



ENERGY AND ENVIRONMENT

MODULE - I

INTRODUCTION TO ENERGY

POWER

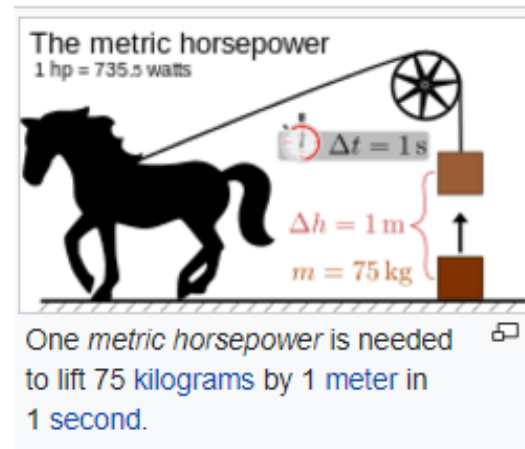
“Power” is a word derived from the Latin word “Posse”, meaning **rate of doing work**.

- ❑ It is the amount of **energy consumed per unit time**.
- ❑ Having no direction, it is a **scalar** quantity.
- ❑ In the SI system, the unit of power is **the joule* per second** (J/s), known as the **watt** in honour of James Watt, the eighteenth-century developer of the steam engine.
- ❑ Another common and traditional measure is **horsepower** (comparing to the power of a horse).

Being the rate of work, the equation for power can be written as:

$$P = \frac{W}{t}$$

*Joule = energy required to lift 1 kg weight by 1 meter, N-m



POWER

- ❑ As a physical concept, **power** requires both a **change in the physical universe** and a **specified time** in which the change occurs.
- ❑ This is distinct from the **concept of work**, which is only measured in terms of a **net change** in the state of the physical universe.
- ❑ The same amount of work is done when **carrying a load up a flight of stairs** whether the person carrying it walks or runs, but more power is **needed for running** because the work is done in a **shorter amount of time**.
- ❑ The output power of an electric motor is the **product of the torque** that the motor generates and the **angular velocity** of its output shaft.

$$P(t) = \tau \cdot \omega$$

POWER

- In **fluid power systems** such as hydraulic actuators, power is given by

$$P(t) = pQ$$

Where,

p is pressure in pascals, or N/m^2 and

Q is volumetric flow rate in m^3/s in SI units.

- The instantaneous **electrical power** P delivered to a component is given by

$$P(t) = I(t) \cdot V(t)$$

Where,

$P(t)$ is the instantaneous power, measured in watts (joules per second)

$V(t)$ is the potential difference (or voltage drop) across the component, measured in volts

$I(t)$ is the current through it, measured in amperes

POWER

- The power involved in moving a vehicle is the **product of the traction force of the wheels and the velocity of the vehicle.**
- The rate at which a light bulb converts electrical energy into light and heat is measured in **watts** - the higher the wattage, the more power, or equivalently the more **electrical energy is used per unit time**

Other units of power include;

- horse power (746 watts),
- kilocalories per hour (859.8 kcal/h in one kilo watt),
- British thermal unit per hour (3412 Btu/h in one kilo watt),
and
- tons of refrigeration (12,000 Btu/h or 3.52 kilo watt)

POWER and ENERGY COMPARISON

- *Power, as a function of time, is the rate at which work is done, so can be expressed by this equation:*

$$P(t) = \frac{W}{t}$$

- *Because work is a force applied over a distance, this can be rewritten as:*

$$P(t) = \frac{W}{t} = \frac{\mathbf{F} \cdot \mathbf{d}}{t}$$

- *And with distance per unit time being a velocity, power can likewise be understood as:*

$$P(t) = \mathbf{F} \cdot \mathbf{v}$$

POWER and ENERGY COMPARISON

- Knowing from Newton's 2nd Law that force is mass times acceleration, the expression for power can also be written as:

$$P(t) = ma \cdot v$$

- Power will change over time as velocity changes due to acceleration. Knowing that acceleration is the time rate of change of velocity, this can then be written:

$$P(t) = mv \cdot \frac{dv}{dt}$$

- Comparing with the equation for kinetic energy:

$$E_k = \frac{1}{2}mv^2$$

- It can be seen from the previous equation that power is mass times a velocity term times another velocity term divided by time.
- This shows how power is an amount of energy consumed per unit time.

ENERGY

INTRODUCTION

- ❑ *“Energy” is a word derived from the Greek word “Energia”, meaning **capacity to do work**.*
- ❑ *In physics, energy is the property that must be transferred to an object in order to perform work on or to heat the object.*
- ❑ *It can be converted form one form to another, but cannot be **created or destroyed (Law of conservation of Energy)**.*
- ❑ *The SI unit of energy is the **joule**, which is the energy transferred to an object by the **mechanical work** of moving it **a distance of one metre against a force of one newton**.*

DIFFERENT FORMS OF ENERGY

- Common forms of energy include the **kinetic energy** of a moving object,
- The **potential energy** stored by an object's position in a force field (gravitational, electric or magnetic),
- The **elastic energy** stored by stretching solid objects,
- The **chemical energy** released when a fuel burns,
- The **radiant energy** carried by light,
- The **thermal energy** due to an object's temperature,
- The **internal energy**, the energy contained in a chemical system by virtue of the motion of and forces between the individual atoms and molecules of the system and
- The **Mechanical Energy** which comes from conversion of either electrical or chemical energy.

ENERGY SOURCES

- All forms of energy are **inter-convertible** by appropriate processes.
- Energy exists in the earth or comes from the outer space.
- The energy existing in the earth is called **capital energy** and that which comes from the outer space is called **celestial or income energy**.
- E.g. of capital energy: fossil fuels, nuclear fuels and heat traps.
- E.g. of celestial or income energy:
 1. Electromagnetic energy,
 2. gravitational energy,
 3. particle energy and
 4. potential energy of meteorites.

ENERGY SOURCES

- *The useful celestial energy sources are the **electromagnetic energy** of the Sun, called **direct solar energy**.*
- *The gravitational energy of the Moon produces **tidal energy**.*

The other energy sources such as

- 1. wind energy,*
- 2. hydel energy,*
- 3. geothermal energy,*
- 4. biofuels etc.*

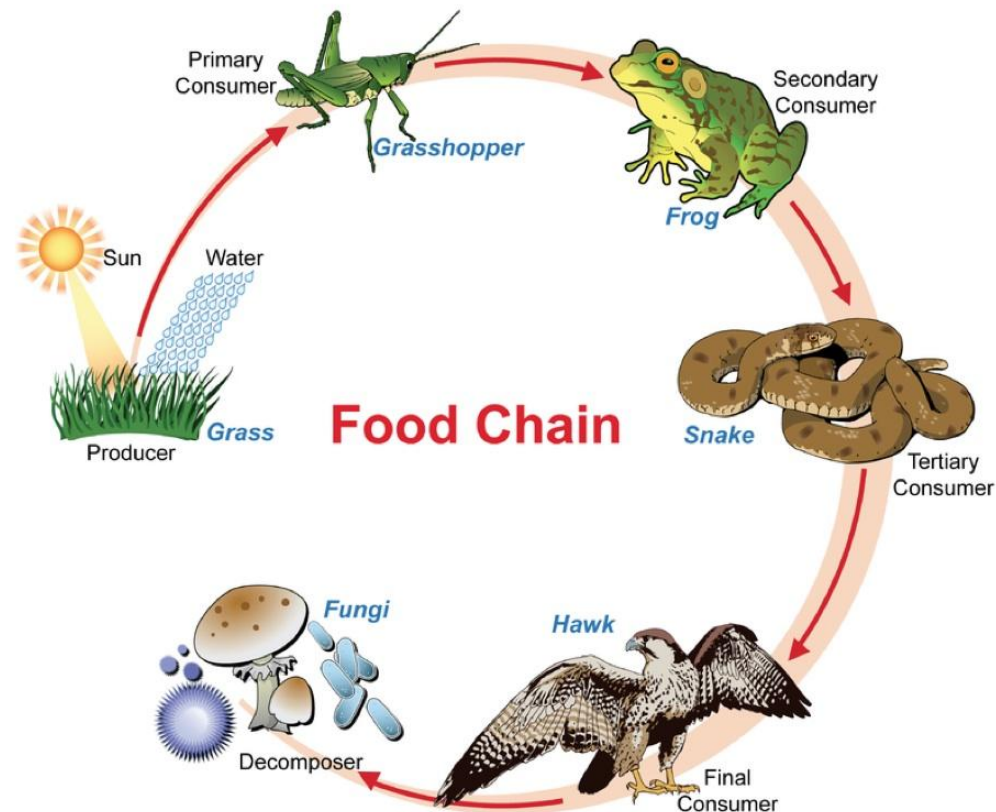
are derived from the direct solar energy.

CONVENTIONAL AND NON-CONVENTIONAL ENERGY SOURCES

- ❑ *Most of our present energy needs come mainly from the **fossil fuels** (coal, petroleum etc.) and **hydel sources** and are in use from over several decades, they are called as **conventional energy sources**.*
- ❑ *The **alternate energy sources** that are being harnessed are, solar energy, wind energy, tidal energy, ocean thermal energy, geothermal energy, bio energy, fuel cells, solid wastes, hydrogen energy etc. These inexhaustible sources of energy are called **non-conventional energy sources**.*

ENERGY FLOW in a ECO-SYSTEM

□ In ecology, energy flow, also called the calorific flow, refers to the **flow of energy through a food chain**, and is the focus of study in ecological energetics.



ENERGY FLOW in a ECO-SYSTEM

- In an ecosystem, ecologists seek to quantify the **relative importance** of different component species and feeding relationships.

A general energy flow scenario:

- Solar energy is fixed by the **photoautotrophs**, called primary producers, like **green plants**.
- **Primary consumers** absorb most of the stored energy in the plant through digestion, and transform it into the form of energy they need, such as **adenosine triphosphate (ATP)**, through **respiration**.
- A part of the energy received by primary consumers, **herbivores**, is converted to **body heat** (an effect of respiration), which is radiated away and lost from the system. (**heat loss by Work, Chicken Example**)

ENERGY FLOW in a ECO-SYSTEM

- ❑ Energy loss also occurs in the **expulsion** of undigested food (egesta) by excretion or regurgitation.
- ❑ **Secondary consumers**, carnivores, then consume the primary consumers, although **omnivores** also consume primary producers.
- ❑ Energy that had been used by the primary consumers for **growth and storage** is thus absorbed into the secondary consumers through the process of **digestion**.
- ❑ As with primary consumers, secondary consumers convert this energy into a more suitable form (**ATP**) during respiration.

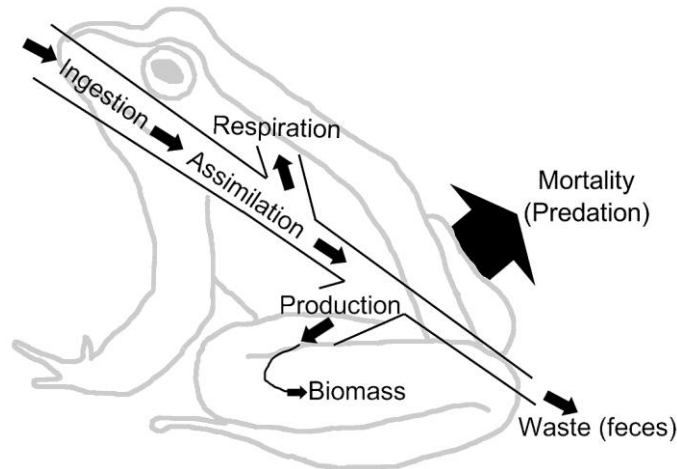
ENERGY FLOW in a ECO-SYSTEM

- Again, some **energy is lost from the system**, since energy which the secondary consumers had used for **respiration and regulation of body temperature** cannot be utilized by the tertiary consumers.
- **Tertiary consumers**, which may or may not be **apex predators**, then consume the secondary consumers, with some energy passed on and some lost, as with the lower levels of the food chain.
- A **final link** in the food chain are **decomposers** which break down the organic matter of the tertiary consumers (or whichever consumer is at the top of the chain) and **release nutrients** into the **soil**.
- They also **break down plants, herbivores and carnivores** that were not eaten by organisms higher on the food chain, as well as the **undigested food** that is excreted by herbivores and carnivores.

ENERGY FLOW in a ECO-SYSTEM

- ❑ *Saprotrophic bacteria and fungi* are decomposers, and play a pivotal role in the **nitrogen** and **carbon** cycles.
- ❑ The **energy is passed** on from trophic level to trophic level and each time about **90%** of the energy is **lost**, with some being lost as **heat** into the environment (an effect of respiration) and some being lost as incompletely **digested food** (egesta).
- ❑ Therefore, primary consumers get about **10%** of the energy produced by autotrophs, while secondary consumers get **1%** and tertiary consumers get **0.1%**.
- ❑ This means the **top consumer** of a food chain receives the **least energy**, as a lot of the food chain's energy has been lost between trophic levels.
- ❑ This loss of energy at each level **limits** typical food chains to **only four to six links**.

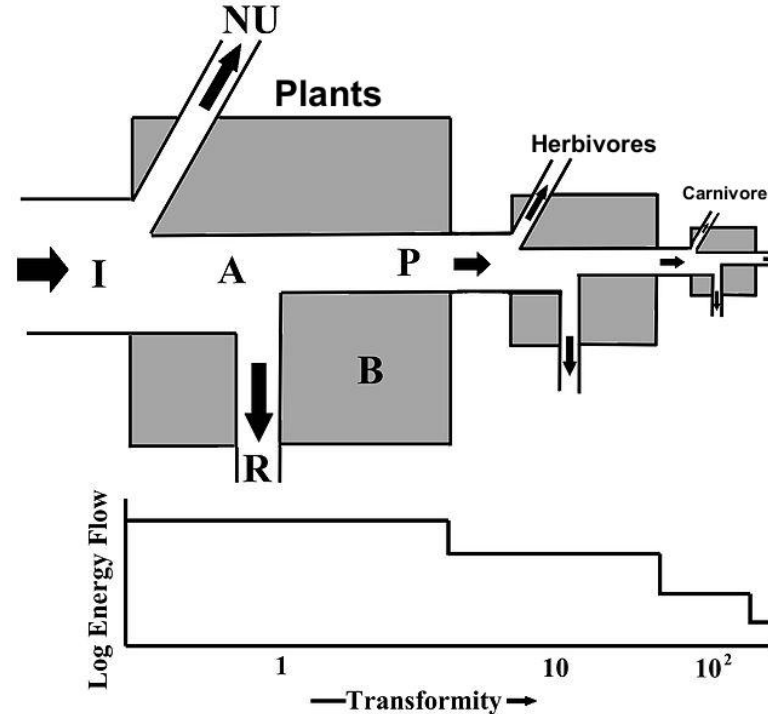
Energy flow diagram of a frog.



- ❑ The energy flow diagram illustrates how energy is lost as it fuels the **metabolic process** that **transform** the **energy** and **nutrients** into **biomass**.
- ❑ The frog represents a **node** in an extended **food web**.
- ❑ The energy ingested is utilized for **metabolic processes** and transformed into **biomass**.
- ❑ The **energy flow continues** on its path if the frog is **ingested by predators**, parasites, or as a decaying carcass in soil.

An expanded three link energy food chain

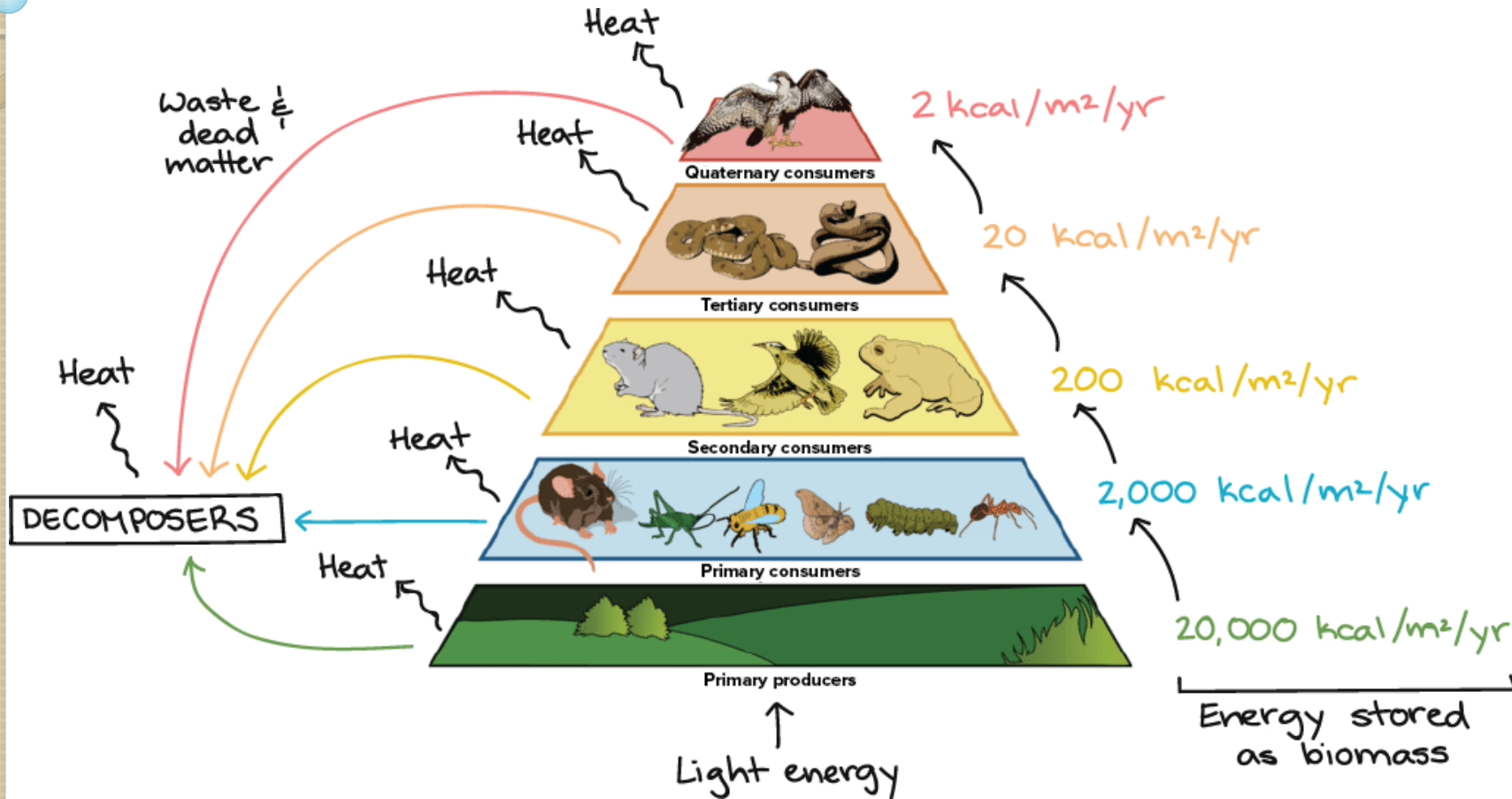
1. plants, 2. herbivores, 3. carnivores



Abbreviations: I=input, A=assimilation, R=respiration, NU=not utilized, P=production, B=biomass.

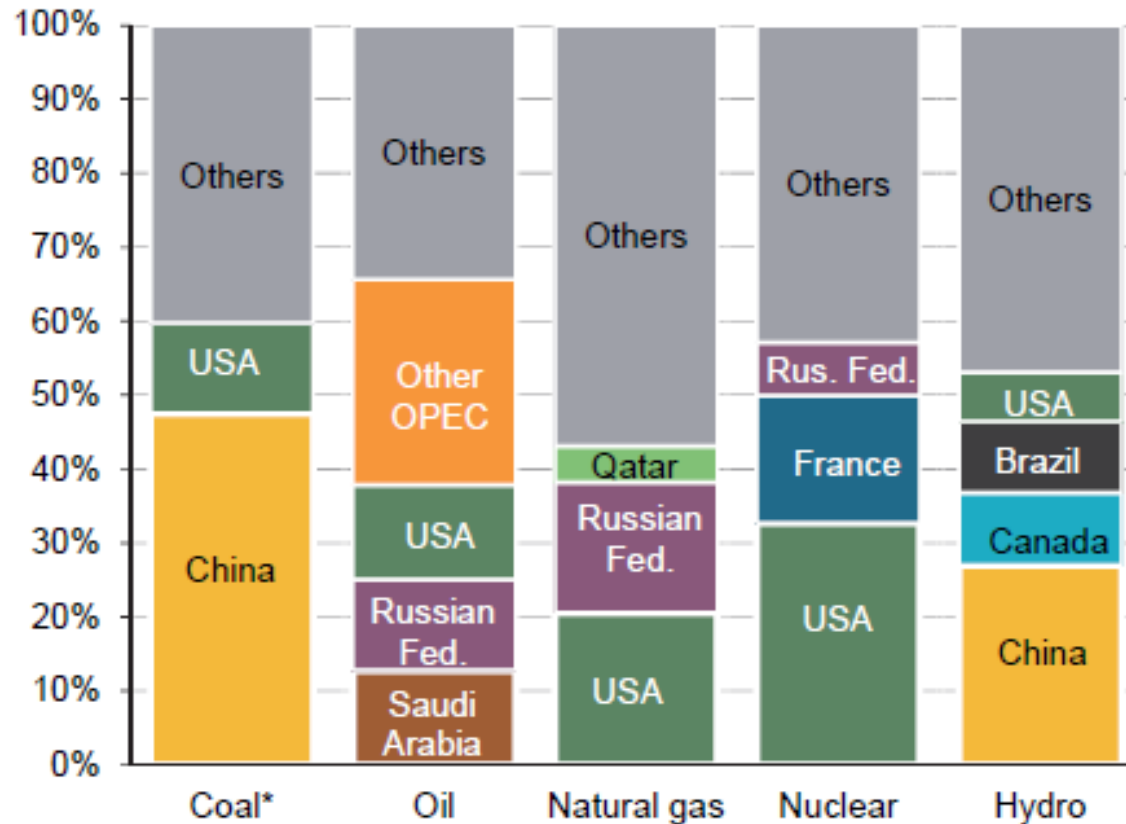
- The **transformity** of energy becomes **degraded, dispersed, and diminished** from **higher quality** to **lesser quantity** as the energy within a food chain flows from one trophic species into another.

Energy flow through ecosystem



World Energy Production and Consumption

Energy Largest producers by fuel in 2014

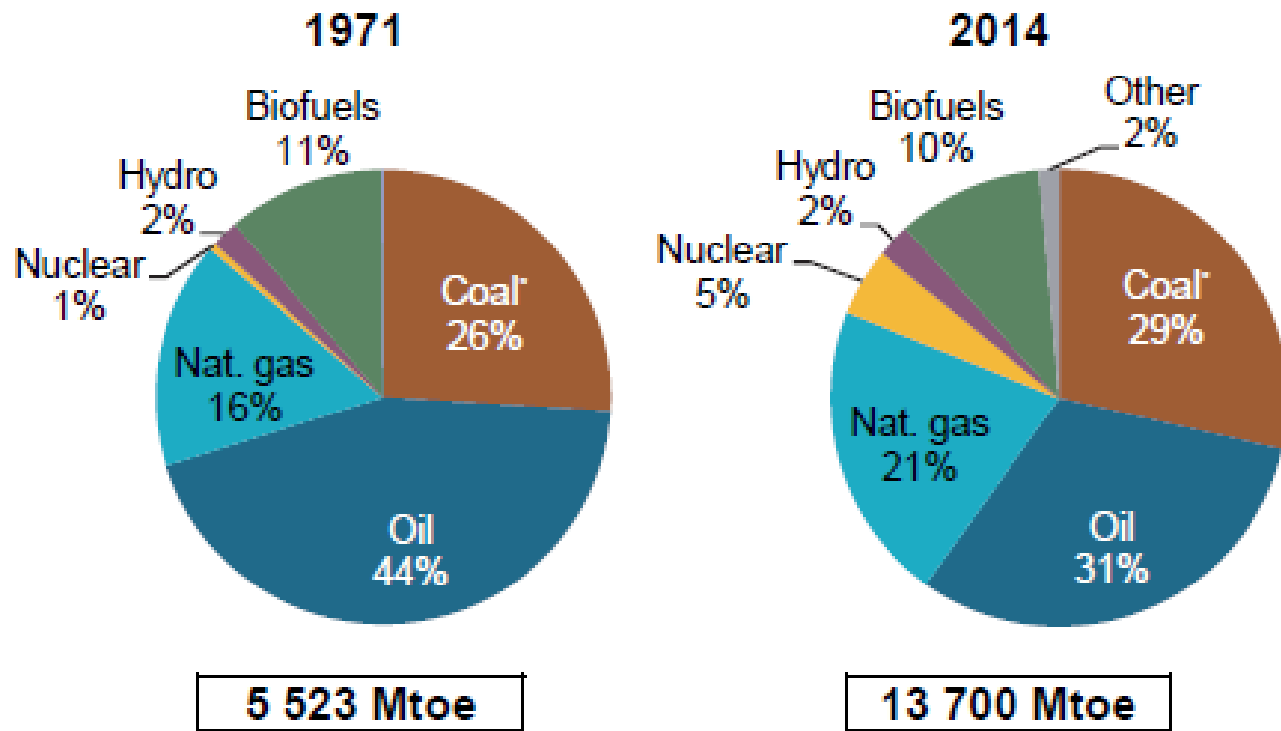


* In this graph peat and oil shale are aggregated with coal.

- *Energy production is not evenly distributed across countries: for each fuel, less than four countries generally account for more than half of global production*

*OPEC – Organization of the Petroleum Exporting Countries

Total Primary energy supply by fuel

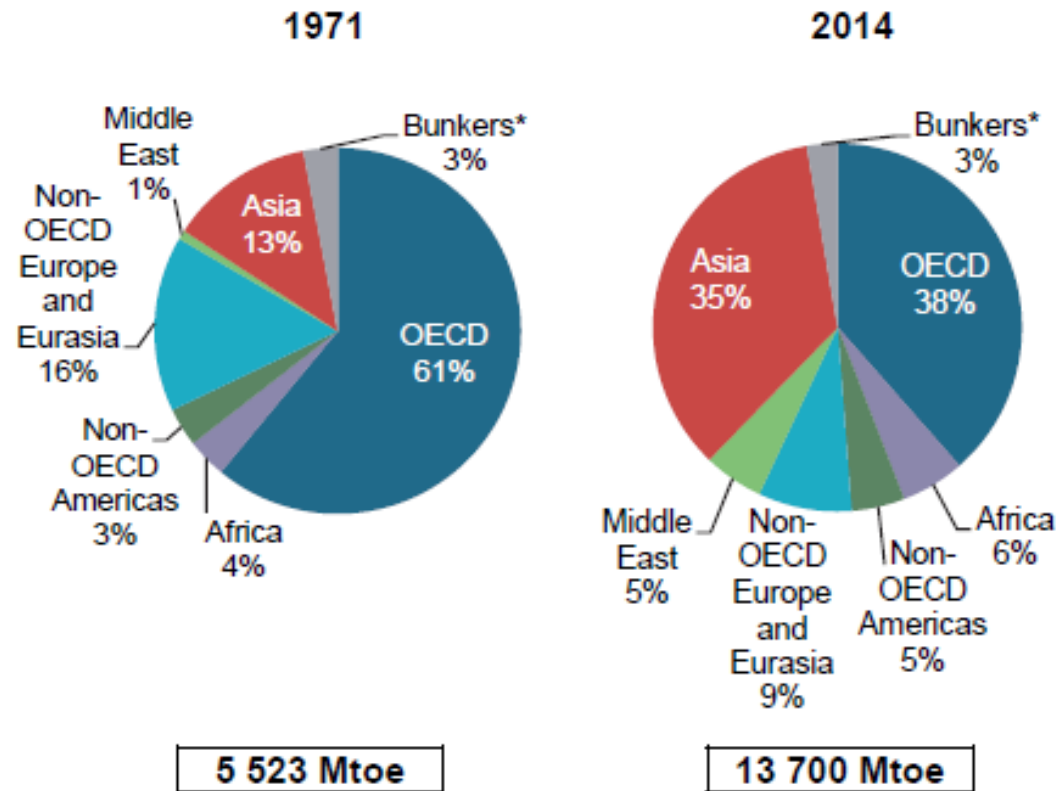


* In this graph peat and oil shale are aggregated with coal.

- Between 1971 and 2014, world total primary energy supply (TPES) was multiplied by almost 2.5 times and changed structure somewhat.
- Oil remained the dominant fuel in 2014, nonetheless fell from 44% to 31% of TPES.

*Mtoe – Million tonnes of crude oil equivalent

Total Primary energy supply by region



* Including international marine and aviation bunkers.

- ❑ Energy demand increased at very different rates in the regions between 1971 and 2014.
- ❑ The OECD's share of global TPES fell from 61% in 1971 to 38% in 2014. It is now almost on par with Asia, where energy demand was multiplied by seven times, and whose share of TPES almost tripled over the period.

*OECD – Organisation for economic co-operation and development

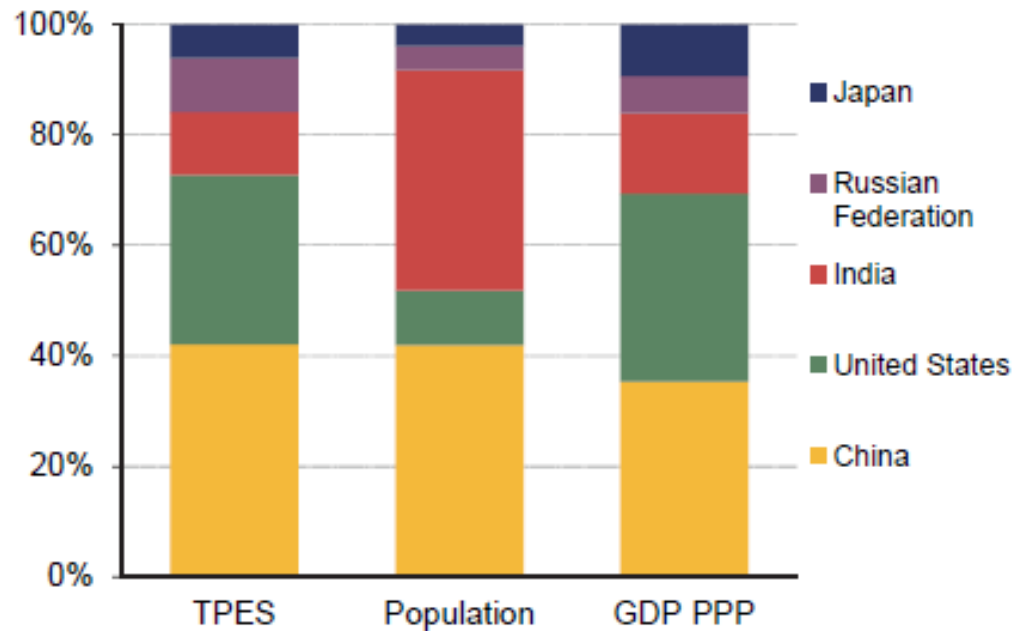
TPES – top – ten countries in 2014 and 1971

Country	TPES (Mtoe)	Share in world TPES	
		2014	1971
People's Rep. of China	3 052	22%	7%
United States	2 216	16%	29%
India	825	6%	3%
Russian Federation	711	5%	N/A
Japan	442	3%	5%
Germany	306	2%	6%
Brazil	303	2%	1%
Canada	280	2%	0.3%
Korea	268	2%	3%
France	243	2%	3%
Rest of the world	5 054	37%	44%
World	13 700	100%	100%

- *Global energy demand was even more concentrated in 2014 compared to 1971, as the top 10 countries represented 63% of global energy demand, as opposed to 56% in 1971.*

Top – five energy consumers

2014 relative shares*



* Relative shares within the top-five, which differ from shares in the world total.

- ❑ *In 2014, the top-five countries in terms of TPES accounted for less than half of the world GDP, and world population (47% and 46% respectively) but consumed 53% of total world energy*
- ❑ *The United States consumed 16% of world energy, with 4% of the world's population. Conversely, China and India consumed 22% and 6% of global energy respectively, but accounted for 19% and 18% of the global population.*

GDP – Nominal

Per the International Monetary Fund (2017)^[1]

Per the World Bank (2017)^[20]

Per the United Nations (2016)^{[21][22]}

Rank ↕	Country ↕	GDP (US\$MM) ↕
	<i>World</i> ^[19]	79,865,481
1	 United States	19,390,600
—	 European Union ^{[n 1][19]}	17,308,862
2	 China ^[n 2]	12,014,610
3	 Japan	4,872,135
4	 Germany	3,684,816
5	 United Kingdom	2,624,529
6	 India	2,611,012
7	 France	2,583,560
8	 Brazil	2,054,969
9	 Italy	1,937,894
10	 Canada	1,652,412
11	 South Korea	1,538,030
12	 Russia ^[n 3]	1,527,469
13	 Australia	1,379,548
14	 Spain	1,313,951
15	 Mexico	1,149,236

Rank ↕	Country ↕	GDP (US\$MM) ↕
	<i>World</i>	80,683,787
1	 United States	19,390,604
—	 European Union ^[23]	17,277,698
2	 China ^[n 5]	12,237,700
3	 Japan	4,872,137
4	 Germany	3,677,439
5	 United Kingdom	2,622,434
6	 India	2,597,491
7	 France	2,582,501
8	 Brazil	2,055,506
9	 Italy	1,934,798
10	 Canada	1,653,043
11	 Russia ^[n 3]	1,577,524
12	 South Korea	1,530,751
13	 Australia	1,323,421
14	 Spain	1,311,320
15	 Mexico	1,149,919

Rank ↕	Country ↕	GDP (US\$MM) ↕
	<i>World</i> ^[24]	75,648,448
1	 United States	18,624,475
2	 China ^[n 5]	11,218,281
3	 Japan	4,936,211
4	 Germany	3,477,796
5	 United Kingdom	2,647,898
6	 France	2,465,453
7	 India	2,259,642
8	 Italy	1,858,913
9	 Brazil	1,795,925
10	 Canada	1,529,760
11	 South Korea	1,411,245
12	 Australia	1,304,463
13	 Russia ^[n 3]	1,246,015
14	 Spain	1,237,255
15	 Mexico	1,076,914
16	 Indonesia	932,259

GDP – PPP

List by the [International Monetary Fund](#) (estimates for 2017)^{[5][6]}

List by the [World Bank](#) (2017)^{[7][8][9]}

List by the [CIA World Factbook](#) (1993–2017)^[1] [Open](#)

Rank ↕	Country ↕	GDP (millions of Current Int\$) ↕
	<i>World</i>	126,687,917
1	China ^[n 1]	23,159,107
—	<i>European Union</i> ^[n 2]	20,982,857
2	United States	19,390,600
3	India	9,459,002
4	Japan	5,428,813
5	Germany	4,170,790
6	Russia	4,007,831
7	Indonesia	3,242,771
8	Brazil	3,240,319
9	United Kingdom	2,914,042
10	France	2,835,746
11	Mexico	2,458,357
12	Italy	2,310,902
13	Turkey	2,173,227
14	South Korea	2,029,032
15	Spain	1,773,906

Rank ↕	Country ↕	GDP (millions of Current Int\$) ↕
	<i>World</i>	127,723,794
1	China ^[n 1]	23,300,782
2	United States	19,390,604
3	India	9,448,659
4	Japan	5,562,822
5	Germany	4,193,922
6	Russia	3,749,283
7	Indonesia	3,242,768
8	Brazil	3,240,524
9	United Kingdom	2,896,833
10	France	2,871,264
11	Italy	2,410,985
12	Mexico	2,344,197
13	Turkey	2,254,114
14	South Korea	1,969,106
15	Spain	1,773,972
16	Saudi Arabia	1,773,549

Rank ↕	Country ↕	GDP (billions of Current Int\$) ↕	Year ↕
	<i>World</i>	127,000	2017 est.
1	China ^[n 1]	23,120	2017 est.
—	<i>European Union</i> ^[n 2]	20,850	2017 est.
2	United States	19,360	2017 est.
3	India	9,447	2017 est.
4	Japan	5,405	2017 est.
5	Germany	4,150	2017 est.
6	Russia	4,000	2017 est.
7	Indonesia	3,243	2017 est.
8	Brazil	3,219	2017 est.
9	United Kingdom	2,880	2017 est.
10	France	2,826	2017 est.
11	Mexico	2,406	2017 est.
12	Italy	2,307	2017 est.
13	Turkey	2,133	2017 est.

GDP – Nominal Per Capita

International Monetary Fund (2017)^[4]

Rank ↕	Country	US\$ ↕
1	 Luxembourg	105,803
2	 Switzerland	80,591
—	 <i>Macau</i>	77,451
3	 Norway	74,941
4	 Ireland	70,638
5	 Iceland	70,332
6	 Qatar	60,804
7	 United States	59,501
8	 Singapore	57,713
9	 Denmark	56,444
10	 Australia	55,707
11	 Sweden	53,218
12	 Netherlands	48,346
13	 San Marino	47,406
14	 Austria	47,290
—	 <i>Hong Kong</i>	46,109
15	 Finland	46,017
16	 Canada	45,077
17	 Germany	44,550

131	 Egypt	2,501
132	 Vietnam	2,354
133	 Moldova	2,280
134	 Nicaragua	2,207
135	 East Timor	2,104
136	 Solomon Islands	2,081
137	 Nigeria	1,994
138	 Djibouti	1,989
139	 India	1,983
140	 Republic of the Congo	1,958
141	 São Tomé and Príncipe	1,785
142	 Kiribati	1,721
143	 Kenya	1,702
144	 Ghana	1,663
145	 Côte d'Ivoire	1,617
146	 Bangladesh	1,602
147	 Pakistan	1,541
148	 Uzbekistan	1,491
149	 Zambia	1,480
150	 Sudan	1,428
151	 Lesotho	1,425

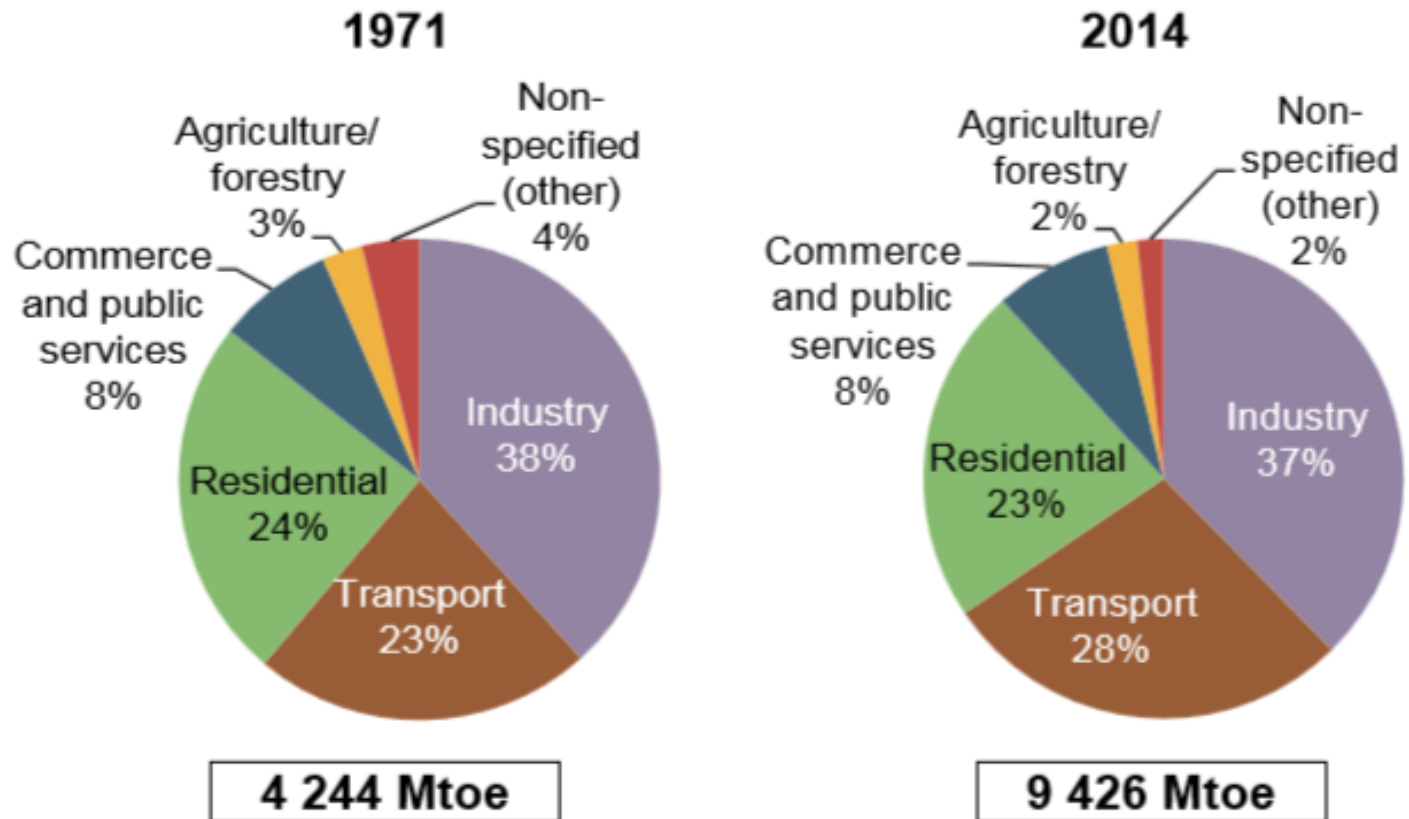
GDP – PPP – Per Capita

International Monetary Fund (2017)^[4]

Rank ↕	Country/Territory ↕	Int\$ ↕
1	 Qatar	124,927
—	 <i>Macau</i>	114,430
2	 Luxembourg	109,192
3	 Singapore	90,531
4	 Brunei	76,743
5	 Ireland	72,632
6	 Norway	70,590
7	 Kuwait	69,669
8	 United Arab Emirates	68,245
9	 Switzerland	61,360
—	 <i>Hong Kong</i>	61,016
10	 San Marino	60,359
11	 United States	59,495
12	 Saudi Arabia	55,263
13	 Netherlands	53,582
14	 Iceland	52,150
15	 Bahrain	51,846
16	 Sweden	51,264
17	 Germany	50,206

116	 Belize	8,341
117	 Guyana	8,266
118	 Philippines	8,229
119	 Guatemala	8,173
120	 Bolivia	7,543
121	 Laos	7,367
122	 India	7,174
123	 Uzbekistan	6,990
124	 Cape Verde	6,942
125	 Vietnam	6,876
126	 Angola	6,813
127	 Congo, Rep.	6,707
128	 Myanmar	6,285
129	 Nigeria	5,927
130	 Nicaragua	5,823
131	 Samoa	5,737
132	 Moldova	5,657
133	 Tonga	5,605
134	 Honduras	5,499
135	 Pakistan	5,354
136	 Timor-Leste	5,008

Total Final Consumption by Sector



- Between 1971 and 2014, total final consumption (TFC) more than doubled. However, the energy use by the different economy sectors did not dramatically change.

Key energy trends in India

- ❑ *India is in the early stages of a major transformation, bringing new opportunities to its **1.3 billion people** and moving the country to centre stage in many areas of international affairs.*
- ❑ *The **energy sector** is **expanding** quickly but is set to face further challenges as India's modernization and its economic growth gather pace, particularly given the policy priority to develop India's **manufacturing base**.*
- ❑ *Energy use has **almost doubled since 2000**, and economic growth and targeted policy interventions have **lifted millions out of extreme poverty**.*
- ❑ *Energy consumption per capita is still **only around one-third** of the **global average** and some **240 million people** have no access to electricity.*

Key energy trends in India

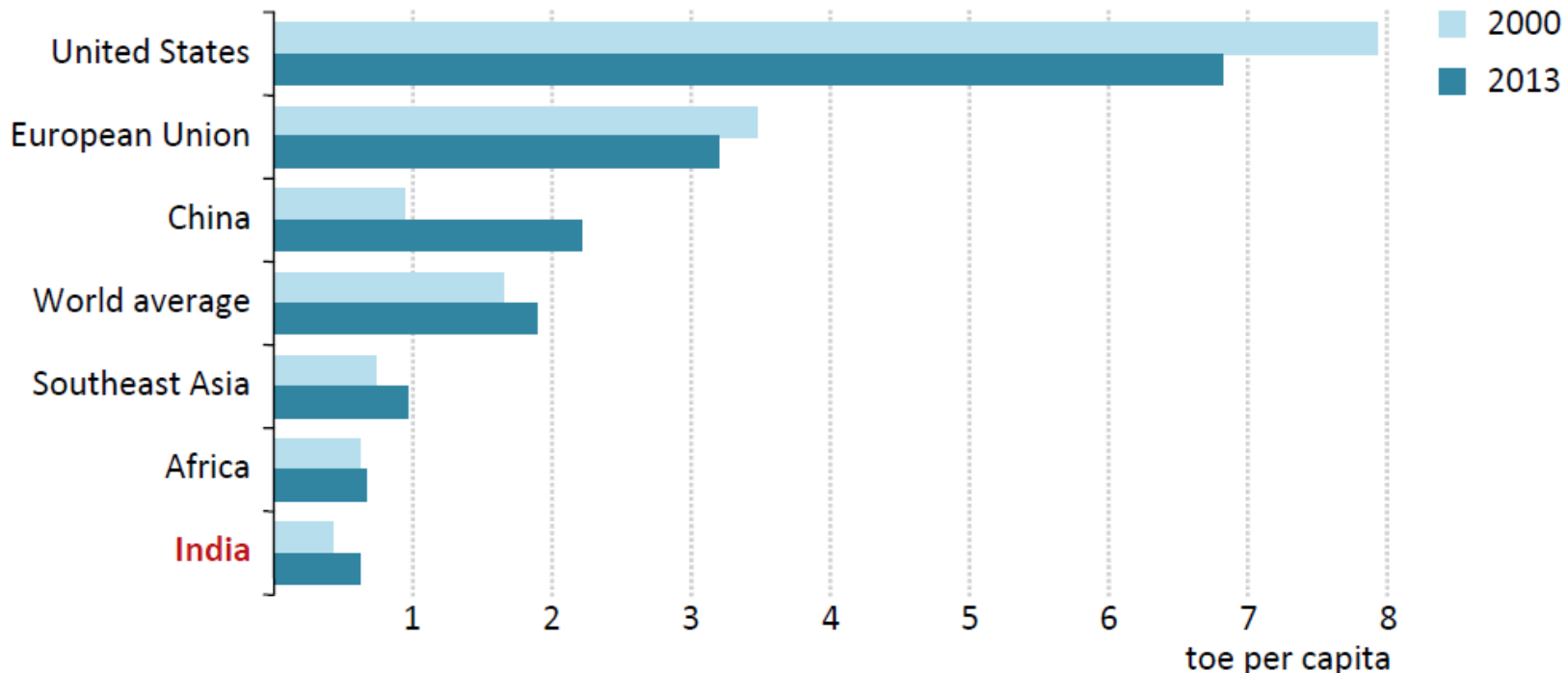
Demand

- ❑ 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** (Figure 1.1).

Key energy trends in India

- ❑ One **reason** is that a significant part of the Indian population remains without modern and reliable energy: around **240 million** people in India lack access to electricity.
- ❑ Residential electricity consumption (for those with access) remains **far below the world average** and is **ten-times lower** than OECD levels.

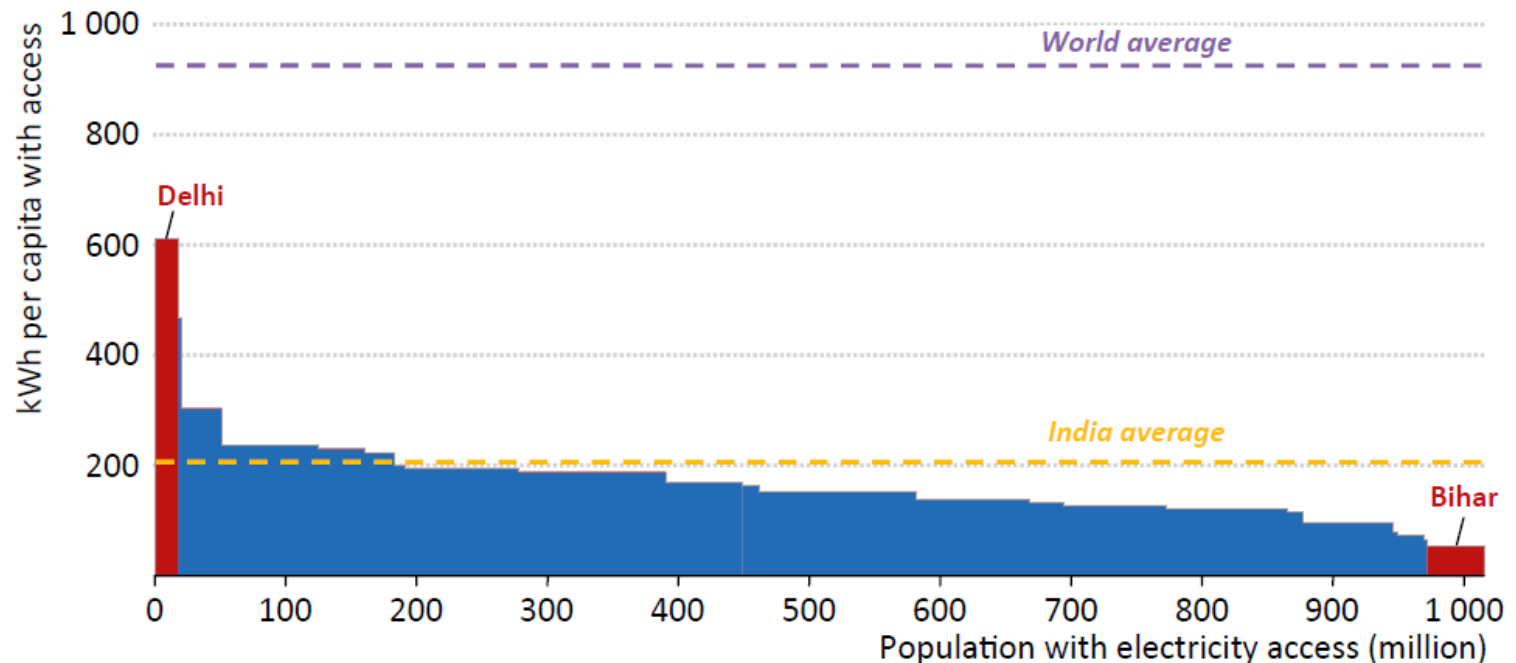
Figure 1.1 ▶ Per-capita energy consumption in India and selected regions



Key energy trends in India

- ❑ Figures for residential electricity consumption per capita show a **broad range** between Delhi and Bihar(Figure 1.2)
- ❑ Average residential consumption in Bihar, at around **50 kilowatt-hours (kWh)** per capita per year, is consistent with an average household use of a fan, a mobile telephone and two compact fluorescent light bulbs for less than five hours per day.

Figure 1.2 ▷ Annual residential electricity consumption per capita by state in India (for those with access), 2013



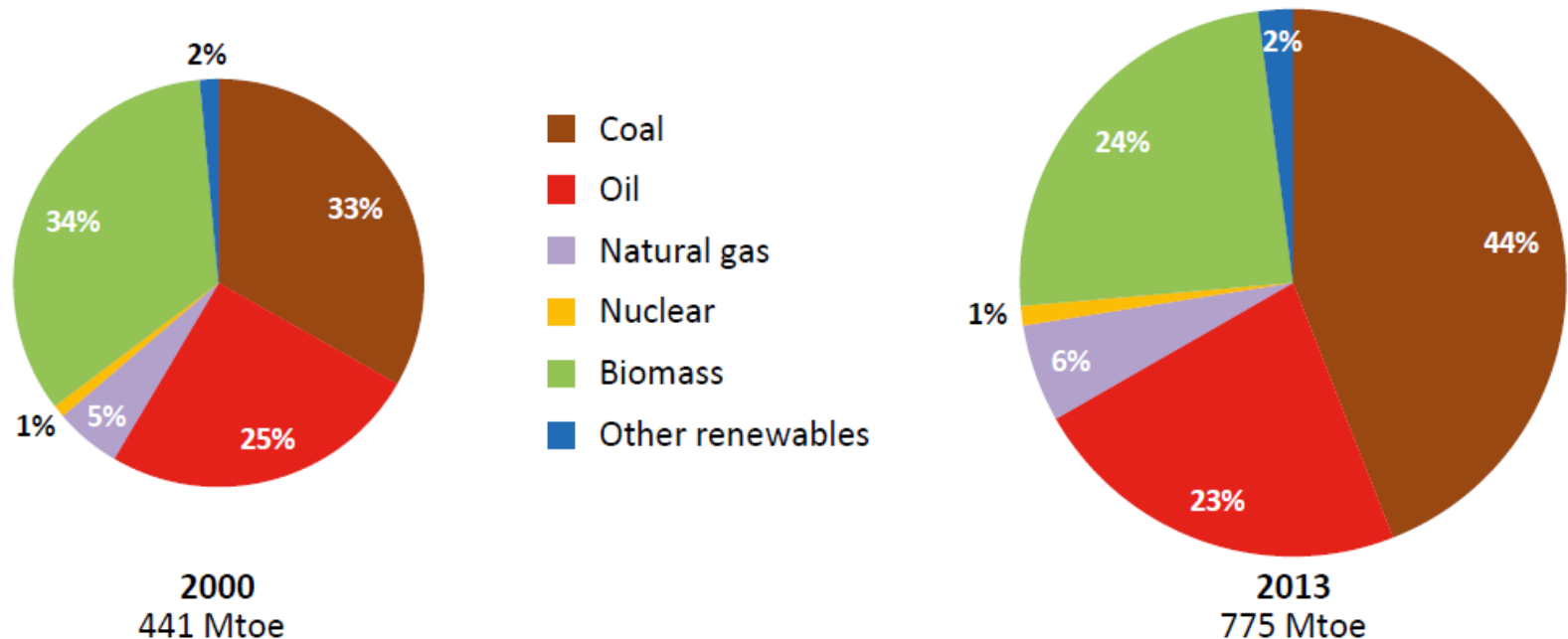
Key energy trends in India

- ❑ In these circumstances, even with a growing focus on **energy efficiency** and **subsidy reform**, there are strong underlying reasons to expect continued **rapid growth in energy demand**.
- ❑ **Three-quarters** of Indian energy demand is met by **fossil fuels**, a share that has been rising as households gradually move away from the traditional use of solid biomass for cooking.
- ❑ **Coal** remains the backbone of the Indian power sector, accounting for over **70% of generation** and is the most plentiful domestic fossil-fuel resource, although, as in the case of oil and gas, **dependence on coal imports** has grown in recent years.
- ❑ India was **the world's third-largest importer of crude oil** in 2014, but is also a **major exporter of oil products**, thanks to a large refining sector.

Key energy trends in India

- ❑ 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 due to the availability and affordability of coal relative to other fossil fuels.
- ❑ Demand for bio-energy has grown in absolute terms, but its share in the primary energy mix has declined as households moved to **other fuels for cooking**, notably **LPG**.

Figure 1.4 ▷ Primary energy demand in India by fuel

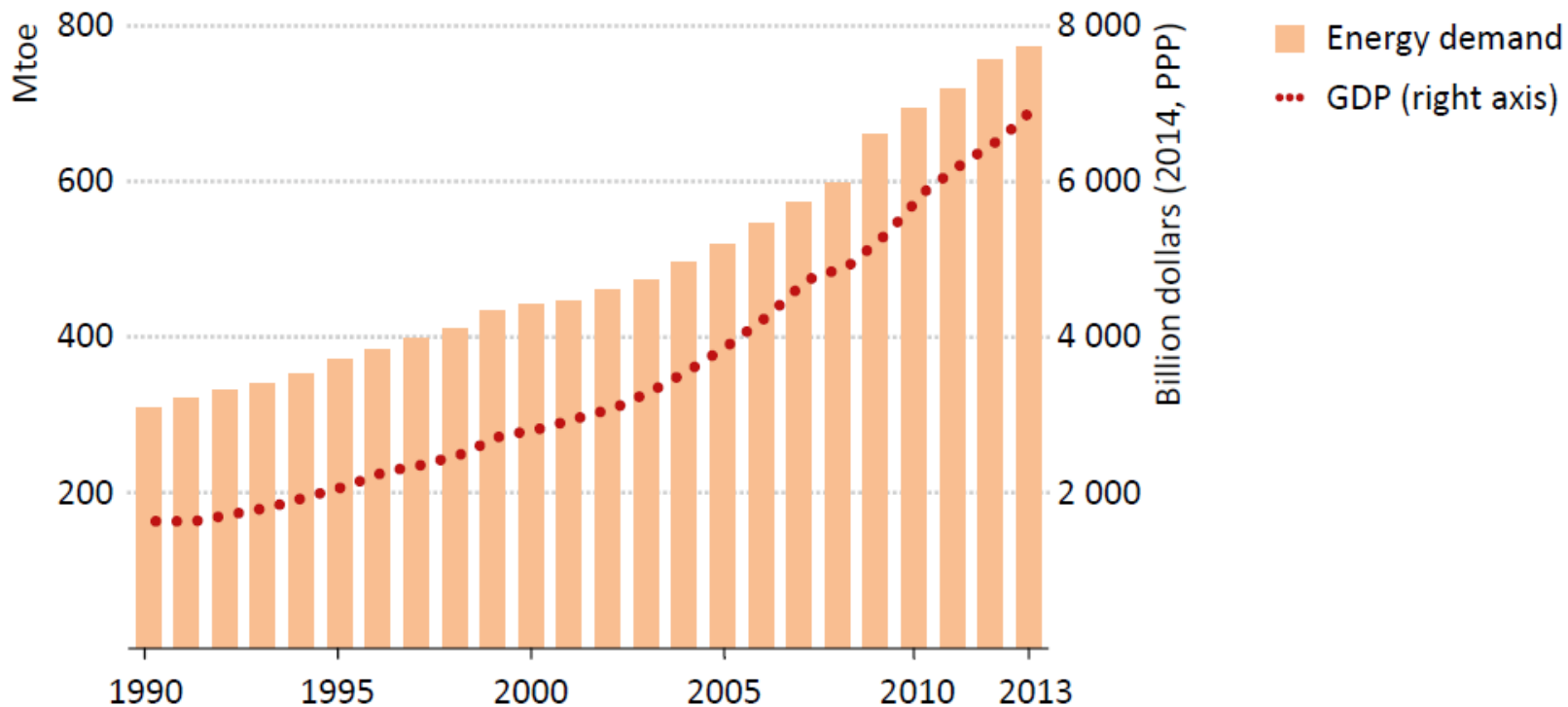


Key energy trends in India

- ❑ Energy demand has **almost doubled** since 2000, but this is **slower than the rate of economic growth** over the same period (Figure 1.3).
- ❑ This is due in part to the shift away from **bio-energy** 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**.
- ❑ As a result, it took **12% less energy** to create a **unit of Indian GDP** (calculated on the basis of purchasing power parity [PPP]) in 2013 than was required in 1990.
- ❑ The amount of energy required to generate a unit of GDP (PPP basis) in India is **slightly lower** than the **global average**, even so, much energy is lost or used **inefficiently**, notably in the **power sector** due to **poor** generation transmission and distribution technologies and relatively **low efficiency** of end-use equipment.

Key energy trends in India

Figure 1.3 ▸ Primary energy demand and GDP in India



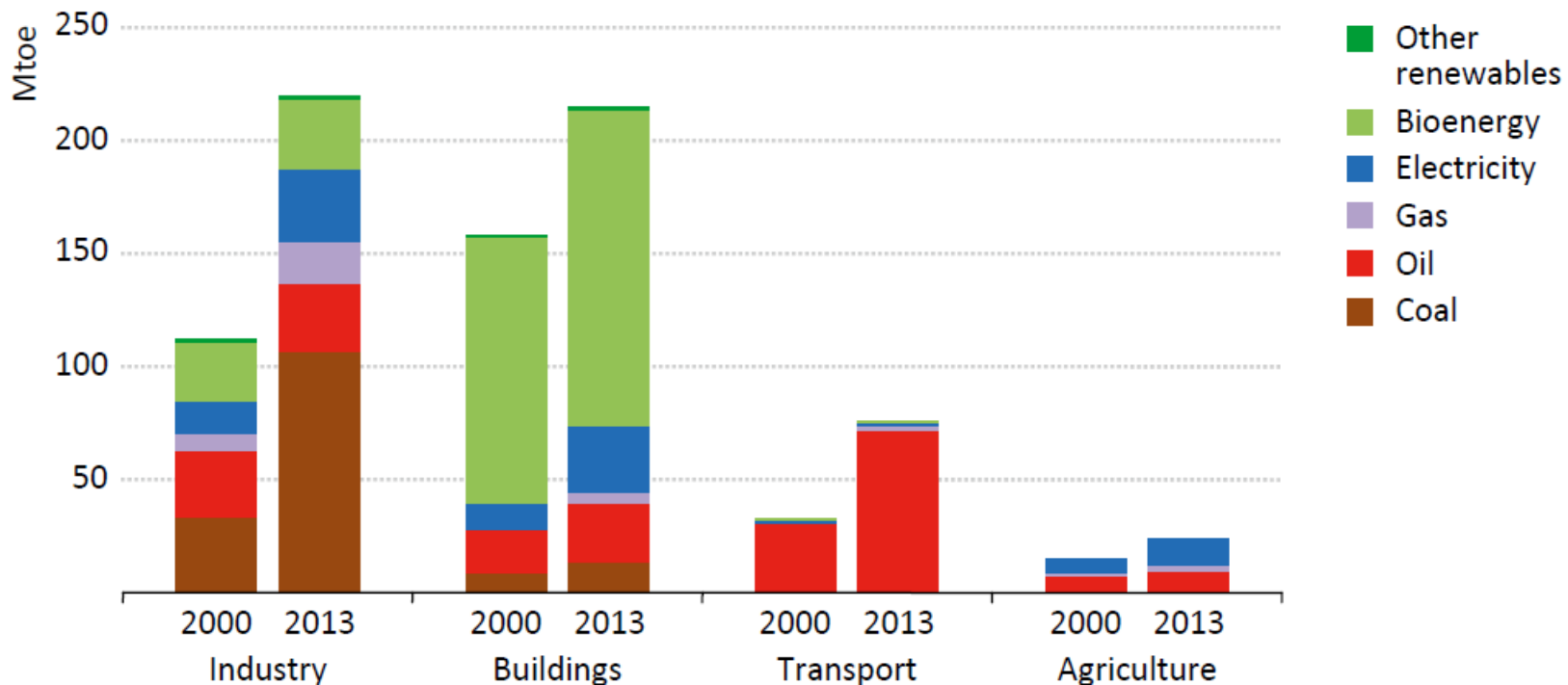
Note: Mtoe = million tonnes of oil equivalent.

- ❑ **Significant *untapped energy efficiency potential* remains across the entire energy system, which could help *temper* the further growth in *energy consumption*.**

Key energy trends in India

- ❑ Energy demand had traditionally been **dominated** by the **buildings sector** although demand in industry has grown more rapidly since 2000, **overtaking buildings** in 2013.
- ❑ The share of bioenergy in the buildings sector 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.

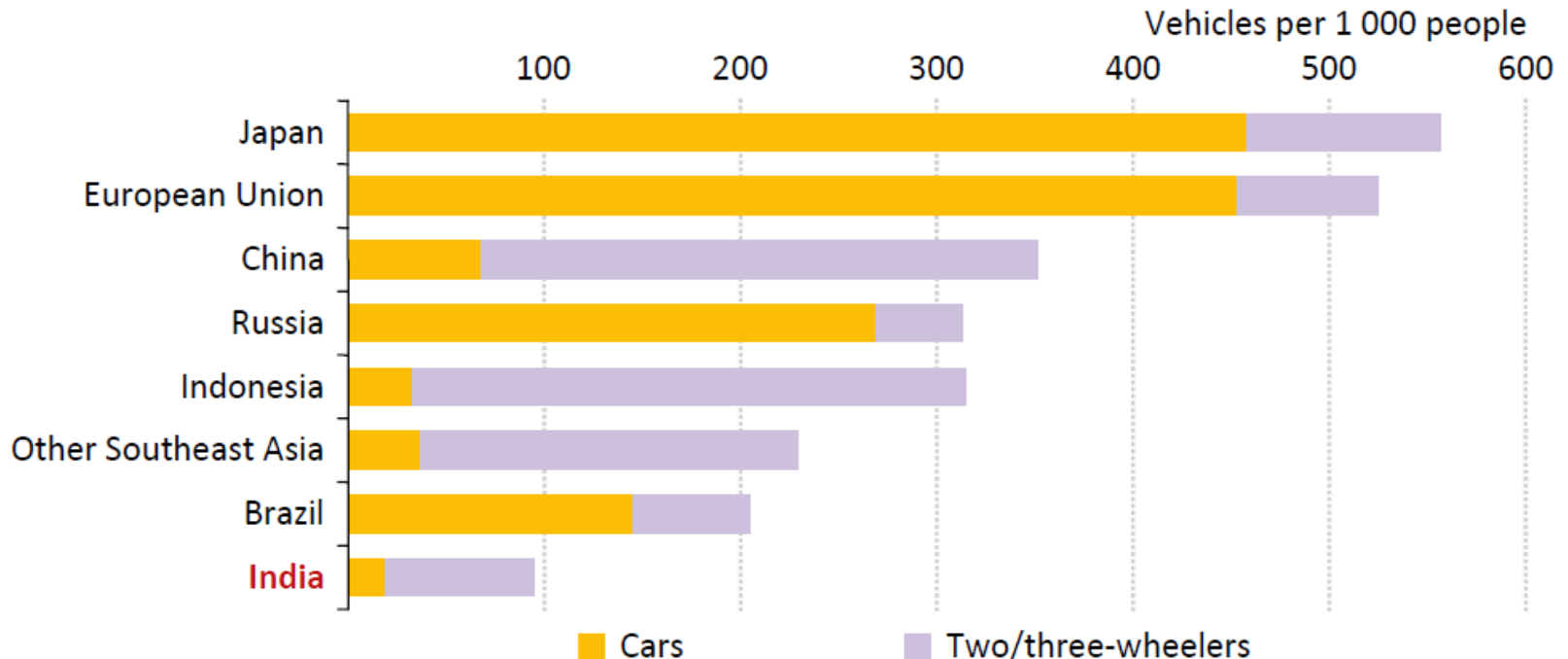
Figure 1.5 ▷ Energy demand by fuel in selected end-use sectors in India



Key energy trends in India

- Over **90%** of energy demand in the transport sector in India is from road transport. The country's passenger light-duty vehicle 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**.

Figure 1.6 ▷ Vehicle ownership in India and selected regions, 2013



Key energy trends in India

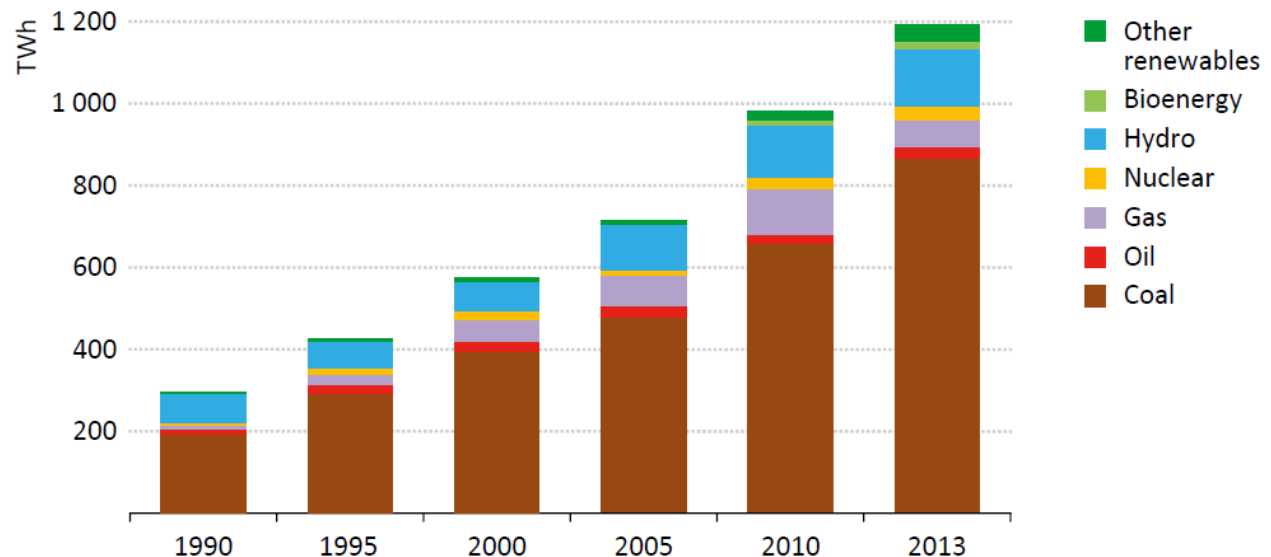
◦ Electricity

- ❑ *The country's electricity demand in 2013 was **897 terawatt-hours**, 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.*

Key energy trends in India

- On the supply side, India has some **290 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**. But, despite the increase in generation, India faces power shortage and power fluctuations.

Figure 1.7 ▷ Total electricity generation in India by fuel



Note: Other renewables includes solar PV and wind.

Key energy trends in India

- India has **45 GW of hydropower** and **23 GW of wind power** capacity, but has barely tapped its huge potential for renewable energy.
- India is, however, aiming high in this area, with a target to reach **175 GW of installed renewables** capacity by **2022** (excluding large hydropower), which is a steep increase from today's level of **37 GW**.
- **Solar power** is a key element of the government's expansion plans.

Key energy trends in India

Access to modern energy

- ❑ 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 1.1).
- ❑ 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%**.

Key energy trends in India

- 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.

Table 1.1 ▷ 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	0	9	35%	4%	27%
Madhya Pradesh	7	1	8	16%	3%	12%
Maharashtra	6	1	6	11%	2%	7%
Gujarat	2	2	3	7%	6%	6%
Chhattisgarh	2	0	3	14%	6%	12%
Karnataka	1	0	1	5%	1%	3%
Other states	3	2	6	2%	2%	2%
Total	221	16	237	26%	4%	19%

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

Key energy trends in India

- ❑ An estimated **840 million people** - more than the populations of the United States and the European Union combined use solid biomass for cooking.
- ❑ There is a host of issues associated with the traditional use of solid biomass for cooking.
- ❑ Using biomass for cooking **releases 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 **subsidized availability of LPG** as an alternative cooking fuel.

Key energy trends in India

Energy production and trade

- ❑ *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 (Figure 1.8), 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**.*

Key energy trends in India

Figure 1.8 ▷ Fossil-fuel production and demand per capita by selected countries, 2013

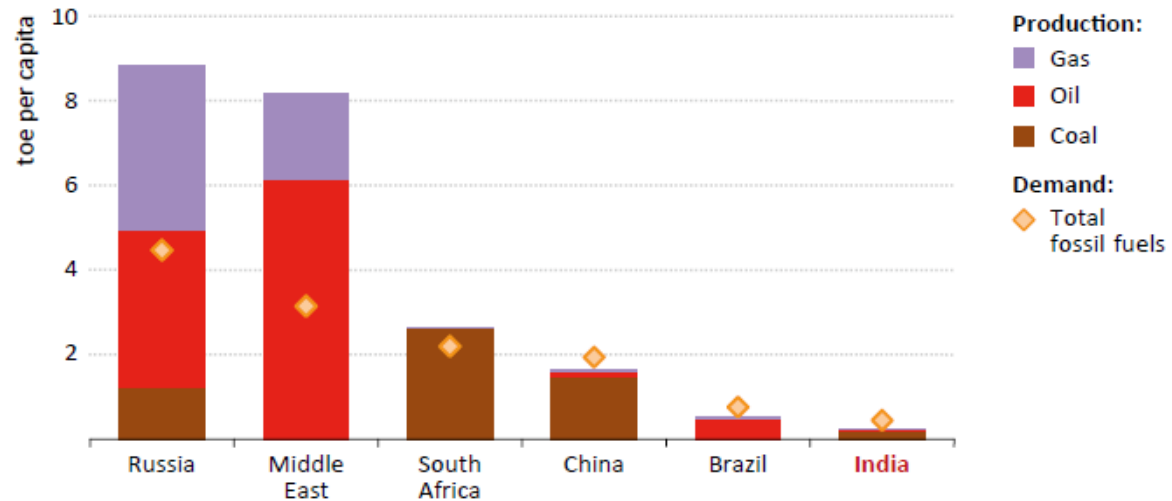
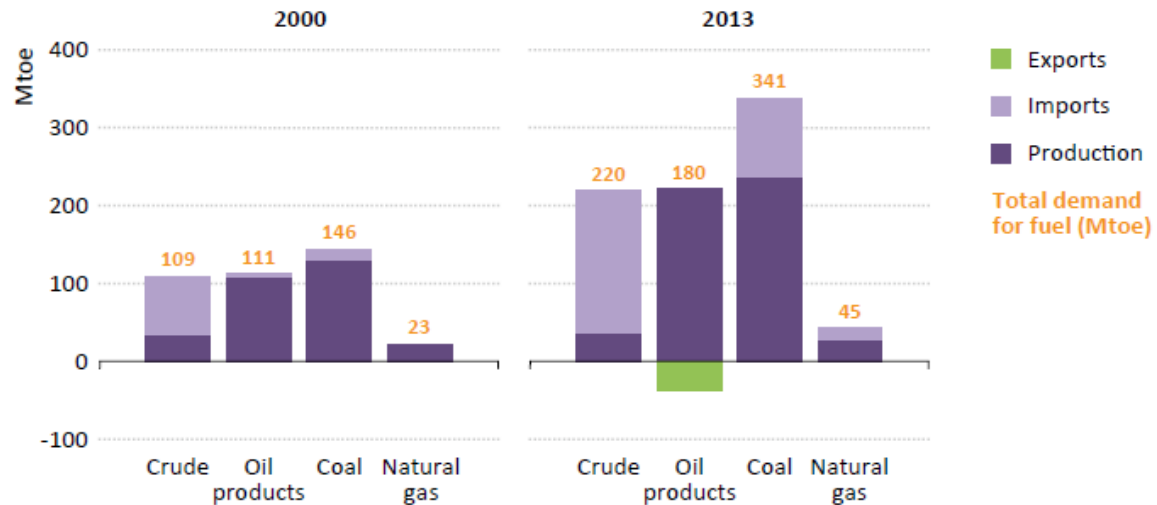


Figure 1.9 ▷ Fossil-fuel balance in India



Note: Demand for crude oil shows refinery intake.

Key energy trends in India

Coal

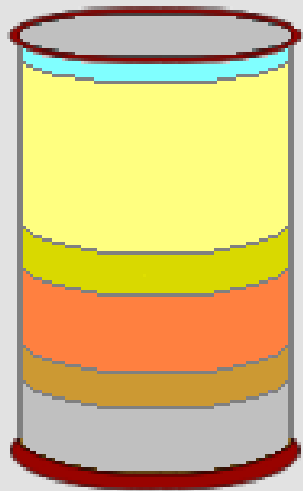
- ❑ India has the **third-largest** hard **coal reserves** in the world (12% of the world total), as well as significant deposits of lignite.
- ❑ In 2013, India produced almost **340 million tonnes** of coal equivalent (Mtce), but it also imported some **140 Mtce** – roughly 12% of world coal imports (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.
- ❑ 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.

Key energy trends in India

Oil and oil products

- ❑ *India is one of the few countries in the world that **rely on imports of crude oil.***
- ❑ *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 **oil resources (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.*

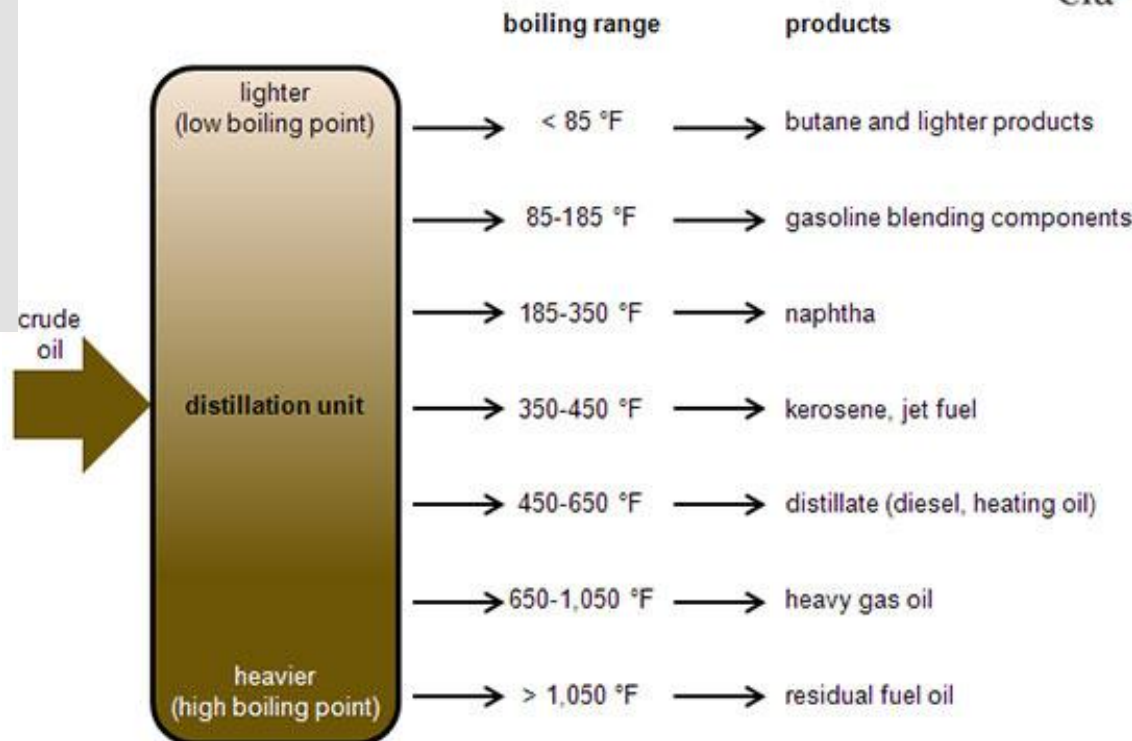
Key energy trends in India



	<u>gallons</u>	<u>litres</u>
LPG	1.7	6.4
Gasoline (Petrol)	19.2	72.7
Fuel oils	3.8	14.4
Diesel oil	9.2	34.9
Jet fuel	3.5	13.2
Others	7.3	27.6
	<u>44.7</u>	<u>169.2</u>

The average products made from a 42 gallon (159 litre) barrel of crude oil in U.S.A. refineries in 2007. Totals are greater than 42 gallon due to volume gain in refining the crude oil.

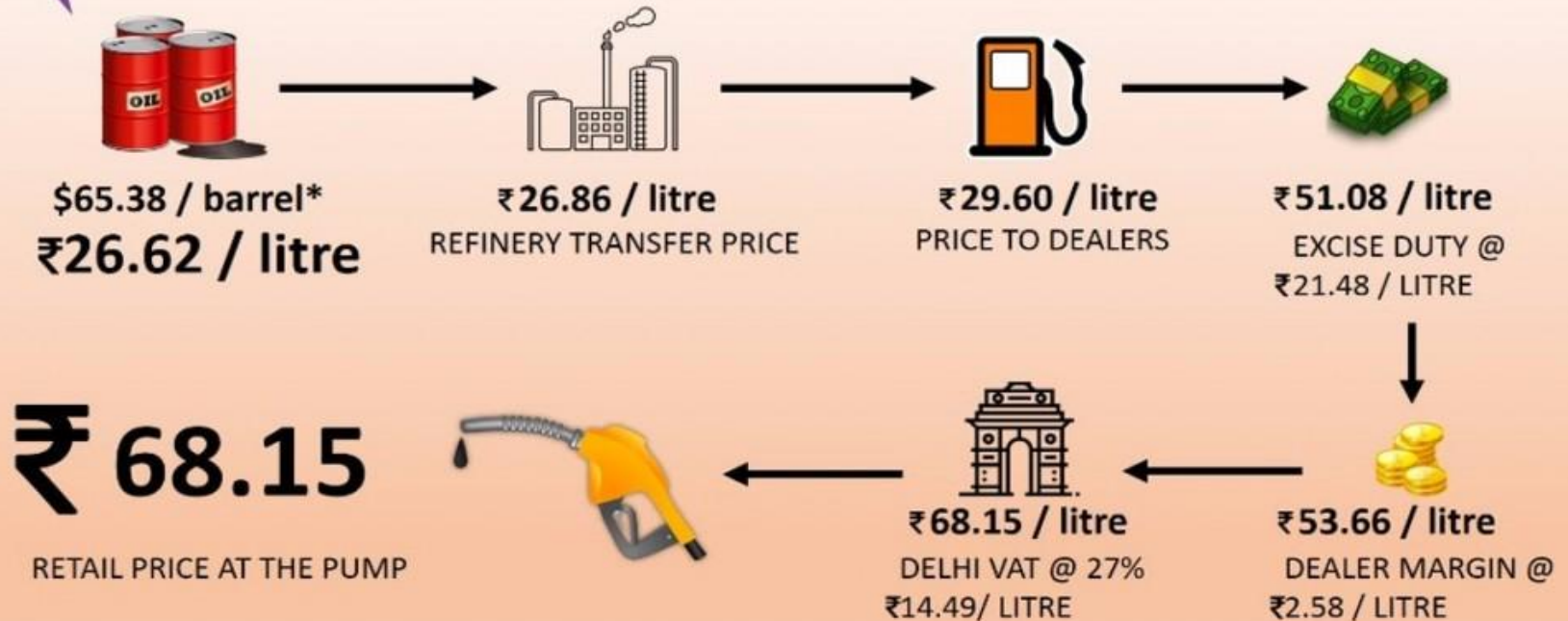
Crude oil distillation unit and products



Key energy trends in India

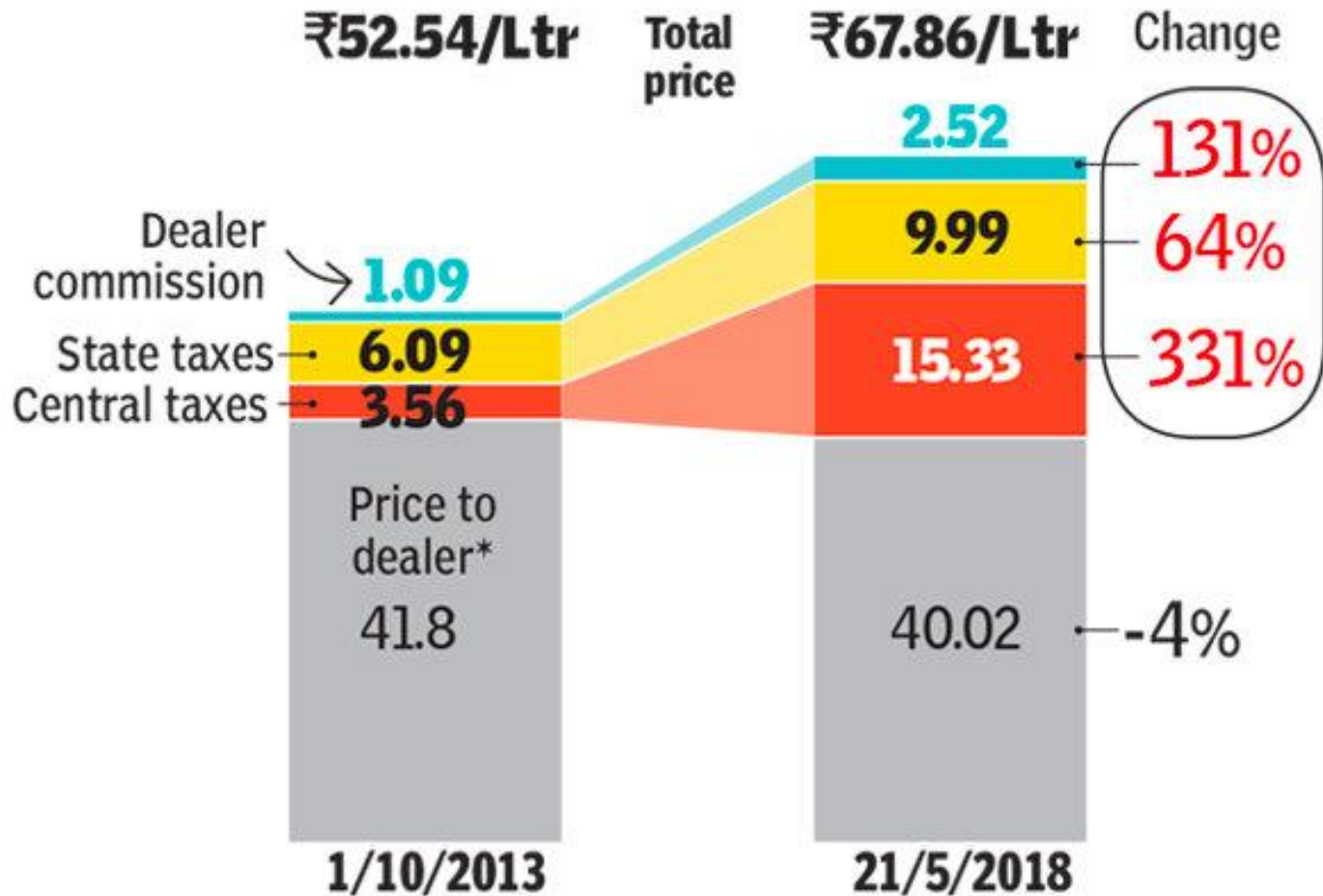


How much does a litre of **PETROL** cost?



Source: Bharat Petroleum – Prices as on April 16, 2017 for New Delhi | *Barrel = 159 litres | \$1 = ₹64.76

Key energy trends in India



Key energy trends in India

Petro products price profile

(in Rs)

	Petrol	Diesel	PDS Kerosene	Domestic LPG/Cylinder
India (Delhi)	63.70	41.29	14.83	399
US	42.82	45.84	NA	NA
France	94.97	69.87	NA	NA
Germany	95.99	72.54	NA	NA
UK	96.39	82.93	NA	NA
Italy	96.79	74.00	NA	NA
Pakistan	41.81	46.70	44.06	757.04
Sri Lanka	50.30	34.37	24.67	863.40
Bangladesh	44.80	27.32	27.32	469.24
Nepal	63.24	45.38	45.38	819.60

Petrol, diesel and PDS kerosene prices are given in per litre.

Key energy trends in India

Natural gas

- ❑ Natural gas has a **relatively small share** (6%) of the domestic energy mix.
- ❑ 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 and offshore 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 re-gasification terminals.

Key energy trends in India

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.
- ❑ A further **14 GW** are **under construction**, although some of these plants have been **delayed** by technical or environmental problems and public opposition.
- ❑ 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.

Key energy trends in India

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.
- ❑ 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** 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.

Key energy trends in India

Biofuels

- ❑ 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.

Key energy trends in India

Wind and solar

- ❑ 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.
- ❑ **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**.

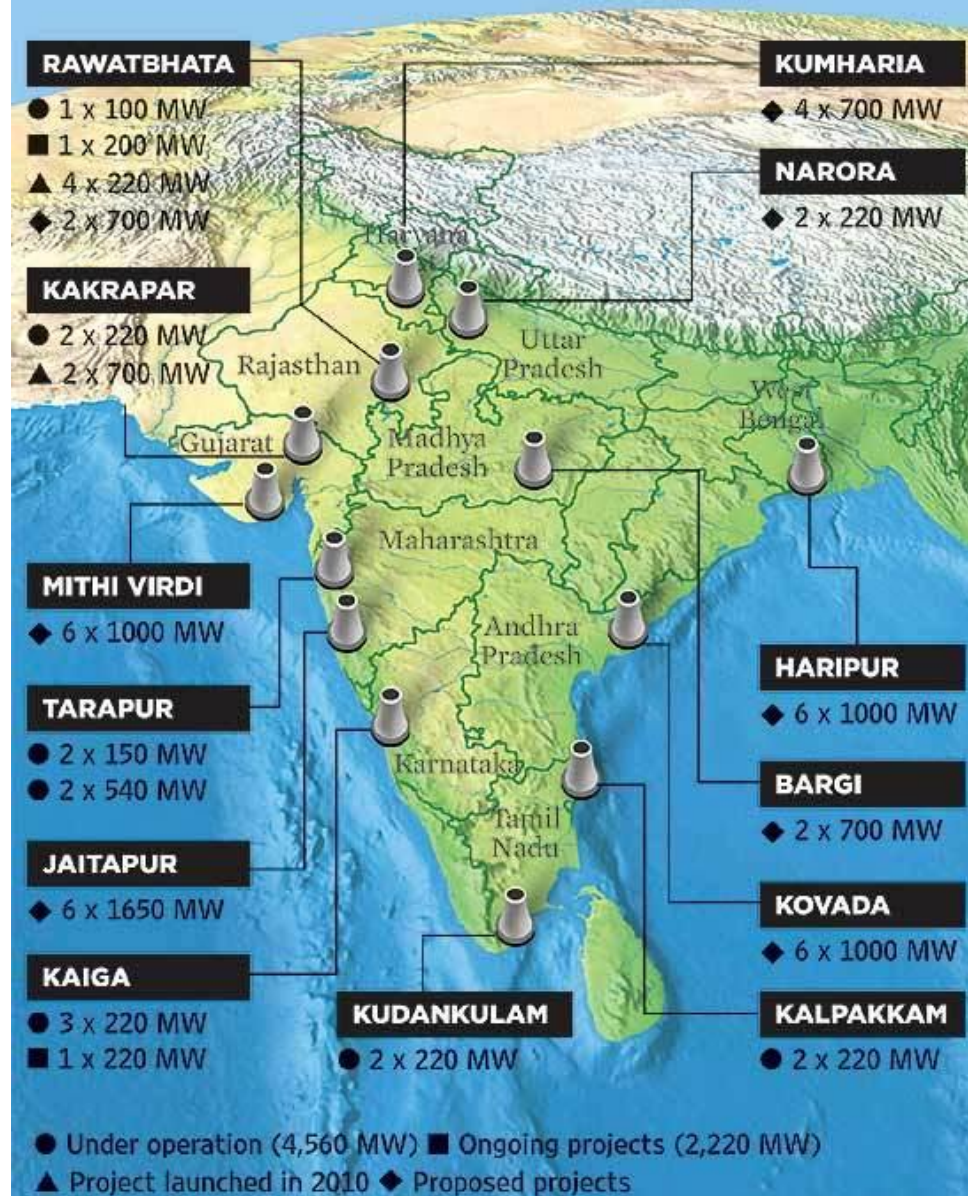
Key energy trends in India

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).*

Key energy trends in India

THE NUCLEAR ENERGY SPREAD



Key energy trends in India

	2015	
	Construction cost	O&M costs
	(\$ per kW)	(\$ per kW)
United States	5500	165
Canada	3400	102
Mexico	3200	96
Europe	3600	108
Japan	3600	108
Korea	3200	96
Australia	3600	108
Russia	3200	96
China	3000	90
India	3200	96
Indonesia	3200	96
Other Asia	3200	96
Brazil	3200	96
Other Latin America	3200	96
Africa	3200	96
Middle East	3200	96

Source: Nuclear Energy in India, IEA

Factors affecting India's energy development

- *Economy and demographics*
- *Policy and Institutional framework*
- *Energy prices and affordability*
- *Social and environmental aspects*
- *Investment*

Factors affecting India's energy development

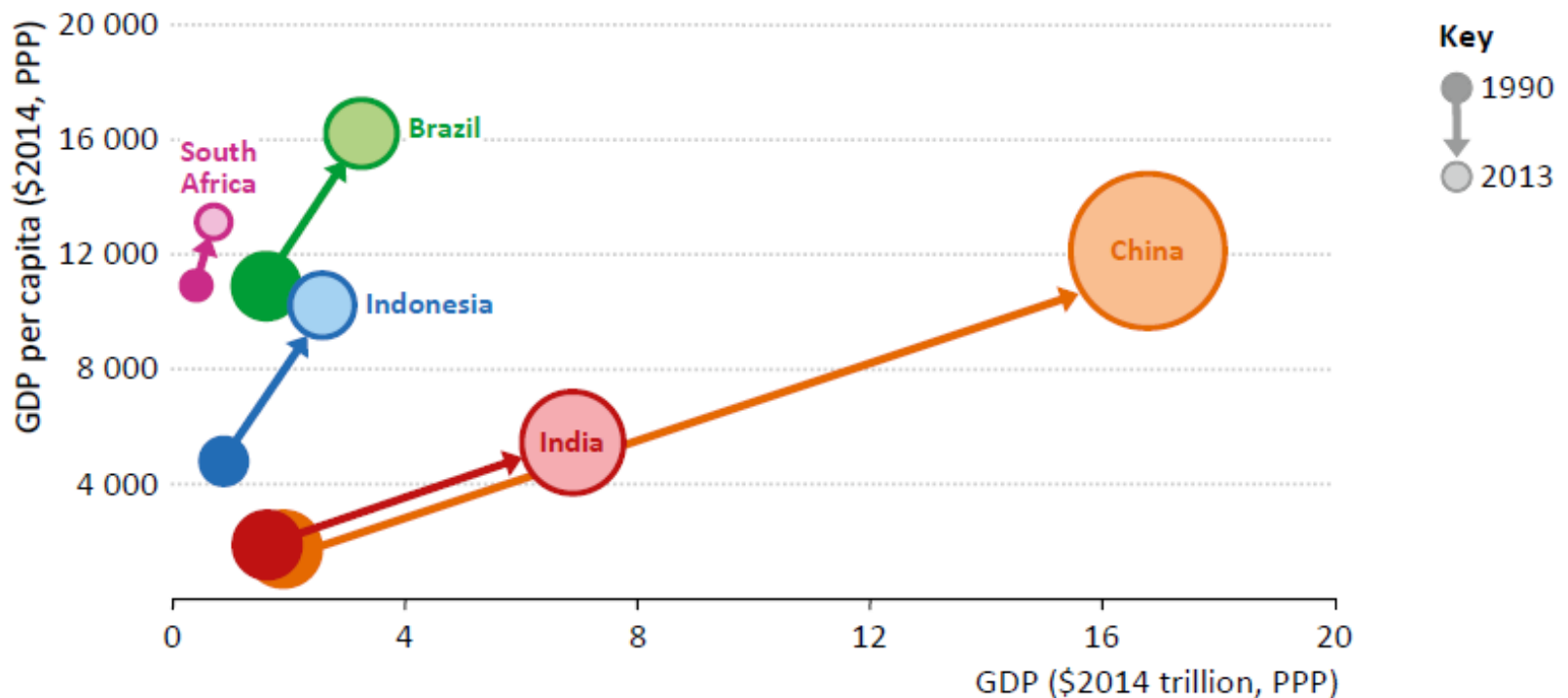
◦ **Economy and demographics**

- ❑ *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**.*
- ❑ *This **propelled India** beyond Japan in 2008, to become the **third-largest** economy in the world, measured on a PPP basis.*
- ❑ *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 terms) **fell by more than half**, from almost **50%** to less than **25%**.*

Factors affecting India's energy development

◦ Economy and demographics

Figure 1.10 ▷ GDP per capita and total GDP for selected countries, 1990 and 2013

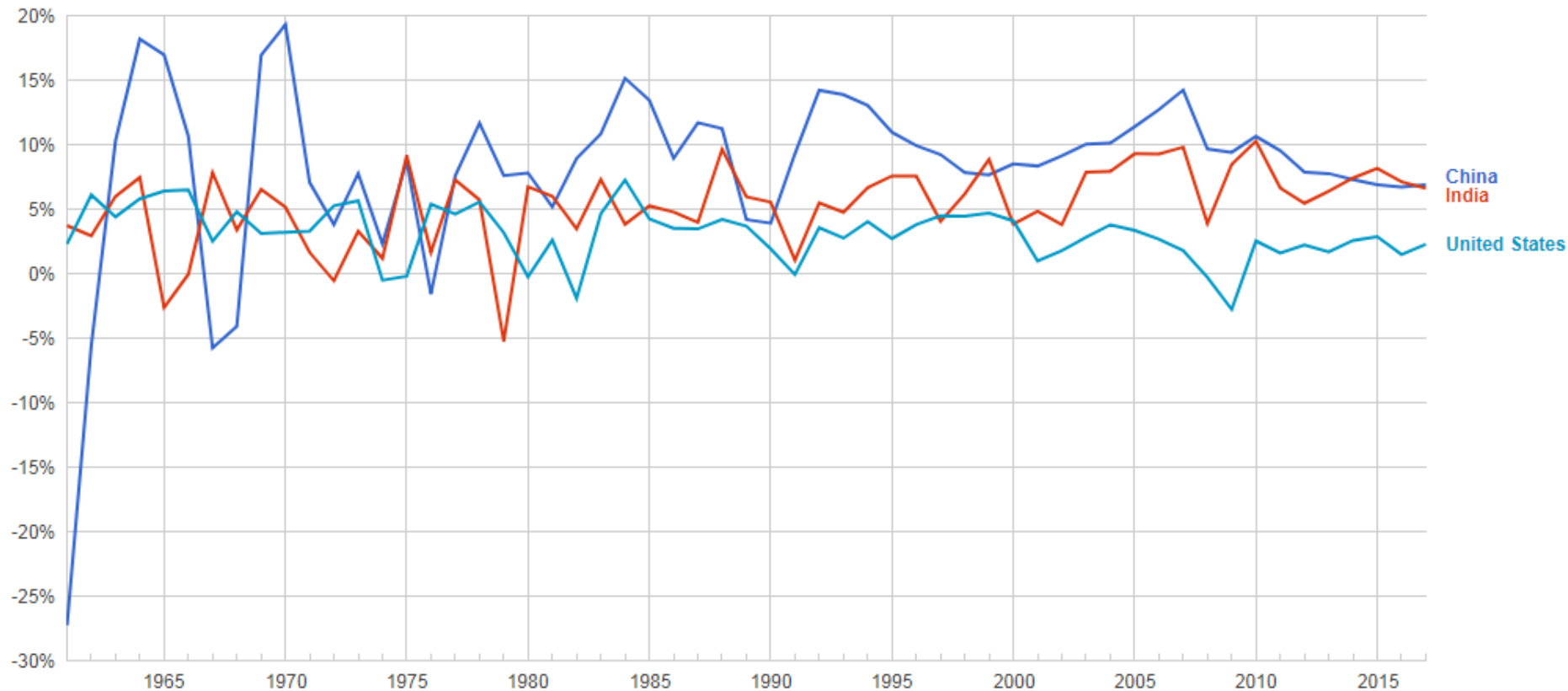


Note: PPP = purchasing power parity.

Factors affecting India's energy development

◦ *Economy and demographics*

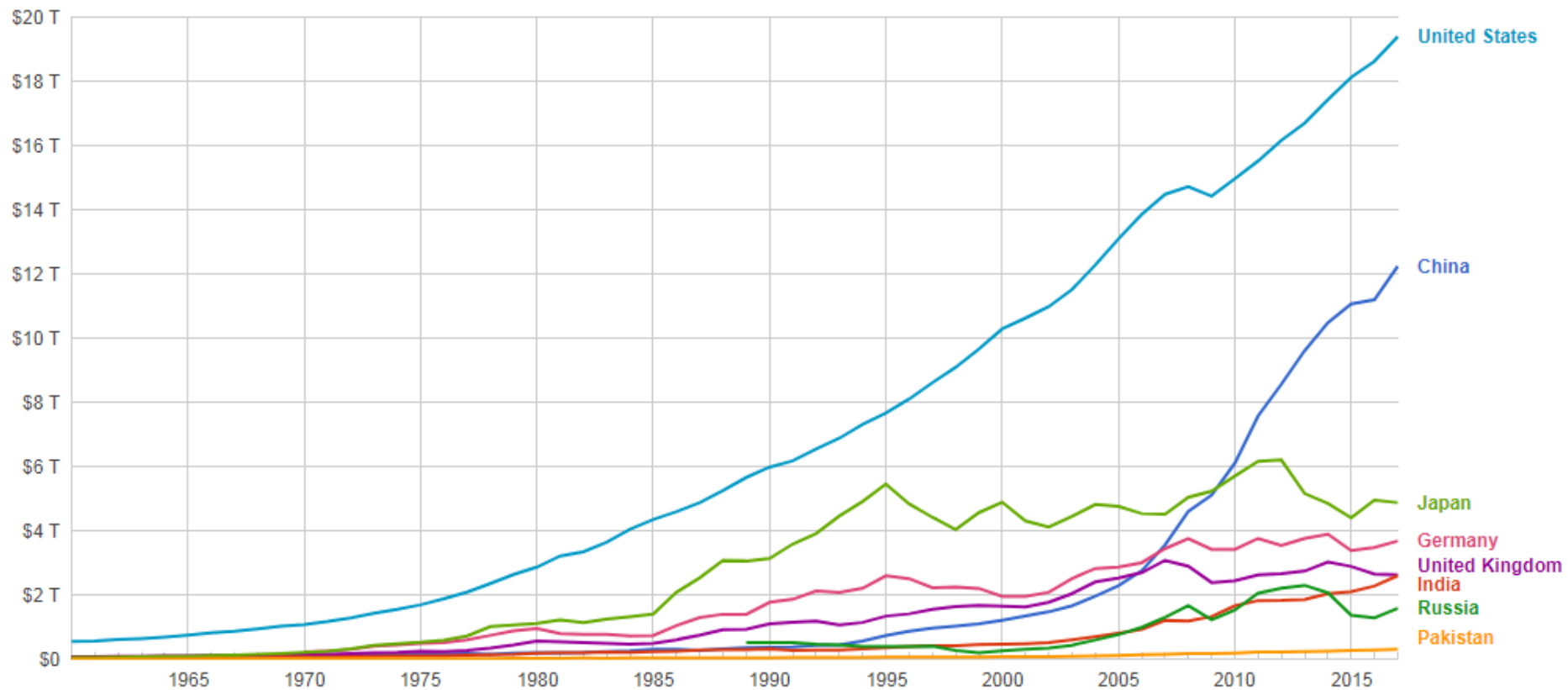
GDP growth rate ?



Factors affecting India's energy development

◦ *Economy and demographics*

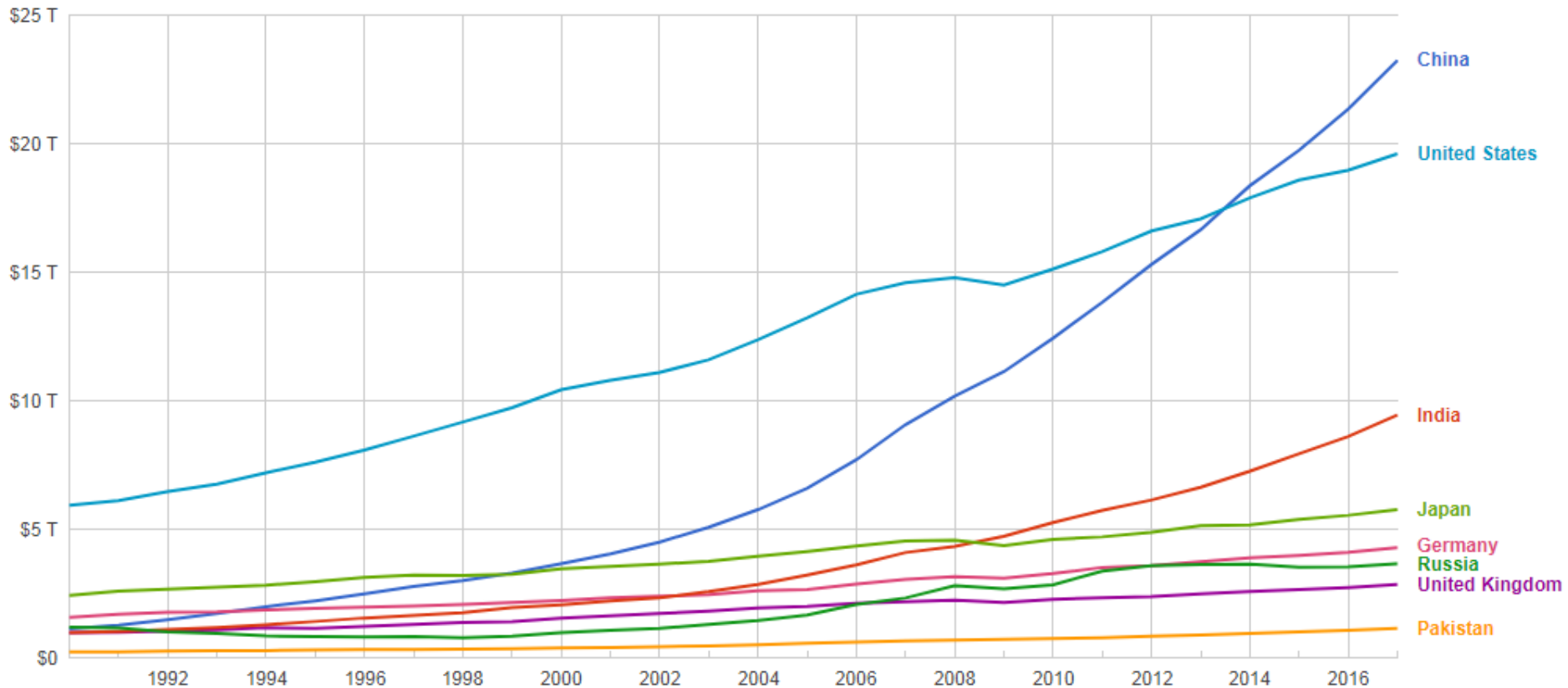
Gross Domestic Product ?



Factors affecting India's energy development

◦ *Economy and demographics*

Gross National Income in PPP dollars ?



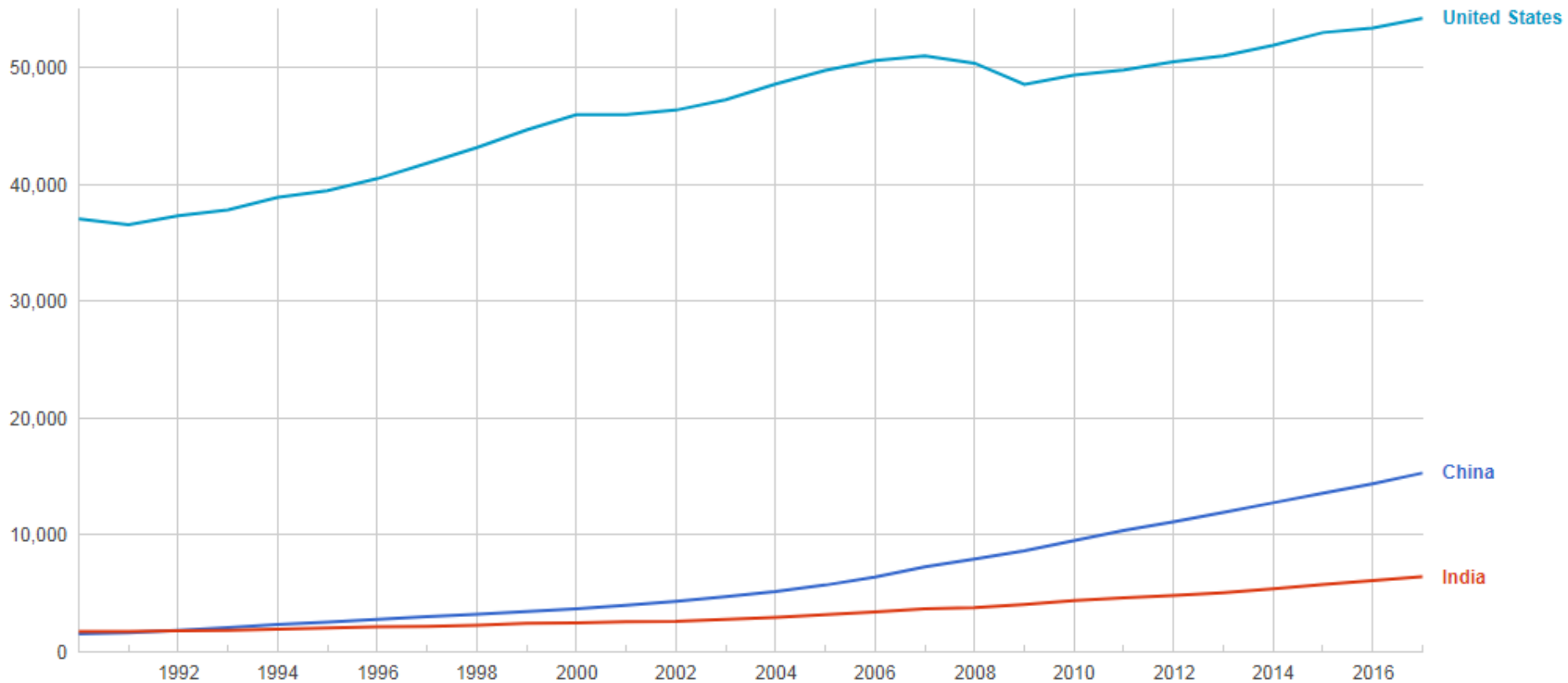
Factors affecting India's energy development

- ❑ 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 (Figure 1.10).
- ❑ 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.

Factors affecting India's energy development

◦ *Economy and demographics*

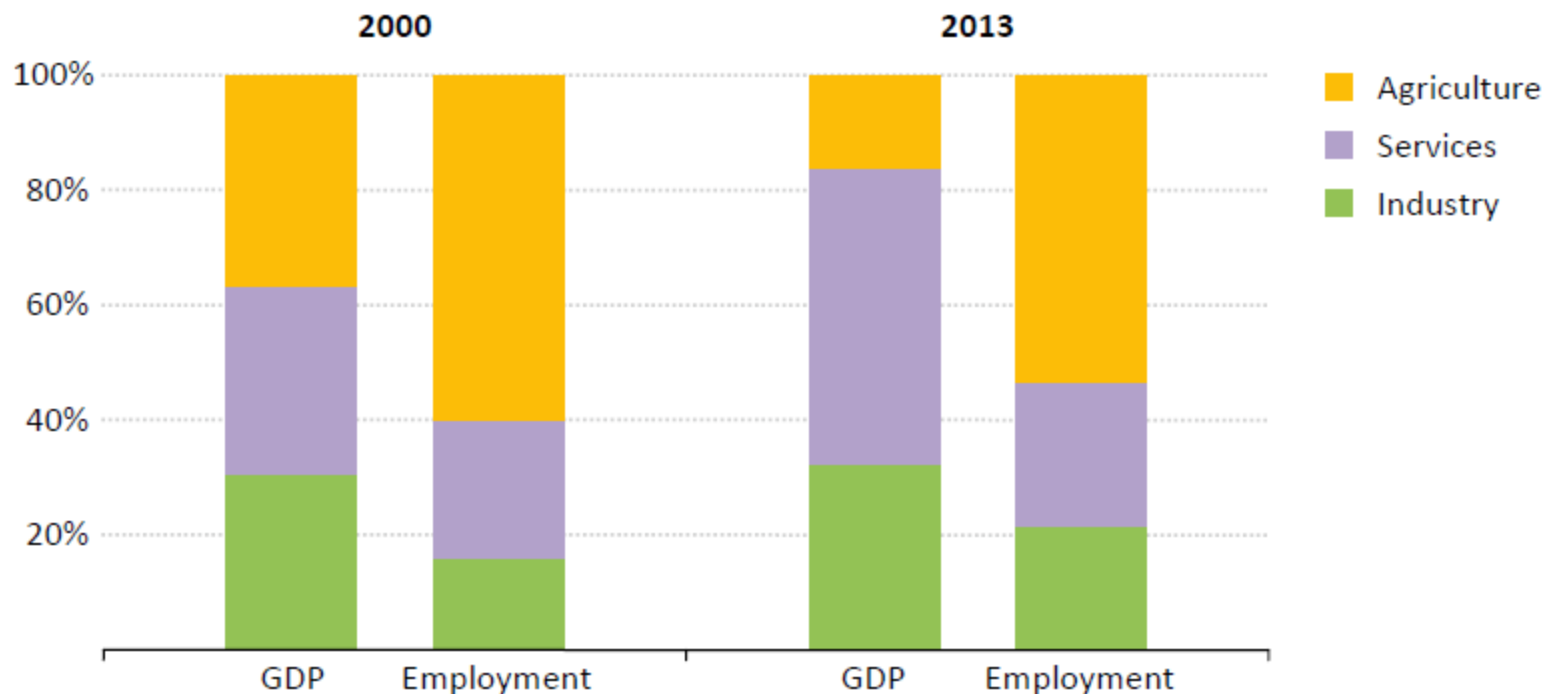
GDP per capita, PPP (constant 2005 international \$) ?



Factors affecting India's energy development

- 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** (Figure 1.11).

Figure 1.11 ▷ Composition of GDP and employment structure in India



Factors affecting India's energy development

- ❑ The **services-led growth** that India has enjoyed since the early 1990s **differs** from the path in many other countries.
- ❑ 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.
- ❑ **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.

Factors affecting India's energy development

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**.*
- ❑ *Some key aspects of the emerging energy vision are:*
 1. *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**)*
 2. *Volumetric target for India to produce **1.5 billion tonnes** of coal by **2020**.*
 3. *Efficiency gains as well as production increases underlie India's energy security objective of reducing reliance on **fossil-fuel imports** by **10%**.*

Factors affecting India's energy development

4. 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.
5. A drive for **market-oriented solutions and increased private investment** (including foreign investment) in energy.
6. 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.
7. The **twin** energy-related commitments to increase the share of **non-fossil** fuel power generation capacity to **40% by 2030** and to **reduce the emissions** intensity of the economy by **33-35%** by the same date, measured against a baseline of **2005**.

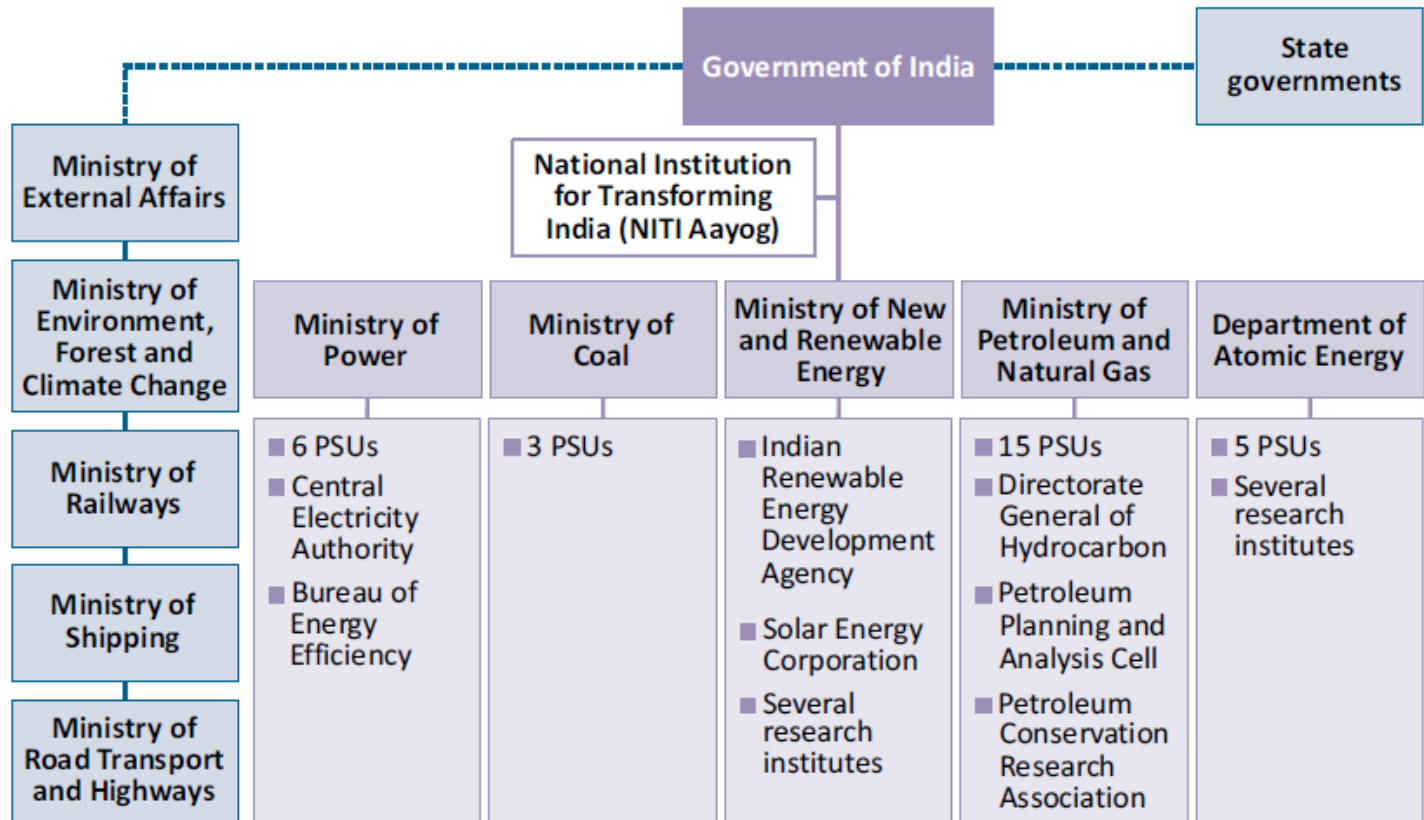
Factors affecting India's energy development

Institutional Framework:

- 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 (Figure 1.12).
- 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**.

Factors affecting India's energy development

Figure 1.12 ▷ Main institutions in India with influence on energy policy



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.

Factors affecting India's energy development

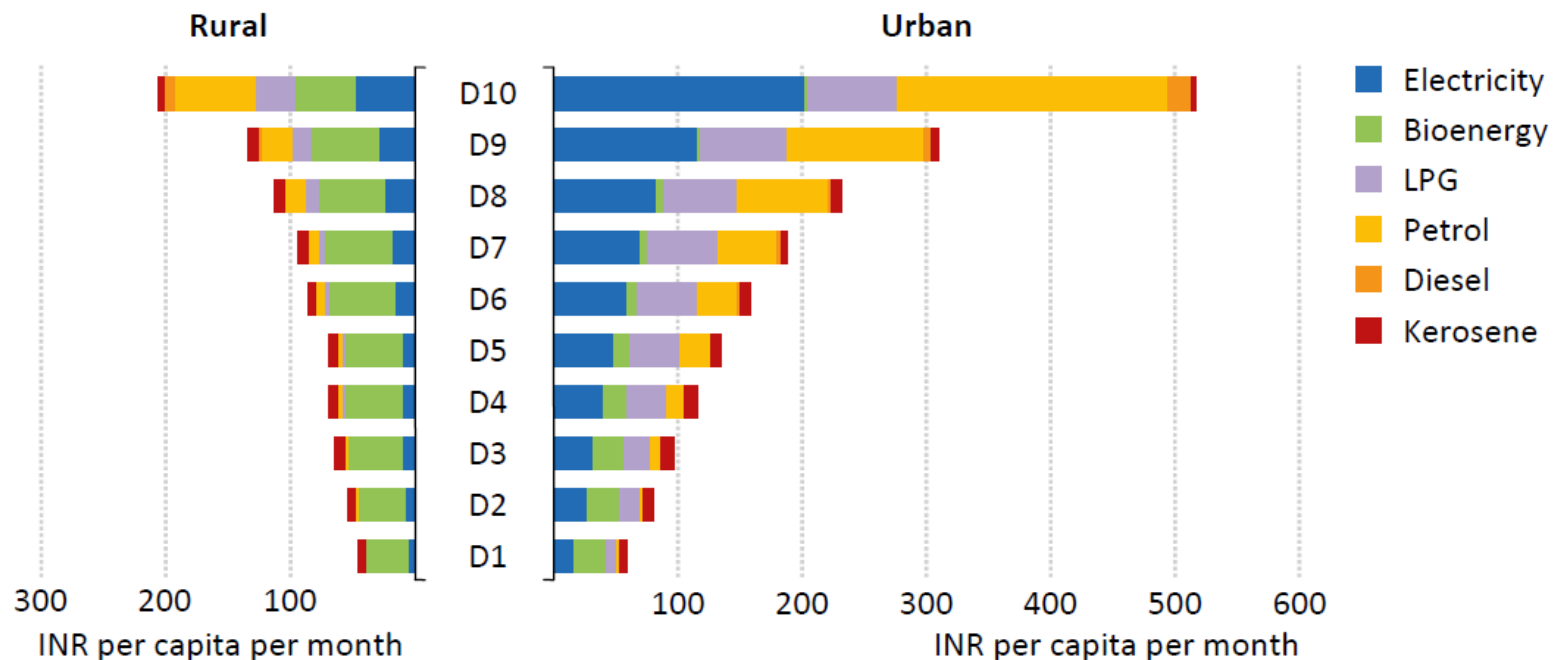
Energy prices and affordability (Expenditure)

- 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.
- **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.
- 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 (Figure 1.13).

Factors affecting India's energy development

- 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.

Figure 1.13 ▷ Per-capita energy expenditure by location and income in India



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.

Factors affecting India's energy development

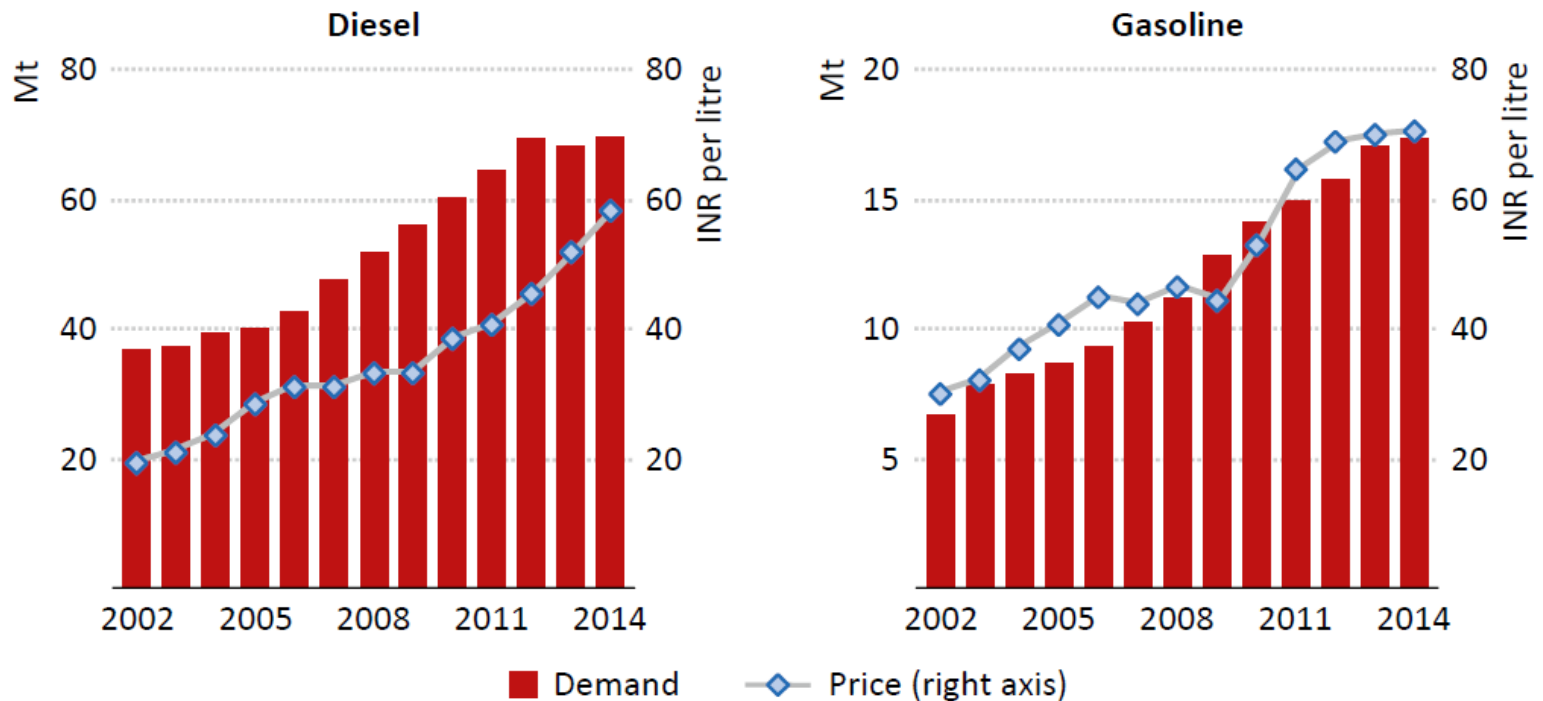
Energy prices:

- ❑ 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**.
- ❑ 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

Factors affecting India's energy development

- Diesel once cheaper than petrol, now is **in par** with petrol in 2014 after the removal of diesel subsidies, resulting in diesel **consumption flattening** as consumer preferences **shifted** towards gasoline.

Figure 1.14 ▷ Diesel and gasoline prices and demand, 2002-2014

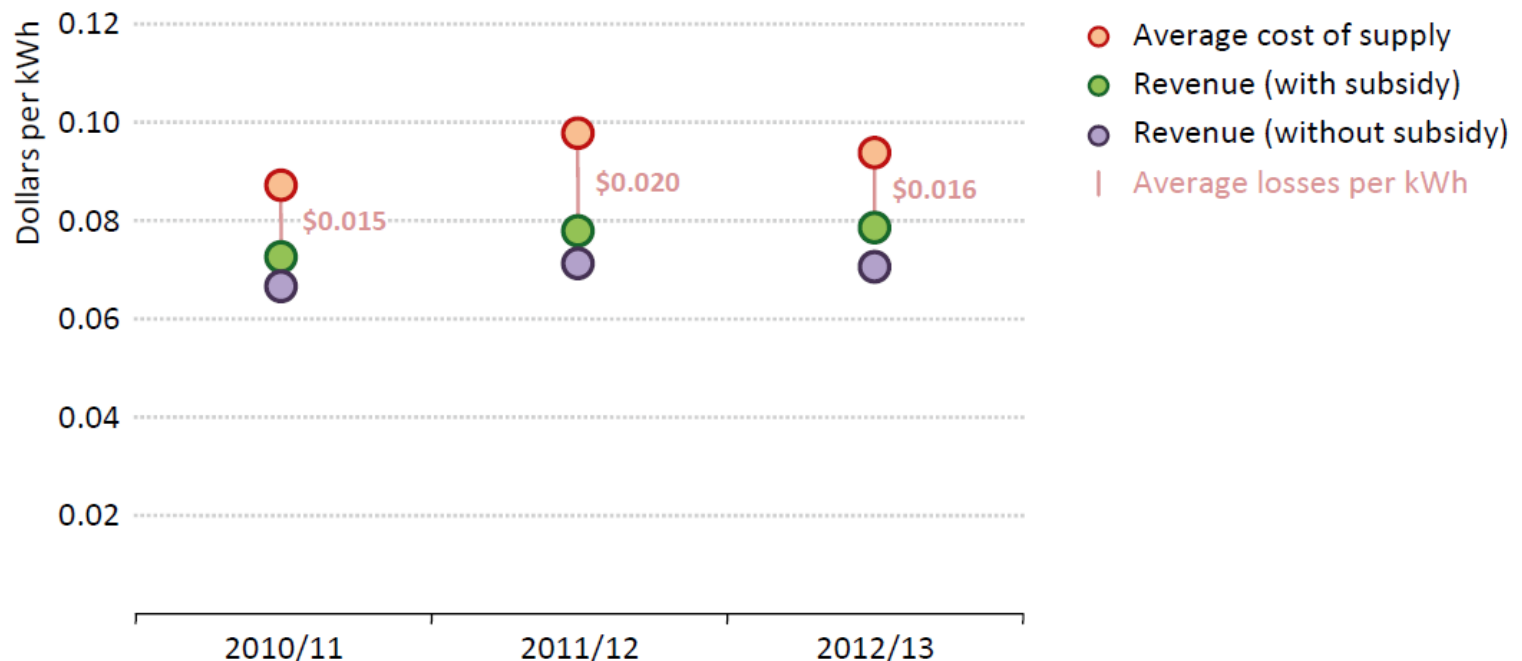


Notes: Mt = million tonnes; INR = Indian rupees. Year denotes fiscal year, starting in April and ending in March.

Factors affecting India's energy development

- As noted in the electricity section, **average end-use electricity tariffs in India do not adequately reflect the cost of electricity supply**, with government **subsidies** covering a part of the gap and the rest being absorbed as **losses** by state-owned distribution utilities (Figure 1.15).

Figure 1.15 ▸ Average cost of electricity and average revenue in India, 2010-2013



Sources: Power Finance Corporation; IEA analysis.

Factors affecting India's energy development

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 PM_{2.5} and Sulphur and nitrogen oxides, into the air.*

Factors affecting India's energy development

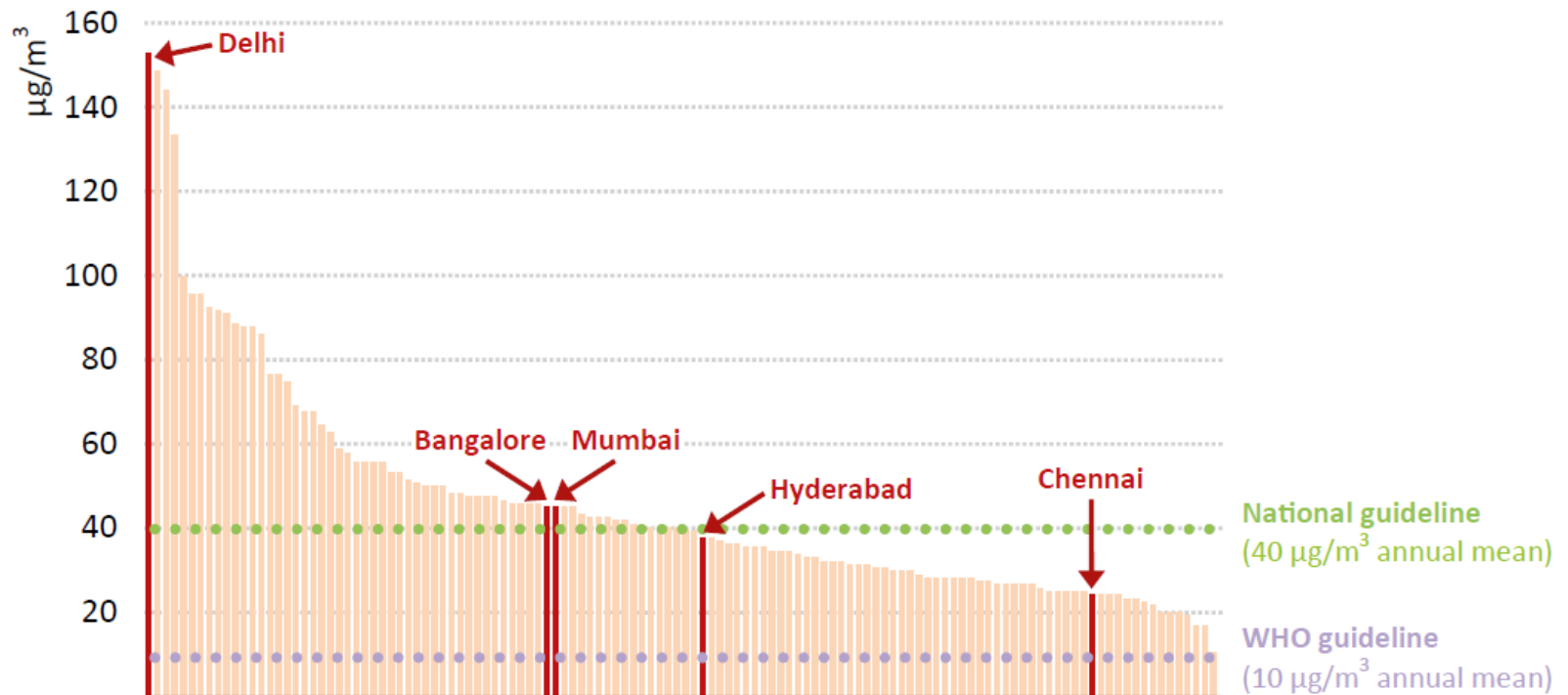
Social and Environmental Aspects

- ❑ 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 (Figure 1.16).
- ❑ Of the 124 cities in India for which data exist, only one, **Pathanamthitta** (with a population of 38 000), 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.

Factors affecting India's energy development

Social and Environmental Aspects

Figure 1.16 ▷ Average annual particulate matter concentration in selected cities in India



Sources: World Health Organization; IEA analysis.

Factors affecting India's energy development

Social and Environmental Aspects

Land

- ❑ **Land acquisition** for public or private enterprises wishing to build infrastructure, from roads and railways to power plants and steel mills, is an **issue fraught with social and political sensitivity**.
- ❑ **Legislative changes** introduced in 2013 introduced **stringent** procedural requirements for land acquisition.
- ❑ At the end of 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**: 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).

Factors affecting India's energy development

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).
- ❏ India's **warm temperatures** and the **poor quality coal** used in the bulk of its power plants add to their **cooling** requirements.
- ❏ In 2010, **more** water was withdrawn in India for agricultural use alone than for all purposes in China (drip irrigation networks).

Factors affecting India's energy development

Carbon-dioxide emissions

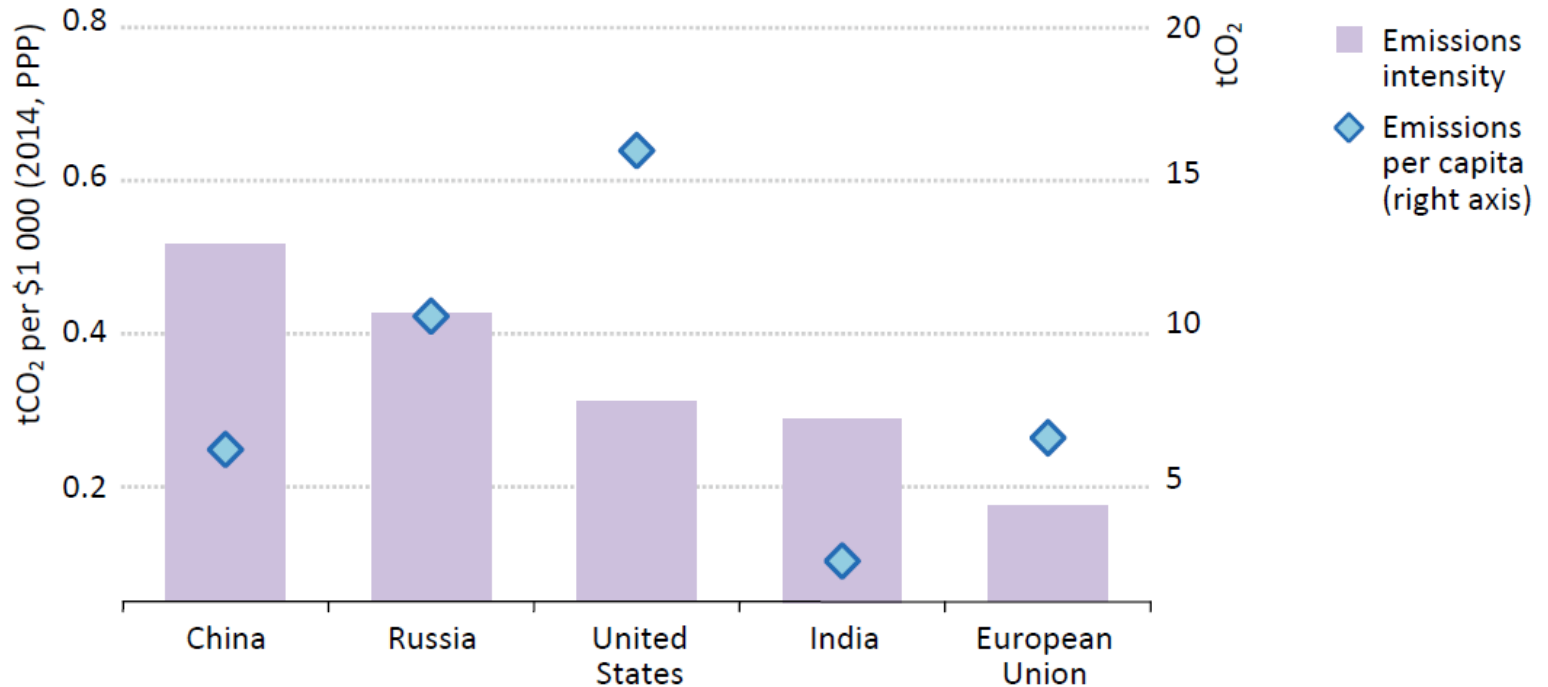
India's CO₂ emissions can be seen in two ways.

- ❑ 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 (Figure 1.17), 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 CO₂ 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 CO₂/kWh), compared to a world average of 522 g CO₂/kWh.

Factors affecting India's energy development

Carbon-dioxide emissions

Figure 1.17 ▷ Carbon intensity of GDP and energy-related CO₂ emissions per capita in selected regions, 2013



Note: tCO₂ = tonnes of carbon dioxide; PPP = purchasing power parity.

Factors affecting India's energy development

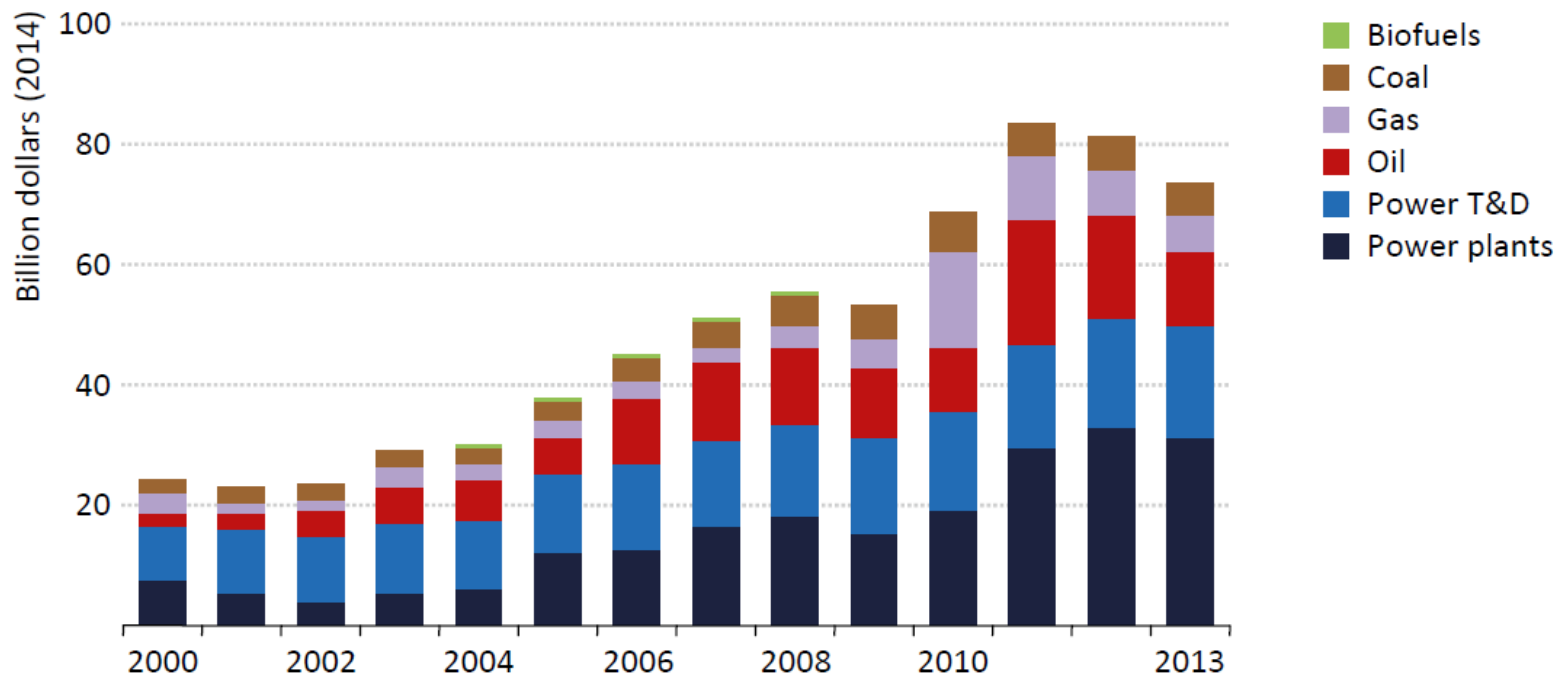
Investment

- ❑ Since 2000, the investment in energy supply in India has **increased substantially**, reaching almost **\$77 billion** on average since 2010 (Figure 1.18).
- ❑ 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.
- ❑ 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**.

Factors affecting India's energy development

- *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*

Figure 1.18 ▷ Energy supply investment by type, 2000-2013



Note: T&D = transmission and distribution.

Factors affecting India's energy development

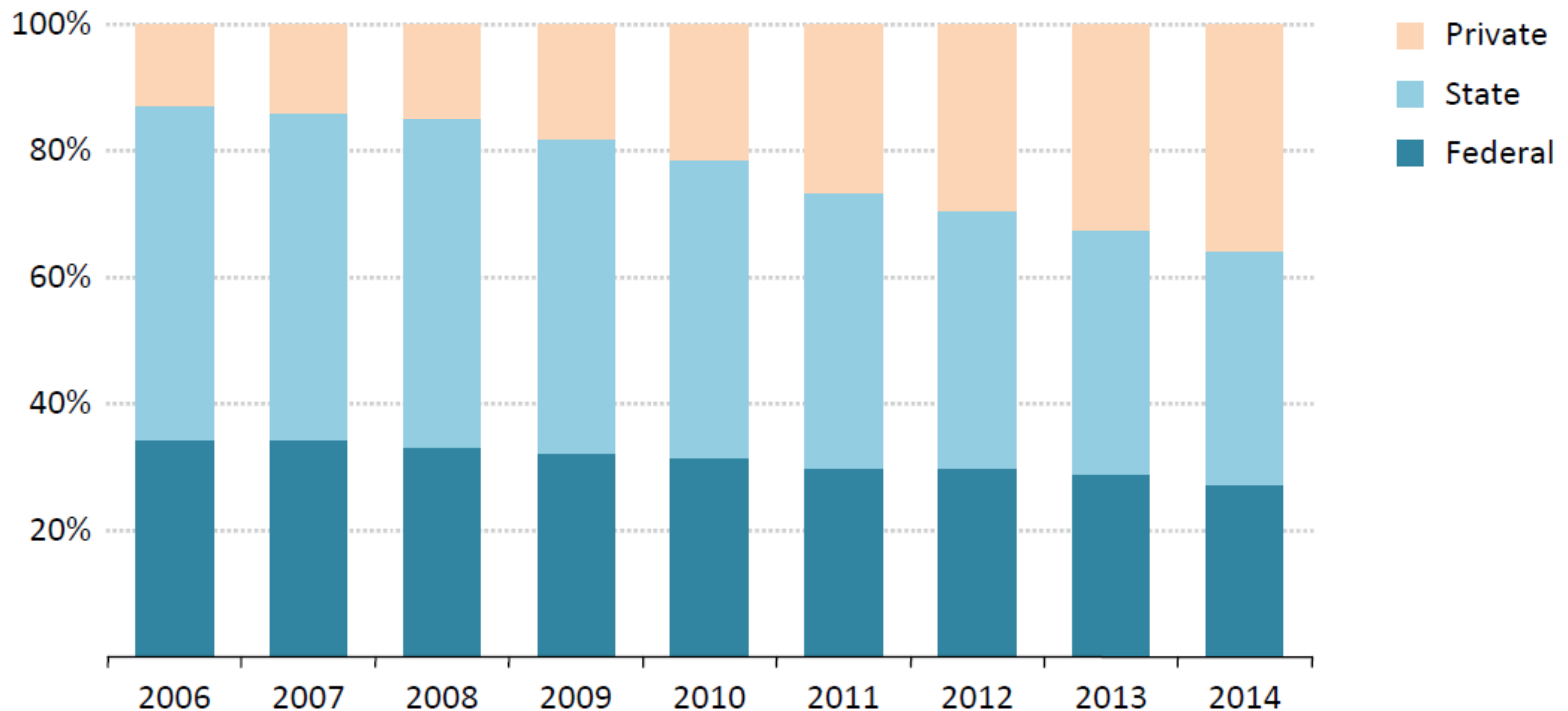
Investment

- ❑ 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).
- ❑ Since the late 1990s, steps have been taken to **deregulate** the oil and gas sectors.
- ❑ 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 (Figure 1.19).

Factors affecting India's energy development

- 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.

Figure 1.19 ▷ Power generation capacity by type of ownership in India



Source: Central Electricity Authority.



THANK YOU