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Asheem Srivastav

Energy Dynamics and Climate Mitigation

An Indian Perspective

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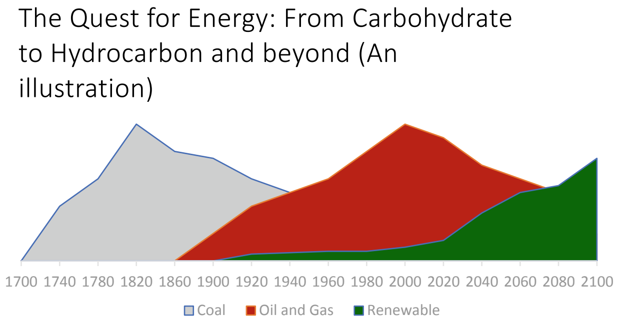
Chapter 1
Energy Security and Sustainability: An Overview

Abstract Every living entity requires internal energy, derived through biological process, for survival, growth, and sustenance. Human being is an exception in the sense that they need additional energy from external sources to accomplish their quest for excellence. The availability and adequacy of external energy and reliability of its supply whether commercial or non-commercial affect economic productivity, development, and sustenance. The process of global split between energy-rich and energy-poor that started with industrial revolution continues till date and each nation is working relentlessly to ensure secure supply of energy from renewable and non-renewable sources. Energy indicators are developed, and projections are done to assess future energy scenario and an understanding of complete energy flow and bottlenecks. India has been undergoing transformative changes since independence with population, poverty, and energy as the pivotal challenge. With the passage of every day, India faces the toughest challenge of energizing its economic development through power generation that is highly dependent on imports of oil, gas, solar panel, and wind turbines. With climate-related disasters becoming too intense and frequent, India has no option but to race ahead in replacing dirty fuels with renewables.

Keywords Calorie · Joule · Watt · Tons of oil equivalent · BTU · Tons of coal equivalent · Energy security · Energy access · Calorific value · British ton · American ton · Metric ton · Energy indicators



The Quest for Energy: From Carbohydrate to Hydrocarbon and beyond (An illustration)

A. Srivastav, *Energy Dynamics and Climate Mitigation*,
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The concept of energy security is of recent origin and has emerged due to high demand for commercial energy consumed for manufacturing goods, providing various services, and for human comfort. Human quest for excellence in knowledge combined with hard work, innovation, perseverance, and dedication has changed the global energy landscape from carbohydrate (wood-based) to hydrocarbon (coal, oil, and gas) economy. Unfortunately, the side effects of hydrocarbon economy have led to many catastrophic phenomena, including ozone hole, pollution of terrestrial and aquatic systems, ocean acidification, and global warming. The industrial revolution that has withstood the test of time so far with external energy derived from non-biological sources has failed the test of sustainability. Wood dominated the socioeconomic development in Europe until the 1500s and was the most important material for building construction, ships, for cooking and heating, as well as for purification of various metals. Rampant and excess extraction of wood eventually led to the disappearance of natural forests in early 1700s. Disappearance of wood was succeeded by emergence of coal in England. Coal was initially obtained through surface mining to avoid risking human lives due to flooding of underground mines. The desire for more coal culminated in invention of steam engine by Thomas Newcomen that saved Britain from energy crisis. By 1800, Britain switched over from carbohydrate to hydrocarbon economy. Hydrocarbon economy has been meticulously controlled by a few nations who have vast resources of coal and oil. These conglomerates have manipulated international price to their advantage frequently threatening the energy security of the world. To counter these forces, many countries, started working on alternative sources of energy such as nuclear (fission in particular), solar, wind, geothermal, and biofuel. In recent years, the climate change disasters have struck humanity with impunity and the scientific community is united in its opinion to stop the use of coal and oil in near future. As the fourth industrial revolution progresses, the world will witness emergence of renewable energy from different sources—and eventually bid farewell to hydrocarbon economy.

1.1 Understanding Various Terms and Conversion Factors

Before embarking on the contents of this chapter, it will be useful for many, if not most, readers to understand the various terms and units of measurement adopted by different countries/institutions/authors.

There are six most common units of energy used at global level (Foresti et al. 2010):

- Calorie
- Joule
- Watt
- BTU (British thermal unit)
- TOE (Tons of oil equivalent); and
- TCE (Tons of coal equivalent)

Almost every science student is conversant with the term ‘calorie’ and ‘joule’. The term ‘*calorie*’ indicates the quantum of energy required to raise the temperature of 1 g of water by one degree centigrade or Celsius (i.e. from 14.5 to 15.5 °C) (Parr 2011), whereas ‘*joule*’ is a measure of quantum of energy (or work) required to generate one watt of power for one second (Chen et al. 2017). ‘*Watt*’, on the other hand, is used to determine power and is equivalent to the rate at which one ampere of current flows through a circuit with potential difference of one volt. Another difference between ‘*Joule and Watt*’ is that the former is a unit of *energy* and the latter is a unit of *energy transfer* in joule per second. In other words, ‘Joule’ is the amount of energy and ‘Watt’ measures the rate at which energy is used. For example, when a light bulb (sold in Indian market as 10, 20, 40, 60, 100 watts) of 100 watts glows for 10 seconds, it will consume 100 × 10 = 1000 Joules of energy.

We can also express the relationship between joule and watt as follows:

i. Joule = Watt × seconds
ii. Watt = Joule/second

In many scientific as well as non-science literature, the words ‘energy’ and ‘power’ (Box 1) are interchangeably used. For example, we use the term thermal power or nuclear power plant/s but not thermal energy plant or nuclear energy plant. Whereas at the policy level, we invariably use the word ‘energy’. Nevertheless, there is a clear distinction between these two words. Power means the rate at which energy is either generated or consumed in a power station and is measured in watts (or kilowatts or megawatts or gigawatt or terrawatt), which in turn means energy per unit time. For example, all power stations have a rating in terms of megawatt or gigawatt. This rating indicates the maximum power output a station can achieve at a given point in time. For example, 1000 gigawatt or 5000 megawatt, and so on. On the other hand, the annual energy output of a power station is mentioned in terms of megawatt-hour or gigawatt-hour or terrawatt-hour. For example,

Power output of 1 terrawatt-hour per year = 1 × 10^{12} *watt-hour/(365 days × 24 hour per day) = 114 megawatt of constant power output for one year.*

Box-1 ENERGY AND POWER

Energy is defined as the ability to do work and is measured in joules (J). One joule is the work done when a force of one newton (N) is applied through a distance of one meter. A newton is the unit of force that, while acting on a mass of one kilogram, increases its velocity by one meter per second every second along the direction in which it acts.

Power, on the other hand, is the rate at which energy is transferred and is commonly measured in watts (W), where one watt is one joule per second.

Newton, joule, and watt are defined in the International System of Units. The oil industry measures energy as tons of oil equivalent or ToE where 1 ToE = 41.87 x 109 Joules and barrels of oil equivalent or BoE where 1 BoE = 5.71 x 109 Joules. In the same manner the coal industry measures energy as tons of coal equivalent where 1 TCE = 29.31 x 109 Joules. Commercial electricity is measured as kilo watthour where 1 kWh equals 3.6 x 106 Joules.

Source [UNDP, 2000]

Besides, calorie and joule, another unit of energy frequently used at international level is BTU. The acronym stands for British Thermal Unit (Davis and Wood 1974) and is equivalent to the amount of heat required to raise the temperature of one pound of water through 1° Fahrenheit. One BTU is equivalent to 252 cal or 0.252 kcal or 0.293 watt-hours or 1055 joules.

1 BTU = 252 cal = 0.252 kcal = 1055 Joules = 0.293 watt-hours

In Indian context, consumers pay their electricity bill in proportion to the 'units' of energy consumed by them. One unit of energy consumed indicates use of an electrical item (e.g., a bulb) of 1000 watt (or 1 Kilowatt) for 1 hour. In other words, one unit is equivalent to 1 kilowatt-hour of energy consumed. In terms of BTU, 1 kilowatt-hour generates 3412 BTU.

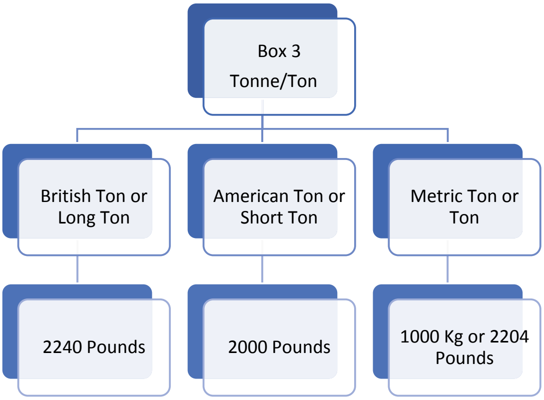
One unit = 1 kilowatt-hour = 3412 BTU = 853,000 cal

At the global level, a normalized unit of energy is being used which is referred to as KgOE (kilograms of oil equivalent) and TOE (tons of oil equivalent) (see Box 2) (Zou 2020). By convention it is equivalent to the approximate amount of energy that can be extracted from 1 kilogram or 1 ton of crude oil, respectively. The World Bank, for example, uses KgOE for energy use per capita in its 'Little Green Data Book' which is published annually.

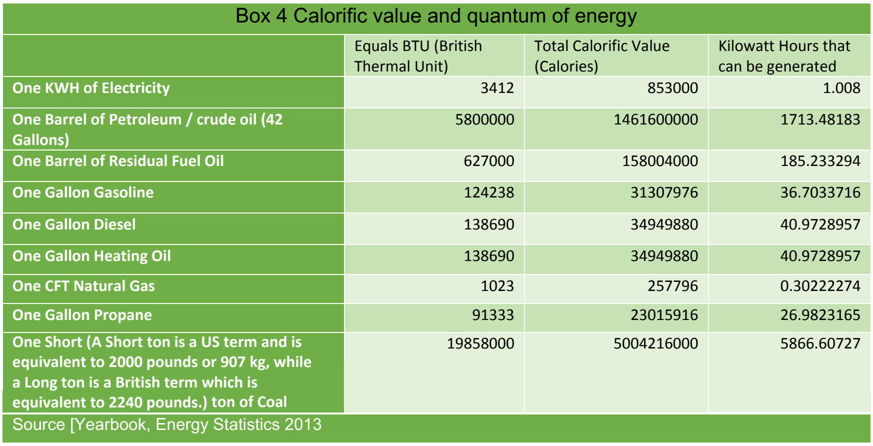
Box-2 TOE (Tons of Oil Equivalent)

1 TOE equals	11.63 Mega-watt Hour (MWH)
	14.868 Giga Joules (GJ)
	39,683,207 British Thermal Unit (BTU)
	1.43 Tons of Coal Equivalent (TCE)
	7.33 Barrels of Oil Equivalent (BOE)

Readers frequently encounter two terms, viz., ‘ton’ and ‘tonne’. Globally, three different types of ‘Ton’ (https://www.quora.com) have been recognized and these are as follows (Box 3):



Let us examine the calorific value and quantum of energy (Box 4) that can be generated from some well-known commercial and non-renewable sources (Yearbook, Energy Statistics 2013).



Box 4 Calorific value and quantum of energy

	Equals BTU (British Thermal Unit)	Total Calorific Value (Calories)	Kilowatt Hours that can be generated
One KWH of Electricity	3412	853000	1.008
One Barrel of Petroleum / crude oil (42 Gallons)	5800000	1461600000	1713.48183
One Barrel of Residual Fuel Oil	627000	158004000	185.233294
One Gallon Gasoline	124238	31307976	36.7033716
One Gallon Diesel	138690	34949880	40.9728957
One Gallon Heating Oil	138690	34949880	40.9728957
One CFT Natural Gas	1023	257796	0.30222274
One Gallon Propane	91333	23015916	26.9823165
One Short (A Short ton is a US term and is equivalent to 2000 pounds or 907 kg, while a Long ton is a British term which is equivalent to 2240 pounds.) ton of Coal	19858000	5004216000	5866.60727

Source [Yearbook, Energy Statistics 2013

Since different types of fuel materials are used for generating commercial energy, their efficiency (Planning Commission 1953) is compared in terms of calorie content. For example, one ton of crude oil is worth 10 billion cal or 42 billion joules. Similarly, one million ton of Indian coal is worth 4.1 billion cal. It is also possible to measure electrical energy in terms of thermal energy. For example, one billion kilowatt-hour equals 0.86 billion cal. Taking the thermal efficiency of a power plant and other losses in the system, the equivalence between electricity and fossil fuels would be one billion kilowatt-hour = 0.28 million tons of oil equivalent (in case of coal-fired

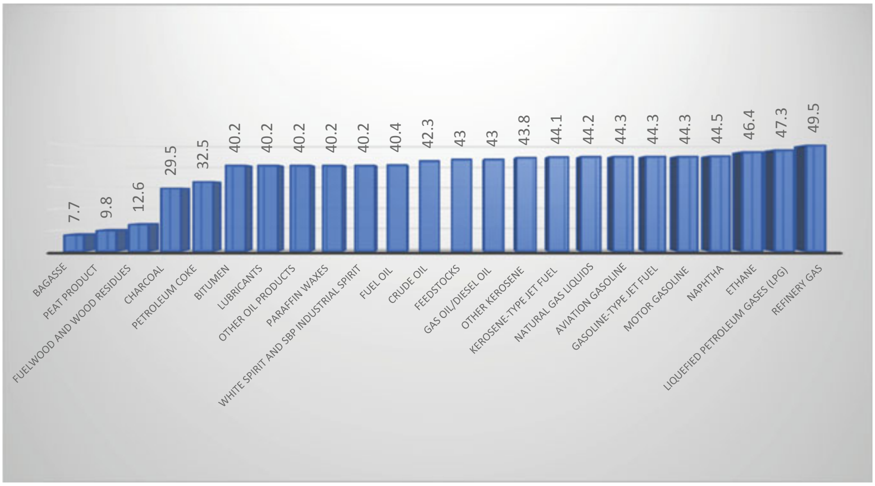


Fig. 1.1 Calorific value of materials used in energy generation (Gigajoule/ton) (Ref-Yearbook, Energy Statistics 2013)

boilers) and 0.261 million tons of oil equivalent (in case of nuclear electricity) (Mason and Mor 2009). One billion kilowatt-hour generated from hydroelectricity or wind power, however, are considered as equivalent to 0.086 million tons of oil equivalent since there is no intermediate stage of heat production while using these primary energies.

A comparison of calorific value of different materials used for energy generation is given in Fig. 1.1.

Bagasse has minimum calorific value (7.7 gigajoule per ton) whereas most of the petroleum derivatives have calorific value in the range of 40–49 gigajoule per ton. Fuelwood too has low calorific value less than a fourth of petroleum derivatives. However, coal generates more energy than petroleum products and byproducts as can be seen in Fig. 1.2.

In many poor countries of Asia and Africa, people rely heavily on thermal energy from firewood, charcoal, plant, and animal residues as well as human and animal energy (Srivastav 2019). Most of these sources are referred to as non-commercial (and non-conventional), although they are often bought and sold in organized markets. Despite their valuable contribution, neither national nor international institutions have yet given sufficient attention to the sources of such non-commercial energy and technologies being used, their economic and environmental consequences, or to the development of alternatives. The acute scarcity of reliable information in this sector calls for more attention to data gathering and research as deforestation and fuelwood shortages have become critical and are appropriately labeled ‘the other energy crisis’ (Eckholm 1975).

In India, poverty and unprecedented rise in the population has forced a substantial part of the population to continue the use of wood, agriculture waste, and animal waste for generating heat energy to meet the cooking and other heating requirements. Unfortunately, this form of energy continues to be categorized as ‘unorganized and

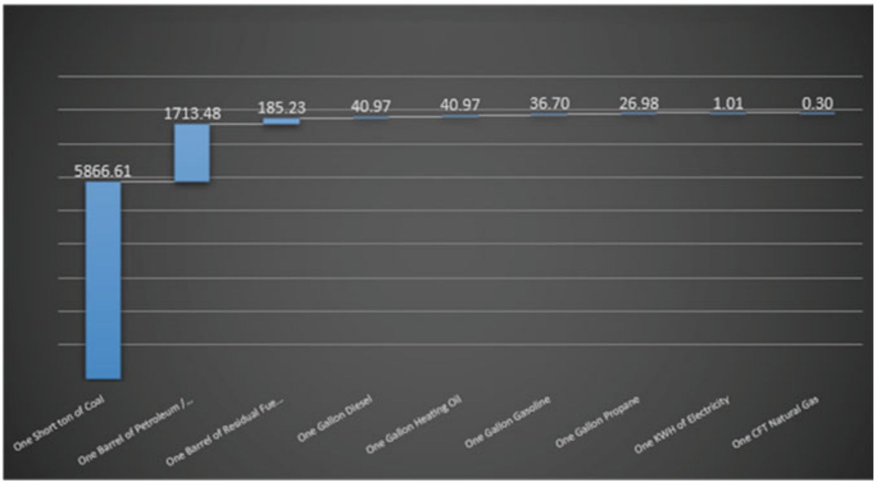


Fig. 1.2 Kilowatt hours generated from different source (Ref-Yearbook, Energy Statistics 2013)

non-commercial' and the planning process does not consider as to how much electricity or gas will be required in future to offset the use of biomass. Every year millions of tons of wood, animal, and plant waste is burnt for cooking food and other purposes. It is a 'no-win' situation as replacing this biomass with coal or gas will cost billions of rupees (for import, extraction, transportation, and distribution). No replacement or slow replacement, on the other hand, would mean loss of trees, soil, and water. For the sake of understanding, Box 5 gives the conversion ratio between wood fuel and coal, crop waste and dung (Srivastav and Srivastav 2015).

Box 5

1 Cubic meter of wood (in volume) = 0.725 Metric Ton (in weight)

1 Metric ton of wood fuel = 0.7 Metric ton of coal

1 Metric ton of wood fuel = 1.53 Metric ton of crop waste

1 Metric ton of wood fuel = 2.35 Metric ton of dried animal dung

Source - Srivastav et al., 2015

1.2 Energy Indicators

Different sectors of economy such as residential, commercial, transport, services, and agriculture require energy in different forms. For example, housing may need electricity, gas, and solar water heaters; transport may require petrol, diesel, gas, electricity, and so on. Availability of adequate energy and reliability of supply whether commercial or non-commercial affect productivity, development, and sustenance. It is, therefore, useful to understand various energy indicators to help policy makers and executors in improving industrial and agricultural productivity, job creation, services, and other economic activities in a country. Energy indicators provide a glimpse of energy scenario and an understanding of complete energy flow and bottlenecks. These are indispensable tools for identifying and understanding energy trends so that decision makers can prioritize interventions and consumption pattern. Indicators keep evolving overtime depending on country priorities, requirements, and capabilities. These indicators (Energy Statistics 2018) are primarily economic indicators of energy and are divided into two sub-indicators, viz., use and production pattern and security. Use of energy and production pattern depends on various factors and sub-factors (Fig. 1.3a, b).

The sub-indicators (Energy Statistics 2018) for energy security include fuel stocks and imports and are described in Fig. 1.4.

1.3 The Paradox of Energy Security and Sustainability

Every living entity requires energy for survival, growth, and procreation of itself. However, the case of human being is different from other living creatures in the sense that they need an external source of energy to accomplish their quest for excellence. Societies cannot survive without incessant use and supply/demand of energy and the original source of energy is human energy—the energy generated by human cells for supplying to muscles. As time passed, humans mastered the science of controlling fire and used combustible materials like wood to cook food, and reshaped metals such as iron to make implements. Subsequently, the energy of flowing water and wind was also harnessed, followed by those of animals before we arrived at industrial revolution and started using coal, oil, and gas for generating energy at commercial scale.

To better understand, let us divide energy into internal energy and external energy. Internal energy comes from consumption of food, air, and water that help us in building protein, fat, carbohydrates, and minerals through a long and complex process and storing it in trillions of cells. Each cell contains hundreds/thousands of mitochondria (biological battery) that contain a substance called adenosine tri phosphate (ATP), which is also known as energy currency of the cell. ATP combines with water to form adenosine di phosphate (ADP) and phosphorus and generates energy within the cell to perform its designated functions. The economics of this conversion process (from ATP to ADP and vice versa) is little understood since this has not been a matter of much concern for the policy makers.

External energy, on the other hand, is required for human comfort, knowledge advancement, exploration, and development in general. This energy is obtained through three processes. One, by direct consumption of combustible materials such as wood, animal waste, coal, charcoal, and kerosene; two, by producing bulk electricity

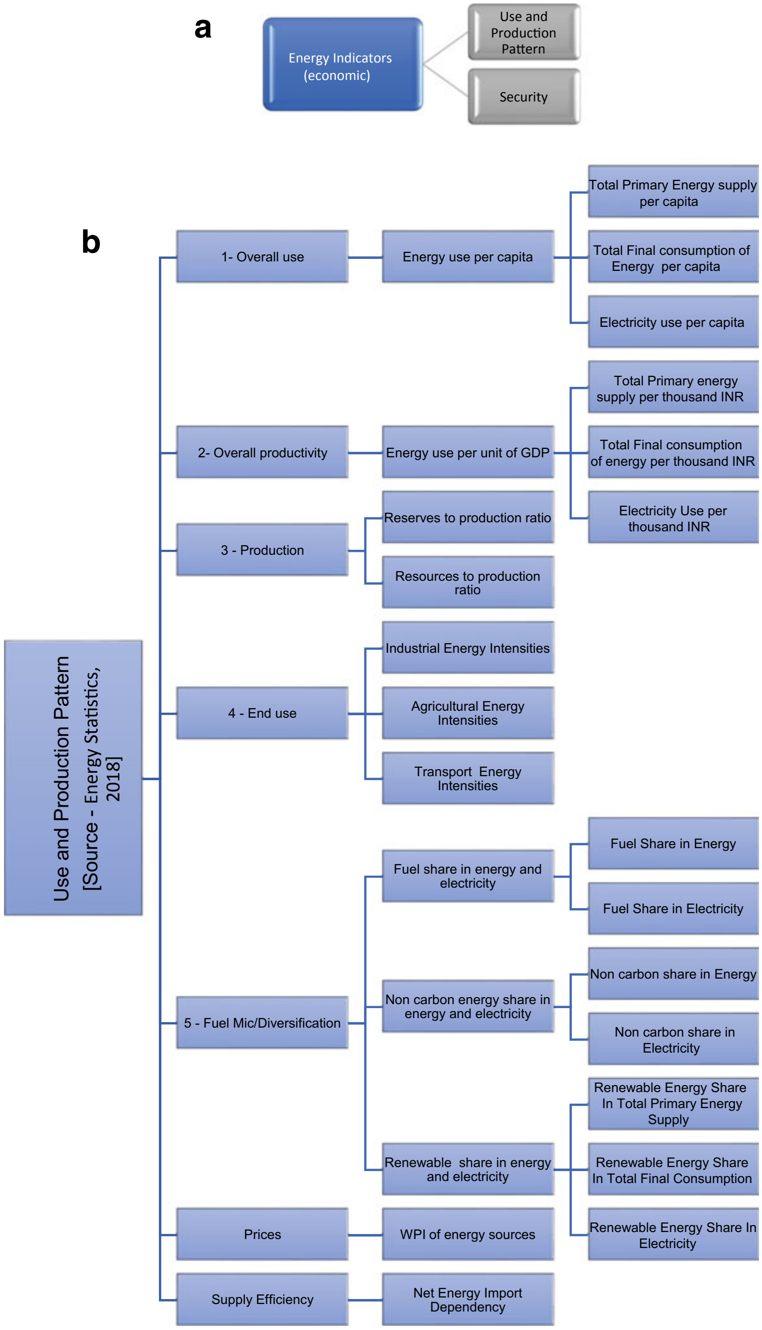
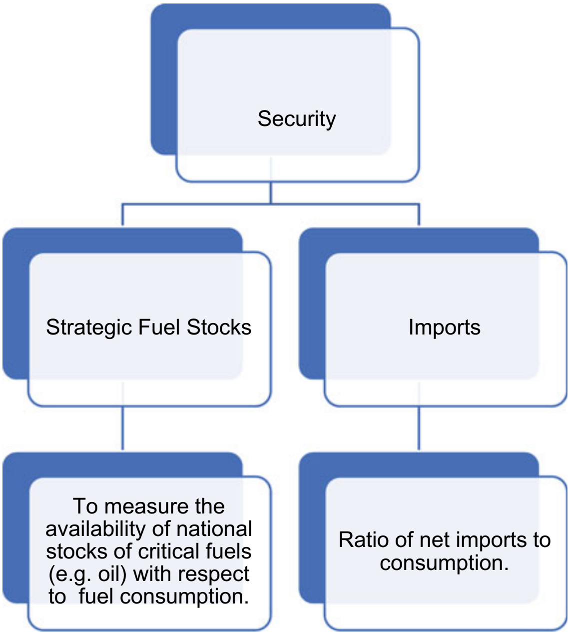


Fig. 1.3 **a** Energy indicators (economic). **b** Use and production pattern (*Source* Energy Statistics 2018)

Fig. 1.4 Security



in power stations which is then transmitted through wire connected with households and commercial establishments. These power stations, in turn, use different products of nature such as water, coal, nuclear, diesel, and so on for generating energy. The third source of external energy comes from batteries such as lead acid, nickel metal, and lithium ion that are used in vehicles, computers, mobile phones, and so on.

The source of external energy comes from matter such as water, air, sunlight, petroleum, coal, biomaterial, radioactive material, and so on. Chapters ahead in the book will deal with various aspects of external energy. Both internal (natural) and external (converted or transformed) energies complement each other. For example, an underfed, unhealthy, and less educated population will fail in improving the GDP even though they have adequate supply of external energy and superior technology. In other words, the sustainable development of a nation will depend on quantitative and qualitative growth and internal as well as external sources of energy. Sustainable development in any and every nation's socioeconomic parameters is possible only when it is based on secure energy infrastructure. It is only a matter of time that the external energy infrastructure would become infructuous in the absence of strong internal energy foundation that can only be ensured through protection, conservation, and preservation of natural forests, farm lands, aquatic resources, and air which are so vital to protect and enrich our soil, ensure the availability of water and food, and stabilize our atmosphere. The concept of GDP in economic development has long been seen as a crude benchmark for measuring the value of goods and services. That is why many nations are now advocating prioritizing quality of life over financial growth (that has destroyed more than it has created). The opponents of GDP-linked economic growth argue that the current standard means of measuring economic growth ignores other factors vital to the wellbeing of the individual and populations such as environmental protection, and sustainable happiness of inhabitants. They argue that besides economic development, there is a need for measuring levels of satisfaction and community interrelationships.

Is energy (commercial) a necessity or basic need? This question has been broadly dealt in the 1987 report 'Our Common Future' prepared by the World Commission on Environment and Development (Brundtland et al. 1987). The report defines sustainable development as

> *development that meets the need of present without compromising the ability of future generations to meet their own needs*

Simply explained—sustainable development is a process of change in which exploitation of resources, technological development, financial investment, and institutional change are in harmony and enhance both current and future potentials to meet the human needs and aspirations.

The relationship between sustainable development and energy security has two important features. One is adequate energy supply that acts as a source of prosperity that satisfies the basic human needs, improves social welfare, and enhances economic growth. The other is that the production and use of energy should not endanger the quality of life of current and future generations and should not exceed the carrying capacity of ecosystems.

Sustainable development with secure energy is possible with the following options:

1. Assured availability of energy to the consumer at all times in adequate quantities, in various forms, and at affordable prices over a long-term period.
2. Increased reliance on renewable energy sources.
3. More efficient use of energy especially at end user level—in heating and cooling buildings, electrical appliances, vehicles, and industrial production systems.
4. Development and deployment of advanced energy technologies (for fossil fuels) at an accelerated pace, especially those that help in near zero harmful emissions.

Unfortunately, more than three decades after the publication of this report, developing world including India continues to rely heavily on non-renewable sources (coal and crude oil in particular), and introduction of advanced energy technologies is much slower than expected.

Energy needs for growing population and economic development are central to the planning process, particularly in oil importing developing countries like India. Uncertainty about fossil fuel prices, the growing risk of fossil fuel dependence, the high levels of GHG emissions, and the cost of alternative energy sources will ensure that wood for fuel remains in great demand at least for the next 20–30 years. Unlike other sources of domestic energy wood is easy to grow, harvest, and use with minimum technical and financial inputs as well as least reliance on outside agencies. Globally, the number of people dependent on biomass resources as their primary fuel are likely to increase to 2.7 billion in 2030 (Broadhead and Killmann 2008) with substantial increases in Asia and Africa. Since wood fuel will continue to be the main source of fuel in poor developing countries, the excess demand will be necessarily met from the trees standing on non-forest wood lands in order to buffer the impact on natural forests and defer the process of extinction.

A 'business as usual' scenario of rapid economic growth and industrialization may result in further environmental damage, and that most of the developing and underdeveloped regions may become more degraded, less forested, more polluted, and less ecologically diverse in the future (Srivastav 2019). Natural forests, in their present state of composition, productivity and extent, are in no position to meet the growing wood fuel demand and in the event of continuous extraction of wood for fuel, these forests will lose their naturalness and integrity.

Human development report of United Nations Development Program (UNDP) for the year 2016 (UNDP, HDR 2016) severely criticizes the pattern of global development that has taken place over the past three decades. The report mentions that while progress on human development front has been impressive and rapid strides have been made during the past three decades, but unfortunately the development has not been universally distributed across nations, societies, and ethnic group. There exist deep fissures in rural and urban areas, men and women, poor and rich. One of the focal areas of human development report is the HDI or Human Development Index which is based on three fundamental issues of human development, namely:

i. A long and healthy life which is measured by life expectancy at birth.
ii. Access to knowledge which is measured by average number of years of education received in a lifetime by people aged 25 years and older and access to learning and knowledge by expected years of schooling for children of school-entry age; and
iii. A decent standard of living measured by Gross National Income (GNI) per capita expressed in constant 2011 international dollars converted using purchasing power parity (PPP) conversion rates.

A new concept (*using both internal and external energy*) was introduced by UNDP during 2010 that was based on the deprivations suffered by households in education, health, and living standard (Fig. 1.5). Ten indicators were used to measure these three deprivations, and a cutoff at 33.3% was fixed in each case to distinguish between poor and non-poor. Of the ten indicators, education and health had two indicators each, whereas living standard had six indicators. In other words, if a household's deprivation score was 33.3% or higher, it was categorized as multidimensionally poor. Households with a deprivation score between 20 and 33.3% were categorized as living near multidimensional poverty. For the purpose of determining poverty, the report used India's data for the year 2005–2006 and concluded that 55.3% of India's population (642,391,000 people) was multidimensionally poor and another 18.2% (212,018,000 people) lived near multidimensional poverty.

A closer examination of the above indicators reveals that if a country has to improve its HDI ranking and index, it will necessarily have to ensure adequate energy supply to its citizens. The term energy in the context encompasses energy for internal growth of individual, that is derived from food, water, and air as well as for