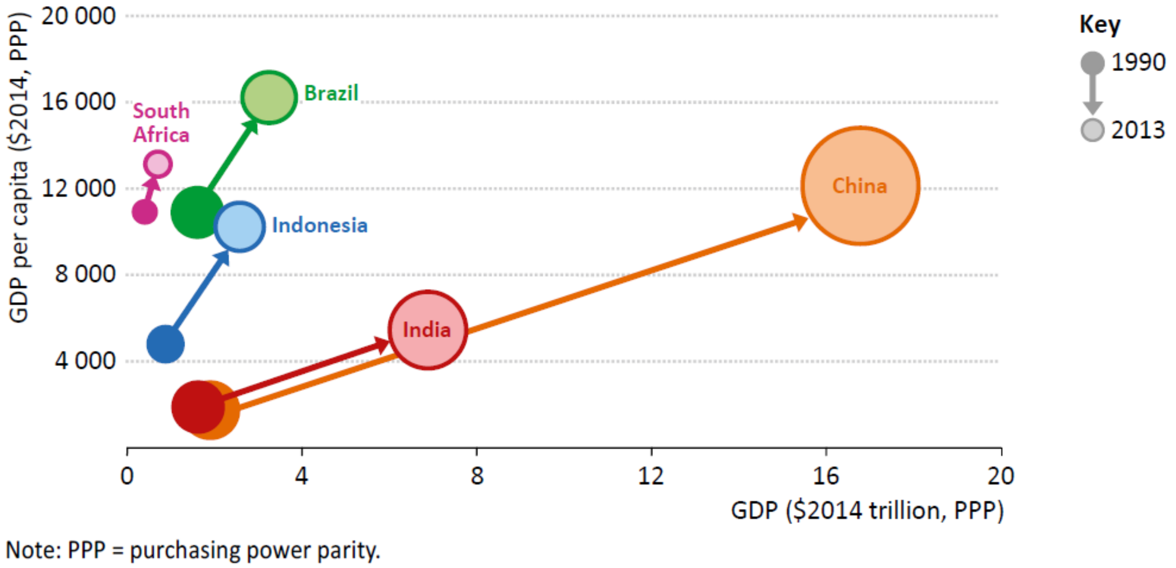


Fig.9: GDP per capita and total GDP for selected countries, 1990 and 2013

The services sector has been the major driver of growth in India's economy, accounting for around 60% of the increase in GDP between 1990 and 2013. This is rooted both in a robust increase in the supply of services but, crucially, also in the increasing share of high-value segments including financial intermediation, information and communications technology, and professional and technical services, which have enabled total factor productivity in the services sector to more than double. However, despite its dominant share in the economy, the services sector employs only around one-quarter of the labour force. The agricultural sector, with less than 20% of GDP (compared with just over 35% in 1990), continues to account for around half of total employment (Fig. 10).

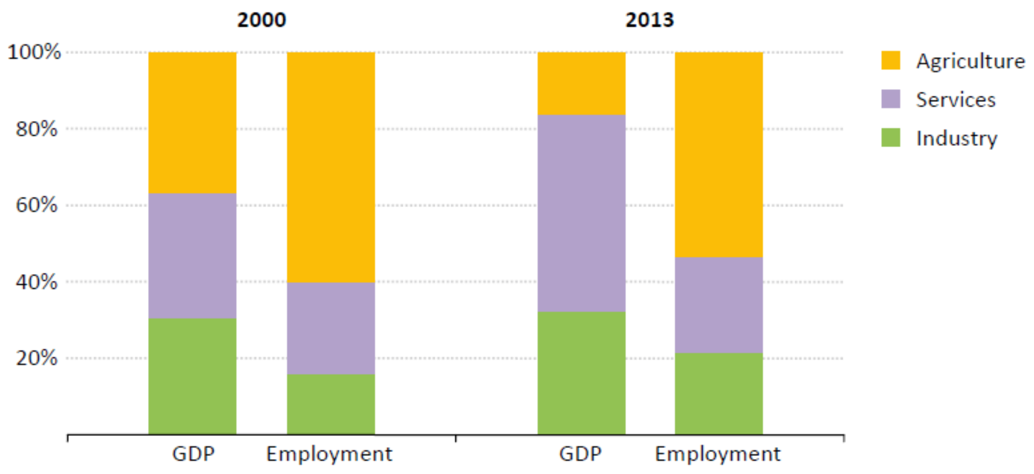


Fig.10: Composition of GDP and employment structure in India

The services-led growth that India has enjoyed since the early 1990s differs from the path of economic development in many other countries, since it was not preceded by an initial strong push from the manufacturing sector. The government has expressed its intention to re-balance the economy and in 2014 announced the "Make in India" initiative, with the intention of increasing the share of manufacturing in GDP to 25% by 2022, creating 100 million jobs in the process. The extent to which this objective is realised will affect India's energy development in two ways. First, mining, oil and gas, renewables and power generation have all been identified as clusters for industrial development, so any success will have implications for energy supply. Second, any change in the share of industry in the economy, and the materials-intensity of future economic growth, will have profound effects on the levels of energy demand. Urbanisation and the build-up of a manufacturing base, including the necessary energy infrastructure, will require significant inputs from the basic materials industry, including steel, cement and chemicals, which are all highly energy-intensive.

Since 1990, India's population has grown by over 380 million people, a number greater than the total population of the United States and Canada together. This includes a near-doubling of the urban population, reflecting the transition away from agricultural employment. Population growth is expected to remain high; India is set to overtake China as the most populous country in the world before 2025 (UNPD, 2015). India's large and growing population is often regarded as one of its major assets; it is relatively young, with almost 60% (around 700 million people) under the age of 30, a large and potentially very vibrant workforce. The large domestic market can also act as a natural driver for economic growth, with levels of private consumption currently around two-and-a-half-times as large as exports. The flip side of this demographic dividend is the likely strain on the country's infrastructure and resources. Water stresses that are already evident in some regions will be exacerbated and create new challenges in relation to food and energy security, and there will be a need to create one million new jobs each month to absorb the new entrants to the labour market.

Policy and institutional framework

The direction that national and state policies take, and the rigour and effectiveness with which they are implemented, will naturally play a critical role in India's energy outlook. Clarity of vision for the energy sector is difficult to achieve in India, not least because of the country's federal system and complex institutional arrangements. However, the drive for a more coherent and consistent energy policy has been a long-standing priority, typified by the Integrated Energy Policy 2008, the National Action Plan on Climate Change and the co-ordination efforts of the Planning Commission (now the National Institution for Transforming India, [NITI Aayog]), all aided by consistent improvements in the quality of Indian energy data. An energy scenario modelling exercise has also been launched, the India Energy Security Scenarios, overseen by NITI Aayog. More recently, the submission of India's Intended Nationally Determined Contribution (INDC) on 1 October 2015 was a milestone in both India's energy and its environmental policy.

India shares the overarching aim of energy policy throughout the world: to provide secure, affordable and universally available energy as a means to underpin development, while addressing environmental concerns. The administration in place since 2014 has given greater definition to many aspects of energy policy, while also seeking to give more rights and responsibilities to the individual states. Some key aspects of the emerging energy vision are:

A commitment to the efficient use of all types of energy in order to meet rapidly growing demand. In the power sector, the decision to increase the target for renewables to 175 GW by 2022 (including the expansion of solar generation capacity to 100 GW) has attracted a lot of attention; but there is also, for example, a volumetric target for India to produce 1.5 billion tonnes of coal by 2020. Efficiency gains as well as production increases underlie India's energy security objective of reducing reliance on fossil-fuel imports by 10%.

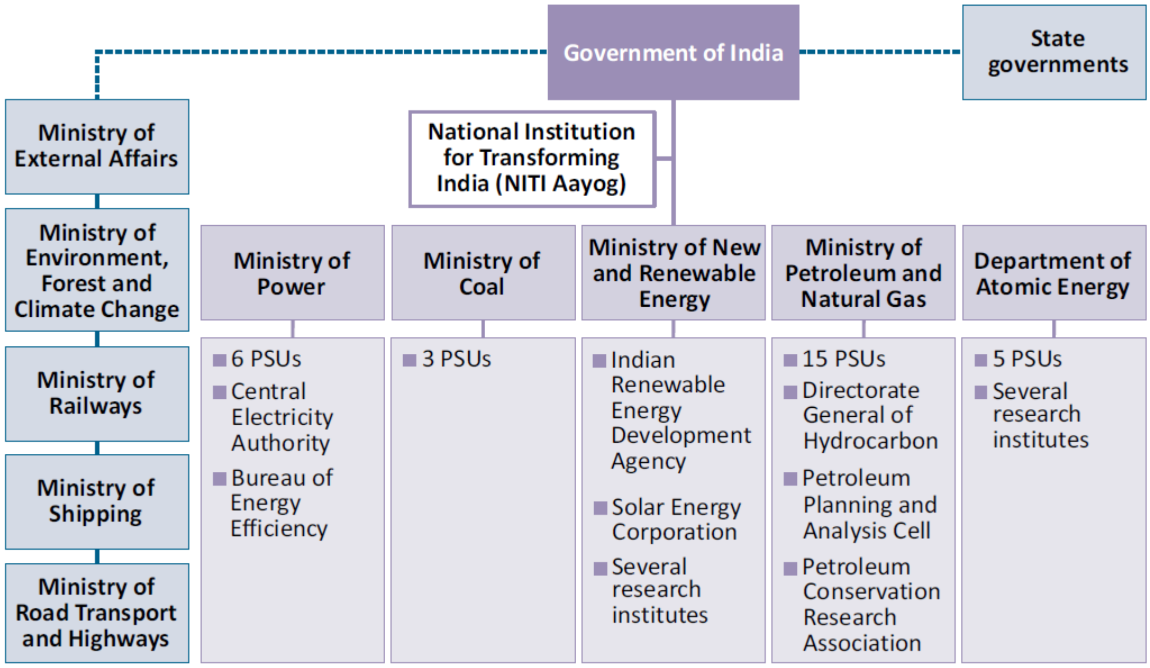
A sharpened focus on achieving universal access to modern energy, including the objective of supplying round-the-clock electricity to all of India's population. This is being accompanied by a reorientation of energy subsidy programmes, away from price controls and towards financial payments to the most vulnerable parts of society.

A drive for market-oriented solutions and increased private investment (including foreign investment) in energy, both through some energy-specific reforms (e.g., to licensing regimes) and via a general drive to simplify and deregulate the business environment. A pledge to pursue a more climate-friendly and cleaner path than the one followed thus far by others at corresponding levels of economic development. India's INDC includes the twin energy-related commitments to increase the share of non-fossil fuel power generation capacity to 40% by 2030 (with the help of transfer of technology and low-cost international finance) and to reduce the emissions intensity of the economy by 33-35% by the same date, measured against a baseline of 2005.

Achievement of these aims is naturally contingent on the broader political and institutional context. India is a federal, democratic country in which regional and local politics and governments play a very important role, via the 29 constituent states and 7 union territories (their role is reflected in the bi-cameral national parliamentary structure, where the lower house, elected by direct popular vote, sits alongside an upper house, representing the states and territories). The constitution divides power between the central and state governments, as well as defines a category of subject areas for which there are concurrent responsibilities. The central government has exclusive competence over inter-state trading and commerce, as well as mineral and oil resources, nuclear energy and some national taxes, e.g., on income. States have jurisdiction over water issues and land rights, natural gas infrastructure, and many specific areas of taxation, e.g., on mineral rights or the consumption or sale of electricity. Concurrent powers include electricity and forestry, as well as economic and social planning, and labour relations.

India's federal structure puts a premium on constructive relations between states and the central government, but also risks duplication and inconsistent decision-making. The model being promoted by the new administration is one of co-operative federalism, which involves increased devolution in certain areas (e.g., a higher regional share of hydrocarbon revenues in some cases) as well as a wider set of regional responsibilities (e.g., for timely implementation and approval of the state-level clearances required for investment projects). There is also a greater accent on tailoring policies and resource use, particularly in the power sector, to the specificities of individual regions and states. Maintaining independent regulatory bodies, free of political interference (for example, as envisaged in the 2003 legislation reforming the power sector), is a challenge at all levels.

The risk of fragmented decision-making also applies at the national level itself, as there is no single body charged with formulating and implementing a unified energy policy. India has several ministries and other bodies, each with partial responsibility for aspects of energy policy and the related infrastructure (Fig.11). Effective co-ordination has been improved by the appointment of a single Minister for Power, Coal, New and Renewable Energy, although the individual ministries themselves continue to exist as separate entities. The institutional structure requires constant effort – not always successful – to achieve co-ordination and resolve disputes.



Notes: PSU = Public sector undertaking (state-owned enterprise). Other ministries with responsibilities relevant to the energy sector include the Ministry of Urban Development, Ministry of Water Resources, Ministry of Agriculture, Ministry of Finance and the Department of Science and Technology.

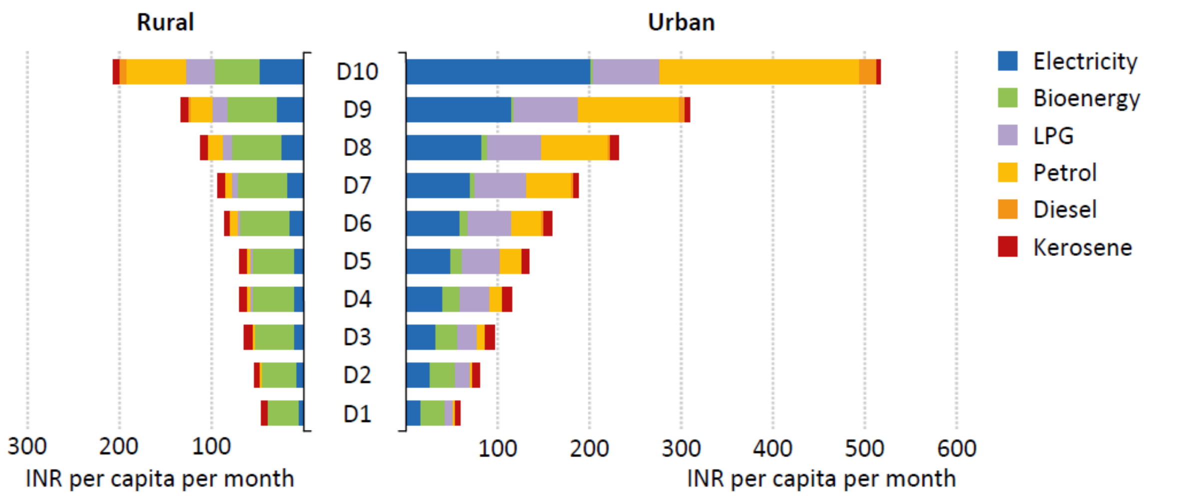
Source: Adapted from (IEA, 2012).

Fig.11: Main institutions in India with influence on energy policy

Energy prices and affordability

Expenditure

The relationship between income levels, energy prices and energy expenditure is fundamental to the evolution of India's energy system. As one would expect, energy consumption increases with income, with the wealthiest 10% of the population accounting for around a quarter of all household energy expenditure, although the poorest segments spend a greater proportion of their income on energy. But the level of consumption and the fuel choice are also affected by location: household expenditure on energy is, on average, almost two-and-a-half-times higher in urban centres than in rural areas, and the most affluent among the urban population spend more than eight-times as much on energy as the poorest, whereas in rural areas they spend four-and-a-half-times as much (Fig.12).



Notes: INR = Indian rupees. The income ranges are by decile (i.e. 10% slices) of the rural and urban population, with D10 being the most affluent 10% and D1 the poorest.

Source: Ministry of Statistics and Programme Implementation (2012).

Fig.12: Per-capita energy expenditure by location and income in India

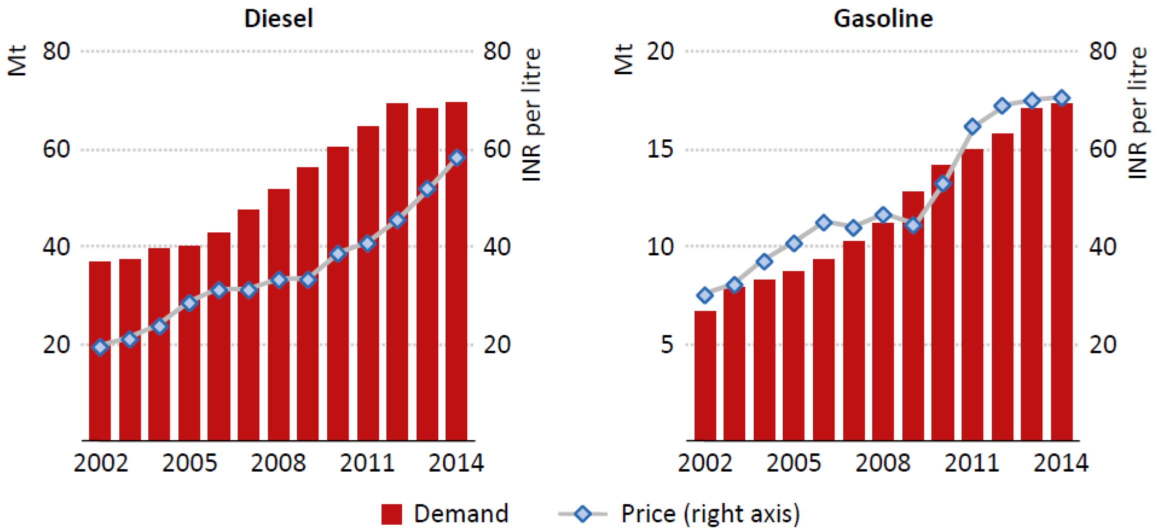
The expenditure pattern across the income groups reflects both an increase in energy consumption as people become more affluent and a switch in fuels, away from bioenergy and kerosene and towards LPG and electricity. In urban areas, spending on bioenergy and kerosene decreases drastically higher up the income groups. Bioenergy and kerosene account for almost 60% of energy expenditure among the poorest income group, but only roughly 1% among the wealthiest group in which 85% of energy expenditure is for electricity and transport fuels.

The pattern is different in rural areas. Here, spending on bioenergy increases as income increases (for all but the wealthiest 20%), driven by a rise in consumption, but also because the poorer segments of society typically collect fuelwood rather than pay for it, an inclination that gradually decreases with increasing levels of wealth. The pattern of expenditure of the most affluent decile in rural areas is significantly different from that of lower income groups, resembling the switch that is observed in urban centres, albeit in a more limited way. Across income levels, rural spending on electricity accounts for around 20% of energy expenditure (compared with almost 40% in urban areas). Rural expenditure is constrained by a lack of access, particularly among the poorest segments of rural communities.

Energy prices

India has made significant moves towards market-based pricing for energy in recent years: gasoline (in 2010) and diesel (2014) prices have both been deregulated, and successive governments have made efforts to ensure that electricity and natural gas prices better reflect market realities. End-use electricity tariffs for most consumers nonetheless remain below the cost of supply. Reform of kerosene and LPG pricing has been much slower, reflecting the role that these fuels play in providing lighting and cooking fuels to the poorest segments of society. As a major consumer and importer of oil, India has also been one of the main beneficiaries of the fall in the oil price since 2014.

Diesel is the most widely consumed petroleum product in India, accounting for around 40% of total oil product consumption. In 2002-2010, the price of diesel was, on average, 70% that of gasoline and this price gap widened when gasoline prices were deregulated in 2010. Price differentials have recently lessened with the removal of diesel subsidies, resulting in diesel consumption flattening as consumer preferences shift towards gasoline (Fig.13). During the period in which transport fuels were subsidised, the benefits accrued disproportionately to the wealthiest strata of society: prior to the deregulation of diesel prices, the bottom two income deciles benefited to the tune of 20 Indian rupees (INR) per capita per month on average from subsidies, while the top two deciles received around INR 120 per capita per month (Anand, 2013). Where subsidies to oil product consumption remain, as in the case of LPG, the government is committed to make them more efficient: the "Aadhaar" system, coupled with recent efforts to spread banking service access to all, will increasingly allow the authorities to make a monetary payment directly to eligible consumers, after they have purchased gas cylinders at market prices. The government also launched a "Give it up" campaign to encourage the wealthiest consumers to abandon their LPG subsidy. As of September 2015, over three million Indians had voluntarily given up the subsidy.



Notes: Mt = million tonnes; INR = Indian rupees. Year denotes fiscal year, starting in April and ending in March.
Source: Petroleum Planning and Analysis Cell (2015).

Fig.13: Diesel and gasoline prices and demand, 2002-2014

The Indian gas market consists of two segments: for domestically produced gas, the price is defined by the government, as are the priority uses (city gas for households and transport, fertiliser plants, grid-connected power plants) which are entitled to gas at this lower price. After a long debate, in October 2014 the government introduced a new pricing formula, linked to a basket of international prices and applicable to most domestically produced gas; this resulted in a price increase from the earlier \$4.2 per million British thermal units (MBtu) to around \$5.6/MBtu, although this has since come down because of the subsequent fall in the reference prices. The new arrangements have kept the price in a range acceptable to domestic gas-consuming sectors, but many gas-producing companies argue that they do not offer sufficient incentive to bring forward new investment in exploration and production in India, particularly in offshore blocks (see Chapter 3). Imported LNG is available at contracted prices that can be significantly higher; there have been proposals to pool LNG with domestically produced gas to make it more accessible to domestic users as well as a subsidy scheme to increase consumption of imported LNG in the power sector.

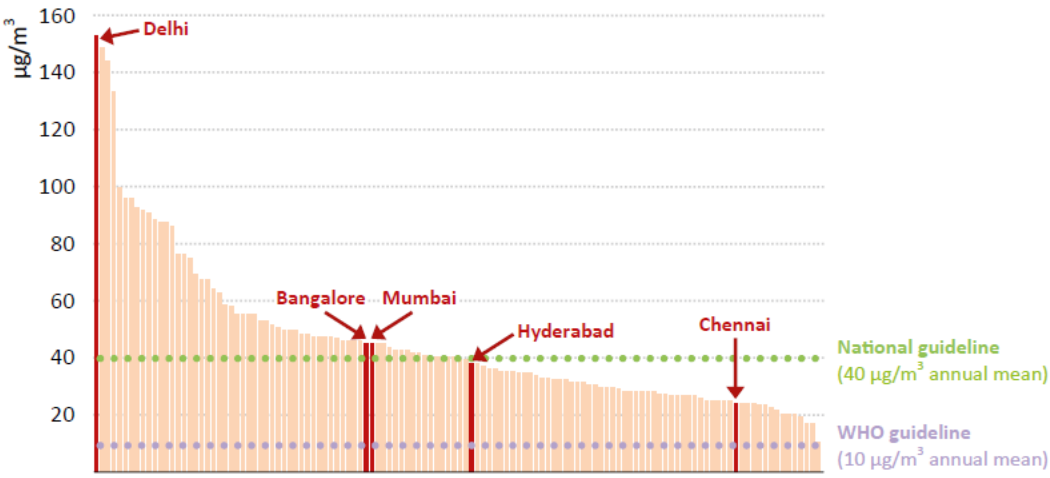
The consumption changes spurred by the recent increase in diesel prices relative to those of gasoline reflect the conventional wisdom that higher prices can act as a brake on demand, spurring consumers to switch fuels, reduce their consumption or opt for more efficient technologies. The inverse relationship, where low tariffs lead to inefficient use of both electricity and water, is evident in the agricultural sector, which accounts for more than one-fifth of final electricity consumption but only 8% of revenue for the utilities.

Social and environmental aspects

Local air pollution

Rapid economic growth and urbanisation create a number of pressures on communities and the wider environment. These can originate from the need to meet growing demand for energy and minerals that increase competition for land, water and other resources, as well as the polluting by-products of the subsequent growth. India is burning more fossil fuels and biomass than it has at any other time in the past, releasing more pollutants, including fine particulate matter (PM2.5) and Sulphur and nitrogen oxides, into the air.

In addition to the problem of indoor air pollution linked to the traditional use of biomass as a cooking fuel, the deteriorating air quality in growing urban centres is becoming an alarming issue for India (Fig.14). Of the 124 cities in India for which data exist, only one, Pathanamthitta (with a population of 38000), meets the World Health Organization guideline for PM2.5 concentrations. Delhi exceeds this guideline by fifteen-times. India has 13 of the world’s 20 most-polluted cities and an estimated 660 million people in areas in which the government’s own national air quality standards are not met. It is estimated that life expectancy, as a result, is reduced by 3.2 years for each person living in these areas.



Sources: World Health Organization; IEA analysis.

$PM_{2.5}$ refers to particulate matter less than 2.5 micrometres in diameter; these fine particles are particularly damaging to health as they can penetrate deep into the lungs when inhaled.

Fig.14: Average annual particulate matter concentration in selected cities in India

Land

The welfare of India's rural population, which is 850 million strong and accounts for almost 70% of the total population, is closely linked to the amount of land they have available for productive use. Land acquisition for public or private enterprises wishing to build infrastructure, from roads and railways to power plants and steel mills, is therefore an issue fraught with social and political sensitivity. Legislative changes introduced in 2013 introduced stringent procedural requirements for land acquisition, defining compensation payments and rehabilitation and resettlement benefits and stipulated those potential developers in the private sector would need to secure the consent of 80% of affected families in the case of land acquisition (70% for acquisitions by public-private partnerships). There have since been attempts to amend this legislation, but finding an appropriate balance between the drive to push ahead with infrastructure projects, on the one hand, and the rights of local communities, especially farmers, on the other, is proving difficult. In the absence of a resolution to this issue, obtaining the required statutory clearances related to community rights, environmental protection and sustainable development has been a major cause of delay. At end-2014, infrastructure projects valued at around 7% of GDP were stalled for these reasons (OECD, 2014). Projects in the energy sector are particularly susceptible to delay: detailed analysis of projection applications showed that the clearance process for some 40-60% of projects in thermal power, hydropower, coal mining and nuclear power sectors went beyond the statutory time limits (Chaturvedi et.al, 2014).

Water

High rates of population and economic growth, along with highly inefficient patterns of water use in the agricultural sector, are putting severe strain on India's water resources. With renewable water resources of some 1 130 cubic metres per capita in 2013, India has now passed the defined threshold for "water stress" (1 700 cubic metres per capita). This has major implications for the energy sector: more than 70% of India's power plants, for example, are located in areas that are water stressed or water scarce (WRI, 2014) and India's warm temperatures and the poor quality coal used in the bulk of its power plants add to their cooling requirements. Global climate change could exacerbate these stresses.

Around 90% of India's water withdrawal is for use in agriculture and livestock, often extracted by tube wells powered from the grid and drawing from groundwater reserves. Subsidised electricity tariffs for agricultural users and a lack of metering have led to hugely inefficient consumption of both electricity and water: in 2010, more water was withdrawn in India for agricultural use alone than for all purposes in China. A number of national and state-level initiatives have sought to encourage more efficient water use, via metering, tariff reform (linked to more reliable supply) and changes to agricultural practices. Plans to introduce more efficient equipment, including solar-powered groundwater pumps, while relieving some pressures on the grid, could reduce incentives for water conservation unless they are accompanied by the introduction of systems that use water more efficiently, such as drip irrigation networks.

Carbon-dioxide emissions

India's CO_2 emissions can be seen through two lenses. Calculated on a per-capita basis, emissions are extremely low, standing at just one-quarter of China's and the European Union's and one-tenth the level in the United States (Fig.15), while India also accounts for only a small share of cumulative historical GHG emissions. On the other hand, India is the third-largest country in volume terms of CO_2 emissions in the world, behind only China and the United States. Heavy dependence on coal for power generation and the use of inefficient subcritical plants to burn it push up the carbon intensity of India's power sector to 791 grammes of carbon dioxide per kilowatt-hour (g CO_2/kWh), compared to a world average of 522 g CO_2/kWh.

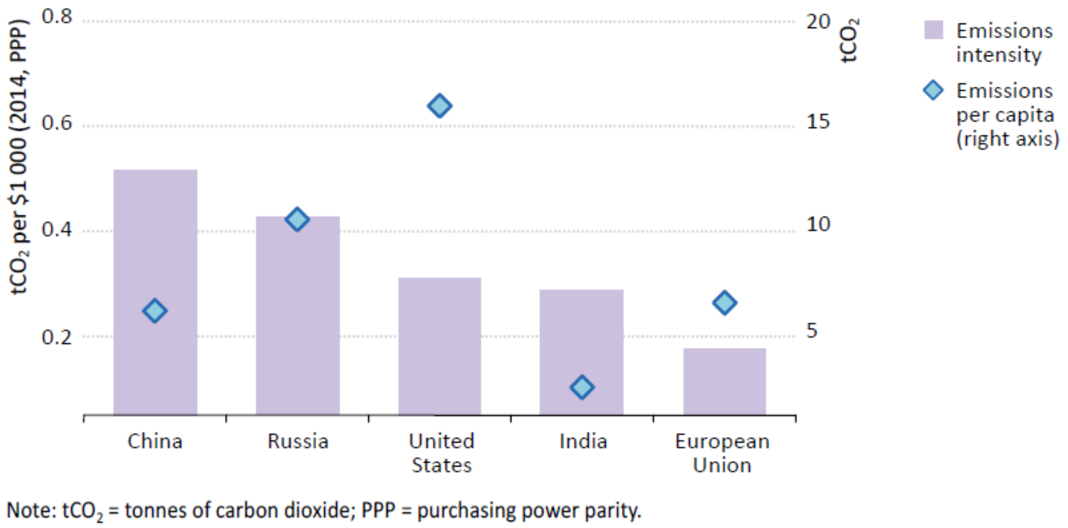
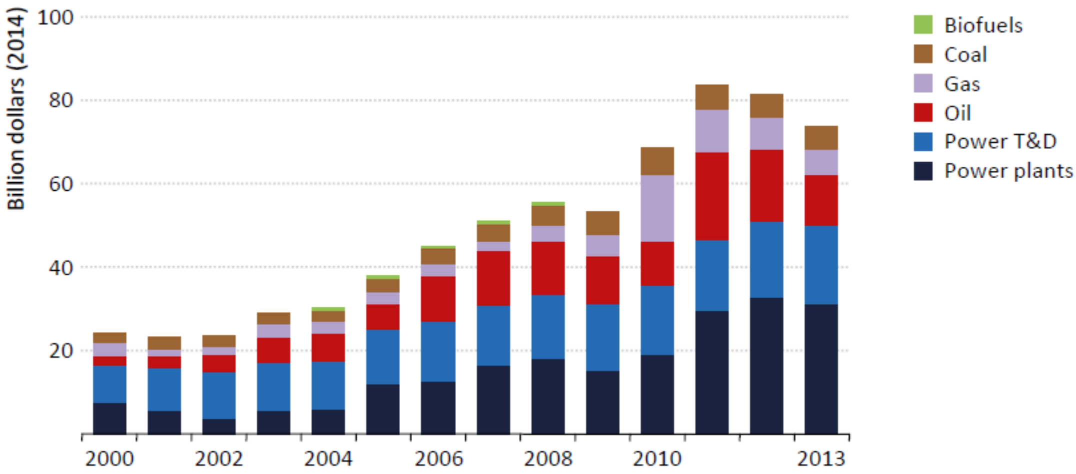


Fig.15: Carbon intensity of GDP and energy-related CO_2 emissions per capita in selected regions, 2013

Investment

Since 2000, we estimate that investment in energy supply in India has increased substantially, reaching almost $77 billion on average since 2010 (Fig.16). The power sector absorbs the largest share, spurred by the rapid increase in demand as encouraged by the liberalisation agenda launched by the landmark Electricity Act in 2003. Maintaining a rising trend in infrastructure spending, especially energy sector spending, is a major government policy priority. India's government aims to increase investment in infrastructure (broadly defined, including communications, road, rail and energy networks, as well as social areas such as schools and hospitals) to 8.2% of GDP, from roughly 7.2% in 2007-2011. More than a third of this $1 trillion in infrastructure spending is to go to electricity, renewable energy, and oil and gas pipeline projects, with around half from private investment.19 Relieving infrastructure bottlenecks, particularly those related to poor road and rail infrastructure, inefficient ports and unreliable electricity supply, is widely recognised as essential to meet India's economic growth and development ambitions (IMF, 2015).



Note: T&D = transmission and distribution.

Fig.16: Energy supply investment by type, 2000-2013

As the Indian government has recognised, public funds sufficient to support the necessary investment projects in the energy sector cannot be taken for granted, in the face of increasing competition from other areas of public spending (including healthcare, pensions, education, etc.). So meeting the country's investment needs will require the mobilisation of increasing amounts of private capital, including foreign direct investment (FDI). Access to such investment opportunities by the private sector though is uneven across the Indian energy economy and a number of broader impediments to attracting investment persist, such as the complex regulatory environment, in relation to which the World Bank has ranked India 142 out of 189 countries in terms of ease of doing business. Despite these impediments, India's vast potential puts it high on the list of prospective destinations for foreign investment, ranking third behind China and the United States. Furthermore, 2014 saw a significant increase in FDI inflows, which rose by 22% compared to the previous year, to a total of over $34 billion (UNCTAD, 2015). Preliminary numbers for FDI in 2015 show a further substantial increase.

Since the late 1990s, steps have been taken to deregulate the oil and gas sectors, notably successive bidding rounds held under the New Exploration Licensing Policy, which have been open to a range of private players. However, these two sectors remain dominated, in practice, by a handful of state concerns and the process of opening the coal sector to private investment is only just beginning. The power generation sector has been open to private participation for some time and the government has offered a range of fiscal incentives to increase the attractiveness of projects. Since 2006, 6 GW out of every 10 GW of net capacity added to the grid has been financed by private investors, whose share of generation has increased quickly, to reach more than one-third of the total (Fig.17). Private sector involvement in the distribution side of the power system is much more limited. Presently the distribution utilities are largely state-controlled and administered, and the priority given to regional social sensitivities often contributes to the under-recovery of costs across the sector.

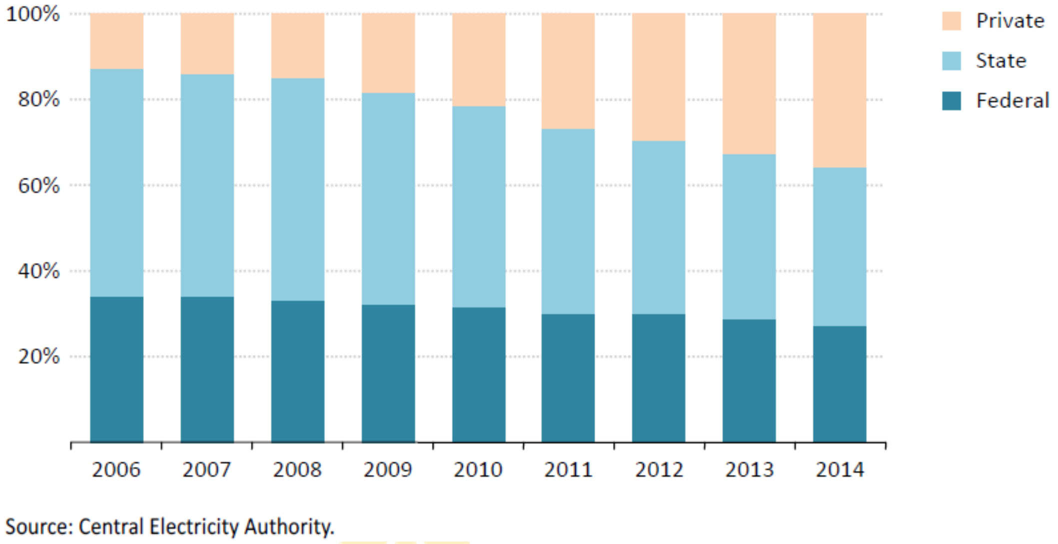


Fig.17: Power generation capacity by type of ownership in India