Lecture - 3

Economics of Energy Supply

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Outline

- The Motivation
- Economics of Fossil Fuel Supply
- Economics of Renewable Energy Supply
- Economics of Electricity Supply

The Motivation

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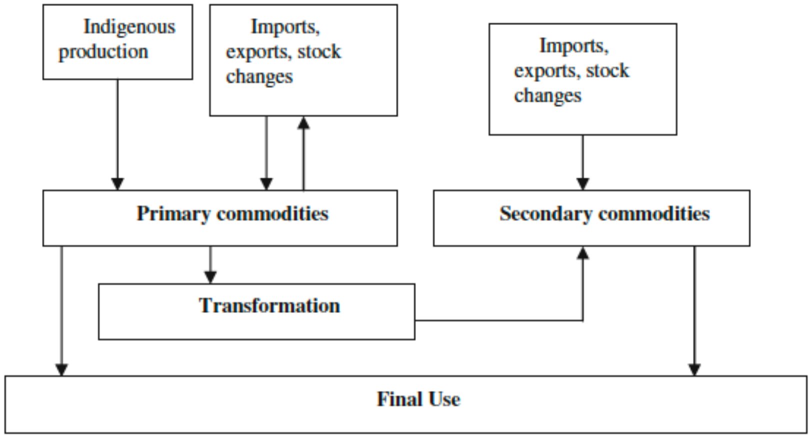
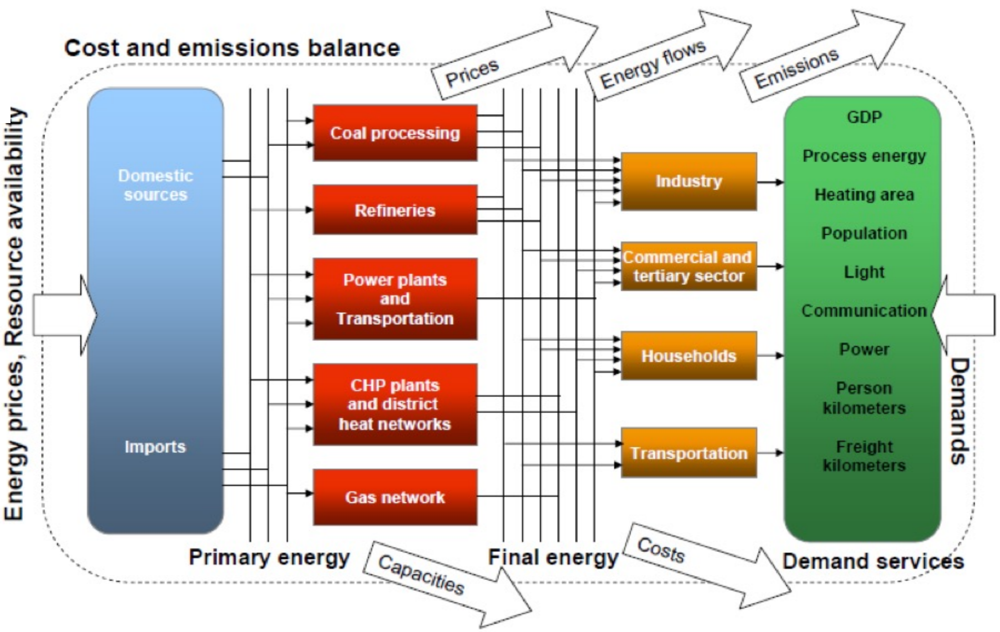
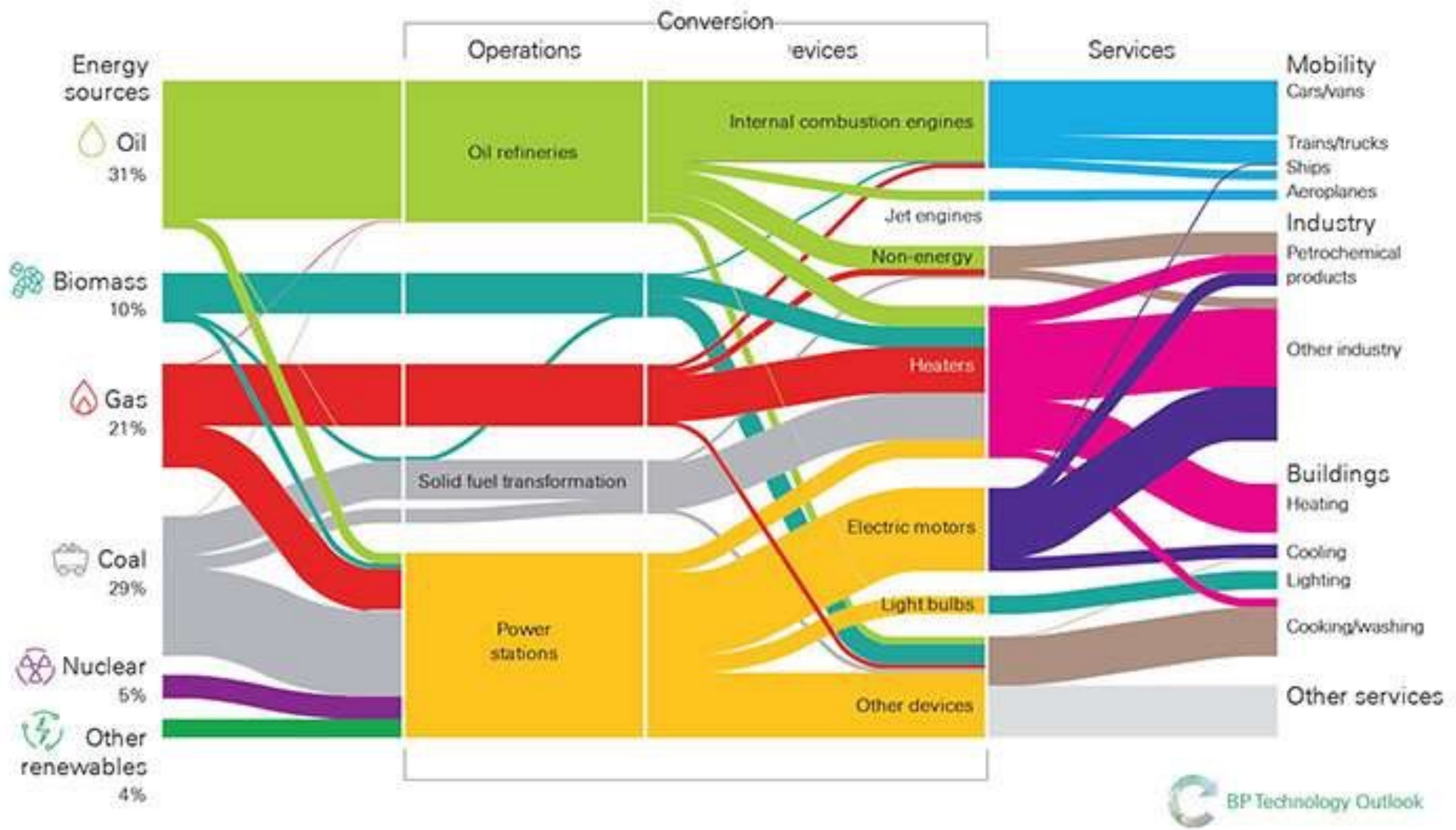


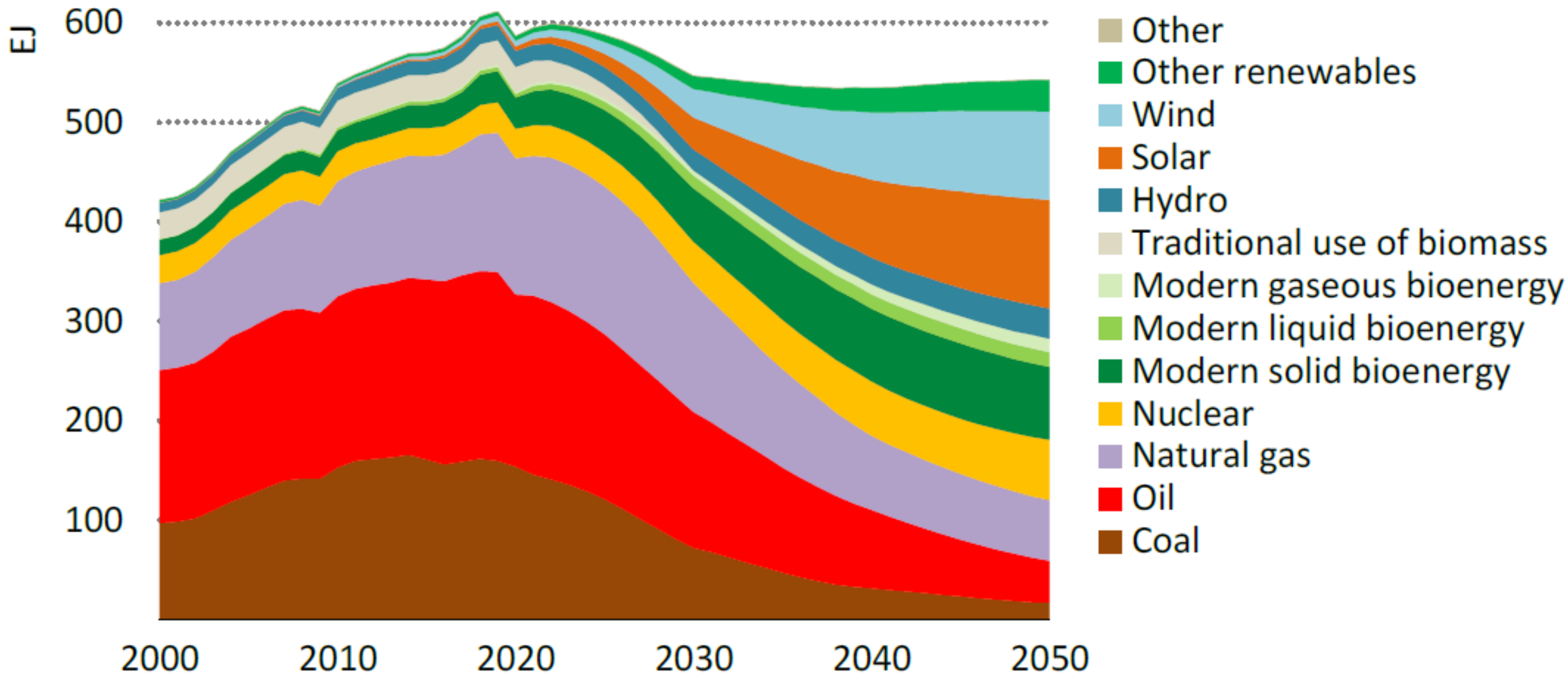


Source: Bhattacharyya, ETSAP

Energy Sankey diagram



Transformation of energy supply



Source: IEA

Main Characteristics of Energy Projects

- *Capital intensiveness*: Energy projects tend to be capital intensive as the initial investment requirement is often high.
- *Asset specificity*: The assets in the energy industry tend to have a high degree of specificity, implying they are less re-deployable in nature. This means that they do not have alternative uses other than their use in the energy sector. This specificity makes assets vulnerable to risks.
- *Long-life of assets*: Most energy investments live long; for example, a conventional power plan can easily operate for 25 years, a hydro power plant can live 50 years, even a diesel plant can operate for more than 10 years. As the life increases, the uncertainty about the future costs and benefits increases.
- *Long gestation period*: Energy projects take longer to build; for example a nuclear power plant can easily take 8–10 years to construct, a dam can also take such a long period, even relatively faster gas plants can take 2 years to build. Any changes in the business environment during the construction could jeopardize the investment. Similarly, it requires investment decisions to be made well in advance, so that the assets are brought into operation at the time of need. This requires that any investment decision has to be based on projected market conditions at a relatively long future date, making the decision making vulnerable.

Source: Bhattacharyya

Identification of Costs

In an economic analysis, care has to be taken about the certain costs. Normally those costs which impose additional cost burdens are considered in the economic analysis.

- *Sunk costs*: If a project uses already existing facilities, for which investments have already been made (i.e. sunk), the economic analysis would exclude these costs as they do not represent any additional costs for the project. These existing facilities would exist even without the project and hence they impose no extra burden to the project.
- *Contingencies*: The part of the contingency that represent additional claims on resources for the project would be included in the economic analysis. As the economic costs are measured in constant price terms (as opposed to nominal terms in financial calculations), the price-related contingencies are not included in the economic analysis.
- *Working capital*: The same logic for contingencies applies here. For economic analysis, the costs that represent real claim on national economic resources would qualify for inclusion. Any transfer payments would have to be excluded.
- *Transfer payments*: These are payments which ''transfer command over resources from one party to another without reducing or increasing the amount of resources available as a whole'' (ADB 1997). Examples include taxes, duties and subsidies which in most circumstances would be considered as transfer payments. As they do not put any addition claim on the resources, they are not considered in economic analysis. However, taxes (duties and subsidies) would be included in the price if the demand for inputs is non-incremental, or if the output is incremental or if the government tries to internalize externalities through the tax.
- *Depreciation*: The economic analysis uses the initial cost of an asset less the residual value (discounted). This fully reflects the cost of using an asset and does not pay any attention to the funding of the resource and its repayment. Accordingly, depreciation is not considered in the economic analysis.
- *Depletion premium*: For non-renewable resources, the economic analysis includes the depletion rent to reflect the economic cost to the society of using such resources. The opportunity cost of the resource includes the cost of substitutes at the time of exhaustion.
- *External costs*: As energy projects often generate externalities the cost of which are not borne by the users but the society as a whole, the economic analysis includes such external costs to arrive at the full economic costs of using the outputs. An economic analysis is incomplete without taking this into account.

Source: Bhattacharyya

Box 7.1: Cost Concepts

Cost has different meanings in different settings.

Historical costs: Costs recorded in the books of accounts can provide some idea about the cost under similar circumstances but this should not be relied on unquestioningly. The financial analysis uses this cost.

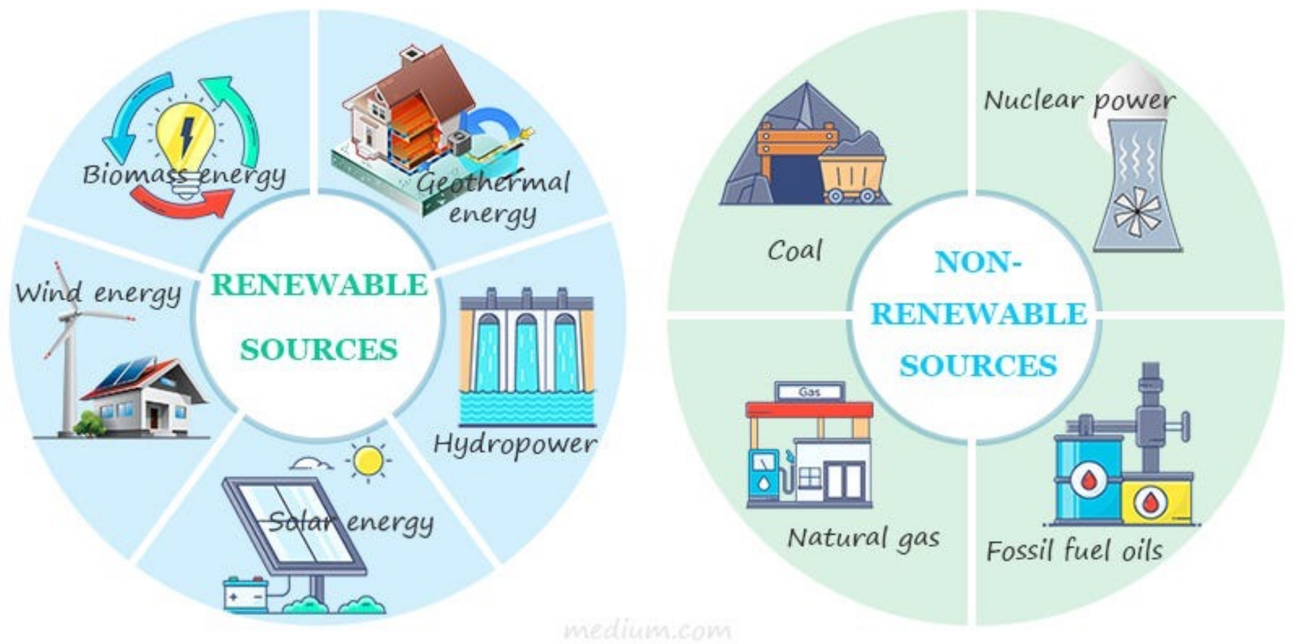
Future or replacement costs: The cost expected in the future to replace a given asset can be significantly different from historical costs. This is the cost to be paid to rebuild the asset at a future date.

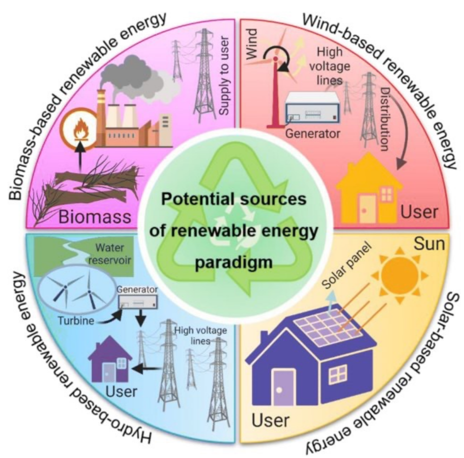
Opportunity costs: Is the value of the foregone benefits; the cost of using a resource is the benefit lost for not having it available for an alternative use. For example, if crude oil is used in the domestic market, the same quantity is not available for exports. Thus an opportunity to earn in foreign currency is foregone. This is a measure of the maximum benefit that can be obtained from an alternative use. This is the appropriate measure of cost of a resource for economic analysis of alternatives but opportunity costs can be hard to estimate.

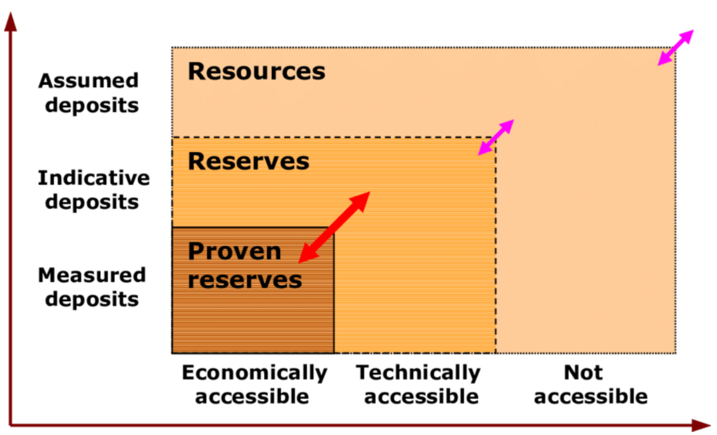
Marginal cost: Is the change in cost for a small change in the output. In mathematical terms, $\mathrm{MC} = \partial C/\partial q$, where MC = marginal cost, C = total cost, and q = output. If total cost is composed of a fixed part F and a variable part v such that $C = F + v \cdot q$, the marginal cost is equal to v.

Source: Bhattacharyya

SOURCES OF ENERGY







Main factors for energy technology choice

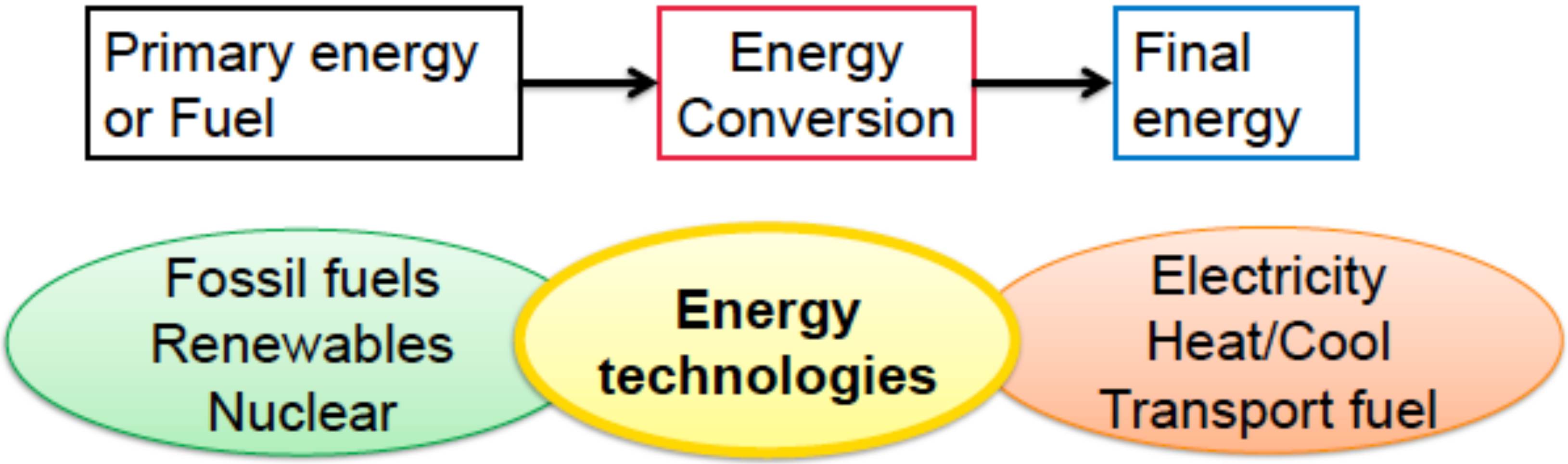
- Energy sources: the price and availability of energy carriers on international, national and regional energy markets, and the availability and cost of extraction of energy carriers from natural resources within the system boundaries;

- Useful energy demand: demand for energy services in different sectors and different geographical regions of the community;

- Technological progress: new, or improved technologies, for conversion and energy conservation, become available as new options for the system; and

- Physical environment: physical constraints on the use of technologies such as availability of natural heat sinks or heat sources, the use of solar radiation. It also includes the environmental regulations e.g. emission restrictions on individual plants, or on parts of the energy system, or on the entire system.

Energy conversion technologies



Rule: 50H/30E/20T

Final Energy or Power Output from the Energy Conversion device:

$P = \eta \times F$; η = efficiency, F= ’fuel’

$\eta(\underline{X})$, $\underline{X}$= technical parameters

Energy technologies

Primary Energy Sources:

- Light Crude
- Heavy Oil
- Tar Sands
- Wet gas
- CBM
- Tight gas
- Nuclear
- Coal
- Solar
- Wind
- Biomass
- Hydro
- Geothermal

Extraction & Conversion Technologies:

- Exploration
- Deeper water
- Arctic
- LNG
- Refining
- Differentiated fuels
- Advantaged chemicals
- Gasification
- Syngas conversion
- Power generation
- Photovoltaics
- Bio-enzyimatics
- H_2 production & distribution
- CO_2 capture & storage

End Use Technologies:

- ICEs
- Adv. Batteries
- Hybridisation
- Fuel cells
- Hydrogen storage
- Gas turbines
- Building efficiency
- Urban infrastructure
- Systems design
- Other efficiency technologies
- Appliances
- Retail technologies

Economics of Fossil Fuels Supply

Non-renewable sources

Nonrenewable energy sources are those that do not regenerate through natural processes, at least on a human time scale. We consider four nonrenewable energy sources in this section:

1) Oil
2) Coal
3) Natural gas
4) Nuclear energy

The first three energy sources are fossil fuels, formed from the fossilized remains of plants and animals that lived millions of years ago. As these energy sources are nonrenewable, one issue to consider is the availability of supplies. Is running out of any of these sources a significant concern?

We also need to consider the environmental impacts of relying on these sources. Average prices, along with the volatility of prices, is another important factor to consider when evaluating different energy sources.

Source: Brian and Harris. 2021

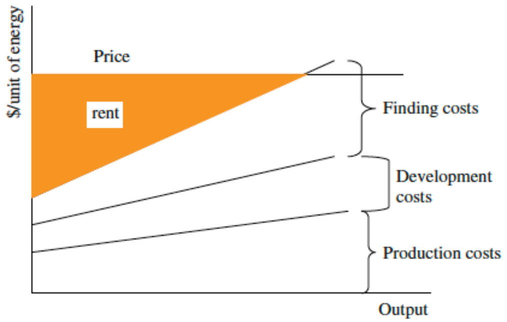
Resource rent

In the energy industry, four types of differential rents are found:

- mining rent due to geological conditions: those fields which could be exploited relatively cheaply compared to others located in difficult geological areas,
- technological rent: this arises due to use of a more efficient technology that reduces the costs of production;
- positional rent: proximity to markets offers added benefits to producers by reducing the cost of transports and related infrastructure
- quality rent: arises due to a favourable chemical or physical characteristics of a fuel. For example, sweet crude oil attracts a premium over the sour crude. Light crude is sold at a premium over the heavy crude oil.

In addition, rents may arise due to a non-competitive market structure (such as monopoly rent due to a monopoly market), scarcity of the resource (discussed in the next chapter) or in some cases due to changes in the market conditions or innovative practices of the firm (known as quasi-rent).

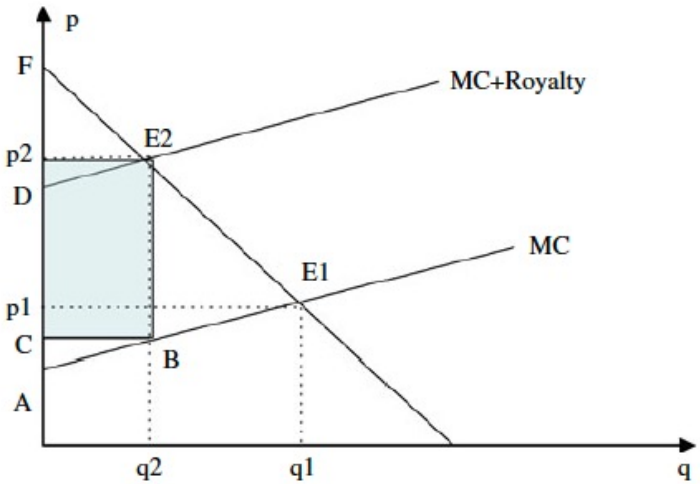
Fig. 8.14 Rent in non-renewable energy exploitation. *Source* Kemp (1992)



Source: Bhattacharyya

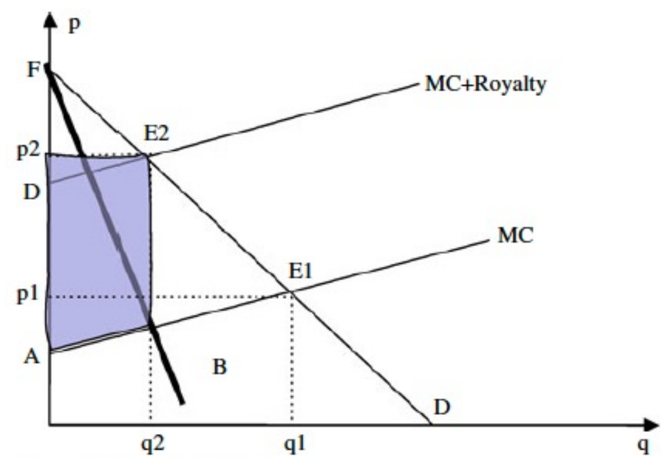
Effect of royalty and monopoly

Fig. 8.15 Effect of royalty



Case 1: Imposition of Royalty

Fig. 8.16 Nationalisation as a possible method of rent capture



Case 2: Monopoly pricing

Source: Bhattacharyya

Classic Hotelling Theory: The Timing Decision

- Suppose you own a well containing exactly 1,000 barrels of oil. Each barrel can be produced for \$30. You have complete flexibility as to when to produce the oil. Currently the price of oil is \$80 per barrel.
- If you knew future oil prices, how would you decide <u>when</u> to produce your oil?
  - Pick *t* (or *t*s) to max discounted net revenue: $(P_t - MC)/(1 + R)^t$
- If *all* the oil in the world is produced from oil wells *exactly* like yours, what will happen to the <u>price</u> of oil?
  - $(P_t - MC)/(1 + R)^t = (P_0 - MC) > 0$; $(P - MC)$ rises at interest rate
  - If LHS < RHS, raise output today, which lowers today's price…
  - Note: P > MC despite competition; today's output lowers later revenue; there is an <u>opportunity cost</u> of producing today

Source: MIT

Classic (Hotelling) Theory II

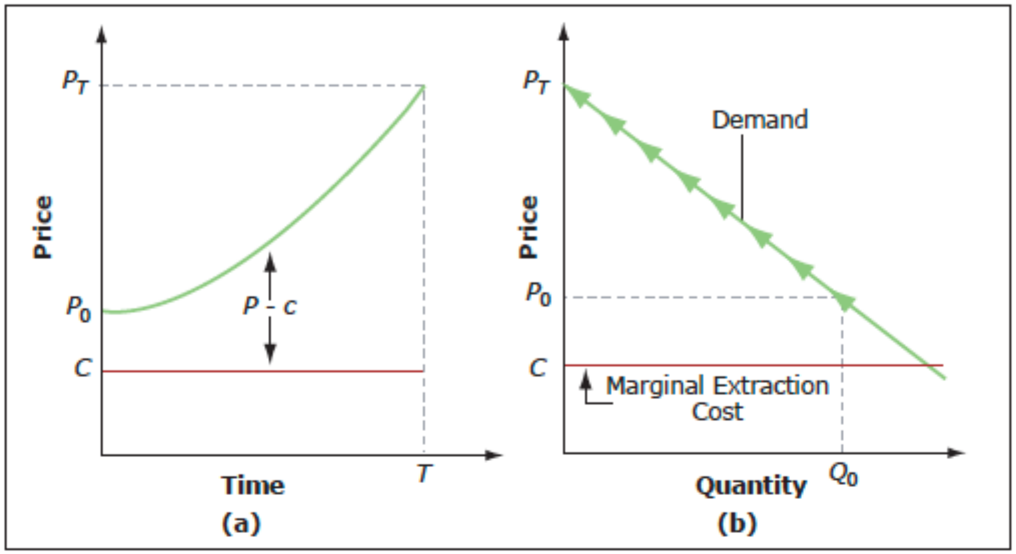


Image by MIT OpenCourseWare.

- Under those assumptions, when should you produce your oil?
  - Doesn't matter
- What if a monopoly has 99.5% of all oil, MC = $30?
  - (MR – MC) rises at rate R; P typically rises more slowly, so produce NOW

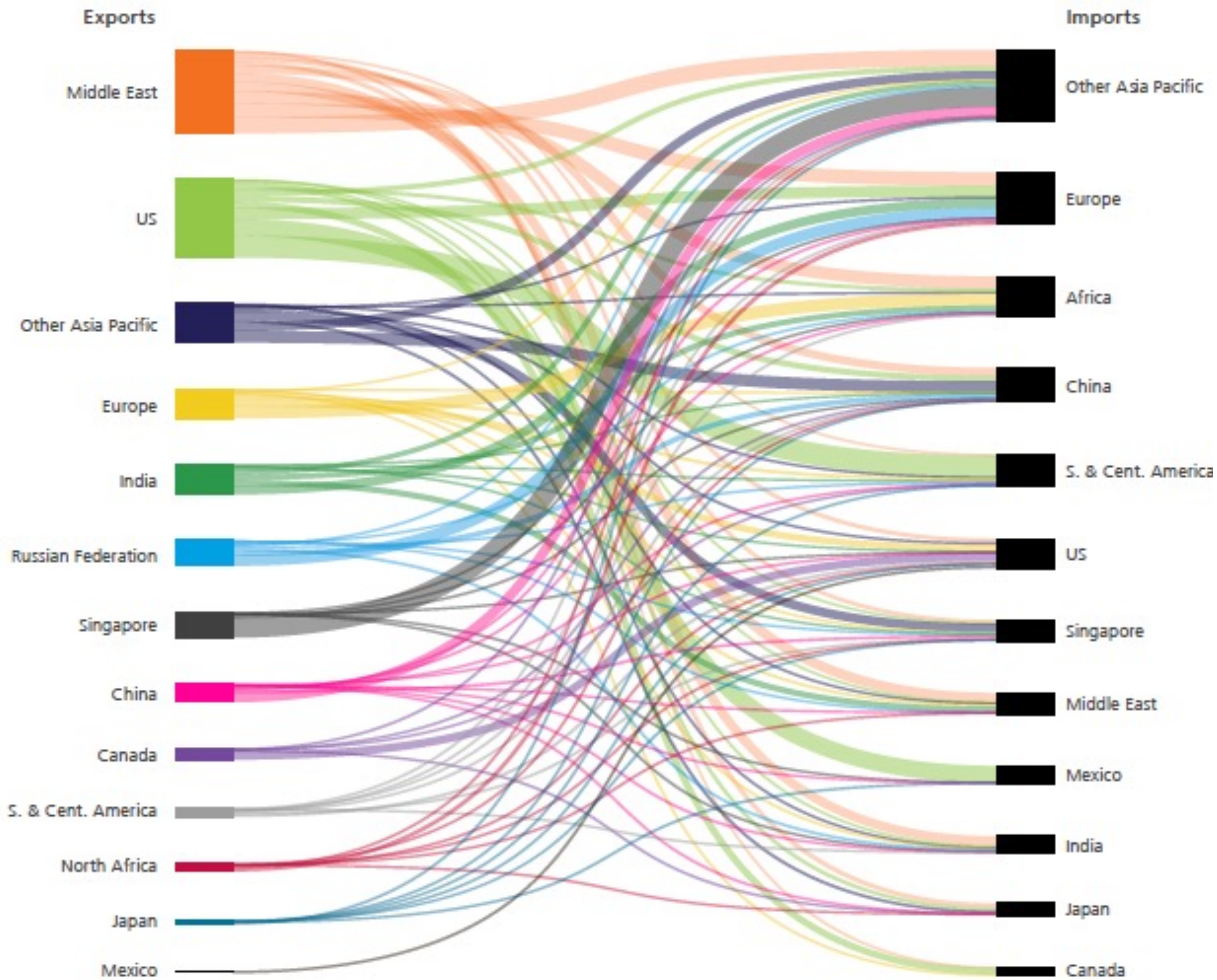
Source: MIT

What’s Missing from the Classic Theory?

- Exploration: Reserves are an *inventory*; decisions to search, to prove, & to drill are intertemporal choices, like classic model.
  - End 1976 to end 2009, US proved reserves ↓ 10.26 B bbl.; production?
  - Production during that period was 78.45 B bbl.
- Depletion: Costs of finding, extracting likely to rise as more is produced from any given area (e.g., US).
- Innovation: Technologies for finding, extracting improve over time – a race with depletion.
- Uncertainty: Future demand, supply are not known.
- SR Inflexibility: Simple model over-states flexibility in output choice – little SR supply flex for oil + inelastic demand ⇒ SR P volatility.
- Cartel Behavior: OPEC behavior is complicated
- Politics: Why else drill miles deep, miles offshore when it is much cheaper to produce in the Middle East?

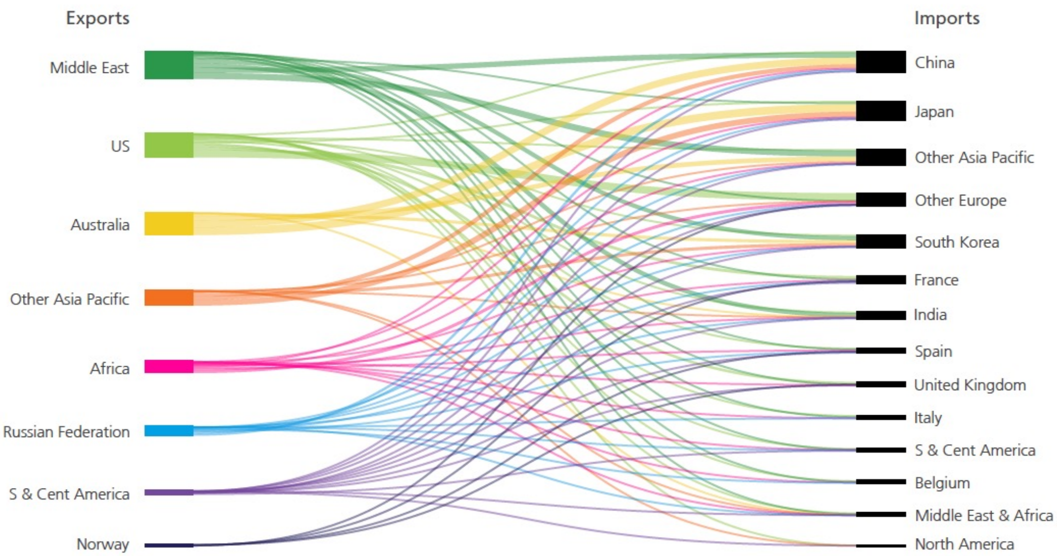
Source: MIT

World oil trade

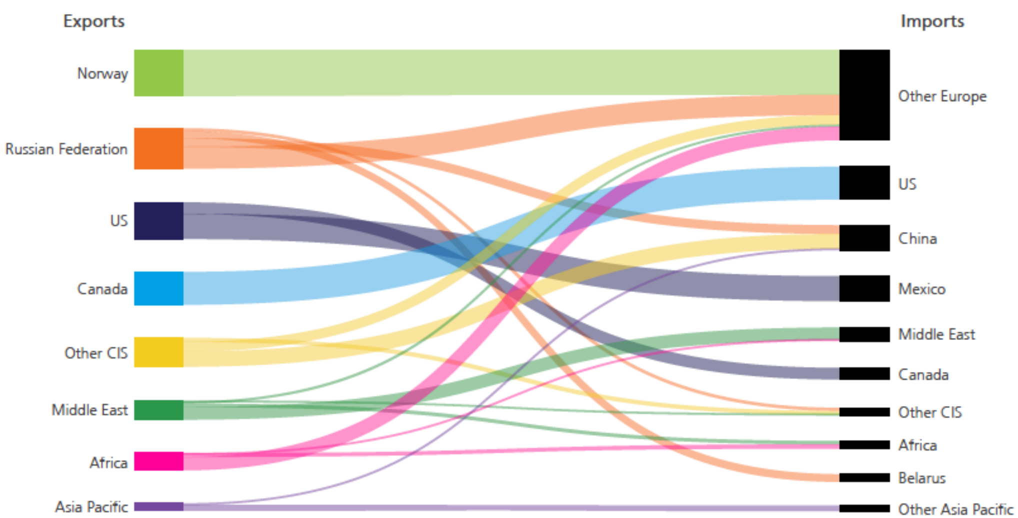


Source: Energy Institute

World LNG and NG pipeline trades



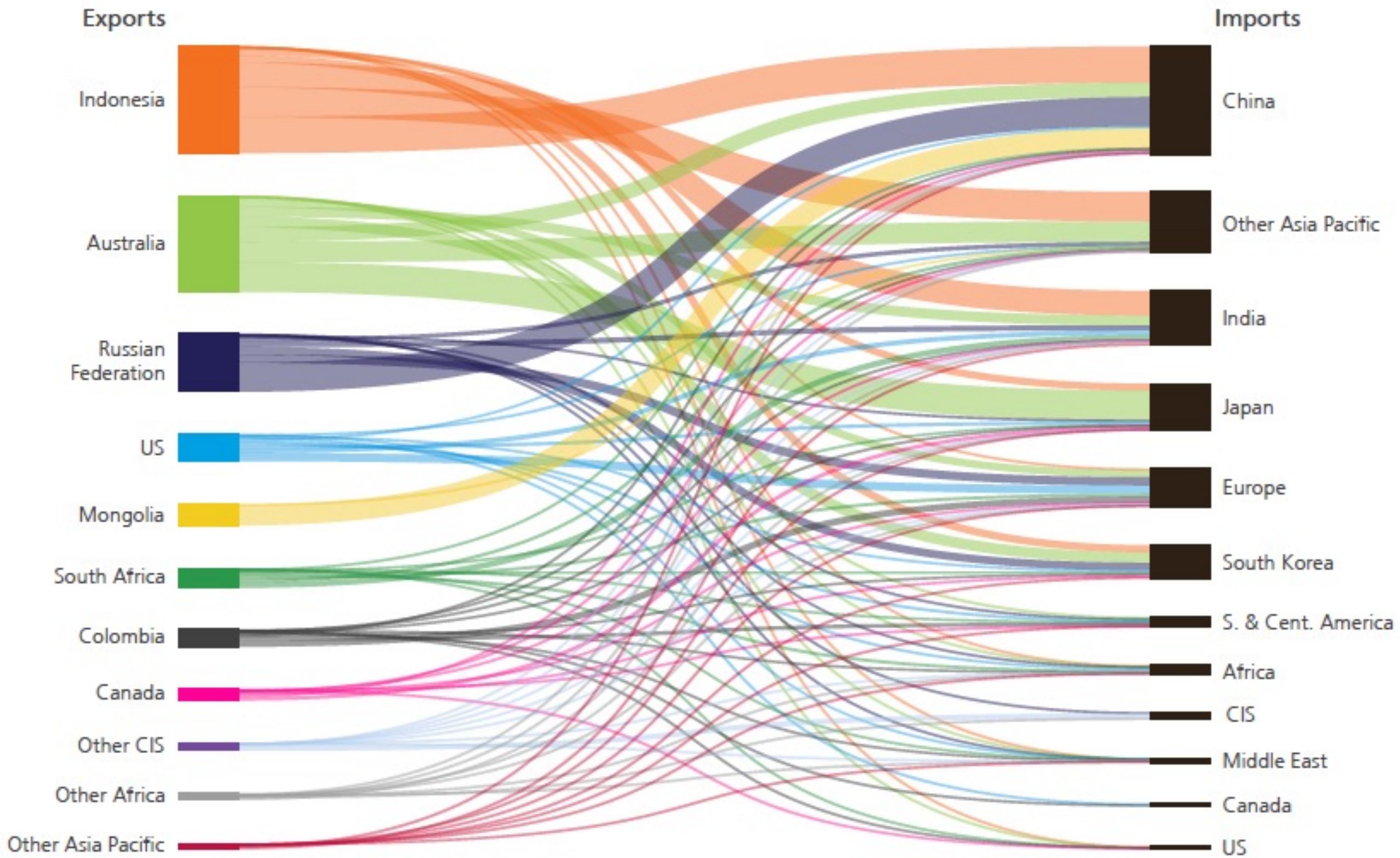
Notes: As far as possible, the data above represents standard cubic metres (measured at 15ºC and 1013 mbar) and has been standardised using a gross calorific value (GCV) of 40 MJ/m³.



Notes: As far as possible, the data above represents standard cubic metres (measured at 15ºC and 1013 mbar) and has been standardised using a gross calorific value (GCV) of 40 MJ/m³.
Source: Includes data from FGE MENA gas service, IHS.

Source: Energy Institute

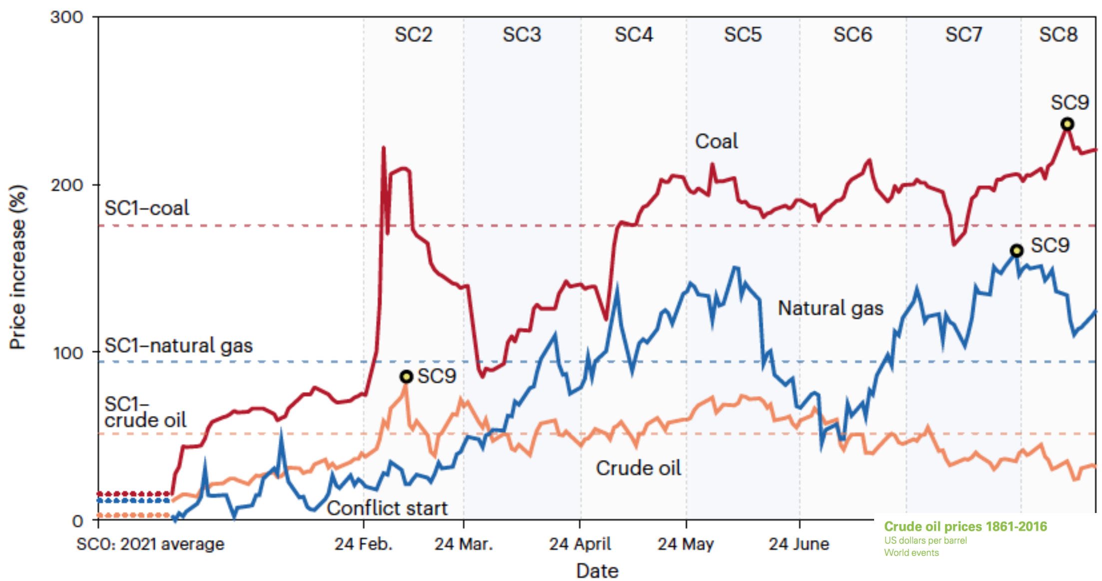
World coal trade

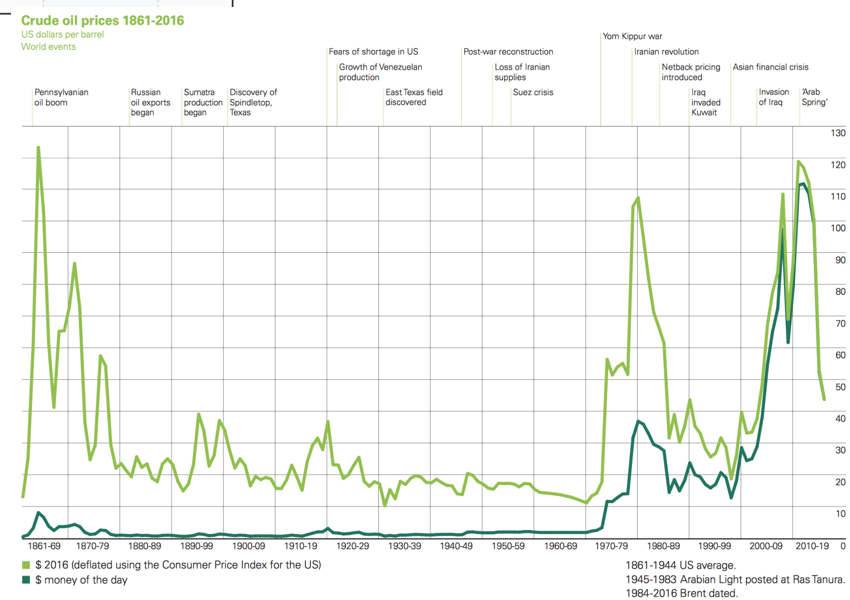


Notes: Commercial solid fuels only, i.e. bituminous coal and anthracite (hard coal), and lignite and brown (sub-bituminous) coal, and other commercial solid fuels. Intra-area movements (for example, between countries in Europe) are excluded.

Source: Energy Institute

Fossil prices





Economics of Renewable Energy Supply

Renewable energy resources

- In one sense, renewable energy is unlimited, as supplies are continually replenished through natural processes. Most renewable energy is ultimately solar energy. The sun's energy can be used directly for heat or electricity.
- Hydropower comes from falling water, which occurs because solar energy evaporates water at low elevations that later rains on high elevations. The sun also creates wind through differential heating of the earth's surface.
- Biomass energy comes from plant matter, produced in photosynthesis driven by the sun. Thus biomass, wind, and hydropower are just secondary sources of solar energy.
- Geothermal resource ~ Oil and Gas

Source: Bhattacharyya

Drivers of Renewable Energy

- *Reduction in CO2 emission and mitigation of climate change*: This is the main driver of renewable energy at present. The concentration of greenhouse gases (GHG) is increasing due to fossil fuel dependence of modern economies.It is believed that the increasing concentration of GHGs has led to warming ofour climate. It is forecast that without any mitigation action, the CO2 concentration in the atmosphere would double the present level by 2050. Renewable energies being carbon free (or neutral) would help reduce the GHGconcentration.
- *Security of energy supply*: Security of energy supply has made a come-back in recent years. This is attributed to recent increases in fossil fuel prices in general and oil prices in particular; concerns for depletion of fossil fuels globally and imminent production decline in the US and UK, and consequent increase in import dependence; increasing competition for supply from emerging consuming countries; political instability in the hydrocarbon resource rich areas; and high economic impacts of energy supply disruption in the developed and rapidly developing countries. As fuel diversification is considered as an important strategy for ensuring supply security, developing alternative energies from locally available resources can reduce import dependence and accordingly, renewable energies are being viewed favourably from this perspective.
- *Improving energy access*: It is now believed that more than 2 billion population worldwide do not have access to clean energies. The problem is more acute in rural areas of poor countries where the supply system may be inexistent. To ensure sustainable development, it is essential to provide clean energy to these people. Renewable energies offer certain advantages in this respect—they reduce environmental and health damages, and save time in fuel collection and improve working conditions. These changes can in turn provide better opportunities for income and reduce poverty.
- *Employment opportunities*: Renewable energy supply has the potential for employment generation, directly due to decentralised, modular structure of the technologies and local level operation of the systems. And indirectly through improved working conditions or saving in time which would otherwise be used in drudgery.
- *Other spill-over effects*: Reliance on renewable energies would help improve macro-economic stability. The logic goes as follows: (1) Promotion of renewable energies reduces import dependence; (2) fossil fuel import being the important constituent of the international trade of importing countries, a switch over to the renewable energies is expected to reduce the trade balance; (3) this in turn reduces the possibility of economic shocks due to external factors.

Source: Bhattacharyya

Share RE by region

Fig. 11.1 Regional distribution of renewable energy use in 2007. *Data source* IEA (2009)

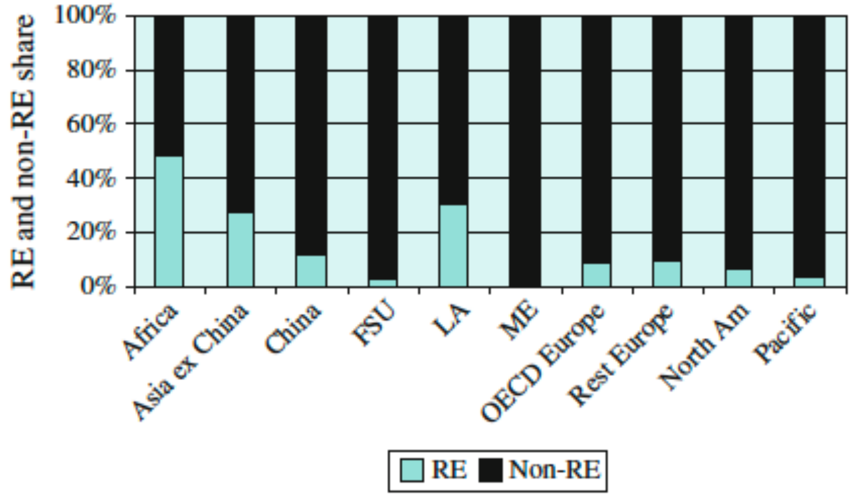
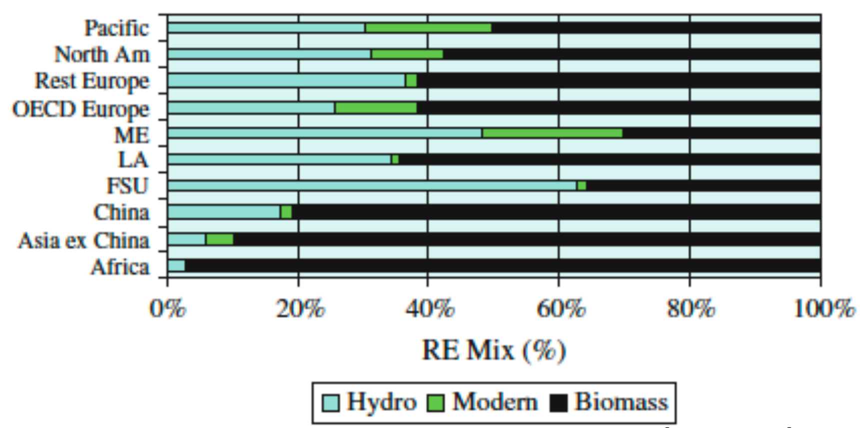


Fig. 11.2 Renewable energy use by type in 2007. *Source* Based on IEA (2009) data



Source: Bhattacharyya

Renewable energy carriers

- Electricity
- Bioenergy, liquid biofuels
- Biohydrogen
- Biomethane

Source: Bhattacharyya

Mode of operation

The load duration curve has significance for plant operation, cost of service and system efficiency. As electricity cannot be stored in significant quantities at low cost, the demand has to be met by modulating the supply to match the demand. Therefore, for smooth system operation, three types of plants (or technologies) are required:

- Those which would be running around the year—all the time they are available— to meet the base demand; these plants normally do not have the capability to vary the supply depending on the demand;
- Another set of plant is required having the capability to follow the demand and vary output frequently during their operation;
- Finally, a third set of plant is required which are suitable for running only during the peak period.

Source: Bhattacharyya

Electricity load

Fig. 10.2 Example of a daily load curve

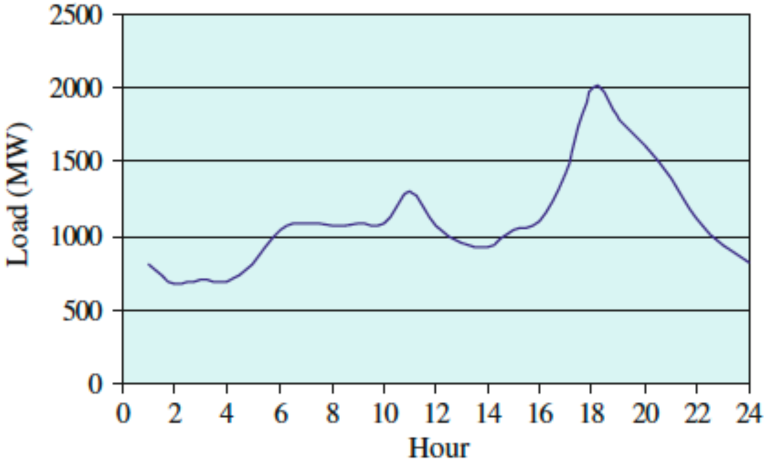
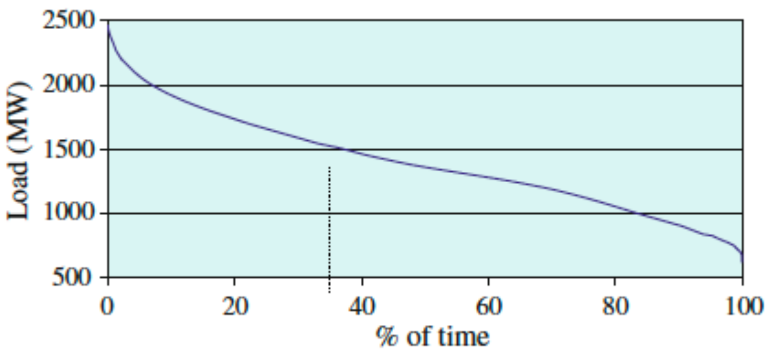


Fig. 10.3 Example of a load duration curve



Source: Bhattacharyya

Renewable electricity

Electricity from renewable resources has a number of technical features:

- most common forms of renewable energies (such as solar, wind or tidal) are intermittent in nature (i.e. they are not available all the time), and
- given that electricity cannot be stored in large quantities in a cost effective manner, these energies have to be used when they are available.

As a result of intermittency, a number of issues arise.

- ✓ Electricity generated from such sources cannot be dispatched following the merit-order dispatch schedule. They have to be used whenever the electricity is available. However, through better forecasting of weather conditions, more accurate assessment of local level generation can be made.
- ✓ As a consequence of the above, the capacity is used only for a limited time, leading to low capacity utilization. it is noted that the average utilization of solar PV systems is less than 10% in Europe, while the average wind capacity utilization is about 20%.
- ✓ Consequently, such systems cannot provide reliable supplies round the clock and will require back-up capacity (or standby capacity). The standby capacity often relies on non-renewable energies and therefore, the benefits of renewable energies are not available. The standby capacity also increases the cost ofsupply.

Source: Bhattacharyya