Lecture 8

Electricity markets

- Energy Demand

Defining energy demand

- It is hard to believe that anybody really wants to consume electricity, natural gas, gasoline, or coal directly; doing so would be unpleasant at best and fatal at worst.

- The demand for energy is, rather, derived from the demand for services it is used to produce.
  - Gasoline, vehicles, and labor are the main inputs into the production of transportation services, for instance.
  - Some residential demand for electricity is derived from the demand for food preparation.
  - Commercial demand for electricity is largely derived from demands for heat, light, cooling, and, increasingly, computation; and these are ultimately derived from demand for firms' outputs.

Defining energy demand

- Demand for energy is derived from wishes to use energy to obtain desired services. It is not derived from preferences for the energy commodity itself. Energy demand depends on demand for desired services, availability and properties of energy conversion technologies, and costs of energy and technologies used for conversion.

- Thus, “energy demand” is defined differently by different users.
- Examples: Gasoline is used to fuel automobiles, converting gasoline to mechanical energy for motive power. The amount of gasoline used is proportional to the miles the auto is driven and inversely proportionate to the efficiency by which gasoline is converted to useful mechanical energy, measured as miles per gallon (M/g) of gasoline of the automobile. Demand for gasoline is thus derived from choices about distances vehicles are driven and their energy conversion efficiencies.
- Electricity is used for lighting, refrigeration, space heating, air conditioning, drying, washing, dish washing, water heating, operating electronic equipment such as computers or televisions. Electrical energy is converted to mechanical energy (motors in refrigerators, air-conditioning units, etc), thermal energy (space heating, clothes dryers, water heating), or radiation (lighting, television, computer monitors.) Electricity demand is derived from demand for the underlying services – comfortable space, refrigeration, cleaning, entertainment, information processing.

Defining energy demand

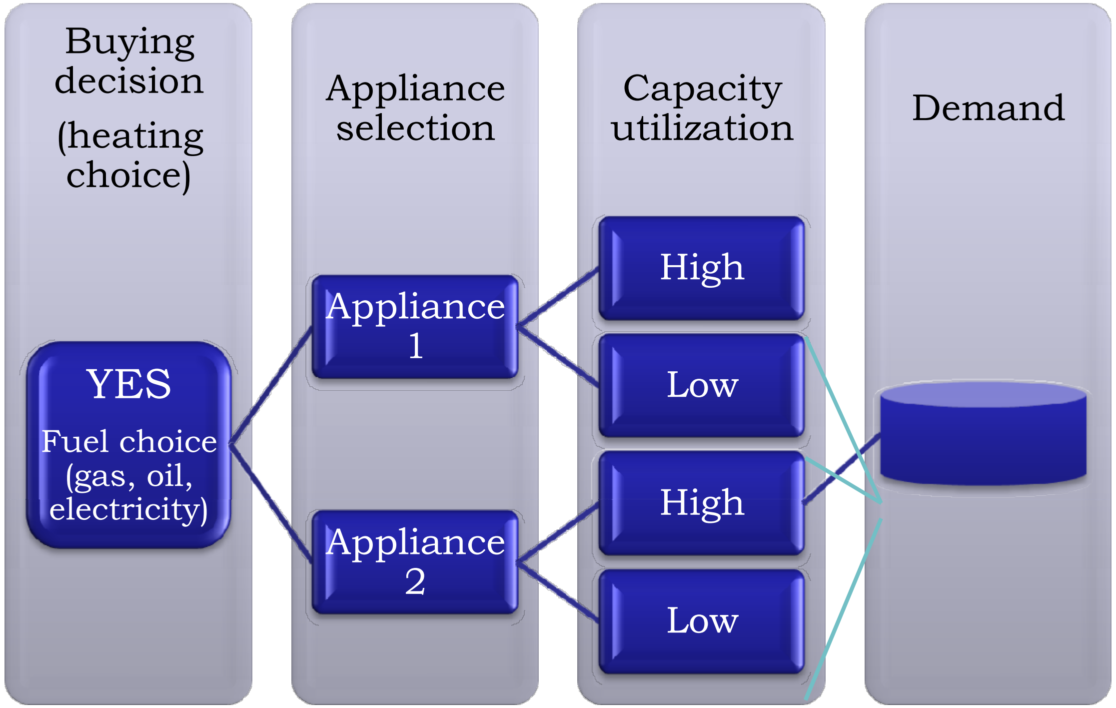
- Therefore, efficiency of energy conversion equipment is very important determinant of energy demand.

- An important consequence is that --to the extent that consumers and firms purchase these units with an understanding of their conversion efficiencies-- expectations of future energy prices can influence choices of particular equipment.
  - For example, high oil and natural gas prices can motivate consumers to invest in home insulation.

- In general, increased energy prices reduce demand by reducing use of energy services and motivating selection of higher conversion efficiency equipment.
  - For example, gasoline prices influence demand through vehicle miles and fuel efficiency of vehicles.

Energy Demand Decisions

- Three-stage decision-making process



- The three-stage decision process influences:

access to energy services, market growth potential in a particular service or use, path dependence, responsiveness in the short run, reaction response, and consumer’s usage behavior.

Demand substitution among energy commodities

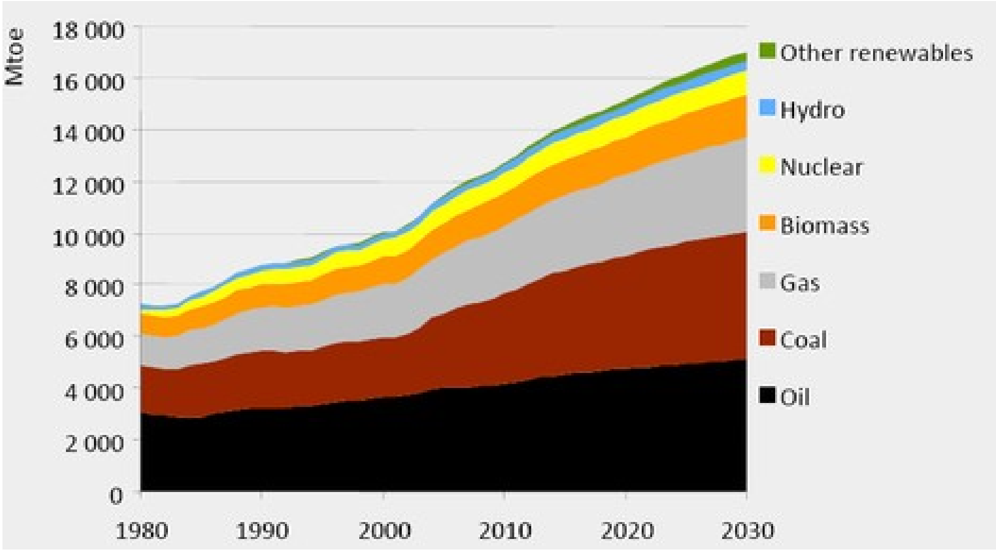
- Some energy services can be provided by several different energy commodities.
  - In the previous example, homes could be heated using electricity, natural gas, oil, or wood, since each can be converted to thermal energy. Cooking could use electricity, natural gas, propane, wood, or charcoal.

- Thus, energy commodities are substitutes: the demand for a particular energy commodity is affected by (is an increasing function of) prices of other energy commodities
  - Energy substitutability depends upon the available set of energy conversion technologies. Because conversion equipment typically is very long lived, substitution among energy commodities occurs only slowly, and then when new equipment is purchased.
  - Energy commodities are imperfect substitutes for one another, with much greater substitutability in the long run than in the short run.

Global demand data

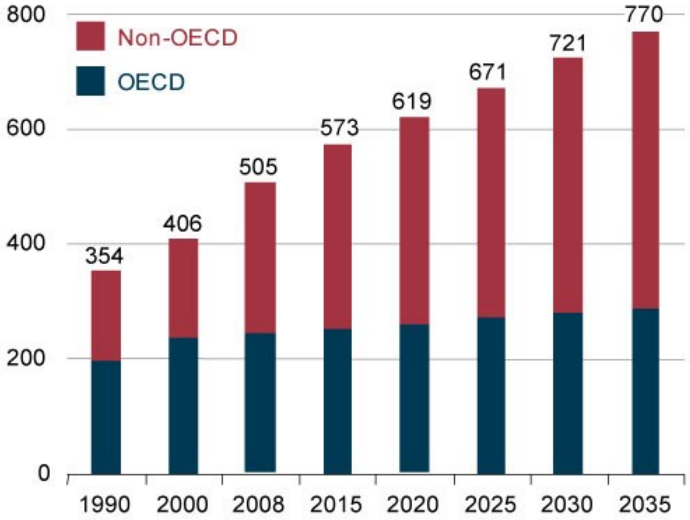
The WEO-2008 Reference Scenario assumes no new government policies, and shows that world primary energy demand grows by 1.6% per year on average between 2006 and 2030—an increase of 45%. This is slower than projected in 2007, mainly due to the impact of the economic slowdown, prospects for higher energy prices and some new policy initiatives.
One truly shocking statistic, bearing in mind that 500 ppm is considered the point of no return, is the projected rise in greenhouse gas emissions if there is no change in government policies. It is predicted that they will rise to an atmospheric concentration of around 1.000 ppm of CO_2-equivalent by the end of this century. This would lead to an eventual global temperature increase of up to 6° C.

WEO-2008 Reference Scenario



IEO2011 Reference Scenario

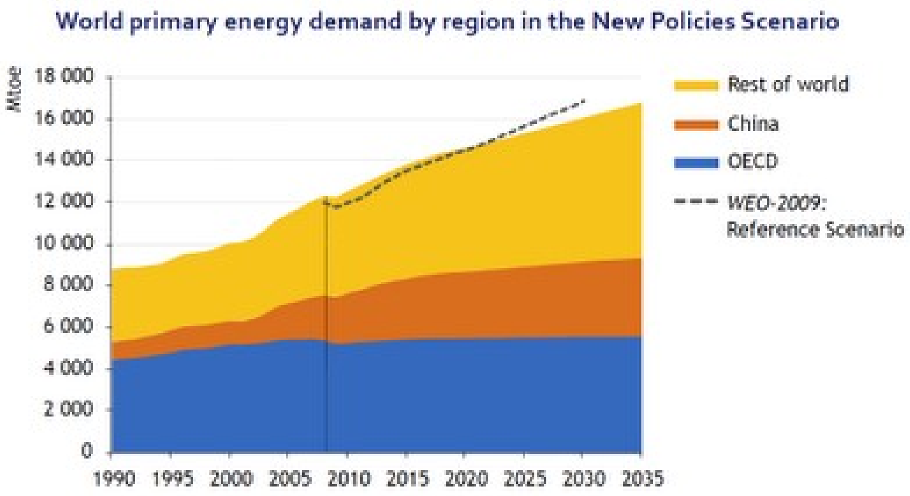
Figure 1. World energy consumption, 1990-2035
(quadrillion Btu)



U.S. Energy Information Administration, International Energy Outlook 2011

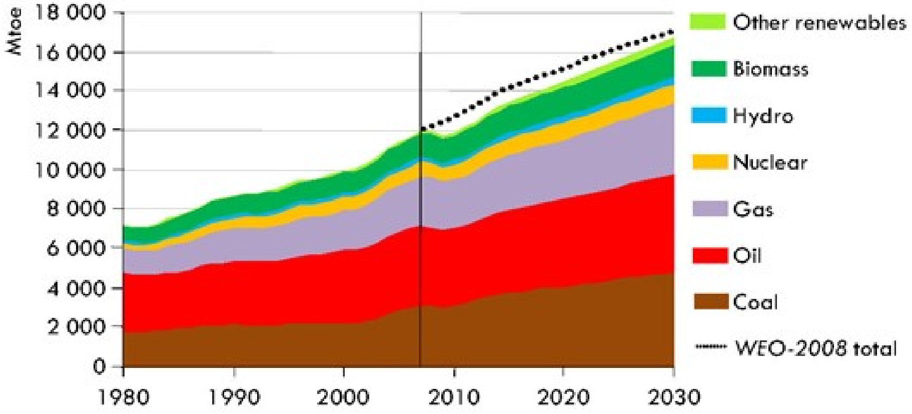
Global demand data (new policies scenario)

- The WEO New Policies Scenario takes into account the broad policy commitments and plans that have been announced by countries around the world, including measures and policies to reduce GGH, subsidies, etc. even those that have not been implemented yet.
  - Demand increases by 36% (2008-35) --a 1.2%/y compared to the 2%/y over the last 27 years-- mostly in the Rest of the World.
  - Coal use is rising the most in absolute terms



World primary energy demand by region in the New Policies Scenario

IEA, World Energy Outlook 2010

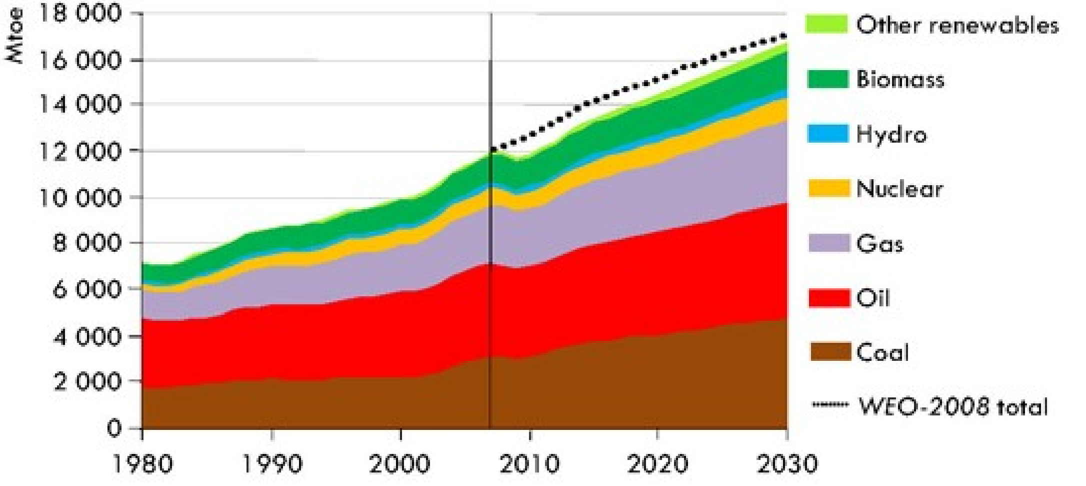


IEA, World Energy Outlook 2009

Global demand data (450 Scenario)

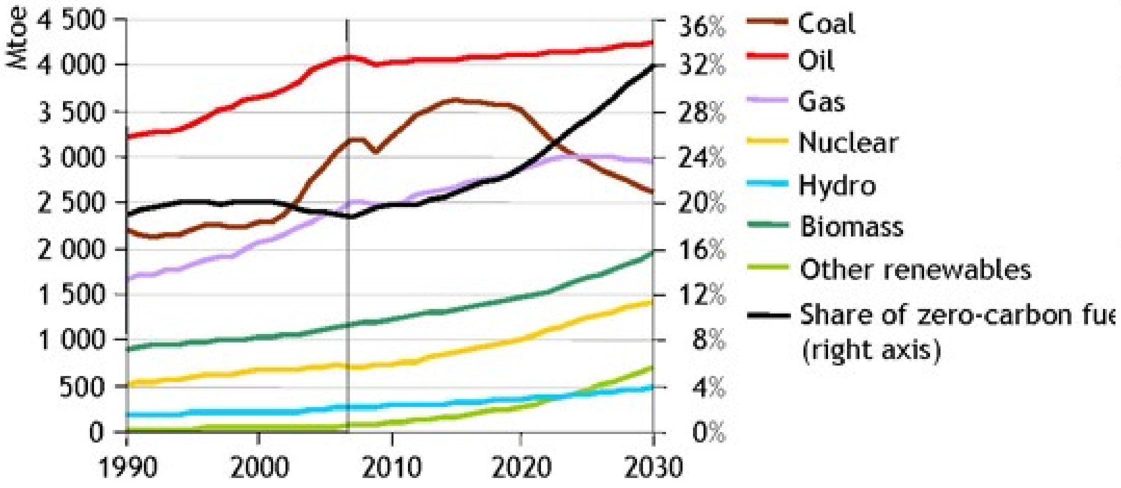
In the 450 (450ppm of $C0_2$ eq) Scenario, energy related emissions peak in 2020, together with global demand for fossil fuels and our use of renewables climbs steadily.
Energy demand increases but only at an annual rate of 0.7%

what we *will* do?



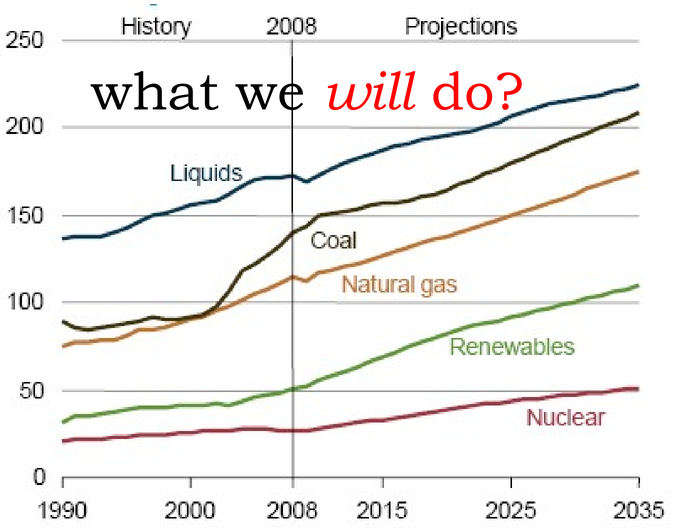
IEA, World Energy Outlook 2009

what we *should* do



IEA, World Energy Outlook 2009

what we *will* do?



World energy consumption by fuel, 1990-2035 (quadrillion Btu)
U.S. EIA, IEO 2011

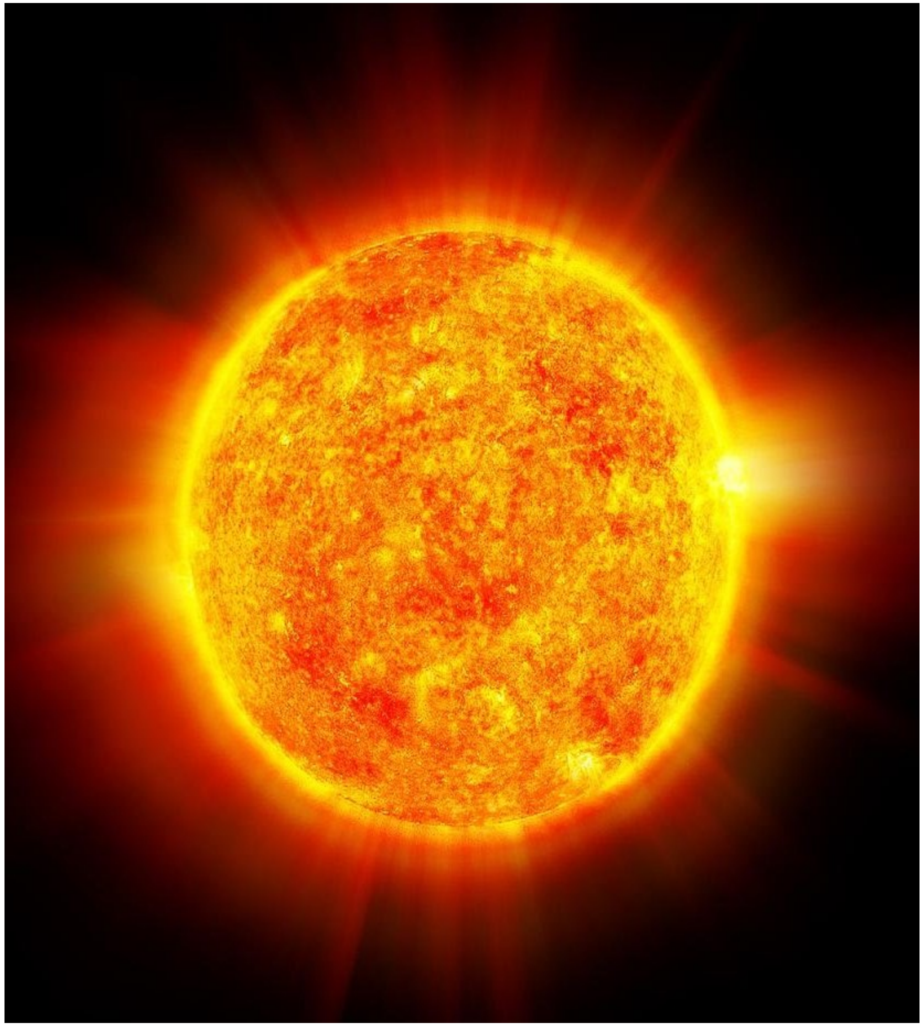
- Energy Supply

The sun and energy supply

- The energy of the **sun** is the original source of most of the energy found on earth.

- We get solar heat energy from the sun, and sunlight can also be used to produce electricity from **solar** (photovoltaic) cells. The sun heats the earth's surface and the air above it, causing **wind**.
- Water evaporated by the sun forms clouds and rain to give us flowing streams and rivers. Both wind and flowing water (**hydropower**) are sources of energy.
- These kinds of energy are all around us all the time, they are produced quickly, and replace themselves constantly as we use them. For this reason we say they are **renewable.**

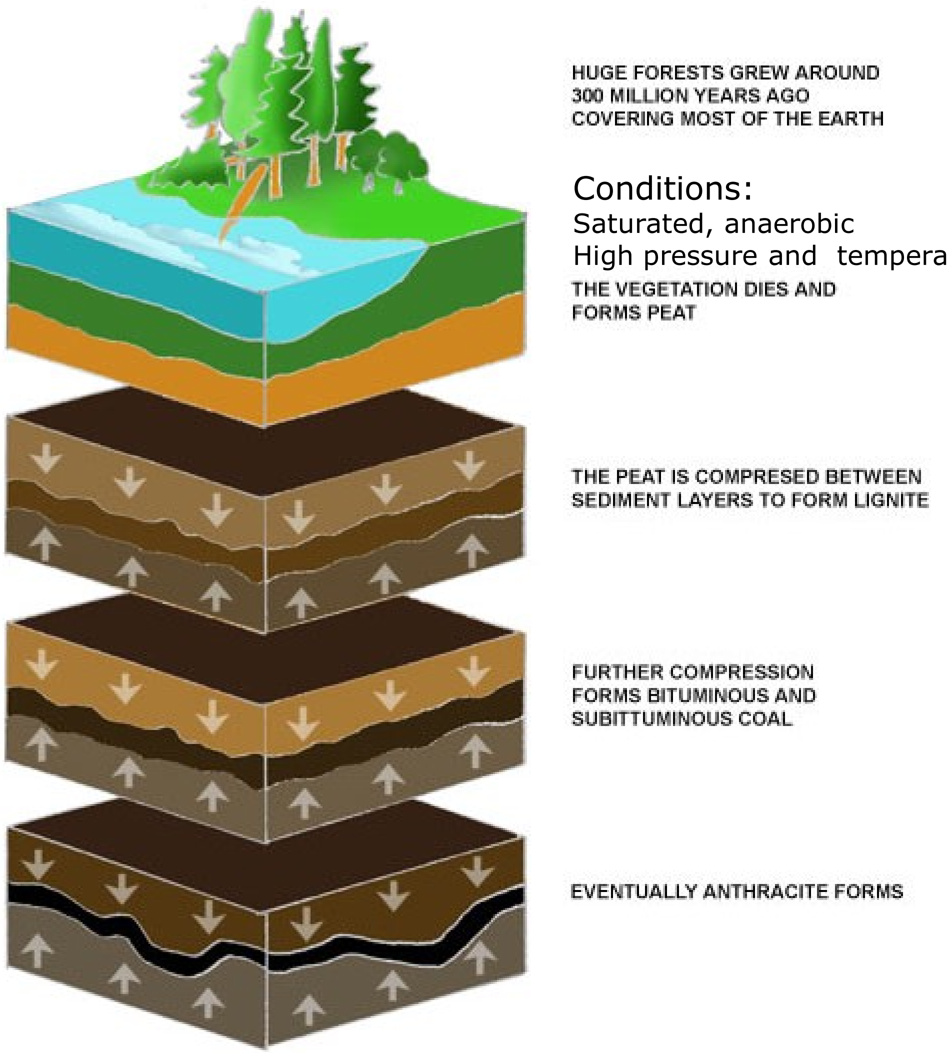
- The sun's energy can also be stored. Plants store energy from the sun as they grow. Fruits, vegetables, and wood from trees, for example, all contain stored solar energy. We call it **biomass** energy, from "bio" for "life" or "living." These kinds of energy are also renewable, but of course it takes longer to grow a plant or a tree than it does to get heat directly from sunlight.
- When energy is stored in a material, we call that material fuel. Food and wood are biomass fuels. When you have become old, old biomass that has become concentrated, you have what we call "**fossil fuel**.“ Given the time they require to form, they are **non-renewable.**



Fossil fuels formation (coal)

- Coal formation
- Coal was formed from the remains of ferns, trees, and grasses that grew in great swamps 345 million years ago. These remains formed layers as they sank under the water of the swamps. The plant material partially decayed as these layers formed beds of peat, a **soft brown coal**: substance that is up to 30% carbon. Peat is the earliest stage of coal formation.
- Shallow seas later covered the swamps and slowly deposited layers of sand and mud over the peat. These sediments exerted pressure on the peat over thousands of years. Slowly chemical changes took place transforming it to **lignite or brown coal**, which is about 40% carbon.
- Millions of years later, increasing pressure and heat changed the lignite into **bituminous or soft coal** (about 66% carbon) and finally into **anthracite or hard coal** (over 90% carbon).

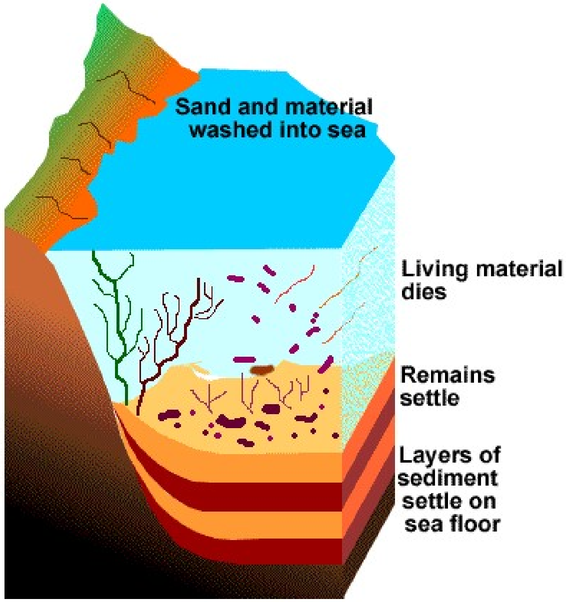
- See: vimeo.com/19478872

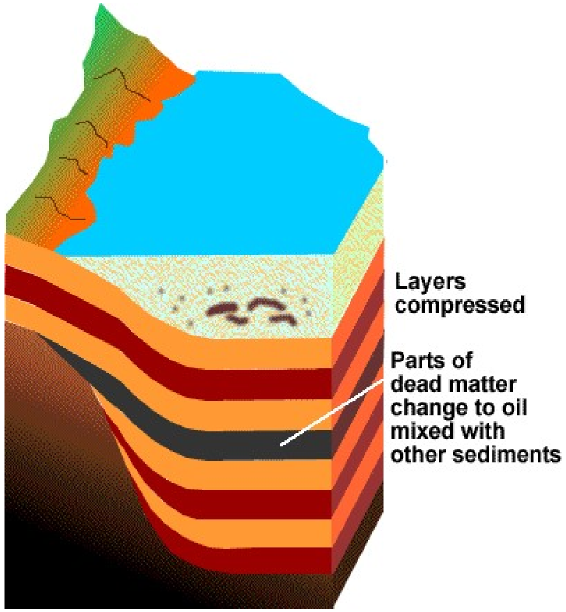


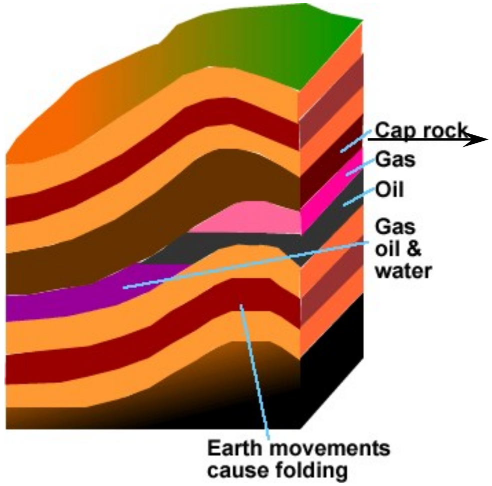
Conditions:
Saturated, anaerobic
High pressure and temperature

Fossil fuels formation (oil, nat. gas)

- Oil and natural gas formation
- Oil and natural gas are also found in beds of sedimentary rock. The sediments were deposited by shallow seas millions of years ago. The remains of plants and animals living in the seas settled to the bottom and were buried under layers of sediment. These layers were subjected to heat and pressure over millions of years. The sediments were transformed into beds of rock, and the plant and animal remains underwent slow chemical change and formed oil and natural gas.





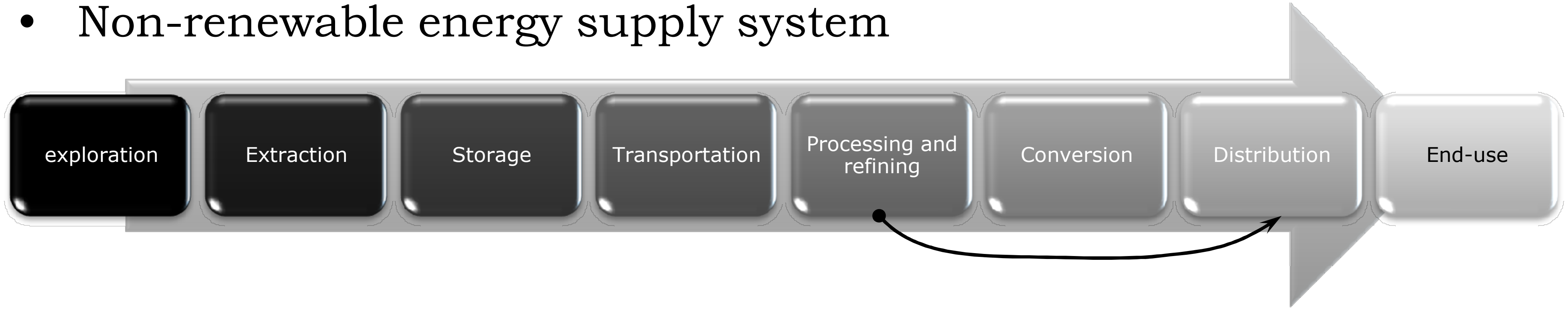


The layer that traps the oil and gas

The oil, gas and sea water occur in porous rock, not big hollows like caves in the rock.

Fossil fuels supply stages

- Non-renewable energy supply system



exploration

Extraction

Storage

Transportation

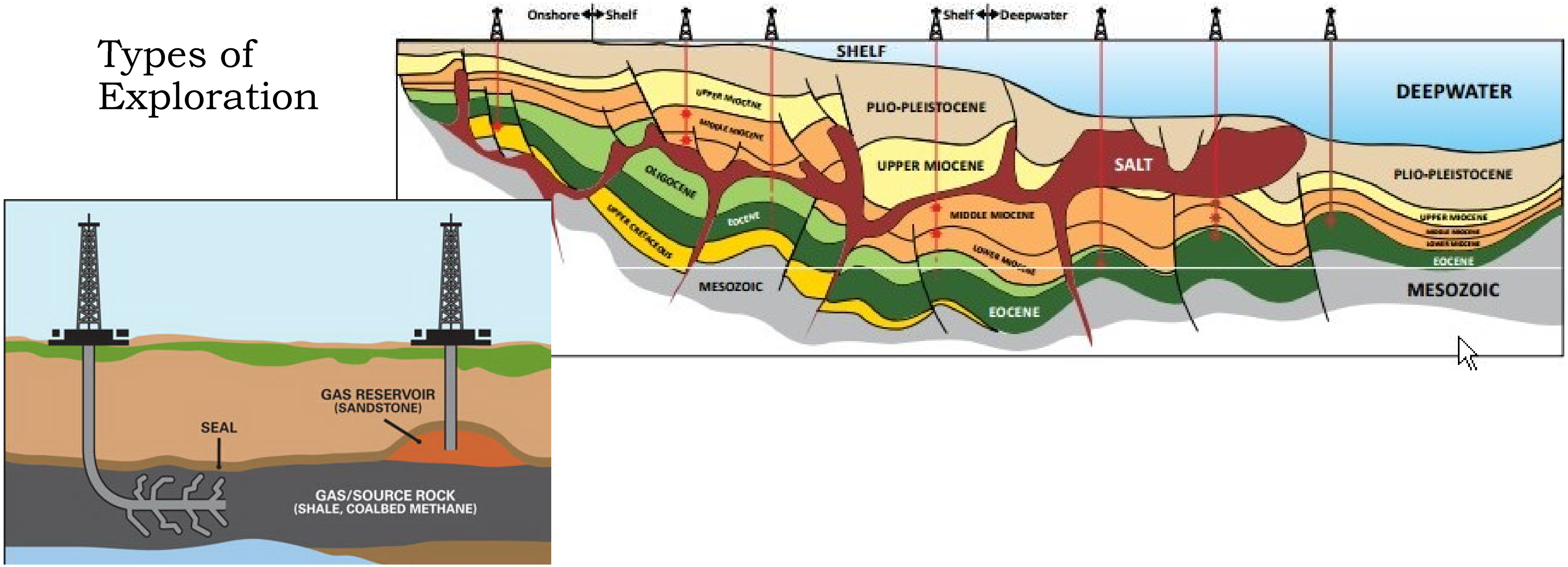
Processing and refining

Conversion

Distribution

End-use

Types of Exploration



Investment decision

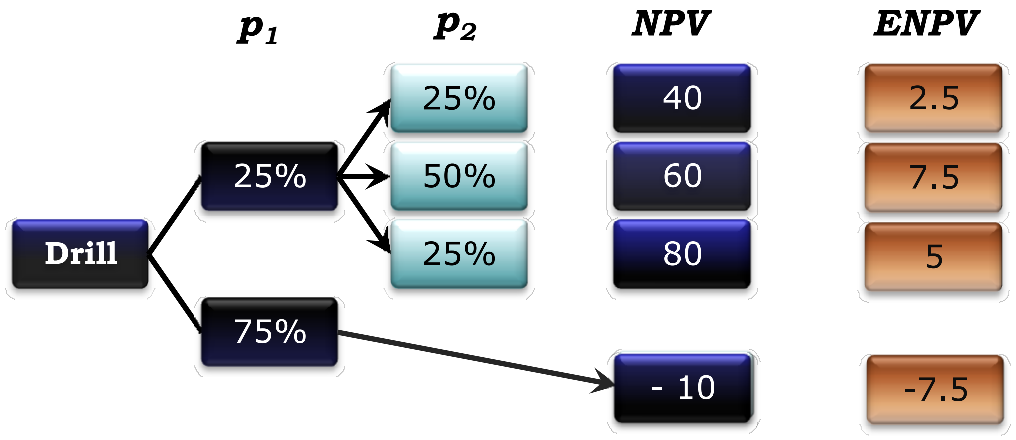
- Exploration decisions involve risks and uncertainties. Thus decisions should be based on expected monetary value (EMV) instead of NPV

$$ENPV = p\ NPV - (1 - p)\ E$$

  - where *ENPV* is the expected net present value, p is the probability of discoveries being made, *NPV* is the net present value of developing the discovered fields, *E* is the exploration costs.

- Example:

  $p_1 = 25\%$ (probability of successful drilling), p_2 probabilities of low, regular and high levels, $E = €10$ million



$$\text{ENVP} = 0.25\begin{bmatrix} 0.25(40)+0.5 \\ (60)+0.25(80) \end{bmatrix} - 0.75(10)$$

$$= 0.25(10+30+20) - 7.5$$

$$= 15 - 7.5 = 7.5$$

Since the ENPV is positive the company should go ahead with drilling

Risks in Exploration Projects

- Risks in Exploration Projects

- Types of risks
  - Contractual risk (possibility of changing the terms of the contract after the discovery is made especially because the contract is made with a government)
  - Commercial risk (less favorable commercial prospects in reality than planned, due to poor geological conditions, smaller size of the reserve than initially estimated, poor quality of the output, etc.)

- Legal arrangements
  - Concessionary systems (lease, concessions, and permits): owner receives royalty and firm assumes the risk.
  - Contractual arrangements (production sharing arrangements, service contracts, risk-sharing service contracts and joint ventures): government and firm share both benefits and risks

Investment decision

- If the country requires a share in profits (but not costs)

$$ENPV = p\ NPV\ (1 - t) - (1 - p)\ E$$

  - where t is the country's share without participating in the risk of exploration.
  - In the previous example, if the country's share is 50% (t = 50%) then the ENVP = 0.
- If the country requires a share in profits and participates in the risks

$$ENPV = p\ NPV\ (1 - t) - (1 - p)\ E\ (1 - r)$$

  - where t is the country's share and r its participation in the risk (t might be equal to r)
  - In our example, if t = r = 50%, then the ENVP = €3.75 million.
- Thus, the type of the state participation can influence the decision to go ahead with the exploration.

Natural gas

Natural Gas: Price Controls

- In the United States a natural gas shortage of 2 trillion cubic feet, or 10% of the marketed production, occurred in 1974–1975.
- In an efficient allocation, shortages of that magnitude would never have materialized. What happened?

- The source of the problem can be traced directly to government controls over natural gas prices.
- In 1938 the Natural Gas Act was passed.
  - The Federal Power Commission (FPC) was charged with maintaining "just" prices.
  - Price controls were imposed on natural gas shipped across state lines.
- In Phillips Petroleum Co., v. Wisconsin (1954), the Supreme Court forced the FPC to extend its price control regulations to the producers. Previously they had limited their regulation to pipeline companies.

Natural Gas: Price Controls

- Price ceilings were imposed which prevented prices from reaching their normal levels:
  - overconsumption of natural gas, causing shortages,
  - causing more of the resource to be used in earlier years and with a sudden jump in price.

- On the supply side, producers who expect price ceilings to be lifted have incentives to slow production and wait for higher prices, thus exacerbating existing shortages.

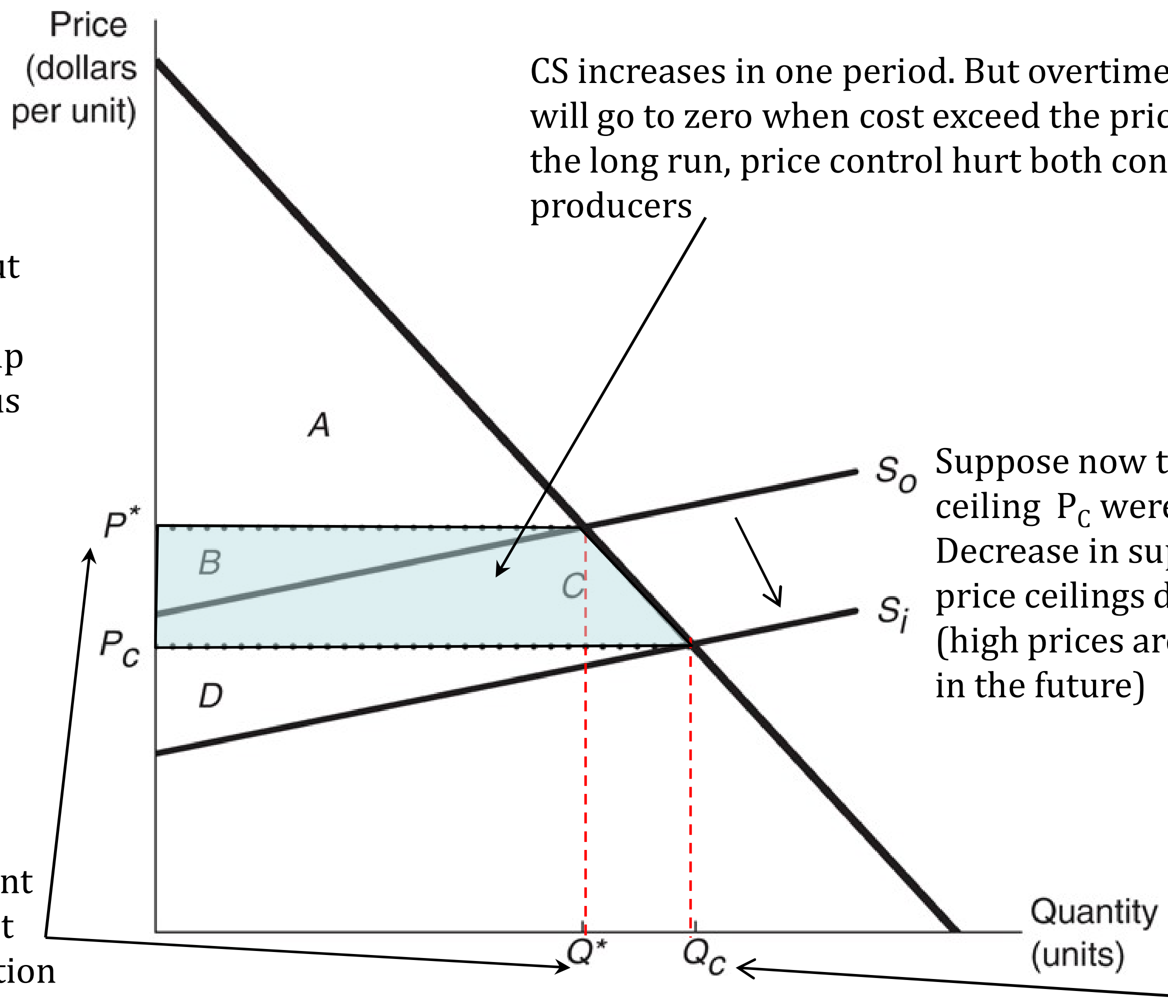
- The combined impact of these demand-&-supply effects would be to distort the allocation significantly. Aspects of particular importance:
  1) more of the resource is left in the ground,
  2) the rate of consumption is too high,
  3) the time of transition is earlier, and
  4) the transition is abrupt, with prices suddenly jumping to new, higher levels.

Natural Gas: Price Controls

- Artificially low prices of natural gas created a bias toward substitutes that could be blended with natural gas and away from substitutes that could not.
- The discontinuous jump to a new technology, which results from price controls, can place quite a burden on consumers. Attracted by artificially low prices, consumers would invest in equipment to use natural gas, only to discover—after the transition—that natural gas was no longer available.

- Why did Congress embark on such a counterproductive policy? The answer is found in rent-seeking behavior that can be explained through the use of our consumer and producer surplus model.
- Let’s examine the political incentives in a simple model described in the figure that follows.

The Effect of Price Controls



CS increases in one period. But overtime, the supply will go to zero when cost exceed the price ceiling. In the long run, price control hurt both consumers and producers

PS increase if D>B. But only in one period. Over time, they give up scarcity rents and thus overall they loose

Suppose now that a price ceiling P_C were established. Decrease in supply since price ceilings decrease MUC (high prices are not possible in the future)

Net benefits are represented by areas A and B.

Efficient market allocation

Current production expands and price falls

The Effect of Price Controls

Since producers would be overproducing, they would be giving up the scarcity rent they could have gotten without price controls. Area D measures current profits only without considering scarcity rent. When the loss in scarcity rent is considered, producers unambiguously lose net benefits.

Future consumers are also unambiguously worse off. The supply curve for each subsequent year would shift up, thereby reflecting the higher MEC for the remaining endowment of the resource. When the MEC ultimately reached the level of the price control, the amount supplied would drop to zero. Since the demand would not be zero at that price, an artificial shortage would develop.

The government may view scarcity rent as a possible source of revenue to transfer from producers to consumers. As we have seen, however, scarcity rent is an opportunity cost that serves a distinct purpose: the protection of future consumers. When a government attempts to reduce this scarcity rent through price controls, the result is an overallocation to current consumers and an underallocation to future consumers. Thus, what appears to be a transfer from producers to consumers is, in large part, also a transfer from future consumers to present consumers.

Natural Gas: Price Controls

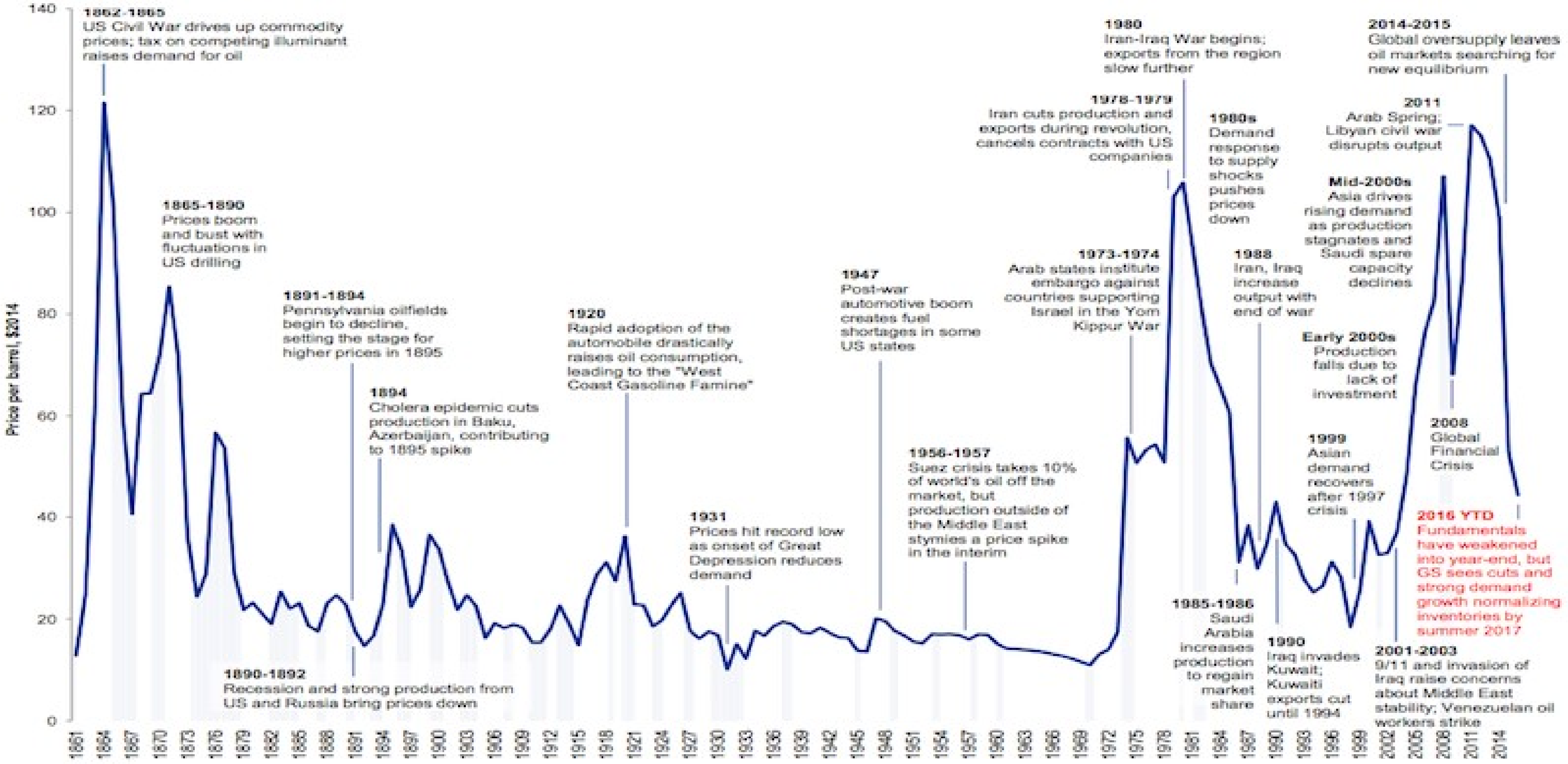
- The Natural Gas Policy Act was passed on November 9, 1977.
  - Natural gas prices began to be decontrolled in the early 1980s causing rapid price rises.
  - By 1993, no sources of natural gas were subject to price controls.

- The demand for natural gas has been rising and as such prices have also been rising.

- Imports have also risen, much in the form of Liquefied Natural Gas (LNG).

Oil

Oil prices



Crud oil prices in 2014 $/barrel

Real Crude Oil Price (2006-2023)

Renewable resources

Renewable energy resources

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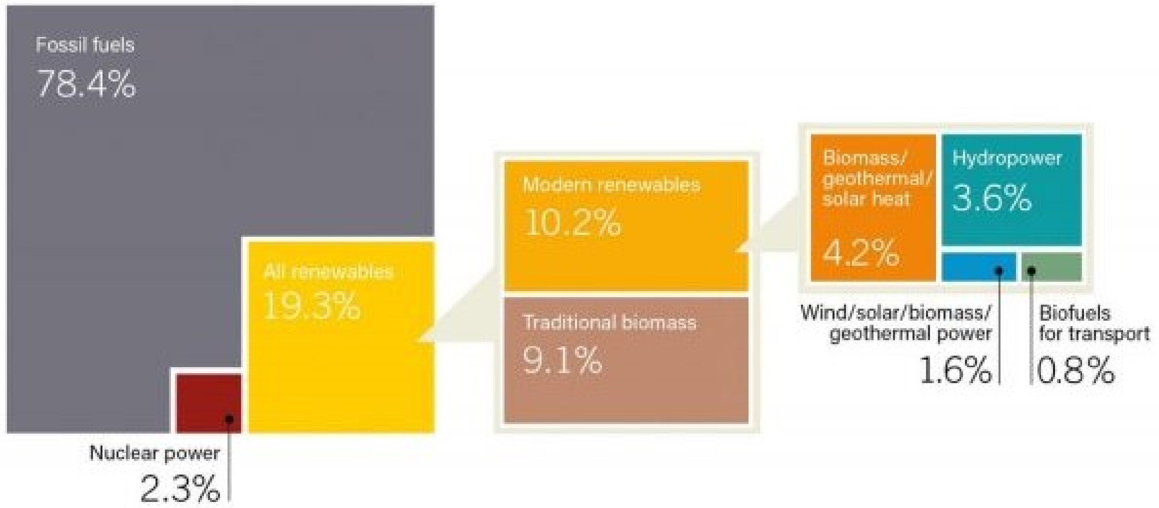
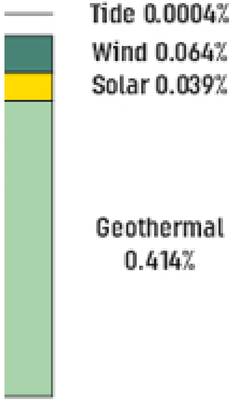
Figure: 01

Estimated Renewable Energy Share of Total Final Energy Consumption, 2015



REN21 *Renewables 2017 Global Status Report*

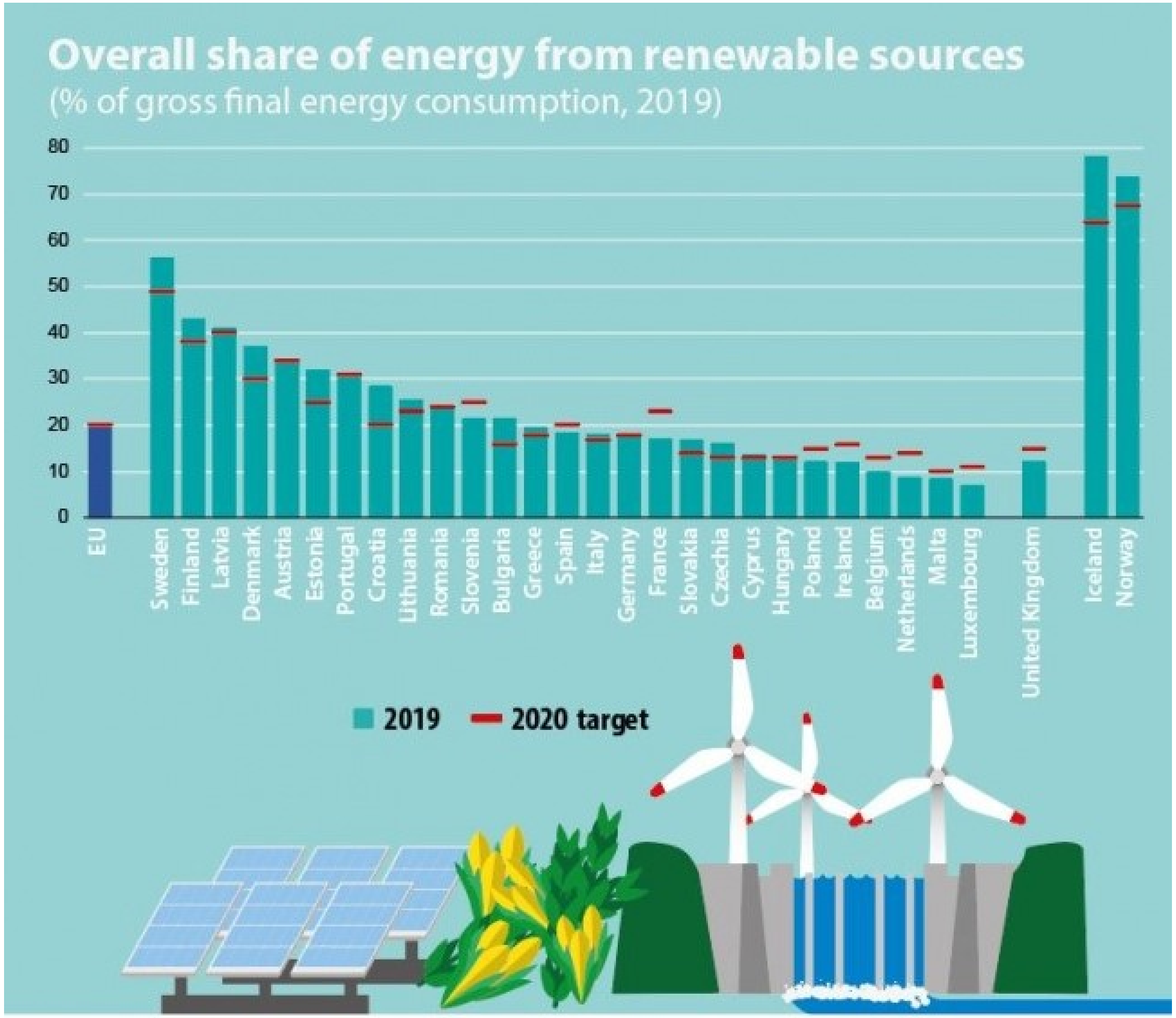


uary 2007

Renewable energy resources

In 2019, renewable energy represented 19.7 % of energy consumed in the EU-27, only 0.3 % short of the 2020 target of 20 %.

The share of energy from renewable sources used in transport activities in the EU-27 reached 8.9 % in 2019.


Overall share of energy from renewable sources
(% of gross final energy consumption, 2019)

ec.europa.eu/eurostat

Renewable energy resources

Despite the current extremely small share of renewables:

- The renewables' supply has grown at an average annual rate of 2.3% over the past 30 years (IEA 2007).

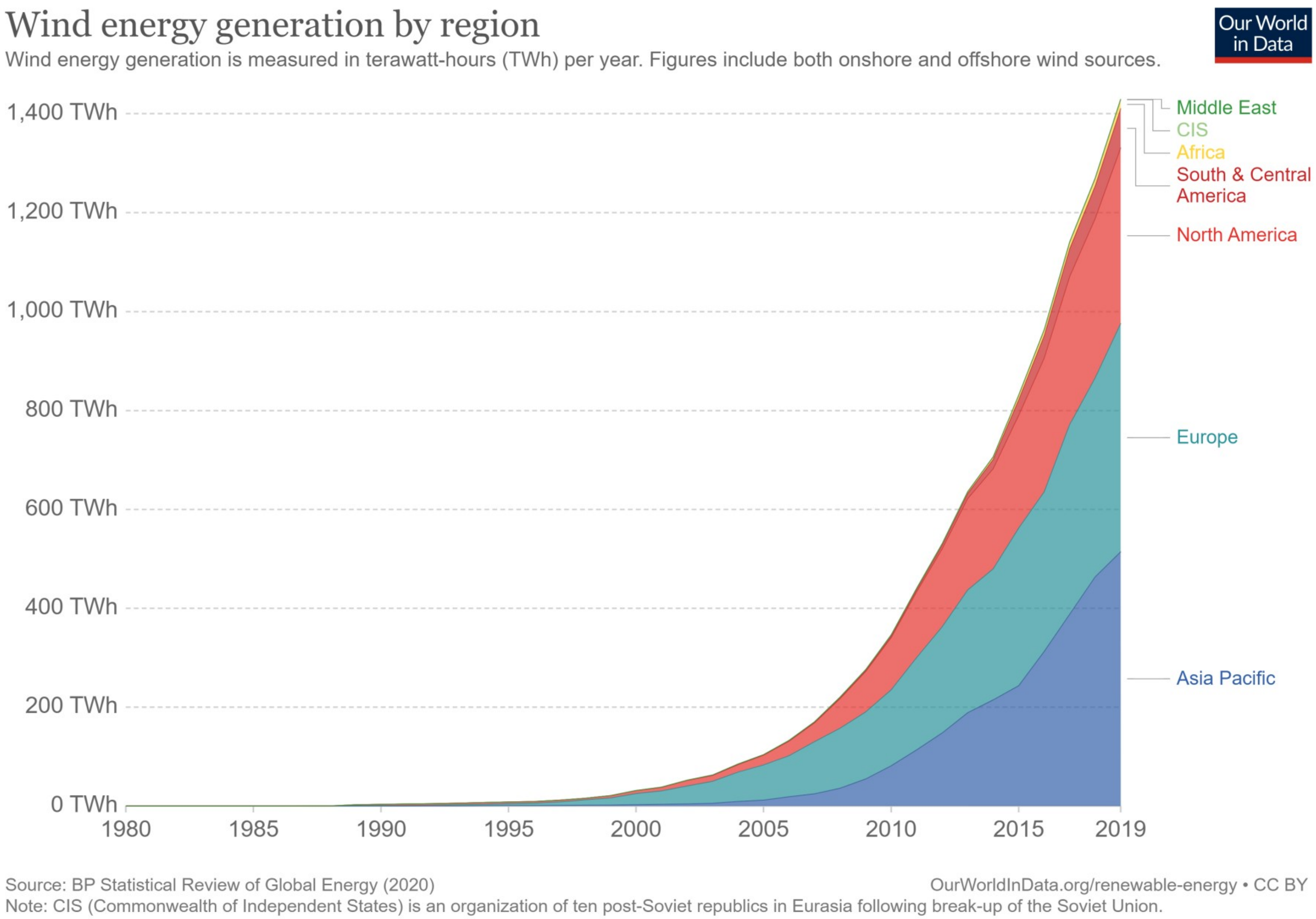
- New renewable energies like wind and solar have recorded very high growth rates

- The present use of renewable energies is a small fraction of the overall estimated technical potential

There are estimates that this potential is likely to increase significantly by 2050.

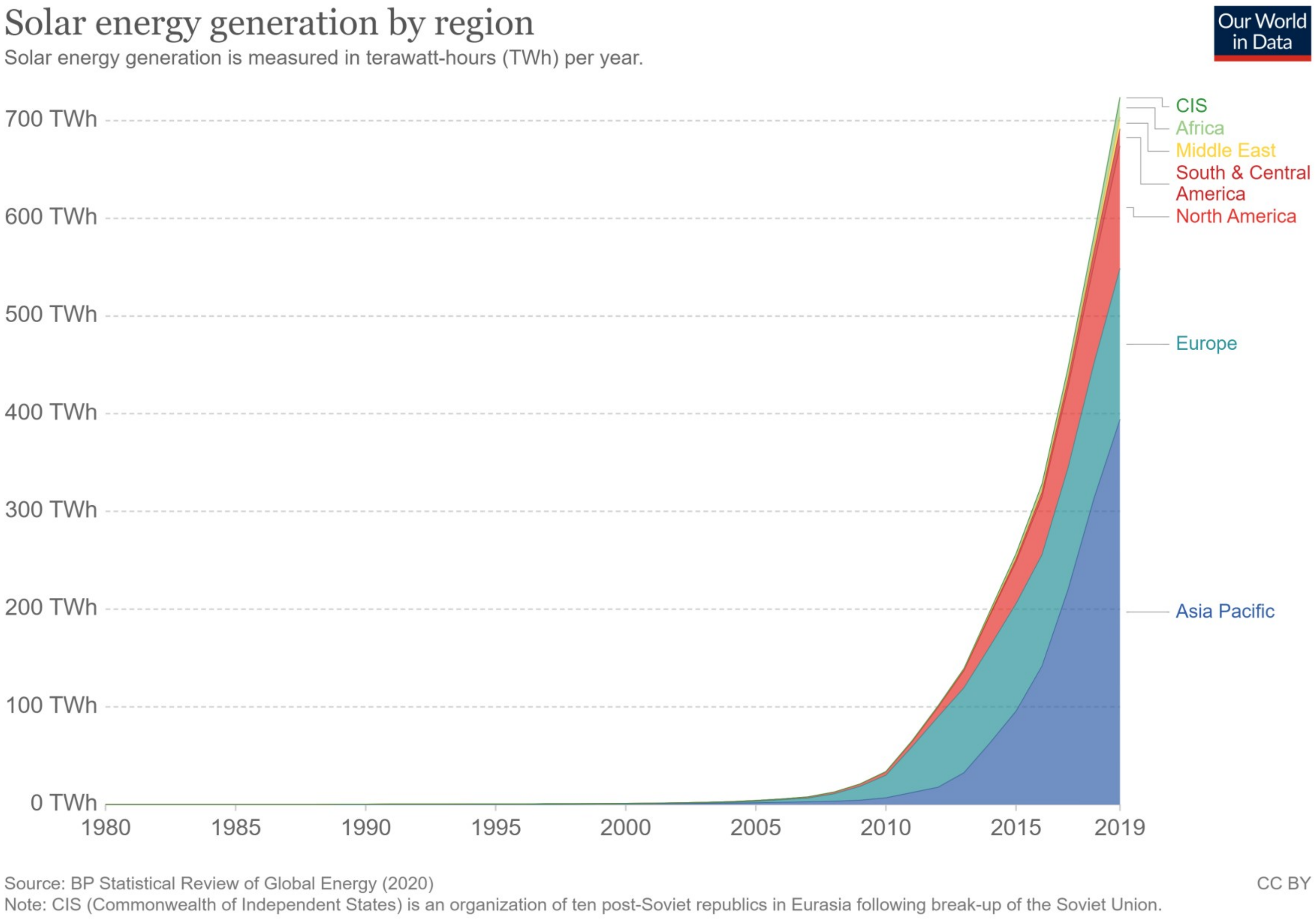
De Vries BJM, Van Vuuren DP, Hoogwijk MM @ Energy Policy 35(4):2590–2610

Renewable energy resources



Source: BP Statistical Review of Global Energy (2020) OurWorldInData.org/renewable-energy • CC BY
Note: CIS (Commonwealth of Independent States) is an organization of ten post-Soviet republics in Eurasia following break-up of the Soviet Union.

Renewable energy resources



Source: BP Statistical Review of Global Energy (2020)
Note: CIS (Commonwealth of Independent States) is an organization of ten post-Soviet republics in Eurasia following break-up of the Soviet Union.

Renewable energy resources

Today’s max world power consumption: 12.5 TW

2030 power consumption:

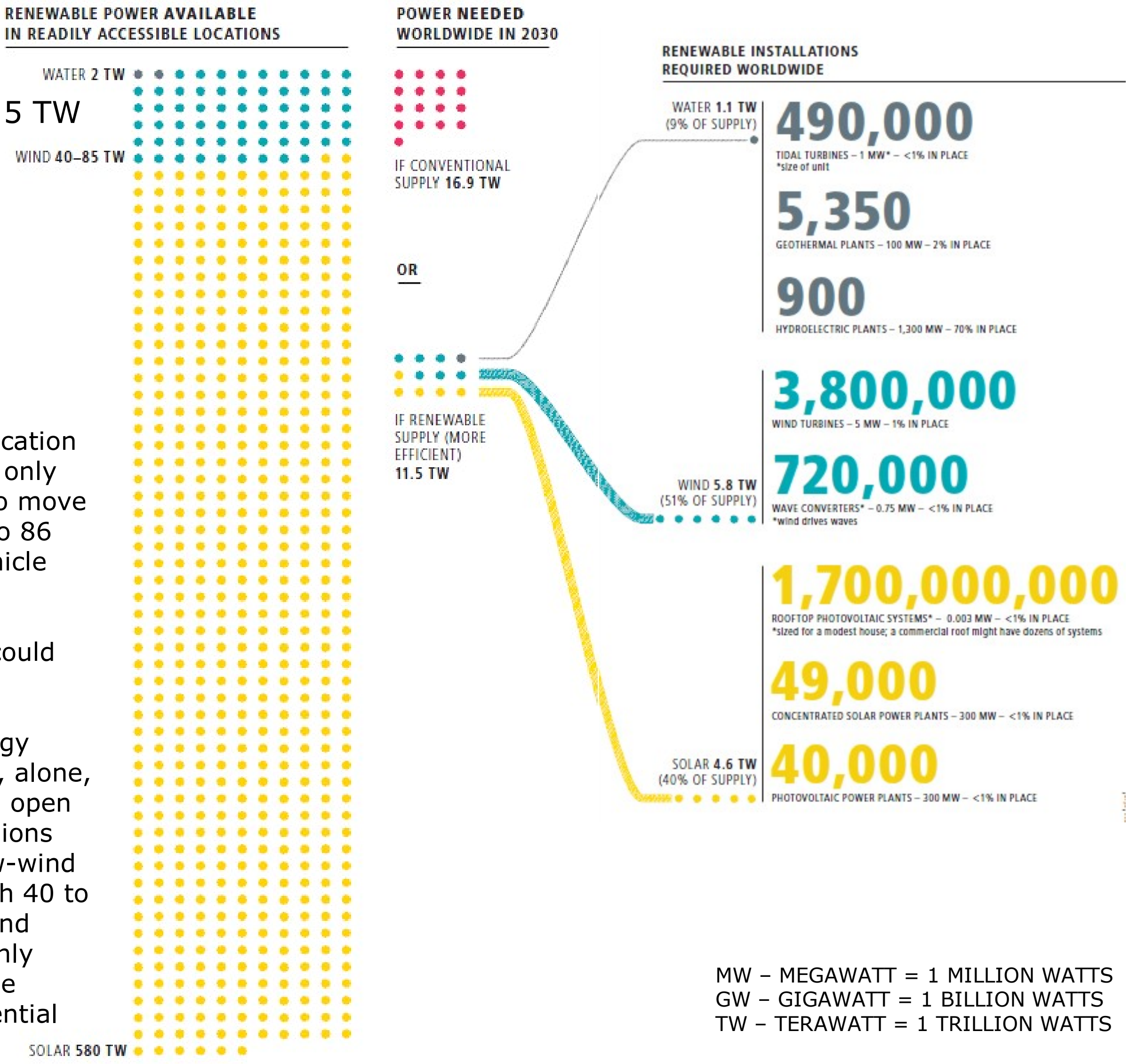
16.9 TW (if the mix of sources is similar to today’s, heavily dependent on fossil fuels)

11.5 TW (if the planet were powered entirely by wind, water, sunlight (WWS))

That decline occurs because, in most cases, electrification is a more efficient way to use energy. For example, only 17 to 20 percent of the energy in gasoline is used to move a vehicle (the rest is wasted as heat), whereas 75 to 86 percent of the electricity delivered to an electric vehicle goes into motion.

Even if demand did rise to 16.9 TW, WWS sources could provide far more power.

Detailed studies by us and others indicate that energy from the wind, worldwide, is about 1,700 TW. Solar, alone, offers 6,500 TW. Of course, wind and sun out in the open seas, over high mountains and across protected regions would not be available. If we subtract these and low-wind areas not likely to be developed, we are still left with 40 to 85 TW for wind and 580 TW for solar, each far beyond future human demand. Yet currently we generate only 0.02 TW of wind power and 0.008 TW of solar. These sources hold an incredible amount of untapped potential



MW – MEGAWATT = 1 MILLION WATTS
GW – GIGAWATT = 1 BILLION WATTS
TW – TERAWATT = 1 TRILLION WATTS

SCIENTIFIC AMERICAN November 2009

Renewable energy resources

Drivers of Renewable Energy

i. Reduction in CO_2 emission and mitigation of climate change (main current driver)

ii. Security of energy supply (insurance against price volatility for non-producing fossil fuels countries)

iii. Improving energy access (especially in developing countries and in remote areas outside the grid)

iv. Employment opportunities (localized production plus clean and healthy working environment)

v. Other spill-over effects (fewer and less severe macro-economic shocks)

- Energy Markets

Electricity markets are non-competitive

- The assumptions of perfect competition, are not present in energy markets

- There are a number of reasons why energy markets deviate from marginal cost pricing
  - Indivisibility of capital
  - Exhaustible resources
  - Asset specificity
  - Capital intensiveness
  - Market failures (natural monopoly)
  - Externalities

- For all these reasons some form of government intervention is required

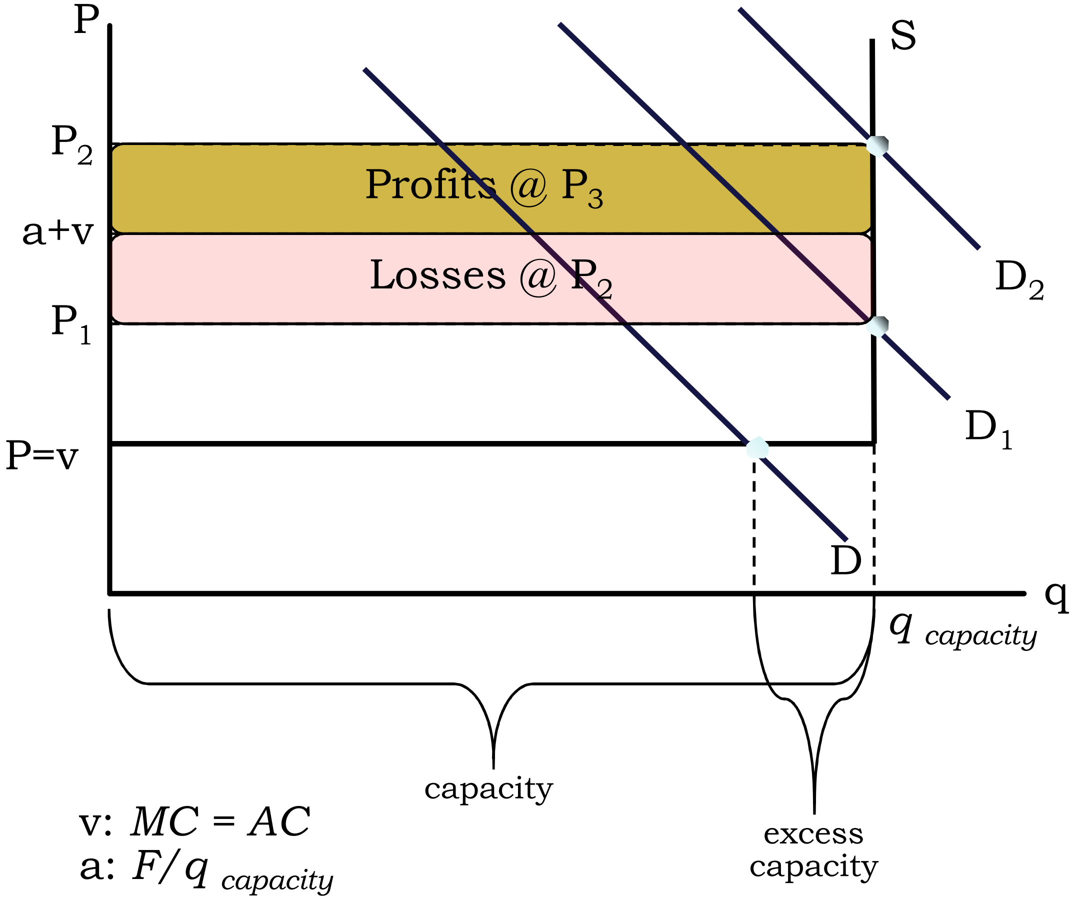
Indivisibility of capital

- In energy, investments are lumpy, which changes the shape of the supply curve, introducing kinks at additional investment points

When demand is D, there is excess capacity, and there are losses equal to fixed costs.

When demand is D_1, the installation works at capacity and there are losses.

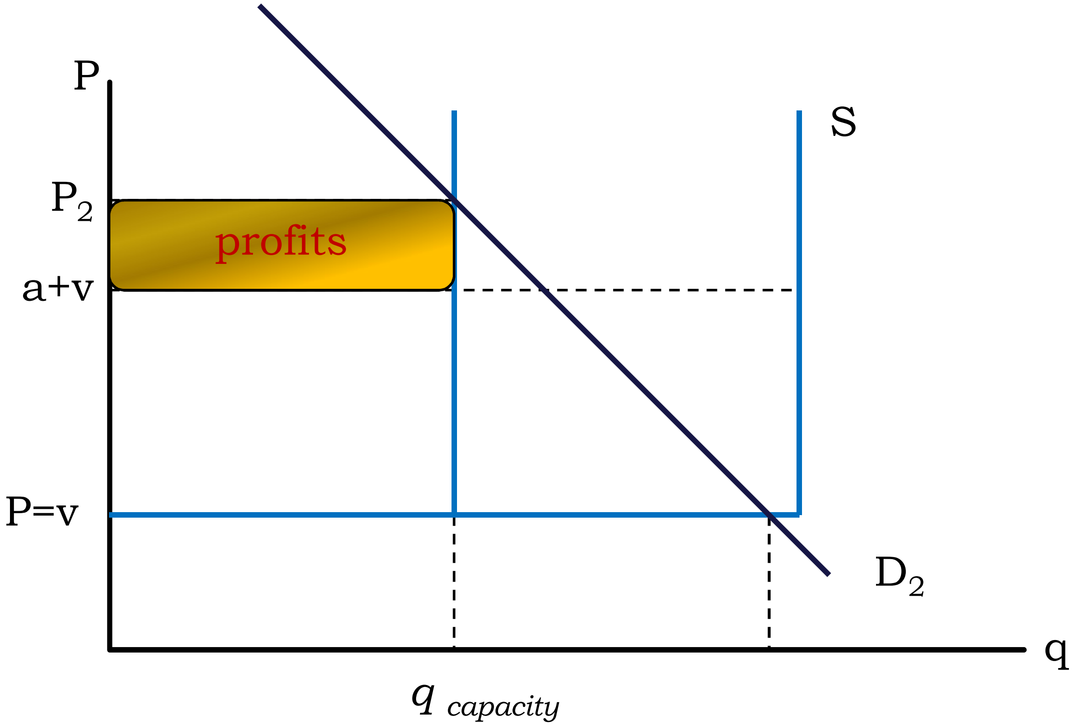
When demand is D_2, the installation works at capacity and there are profits.



Indivisibility of capital

The profits made when demand increases to D_2, will attract new investment, which will increase capacity and bring the price down to marginal cost

The volatility of energy prices does not provide the best environment for investors.



Thus, the indivisibility of capital in energy investment puts marginal cost pricing seriously under question

Asset specificity

- Capital in the energy sector is very specific and its very difficult to move it and use it in other sectors.
  - For example, a power generating plant has little alternative use, investments in an oil filed could hardly be redeployed elsewhere in any other use

- Reasons for asset specificity:
  - Site specificity (“Mine-mouth” Power Plants)
  - Capital specificity (Boiler specification for different kinds of coal)
  - Labor skills specificity (Specialized engineers)
  - Idiosyncratic investment (Dedicated Assets)

- Asset specificity contributes to transaction costs
- If both a buyer and a seller contemplate a transaction that requires investments that are unique to that particular exchange relationship, then the two parties are locked into a bilateral monopoly structure. Once this investment is made by both parties, either or both parties might engage in opportunistic behavior (because of the “sunk cost” nature of the investment).

Asset specificity

- Example: Imagine you have a buyer and a seller for parts that go into making a car. The specifications for the parts are very specific, so the parts made can only go into one model of car, and only this supplier can make the parts. Now imagine that the buyer and seller enter into a contract where the seller will provide this part at $100 each. After the parts are made, the seller realizes that the parts are critical to the functioning of the car, and it says that, regardless of the contract terms, it's not going to let the parts go for less than $150 each. Now the buyer is in a bind since it can't just turn around and buy them from someone else. The "holdup" could also go the other way, with the buyer saying wait, I'm going to only pay you $75 each, since I know that once these parts are made you can't sell them to anyone else.

- Williamson (Transaction cost-economics: The governance of contractual relations, Journal of Law and Economics, 1979, 233-61) formalized the transaction-cost framework by identifying three critical aspects of transactions: uncertainty, the frequency with which transactions occur and the degree of asset specificity. He then argued that, ceteris paribus, as the degree of asset specificity increases, the optimal governance structure moves from spot-market exchange, to bilateral governance (short and long-tern contracts), on to unified governance or vertical integration.

Capital intensiveness

- The fact that production in the energy sector is capital intensive, means that fixed costs are high.

At price P_2 the firm makes profits since $P_2 > ATC(Q_2)$.

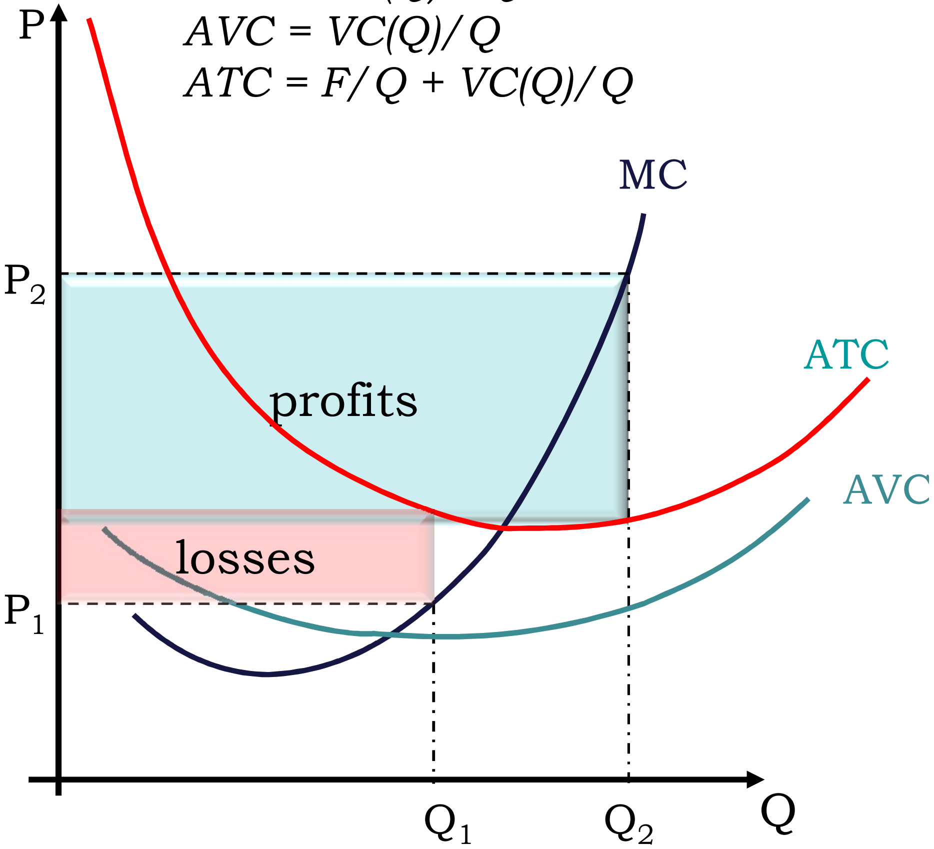
However, at P_1 it makes losses since it covers only part of the fixed cost. In the long run the firm should exit the market. However, if fixed costs are considered sunk (non-recoverable), then the firm will stay in and produce to maximum capacity.

$TC = F + VC(Q)$

$MC = \partial VC(Q)/\partial Q$

$AVC = VC(Q)/Q$

$ATC = F/Q + VC(Q)/Q$



Capital intensiveness

- In the energy industry the high sunk costs have led either to market regulation (in the electricity sector) or to horizontal integration and to cartel formation

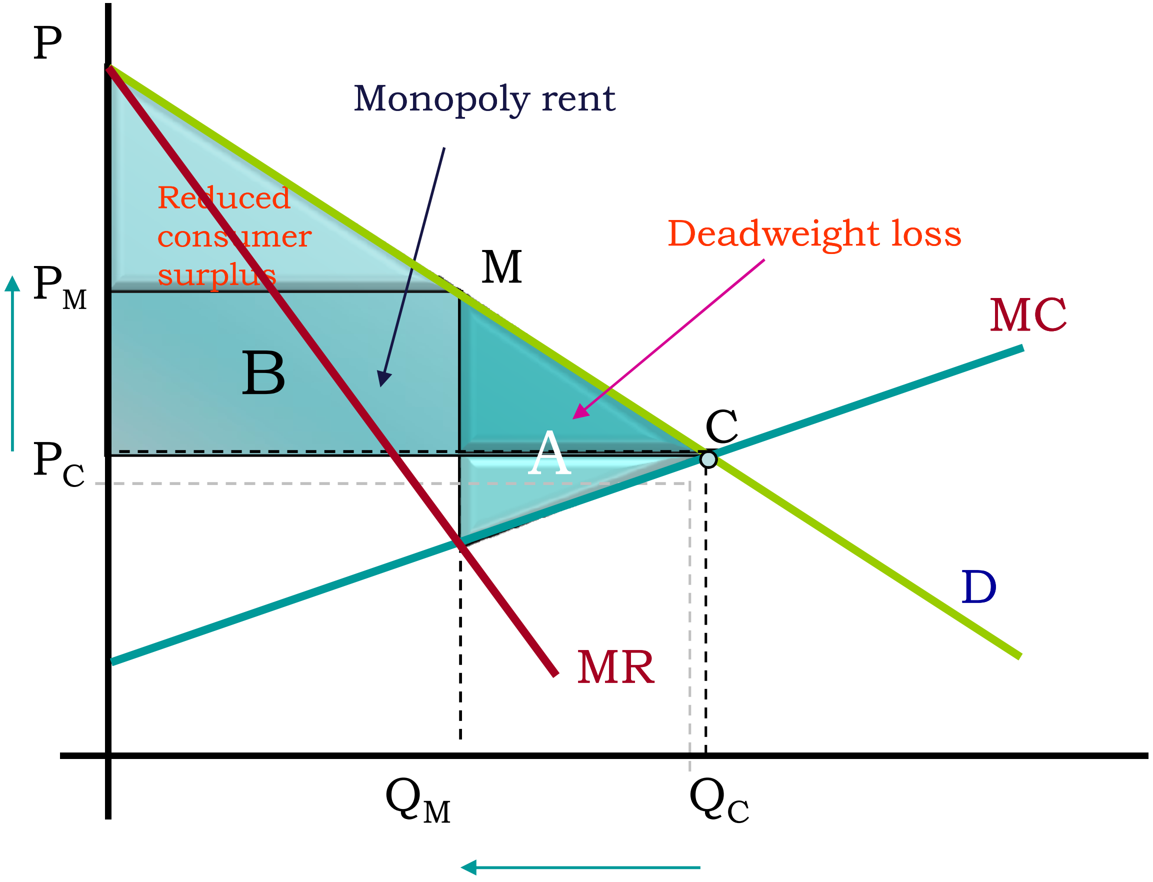
- Regulation, attempts through various pricing instruments to maintain certain mix of assets

- Horizontal integration and cartels attempt to control the price either directly or through controlling production, allocating production quotas among cartel members for example.

- Natural monopoly & cartels

Monopoly (reminder)

- High fixed costs is one of the main reasons for monopolies



$$\max \pi = p(Q)Q - C(Q)$$

$$f.o.c.:$$

$$\frac{d\pi}{dQ} = p(Q) + \frac{\partial p}{dQ}Q - \frac{\partial C(Q)}{dQ} = 0 \Rightarrow$$

$$p\left[1 + \frac{\partial p}{dQ}\frac{Q}{p}\right] = MC \Rightarrow$$

$$1 - \frac{1}{e} = \frac{MC}{p} \Rightarrow \boxed{\frac{p - MC}{p}} = \frac{1}{e}$$

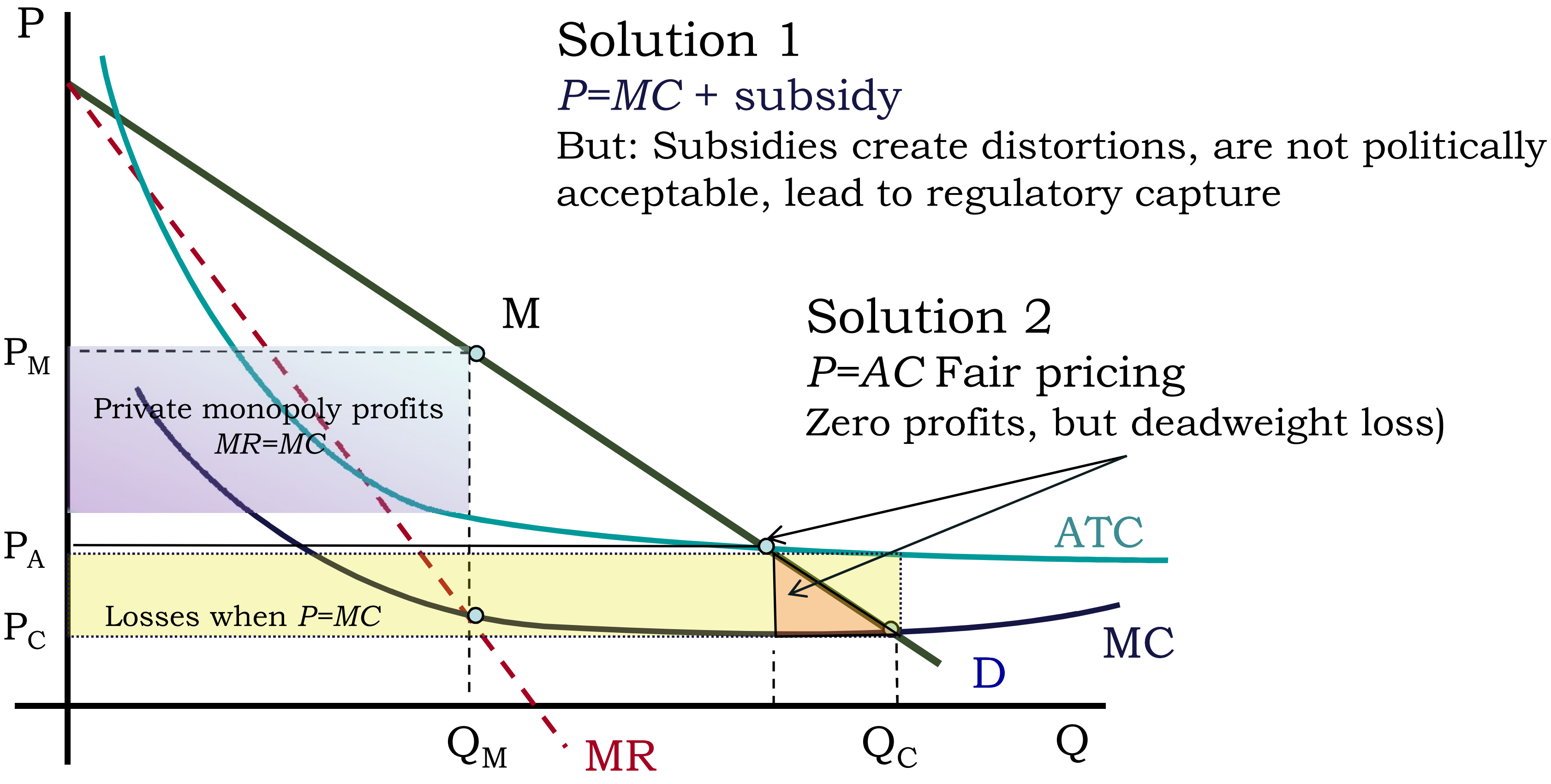
Price-cost margin
(Lerner index of
market concentration)

Monopoly leads to:

- Deadweight losses
- X-inefficiencies
- Rent-seeking
- Product and price differentiation

Natural monopoly

- A situation (combination of technology, preferences, etc) in which a single firm can provide a good at the minimum cost



Solution 1

P=MC + subsidy

But: Subsidies create distortions, are not politically acceptable, lead to regulatory capture

Solution 2

P=AC Fair pricing

Zero profits, but deadweight loss)

Pricing electricity (natural monopoly)

- A natural monopoly (if left unregulated) will maximize profits by producing at the quantity where marginal revenue (MR) equals marginal costs (MC), leading to low quantity and high prices.
- Alternatively, the government could regulate the price in the following ways:
- Marginal cost pricing: the regulator requires that the firm produce the quantity of output where marginal cost crosses the demand and charge the price which is equal to marginal cost (but makes losses).
- Average cost pricing: let the natural monopoly charge enough to cover its average costs, so that it can continue operating, but prevent the firm from raising prices and earning high monopoly profits.
- Cost-plus, or rate of return regulation: calculate the average cost of production, add in an amount for the normal rate of profit the firm should expect to earn, and set the price for consumers accordingly.
- Peak-load pricing is a pricing structure where consumers using power during peak periods are charged higher rates during the peak periods

Natural monopoly (numerical example)

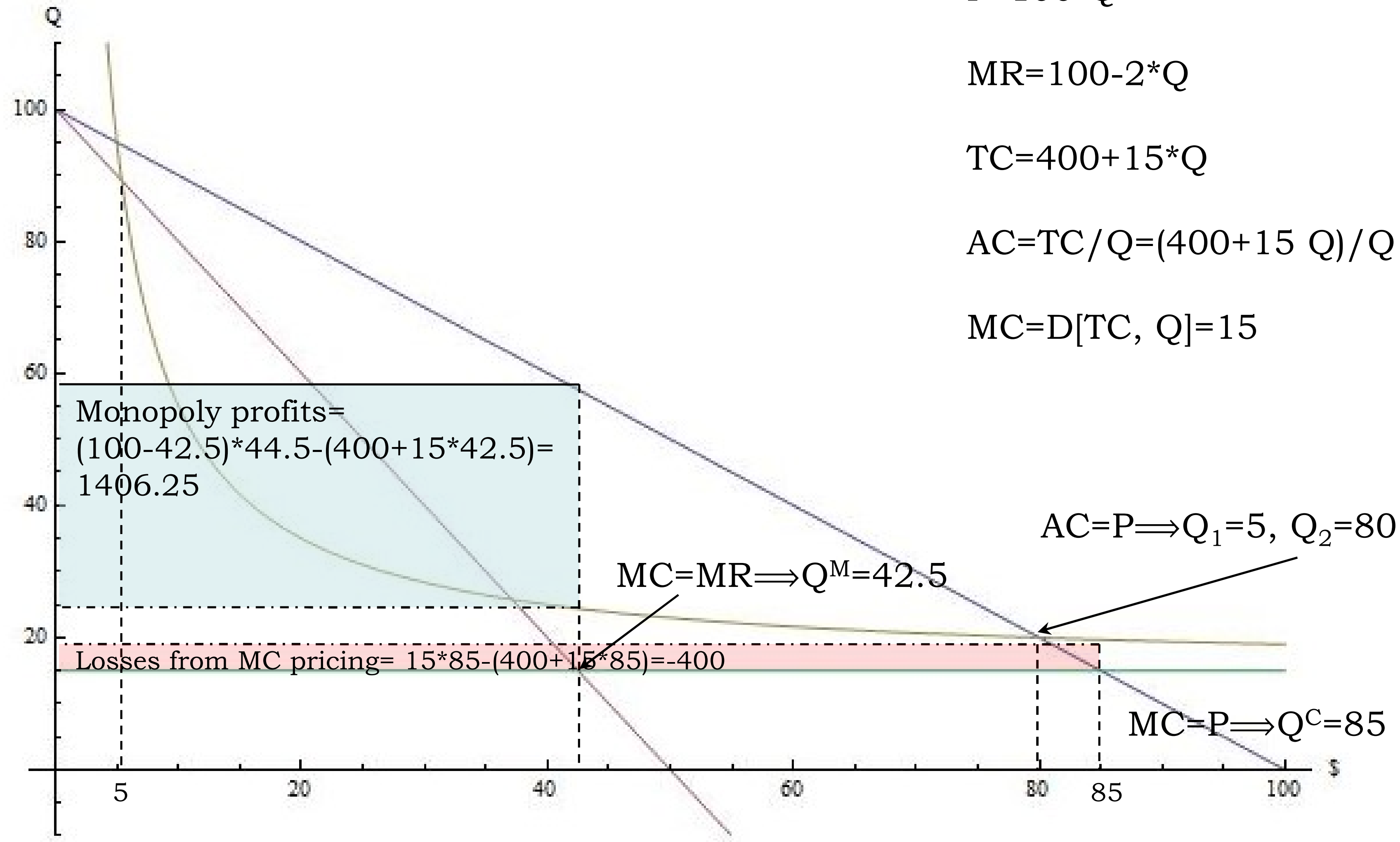
P=100-Q

MR=100-2*Q

TC=400+15*Q

AC=TC/Q=(400+15 Q)/Q

MC=D[TC, Q]=15



Monopoly profits=
(100-42.5)*44.5-(400+15*42.5)=
1406.25

$MC=MR\Longrightarrow Q^M=42.5$

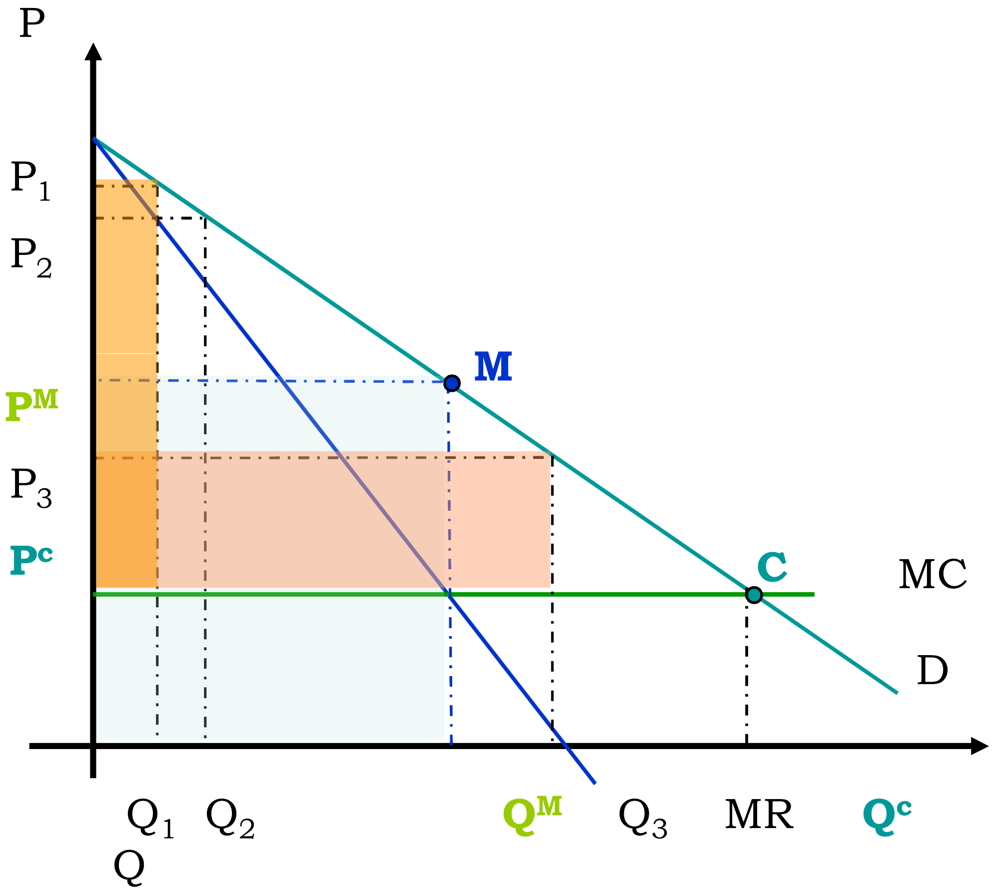
$AC=P\Longrightarrow Q_1=5,\ Q_2=80$

Losses from MC pricing= 15*85-(400+15*85)=-400

$MC=P\Longrightarrow Q^C=85$

Price discrimination (reminder)

1st and 2nd degree price discrimination



Perfect competition at point C(Q^C,P^C) in the graph

Single price (linear pricing) monopoly at point M(Q^M,P^M)

The monopolist can increase its profits by charging different price to each unit sold. Charging P_1 for Q_1, P_2 for Q_2, etc. the monopolist can get the full consumer surplus, selling up to Q^C units.

Since it is very difficult , if not impossible, to know each consumer's willingness to pay, the monopolist might separate consumers in groups and charge different prices to different groups (students, seniors, businessman, etc)

Electricity demand

- Given the problems with increased prices of inputs (fossil fuels), for a number of electric utilities conservation has assumed an increasing role.

- The most significant role for conservation is its ability to defer capacity expansion. Each new electrical generating plant tends to cost more than the last, and frequently the cost increase is substantial. When the new plants come on line, rate increases to finance the new plant are necessary. By reducing the demand for electricity, conservation delays the date when the new capacity is needed. Delays in the need to construct new plants translate into delays in rate increases as well.

- Governments are reacting to this situation in a number of ways. One is to promote investments in conservation (such as incentives for installing solar water heating systems, home insulation, etc), rather than in new plants, when conservation is the cheaper alternative.

Electricity demand

- However, the total amount of electric energy demanded in a given year is not the only concern. How that energy demand is spread out over the year is also a serious concern.

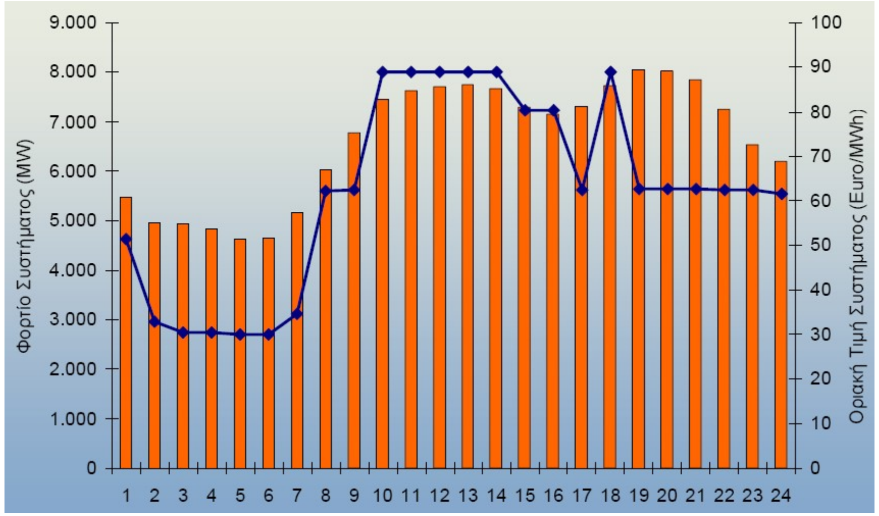
- The capacity of the system must be high enough to satisfy the demand even during the periods when the energy demand is highest (called *peak periods).* During other periods, much of the capacity remains underutilized.

- Demand during the peak period imposes two rather special costs on utilities.
    - First, the peaking units produce electricity at a much higher marginal cost than do base-load plants, those fired up virtually all the time. Typically, peaking units are cheaper to build than baseload plants, but they have higher operating costs.
    - Second, it is the growth in peak demand that frequently triggers the need for capacity expansion. Slowing the growth in peak demand can delay the need for new, expensive capacity expansion, and a higher proportion of the power needs can be met by the most efficient generating plants.

- Utilities respond to this problem by adopting load-management such as *peak-load pricing* which attempts to impose the full marginal cost of supplying peak power on those consuming peak power by charging higher prices during the peak period.

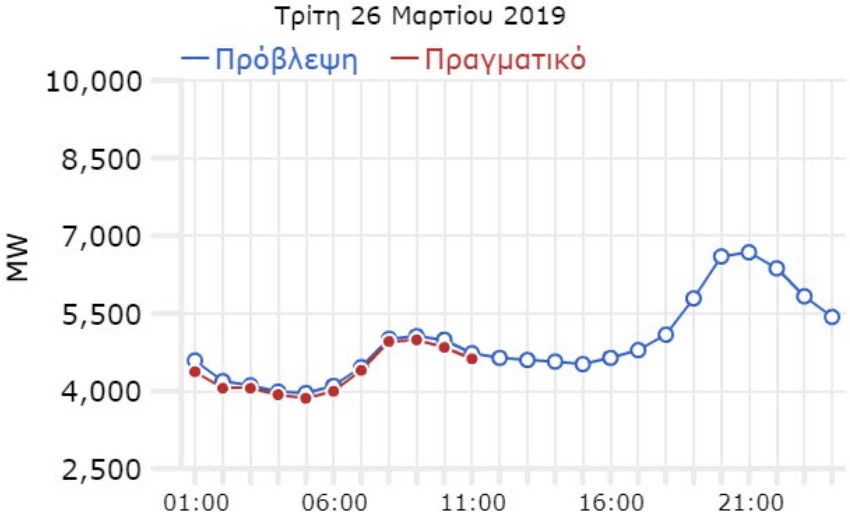
Electricity demand

- Energy demand exhibits high volatility daily and seasonally.
- On energy products that can be stored demand variations can be handled (when the difference between peak and off-peak prices can cover storage costs)
- In the case of commodities that cannot be stored variations in demand can be handled by varying prices



Source: Hellenic Transmission System Operator (HTSO) 09/01/2009

Daily variation of demand and marginal price



ΑΔΜΗΕ

INDEPENDENT POWER TRANSMISSION OPERATOR

Peak-load pricing

- When demand is not evenly distributed, and the product non-storable, a firm needs to have facilities to accommodate periods of high demand.

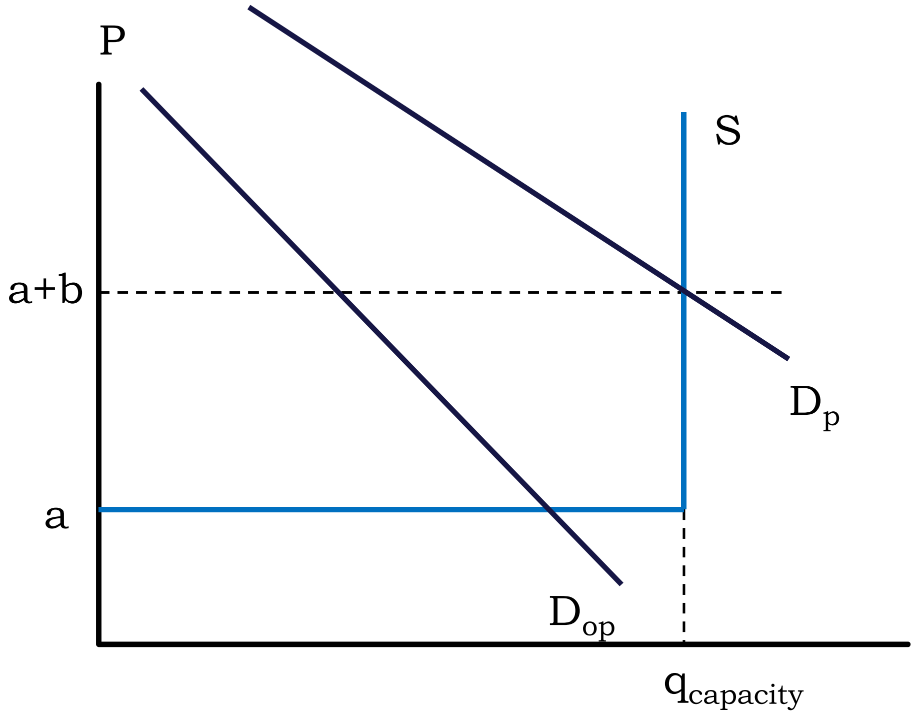
- Even with large facilities, the firm may experience times when the demand is greater than can be handled. Then the firm may experience costly computer system crashes.
- During off-peak times (periods of lower demand), there is excess capacity.
- The firm charges less at off-peak times.

- Example: More phone calls are made during business hours than in the evenings and on weekends. So the phone companies charge more during business hours.

Peak-load pricing

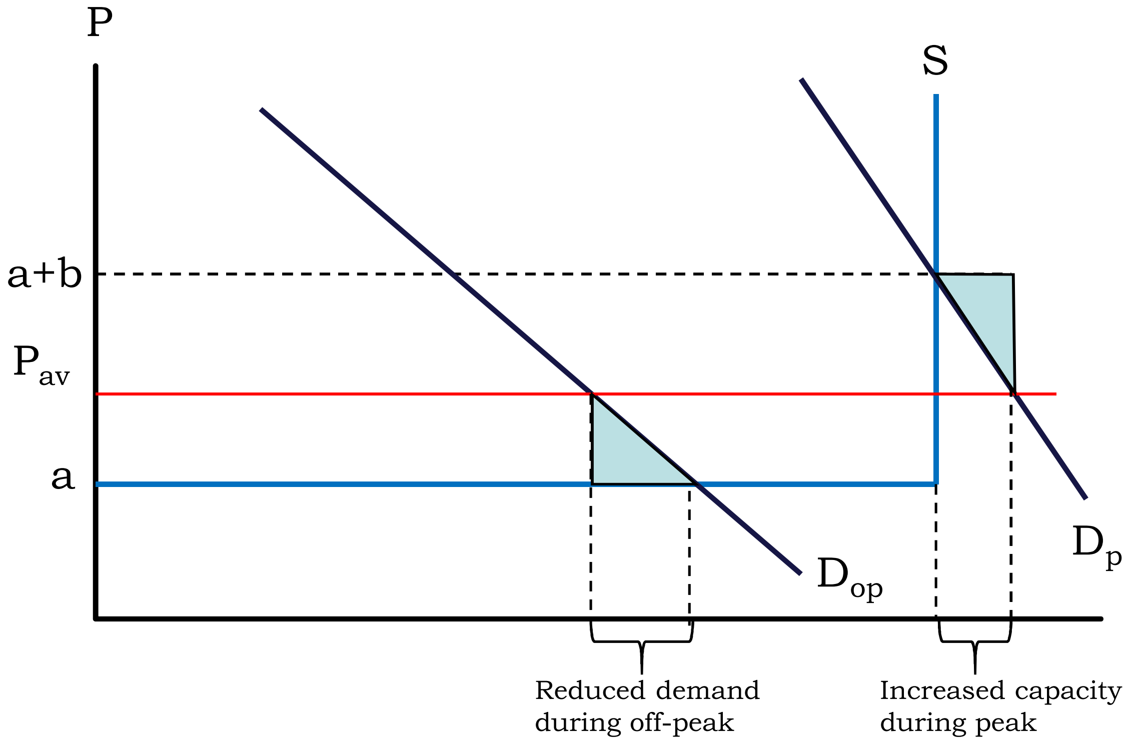
- Assume for simplicity:
  - *a*: constant operating cost (S-R MC)
  - *b*: fixed cost (per unit of capacity)
  - *a*+*b*: L-R MC

- During off-peak, customers are charged with the S-R MC, while costumers that come to the grid during peak hours, they are charged the full cost, that is, capacity and operating costs



Peak-load pricing

- In the case that peak-load pricing is not followed, but instead the utility is charging an average price P_{av}, then society losses both from the consumers during off-peak and the consumers during peak period



Peak-load pricing

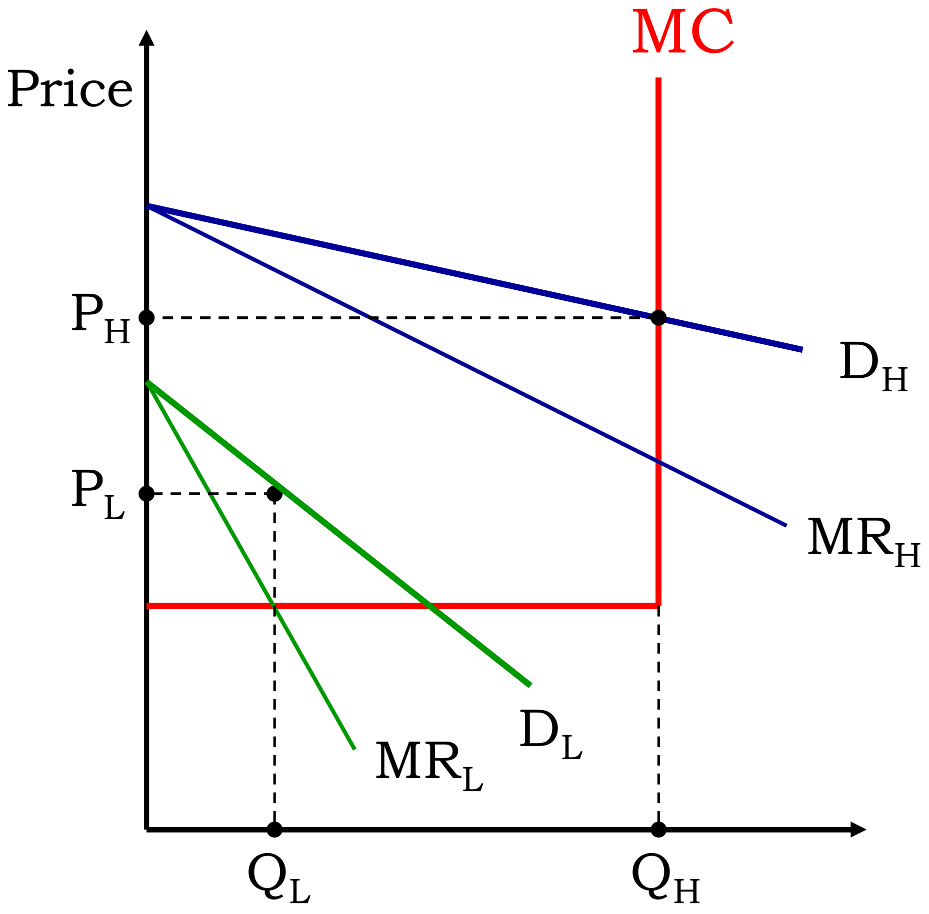
- When demand during peak times is higher than the capacity of the firm, the firm should engage in *peak-load pricing*.

- Peak times (days):

$$P_H = 74 - 5\,Q$$

- Off-peak times (nights):

$$P_L = 26 - 5\,Q$$



Peak-load pricing

- Peak-Load Pricing Example:

Suppose the demand function for a firm’s service is
Peak times (days): $P = 74 - 5Q$
Off-peak times (nights): $P = 26 - 5Q$
The marginal cost of providing the service is $MC = 2 + 2Q$.
Determine the day & night profit-maximizing prices.

We need to find when MR = MC for days & for nights.

For days,
$TR = PQ = (74 - 5Q)Q = 74Q - 5Q^2$
$MR = dTR/dQ = 74 - 10Q$.

$MR = MC$ implies $74 - 10Q = 2 + 2Q$ or $72 = 12Q$, so $Q = 6$

Peak price is $P = 74 - 5Q = 74 - 5(6) = \$44$ per unit.

Peak-load pricing

Next we need to do the same thing for nights to find the off-peak price.

We had these demand functions:

Peak times (days): $P = 74 - 5Q$

Off-peak times (nights): $P = 26 - 5Q$

and the marginal cost function was $MC = 2 + 2Q$.

For nights,

$TR = PQ = (26 - 5Q)Q = 26Q - 5Q^2$

So $MR = dTR/dQ = 26 - 10Q$.

$MR = MC$ implies $26 - 10Q = 2 + 2Q$, or $24 = 12Q$, so $Q = 2$

Off-peak price is $P = 26 - 5Q = 26 - 5(2) = \$16$ per unit (instead of $44 per unit as it was for peak times).

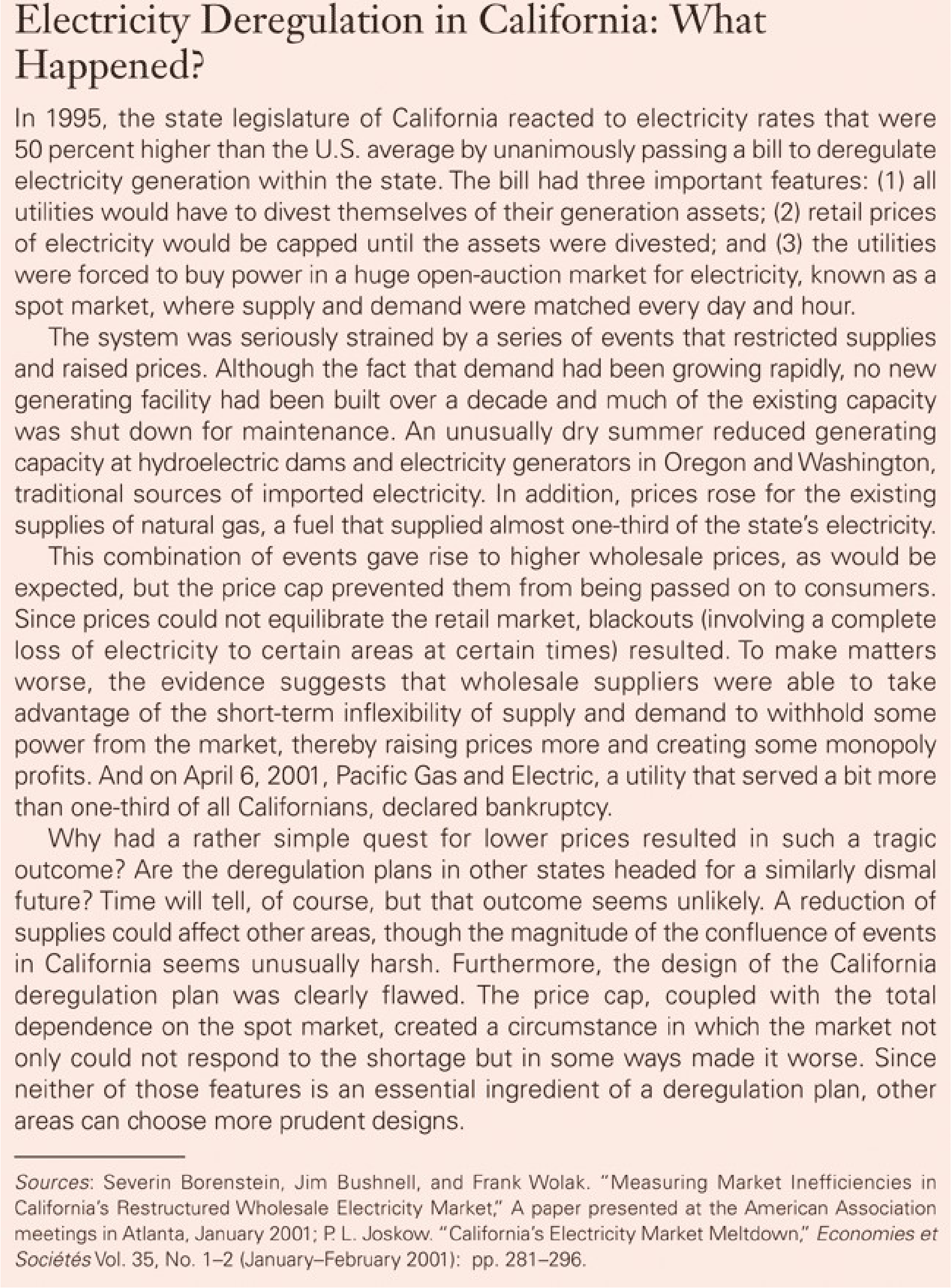
Electricity deregulation

- Historically, electricity was generated by regulated monopolies. In return for accepting both government control of prices and an obligation to service all customers, utilities were given the exclusive rights to service-specific geographic areas.

- In the 1990s, it was recognized that while electricity distribution has elements of a natural monopoly, generation does not. Therefore, several states and a number of national governments have deregulated the generation of electricity, while keeping the distribution under the exclusive control of a monopoly.
- In the US, electricity deregulation began in 1992 when Congress allowed independent energy companies to sell power on the wholesale electricity market.

- Forcing generators to compete for customers, it was believed, would produce lower electricity bills for customers. Experience reveals that lower prices have not always been the result.

EXAMPLE 7.4



Electricity Deregulation in California: What Happened?

In 1995, the state legislature of California reacted to electricity rates that were 50 percent higher than the U.S. average by unanimously passing a bill to deregulate electricity generation within the state. The bill had three important features: (1) all utilities would have to divest themselves of their generation assets; (2) retail prices of electricity would be capped until the assets were divested; and (3) the utilities were forced to buy power in a huge open-auction market for electricity, known as a spot market, where supply and demand were matched every day and hour.

The system was seriously strained by a series of events that restricted supplies and raised prices. Although the fact that demand had been growing rapidly, no new generating facility had been built over a decade and much of the existing capacity was shut down for maintenance. An unusually dry summer reduced generating capacity at hydroelectric dams and electricity generators in Oregon and Washington, traditional sources of imported electricity. In addition, prices rose for the existing supplies of natural gas, a fuel that supplied almost one-third of the state's electricity.

This combination of events gave rise to higher wholesale prices, as would be expected, but the price cap prevented them from being passed on to consumers. Since prices could not equilibrate the retail market, blackouts (involving a complete loss of electricity to certain areas at certain times) resulted. To make matters worse, the evidence suggests that wholesale suppliers were able to take advantage of the short-term inflexibility of supply and demand to withhold some power from the market, thereby raising prices more and creating some monopoly profits. And on April 6, 2001, Pacific Gas and Electric, a utility that served a bit more than one-third of all Californians, declared bankruptcy.

Why had a rather simple quest for lower prices resulted in such a tragic outcome? Are the deregulation plans in other states headed for a similarly dismal future? Time will tell, of course, but that outcome seems unlikely. A reduction of supplies could affect other areas, though the magnitude of the confluence of events in California seems unusually harsh. Furthermore, the design of the California deregulation plan was clearly flawed. The price cap, coupled with the total dependence on the spot market, created a circumstance in which the market not only could not respond to the shortage but in some ways made it worse. Since neither of those features is an essential ingredient of a deregulation plan, other areas can choose more prudent designs.

Sources: Severin Borenstein, Jim Bushnell, and Frank Wolak. "Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market," A paper presented at the American Association meetings in Atlanta, January 2001; P. L. Joskow. "California's Electricity Market Meltdown," *Economies et Sociétés* Vol. 35, No. 1–2 (January–February 2001): pp. 281–296.

Electricity and environment

- Electricity deregulation has also raised some environmental concerns. Since electricity costs typically do not include all the costs of environmental damage, the sources offering the lowest prices could well be highly polluting sources. In this case, environmentally benign generation sources would not face a level playing field; polluting sources would have an inefficient advantage.
- One policy approach for dealing with these concerns involves renewable energy credits (REC)
  - Deregulation and environmental concerns
  - Two saleable commodities: the electricity itself, which can be sold to the grid, and the renewable energy credit that turns the environmental attributes into a legally recognized form of property
  - Voluntary markets and compliance markets
  - Effects of renewable energy credits in U.S.

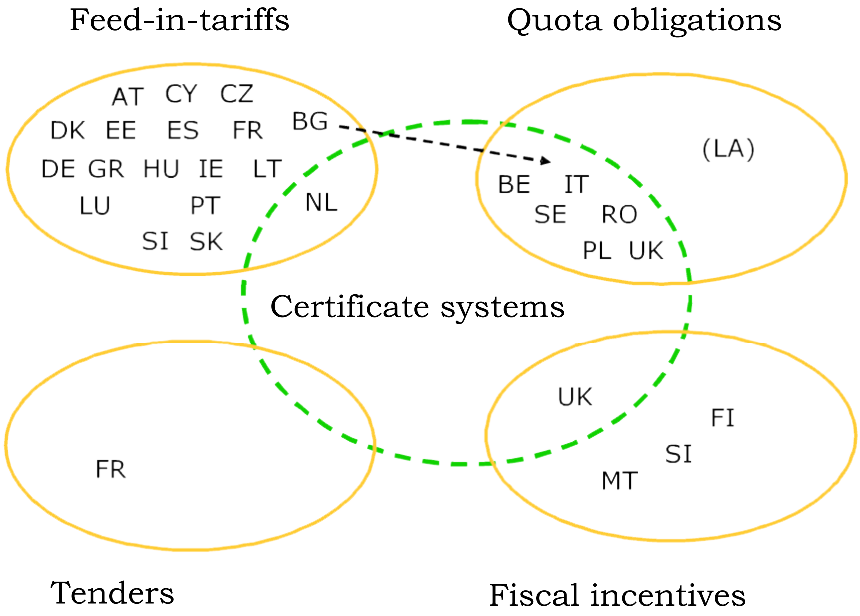
Policies supporting renewables

Different types of policies:

Price-based policies:
- Feed–in tariffs (also known as FITs)

Quantity based policies:
- Competitive bidding processes
- Renewable quota obligations

Fiscal incentives
- Tax relief (income tax reduction, investment credit, reduced VAT rate, accelerated depreciation, etc.)
- Rebates or payment grants (that refunds a share of the cost of installing the renewable capacity)
- Low interest loans, etc.



Feed-in-tariffs

AT CY CZ
DK EE ES FR BG
DE GR HU IE LT
LU PT NL
SI SK

Quota obligations

(LA)
BE IT
SE RO
PL UK

Certificate systems

FR

Tenders

UK
FI
SI
MT

Fiscal incentives

Tenders

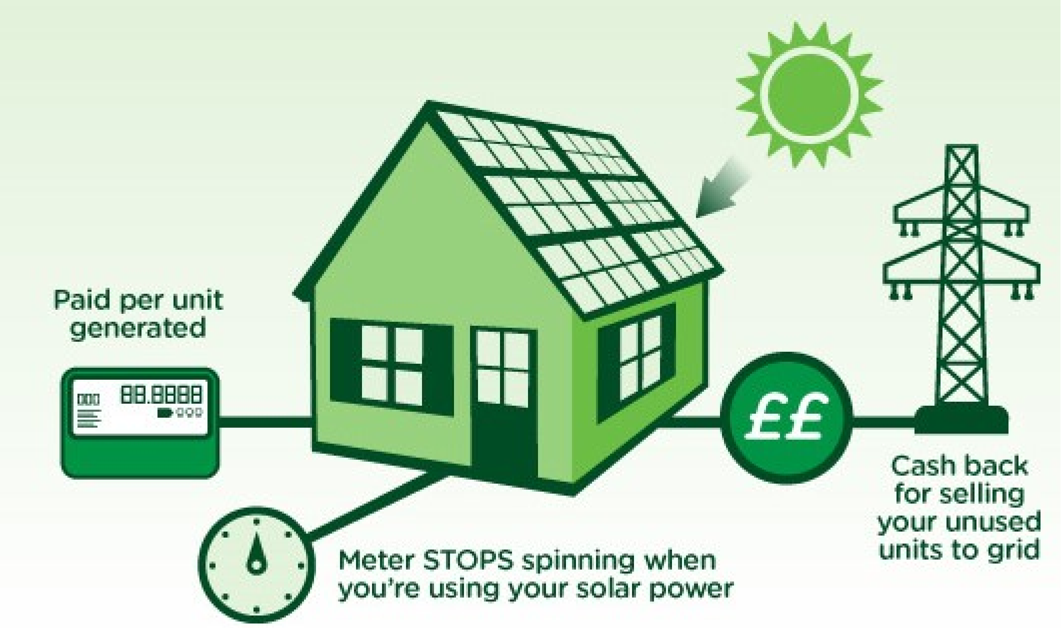
And taxes on fossil fuels

Policies supporting renewables

Feed–in tariffs (also known as FITs)

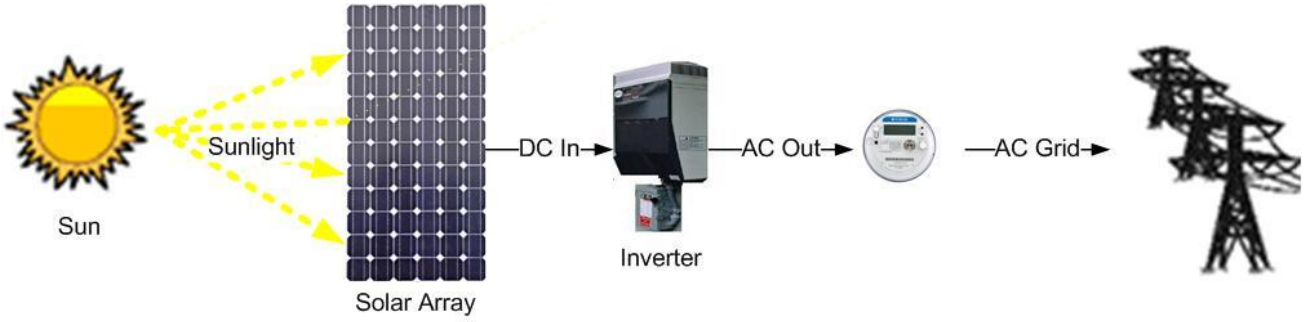
Electric utilities are required by law or regulation to buy renewable electricity at fixed prices set normally at higher than the market price.

The fixed price declines over time and is adjusted periodically but the tariffs are long-term in nature.



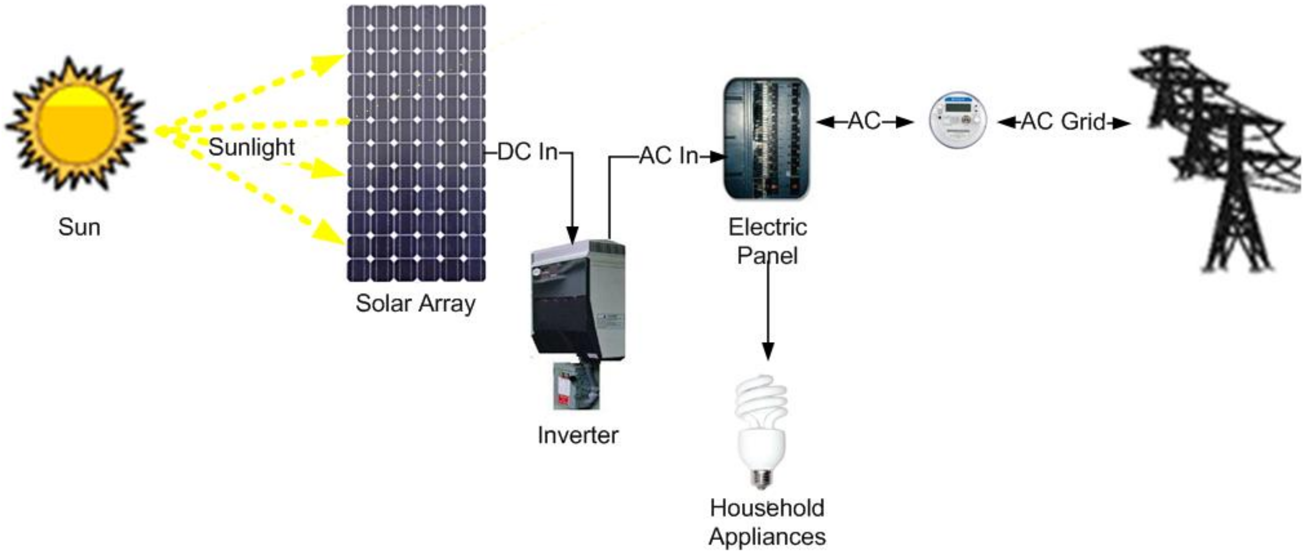
Generally the cost of subsidizing renewable electricity is passed on to the electricity consumers through the electricity tariff.

Policies supporting renewables



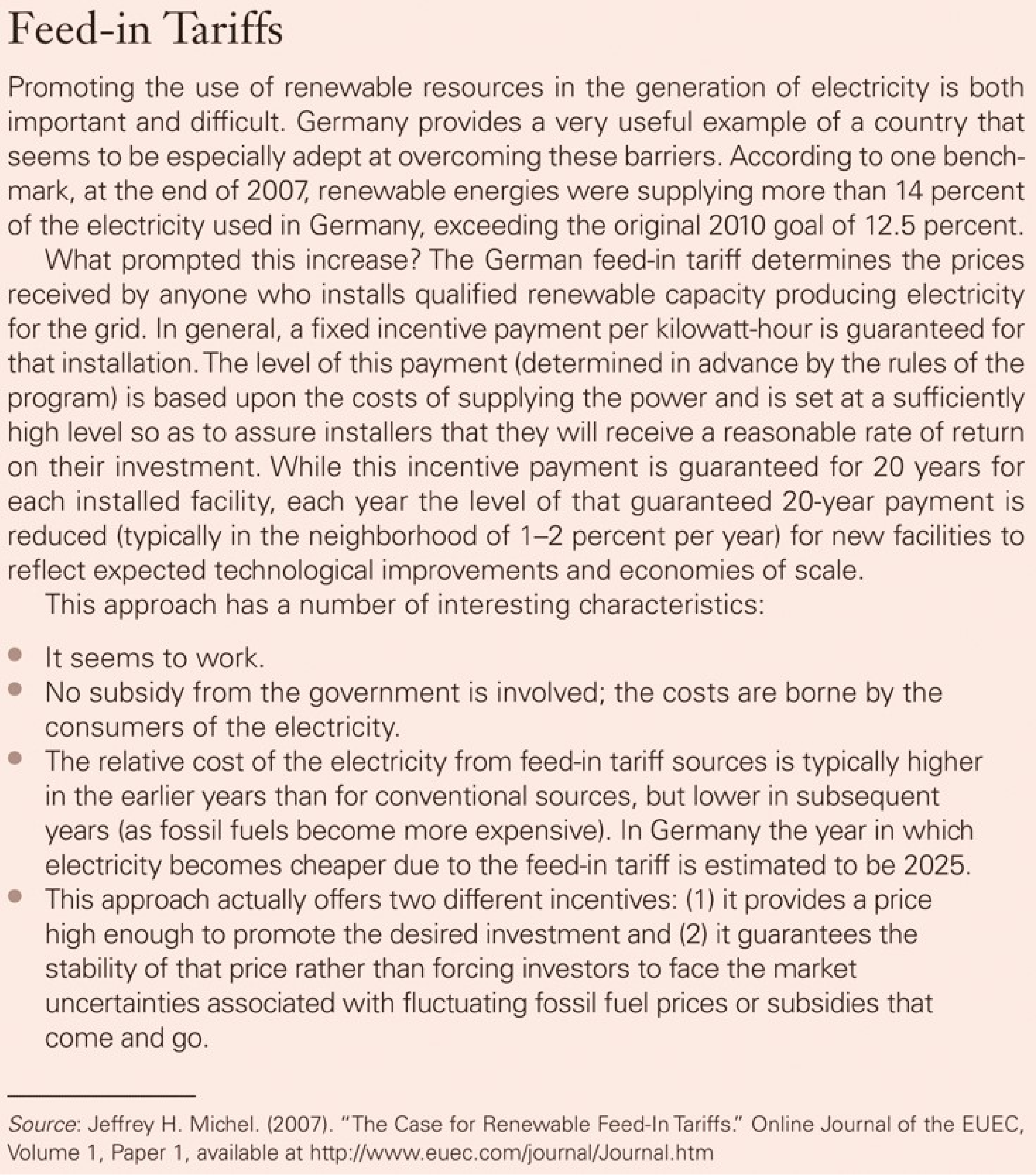
There are two models available for Solar PV systems:

Feed-In Tariff (FIT) Model



Netmetering Model

EXAMPLE 7.6



Feed-in Tariffs

Promoting the use of renewable resources in the generation of electricity is both important and difficult. Germany provides a very useful example of a country that seems to be especially adept at overcoming these barriers. According to one benchmark, at the end of 2007, renewable energies were supplying more than 14 percent of the electricity used in Germany, exceeding the original 2010 goal of 12.5 percent.

What prompted this increase? The German feed-in tariff determines the prices received by anyone who installs qualified renewable capacity producing electricity for the grid. In general, a fixed incentive payment per kilowatt-hour is guaranteed for that installation. The level of this payment (determined in advance by the rules of the program) is based upon the costs of supplying the power and is set at a sufficiently high level so as to assure installers that they will receive a reasonable rate of return on their investment. While this incentive payment is guaranteed for 20 years for each installed facility, each year the level of that guaranteed 20-year payment is reduced (typically in the neighborhood of 1–2 percent per year) for new facilities to reflect expected technological improvements and economies of scale.

This approach has a number of interesting characteristics:

- It seems to work.
- No subsidy from the government is involved; the costs are borne by the consumers of the electricity.
- The relative cost of the electricity from feed-in tariff sources is typically higher in the earlier years than for conventional sources, but lower in subsequent years (as fossil fuels become more expensive). In Germany the year in which electricity becomes cheaper due to the feed-in tariff is estimated to be 2025.
- This approach actually offers two different incentives: (1) it provides a price high enough to promote the desired investment and (2) it guarantees the stability of that price rather than forcing investors to face the market uncertainties associated with fluctuating fossil fuel prices or subsidies that come and go.

Source: Jeffrey H. Michel. (2007). "The Case for Renewable Feed-In Tariffs." Online Journal of the EUEC, Volume 1, Paper 1, available at http://www.euec.com/journal/Journal.htm

Transitioning to Renewables

- Hydroelectric Power
  - Clean energy source
  - Helpful with national security concerns
  - Having impact on ecosystem
- Wind
  - Cost effective in favorable sites
  - Environmental effects have triggered debates
  - (insert Debate 7.2)
- Photovoltaics
  - Direct conversion of solar energy into electricity
  - Attractive in developing countries

Transitioning to Renewables

- Active and Passive Solar Energy for heating
  - Input energy is costless while transformation and distribution requires capital investment.
- Ocean Tidal Power
  - The plant has impact on coastal ecosystem.
  - Construction costs are high.
- Liquid Biofuels
  - Have the potential to reduce greenhouse gases and imports on oil
  - They include two alcohols: ethanol and methanol, and biodiesel.

Transitioning to Renewables

- Geothermal Energy
  - Derived from the earth's heat
  - Initial cost is high, the payback periods vary from 2-10 years.
- Hydrogen
  - Technologies of using hydrogen is expensive, and the infrastructure is undeveloped.
  - Using government subsidies has impact on promoting the renewable energy resources.