Energy Economics and Policy
AUEB

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Lecture 1:
Introduction
and basic concepts

Communication

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About me

I am a senior consultant at the Quant and Analytics team of Ernst & Young, Switzerland, with a focus on sustainable finance and climate change risk management for financial services. At the same time I am lecturing climate, environmental and energy economics. As an academic, my research focus is in the areas of climate finance, growth theory, environmental & energy economics, development economics.

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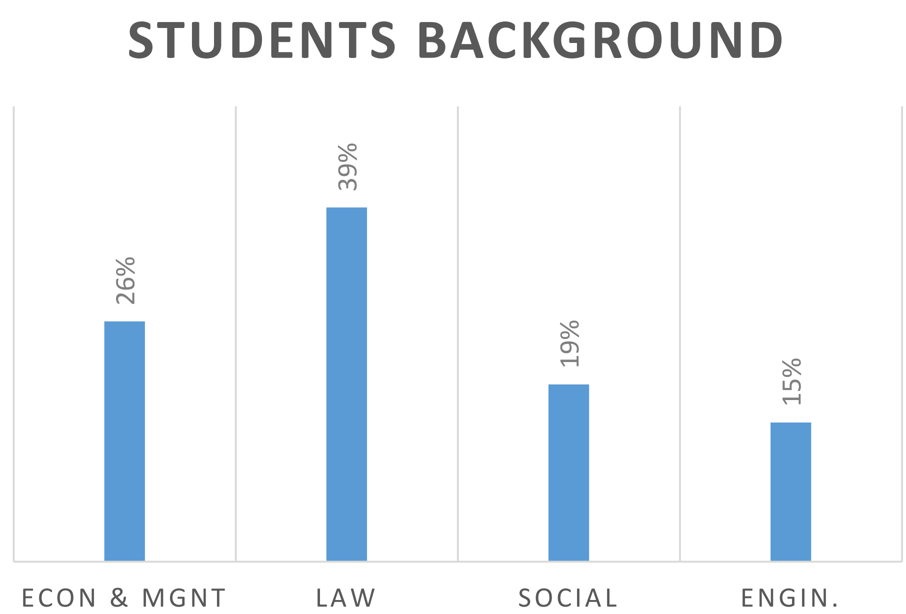
What is this course about?

- Economics deals with optimization under scarcity
- Optimization: monetary and/or welfare-based
- Energy economics lies at the crossroad between engineering and economics
- Our course deals with fundamental *economic* concepts, *technical and institutiona*l background and *policy* evaluation related to energy industries

Objectives – What's in it for you?



- Learn and apply economic theory on energy markets
- Study the economics of fossil energies and electricity
- Evaluate energy and environmental policies
- Understand the role of energy for sustainable development
- Real world examples and current issues

Syllabus

1. Introduction
2. Economic principles
3. Energy economic modelling (+ 1st Exercise set)
4. Electricity markets ← Guest lecturer: Prof. Antony Papavasiliou NTUA
5. Oil and gas markets (+ 2nd Exercise set)
6. Non-renewable resources
7. Sustainable development (+ 3rd Exercise set)
8. Policy evaluation (+ Wrap-up)

→ Exam

Organization of the course

- 8 Weekly lectures (3 x 45' each)
- Grading:
  - Exam – 70%
  - 3 Exercise sets – 30% (best 2 out of 3)
- Slides and exercises on eClass
- Exercises will be solved and handed in individually (although groupwork is encouraged); solutions will be provided
- Requirements: basic calculus, basic Microsoft Excel (free alternative – e.g. libreoffice), motivation
- Reading on theory: Pindyck and Rubinfeld, "Microeconomics", 9^{th} ed.
  - Syllabus from book will be provided
- Additional reading will be paper-based

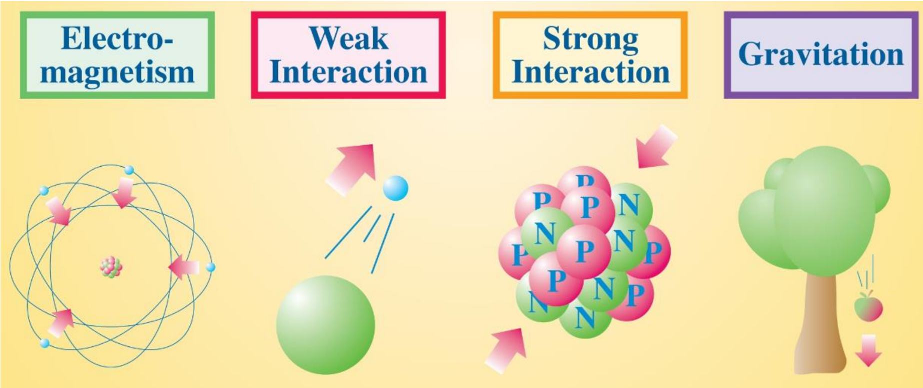
Economic concepts covered

- Demand and supply
- Elasticities
- Market equilibrium
- Tax incidence
- Market arrangements (e.g. competition, monopoly)
- Optimization
- Externalities
- Public goods
- Sustainable development
- ...

Fundamental forces of Physics

From macro to micro…

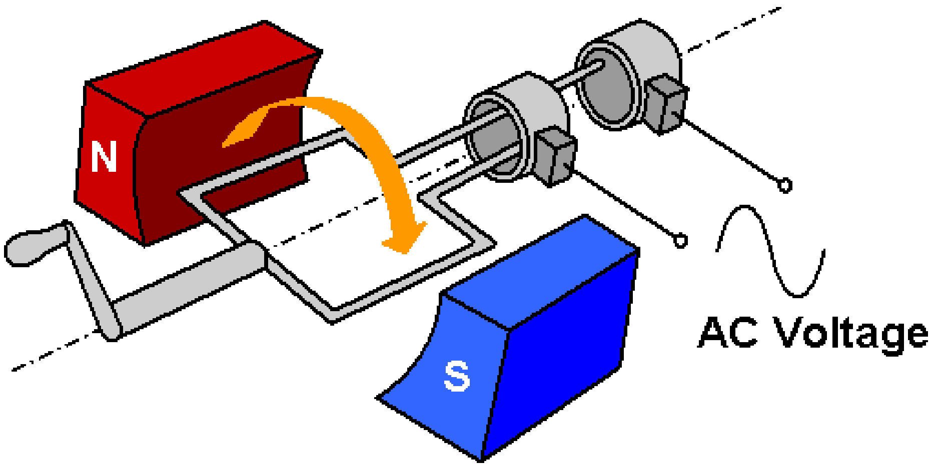
- **Gravity**: holds the universe together
- **Electromagnetism**: Attraction between +- charge / repulsion when - - or ++. It is carried by photons with various wavelengths (energy) ranging from radiofrequencies, visible light, …to X- and γ-rays. It is responsible for holding molecules together and for chem. reactions
- **Weak nuclear** force: governs radioactive decay
- **Strong nuclear** force: holds nuclei of atoms together irrespective of their charge. When large atoms are split energy is released (nuclear)

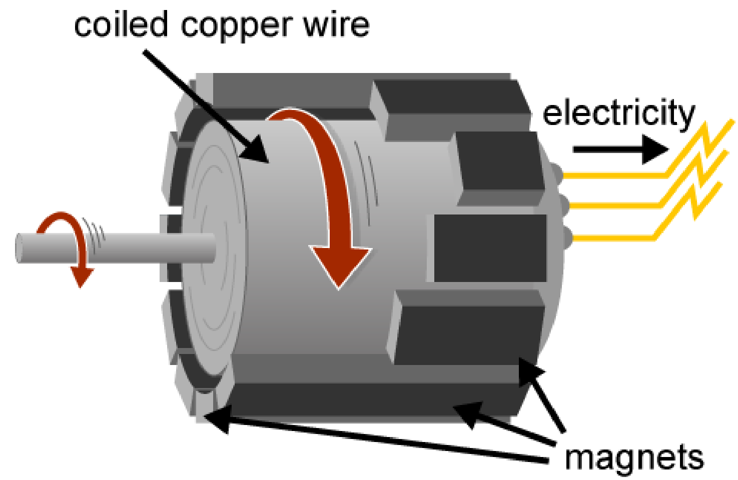


Forms of commercial energy

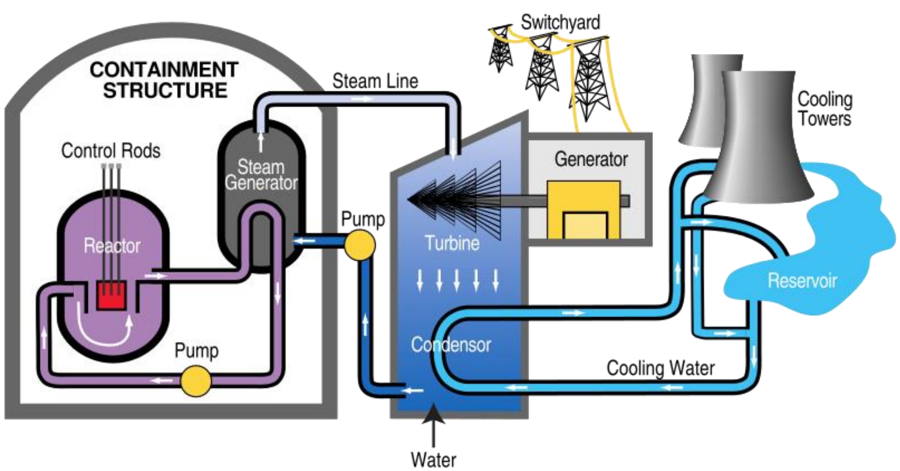
- **Mechanical**: associated with motion, e.g. water falls, tides, wind
- **Chemical**: associated with energy released when molecular bonds are changed, e.g. the combustion of fossil fuels
- **Thermal**: associated with the vibration of molecules, e.g. by-product of combustion – CHP power plant
- **Radiant**: all forms of electromagnetic radiation, e.g. solar
- **Nuclear**: results from strong molecular force
- **Electric**: movement of electrons as a consequence of the electromagnetic force

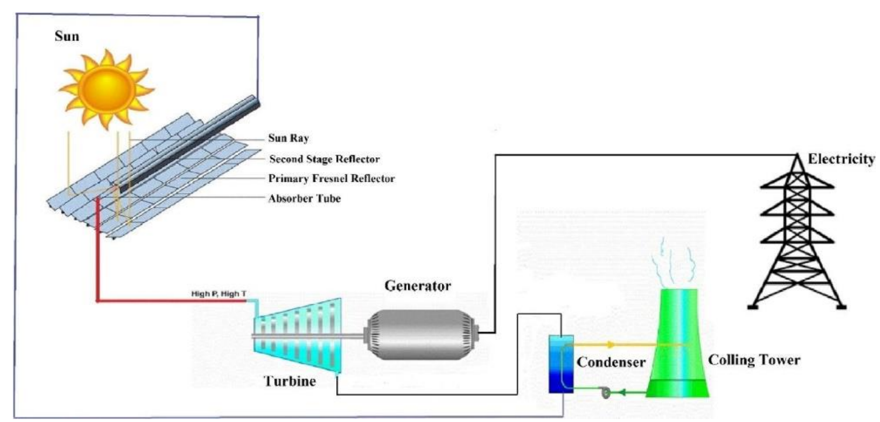
Let there be light!





Changes in magnetic fields create electricity

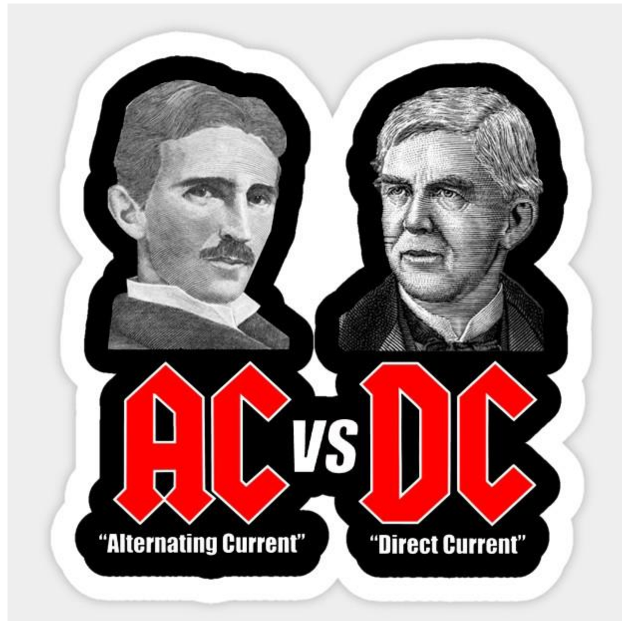




nuclear power plant

solar thermal power plant

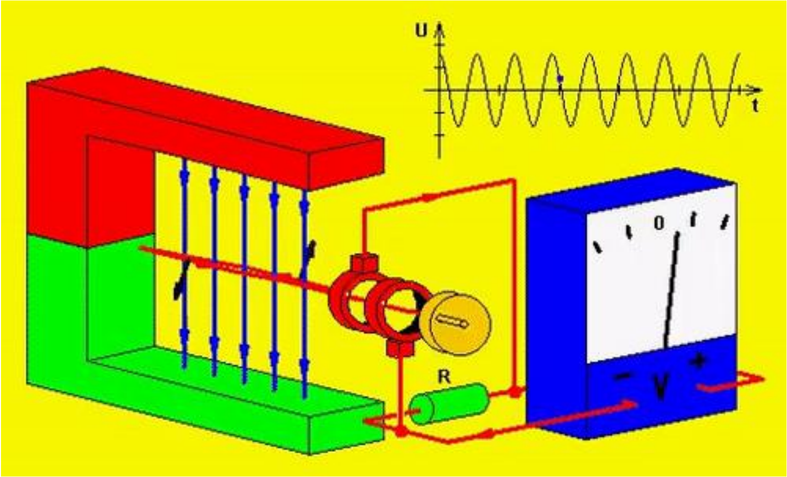
The war of currents (1880-1893)

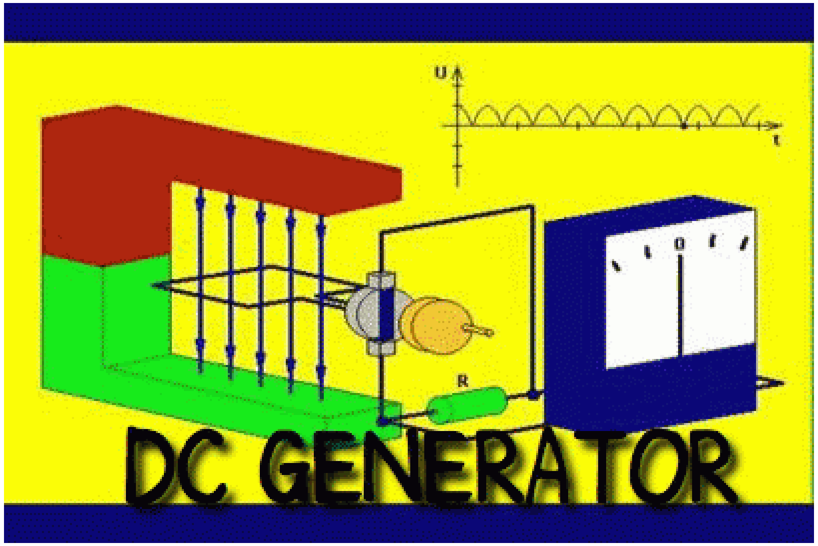


Tesla vs. Edison

Nikola Tesla & George Westinghouse supported AC power generation while Thomas Edison DC. The goal was incandescent lighting. War came to an end in 1893 when Chicago World's Fair gave the contract to Westinghouse to provide electricity.

The war of currents (1880-1890)

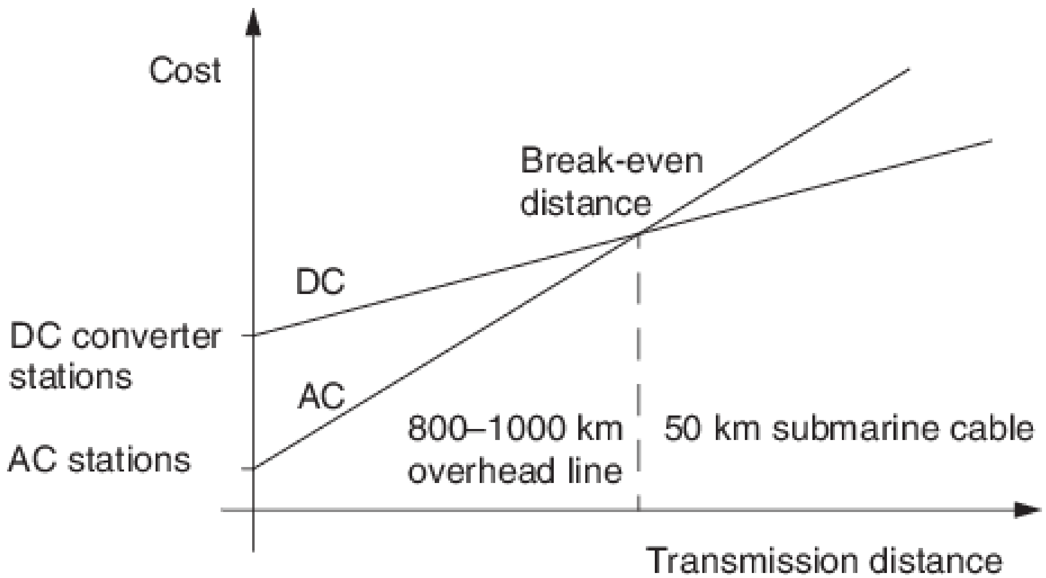




AC vs. DC

Actually war goes on..

Biggest issue: AC can change voltage and transfer big amounts of energy over long lines



https://www.entsoe.eu/data/map/

Energy vs. Power

- **Energy** is the ability to create a change, create motion, do work
  - Lifting a box requires a specific amount of energy from start to finish
  - Work is the act of exerting a force over a distance
  - Energy units: kWh, Joules, tons of oil equivalent (toe), BTU,…

- **Power** is how fast energy is used or transmitted, i.e. the amount of energy divided by the time it took to use energy ($P=\Delta E/\Delta t$)
  - Working faster = more power
  - Rate at which energy flows
  - Energy at peak capacity – how much *power* can a system deliver at any moment
  - Measured in Watts (W), kW (1000 W), MW (1000 kW), hp …

Some dimensions

- Electricity consumption of a 2-person household: ~3 MWh/a
- Electricity consumption of an office with 20 workstations: ~20 MWh/a
- Peak demand of a medium hospital: ~2.5 MW

- 1 kWh:
  - 1 washing machine cycle
  - 200 h lighting of a room with a 5W LED lamp
  - Cook dinner for 4
- 5 MWh (=5000 kWh):
  - Annual production of 5 kWp PV power plant (50 sqm)
  - 50 min. production of a 6 MW wind turbine (63 m radius, 135 m hub height)
  - 5 min. production of a 60 MW hydro power plant

The demand for energy

Energy is an essential factor of production of all goods and services

$$Y = f(K, L, E; A)$$

represents a production function, i.e., the **output** of a production process *f* that for a given technological level *A,* uses as **inputs** capital K (e.g. buildings, machinery and human capital), labor L (man-hours spent at work) and energy E (heating, electricity, raw oil?)

E is **essential** for the production of *Y* if *Y=0 when E=0* → *no production without energy*

The demand for energy

The demand for energy is determined by

- The demand for energy services (lighting, cooking, heating, cooling, mobility, washing, …)
- The demand for industrial goods (cars, machines, computers,…)
- Consumers and firms don’t consume energy directly (raw forms) – transformation of chemical energy (gasoline) to mechanical energy (engine) to kinetic energy (motion)

What kind of “energy”?

Primary energy: energy content of natural resources / raw fuels

- Before any engineering / chemical process takes place
- Non renewable: minerals – oil, gas, coal, uranium
- Renewable: solar, wind, hydro, tidal, geothermal, biomass

Secondary energy: energy ready for transportation or transmission

- Converted by an energy system, e.g. oil refinery, power station
- Main energy carriers: fuel oil, electricity, mechanical work, district heating

Final energy: what the consumer buys

Useful energy: energy used as an input in an end-use application

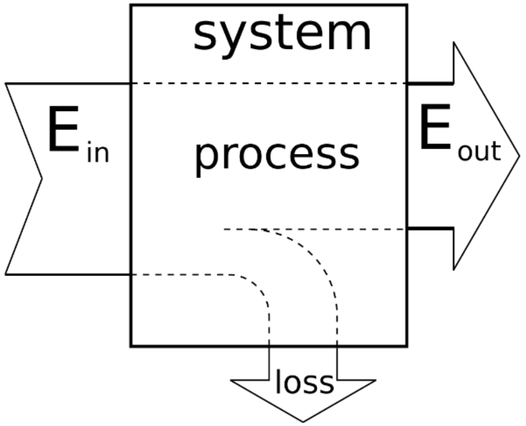
→

Energy efficiency: energy in vs energy out

- Energy conversion from primary to consumed energy produces losses, e.g., waste heat by light bulbs or by power plants
- Efficiency: how well primary energy is converted to secondary

Efficiency

Conversion process	Conversion type	Energy efficiency
Electricity generation		
Gas turbine	Thermal to electrical	up to 40%
Gas turbine plus steam turbine (combined cycle)	Thermal to electrical	up to 60%
Water turbine	Gravitational to electrical	up to 90% (practically achieved)
Wind turbine	Kinetic to electrical	up to 59% (theoretical limit)
Solar cell	Radiative to electrical	6–40% (technology-dependent, 15-20% most often, 85–90% theoretical limit)
Fuel cell	Chemical to electrical	up to 85%



Understanding the economical use of energy involves understanding both the technical and the social factors (e.g. prices, income etc)

Origins of energy economics

Prehistory:

- 4000BC (Iraq) animals were first used in agriculture
- Animals were the energy source. They convert hay to mechanical energy.
- Availability of land (food for animals and men) limiting factor in ancient times
- Wood was the main fuel – 13th century England faced extensive deforestation

Industrial revolution (1800s):

- Extensive use of coal with higher energy content (x5) than wood
- 50 horses were replaced by a single steam engine (Newcomen)
- Energy efficiency of first coal engine 1% - also high sulphur emissions
- Expanded income per capita and lead to investment in human capital
- Demographic transition also started then

Origins of energy economics

From coal to oil

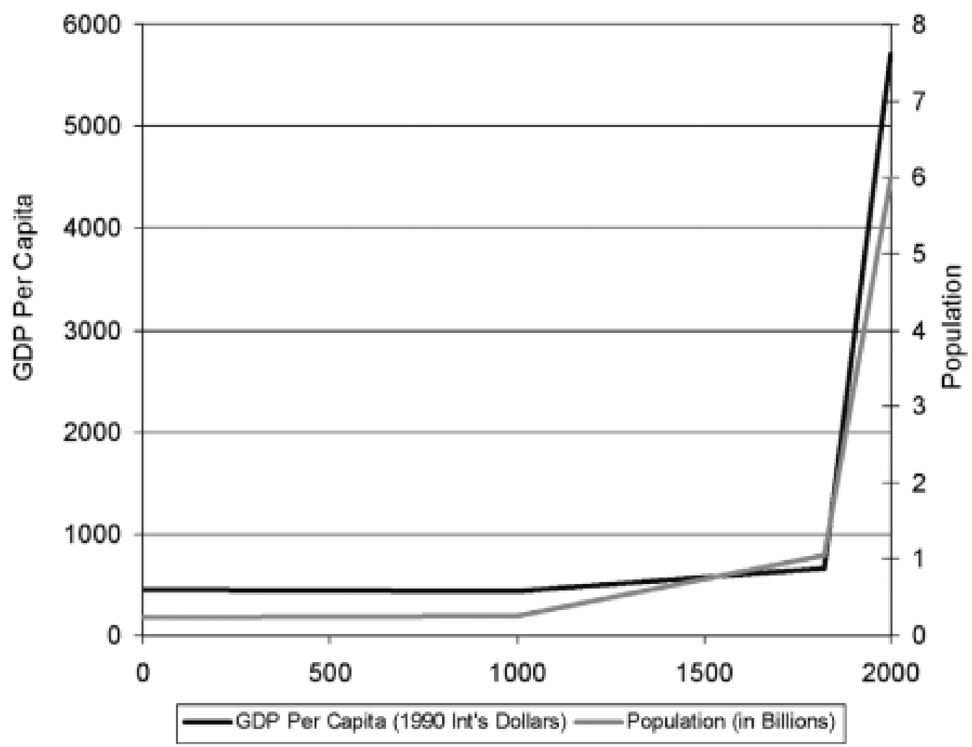
- Al and Curt Hammil first struck oil at Spindletop (Texas) in 1901
- Henry Ford introduced Model A burning oil
- Oil offered higher energy density than coal
- Coal with a higher carbon content burns cleaner

The end of oil? The end of the economy?

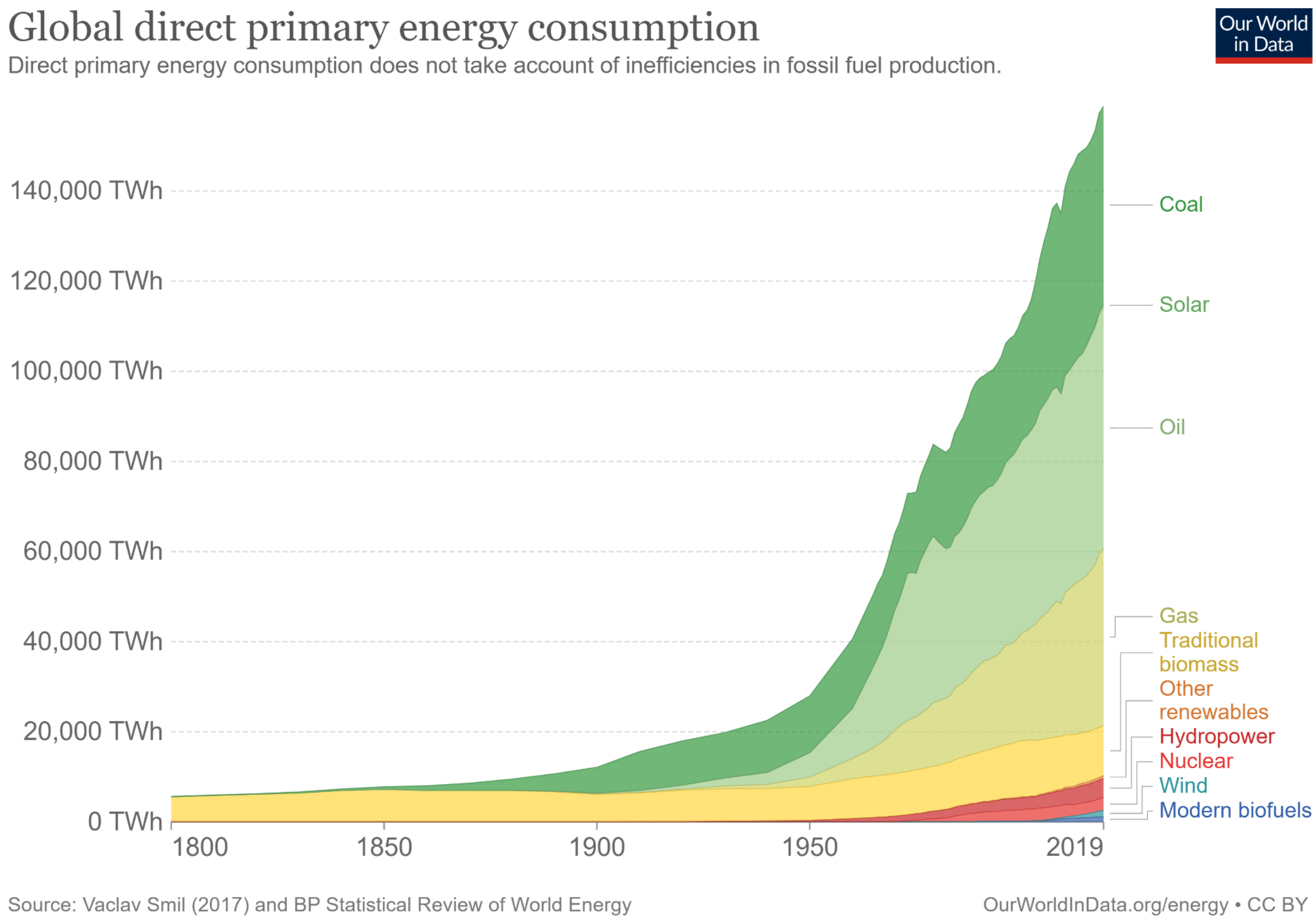
- Peak of oil
- Limits to growth (Club of Rome, Meadows et al. 1972)
- Innovation and R&D create substitutes and improve efficiency
- Substitutes to fossil energy: Renewables and other forms of capital (physical, human, intellectual)

The Malthusian era (pre 1820)

- Constant income p.c. before the ind. Revolution (Malthusian trap)
- Industrial revolution and technological development increased the need for energy

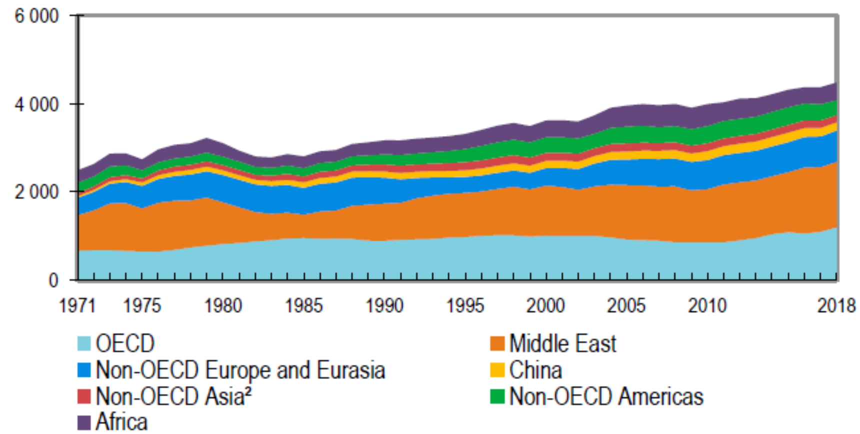


How much energy?

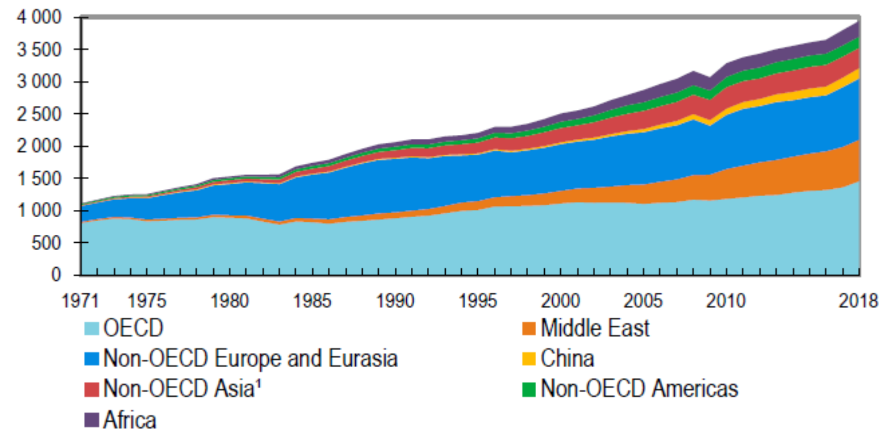


Mineral resources

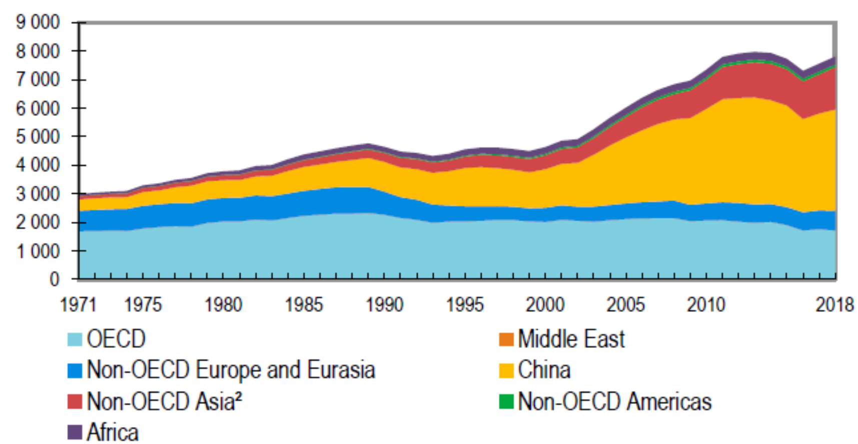
World crude oil[1] production from 1971 to 2018 by region (Mt)



World natural gas production from 1971 to 2018 by region (billion cubic metres, bcm)

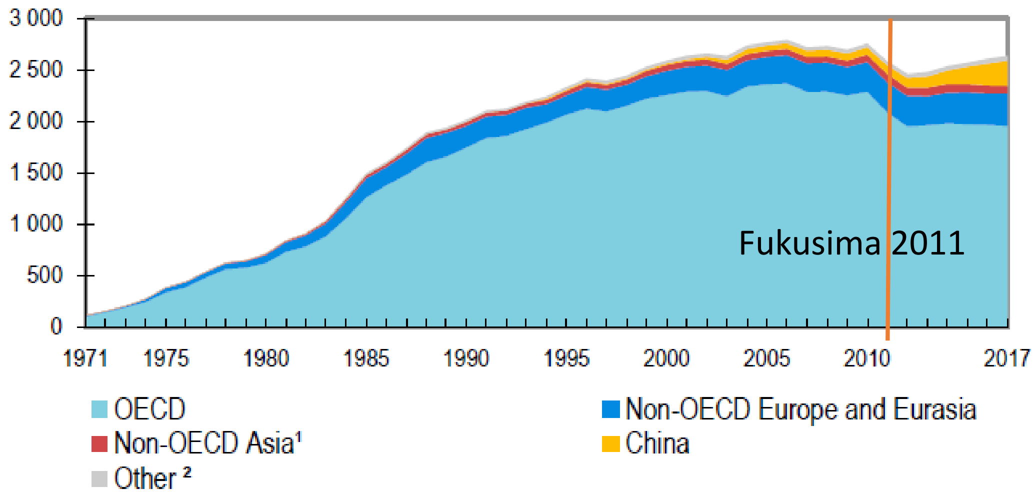


World coal[1] production from 1971 to 2018 by region (Mt)



Nuclear electricity

World nuclear electricity production from 1971 to 2017 by region (TWh)

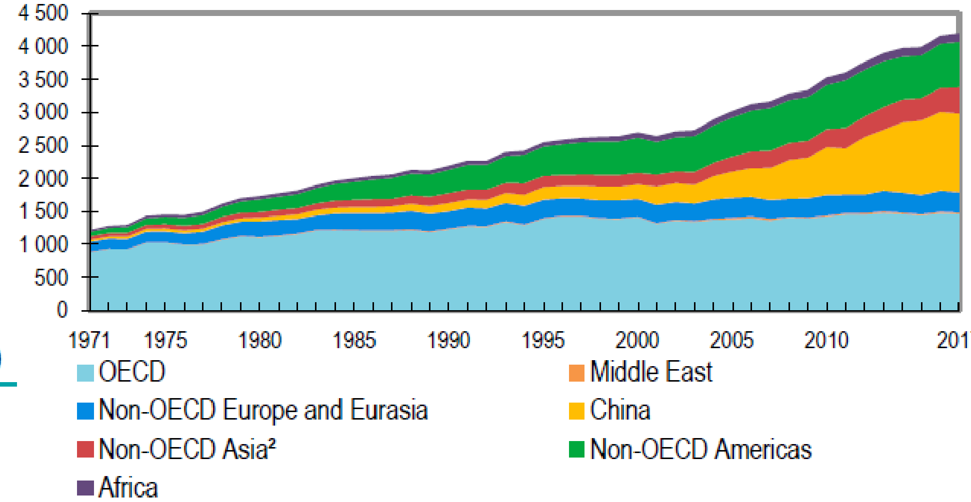


Producers	TWh	% of world total
United States	839	31.8
France	398	15.1
People's Rep. of China	248	9.4
Russian Federation	203	7.7
Korea	148	5.6
Canada	101	3.8
Ukraine	86	3.3
Germany	76	2.9
United Kingdom	70	2.7
Sweden	66	2.5
Rest of the world	401	15.2
World	**2 636**	**100.0**

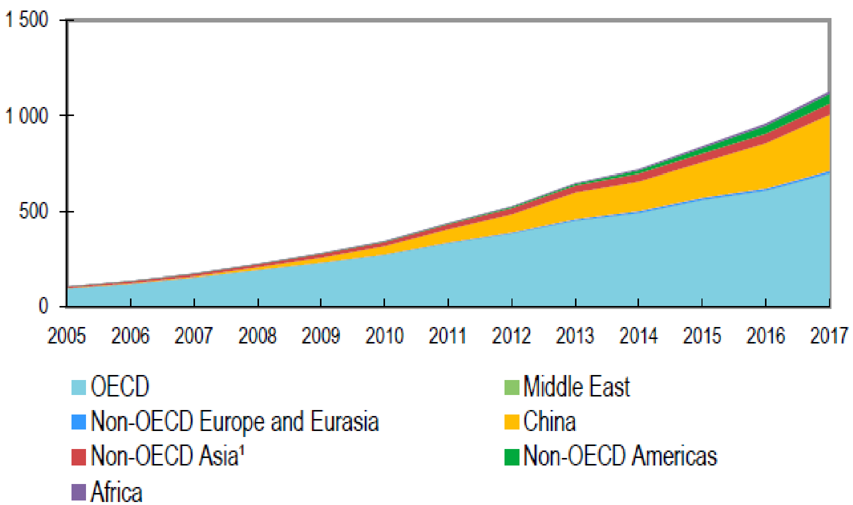
2017 data

Renewables

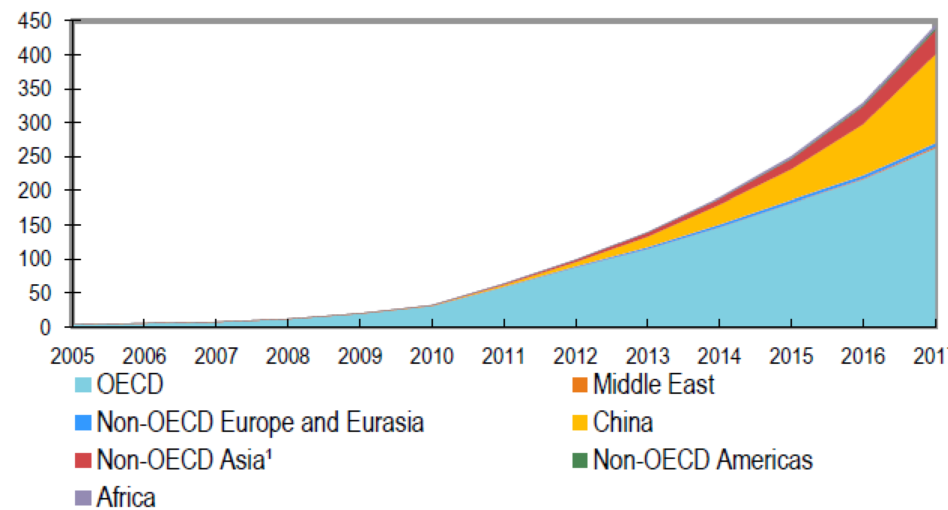
World hydroelectricity production[1] from 1971 to 2017 by region (TWh)



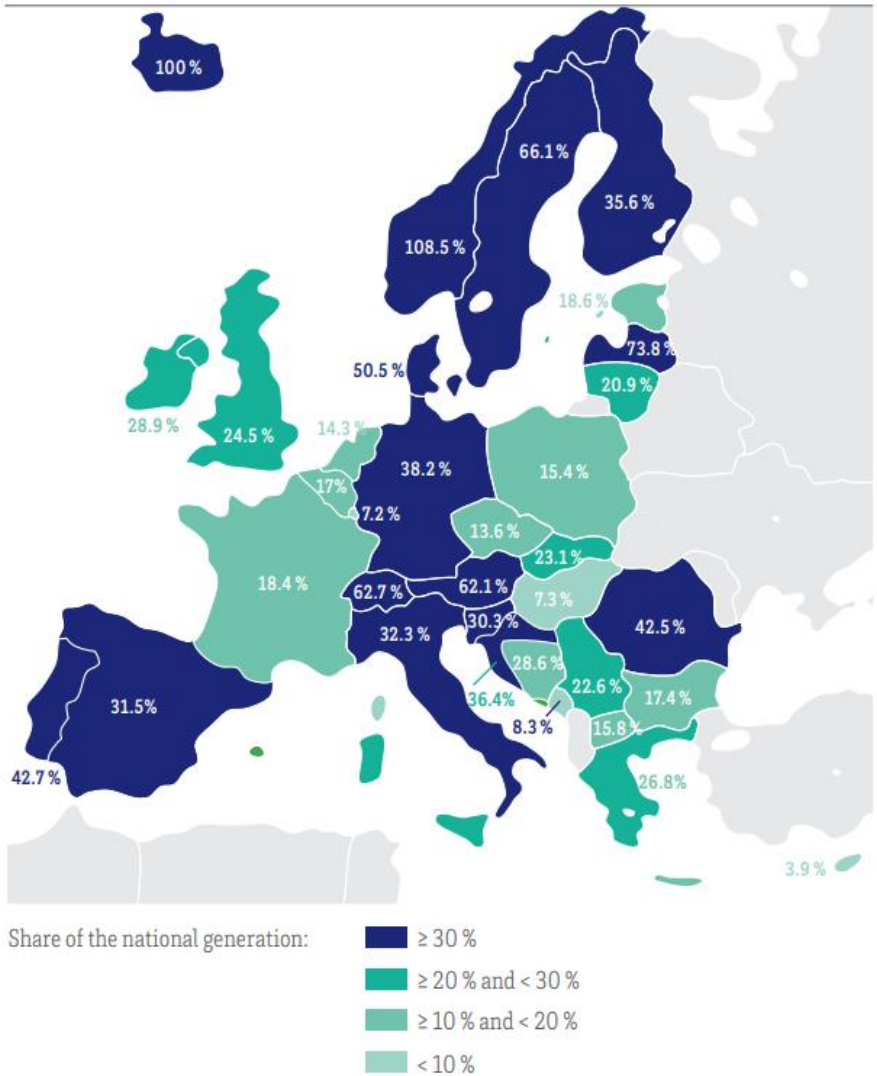
World wind electricity production from 2005 to 2017 by region (TWh)



World solar PV electricity production from 2005 to 2017 by region (TWh)

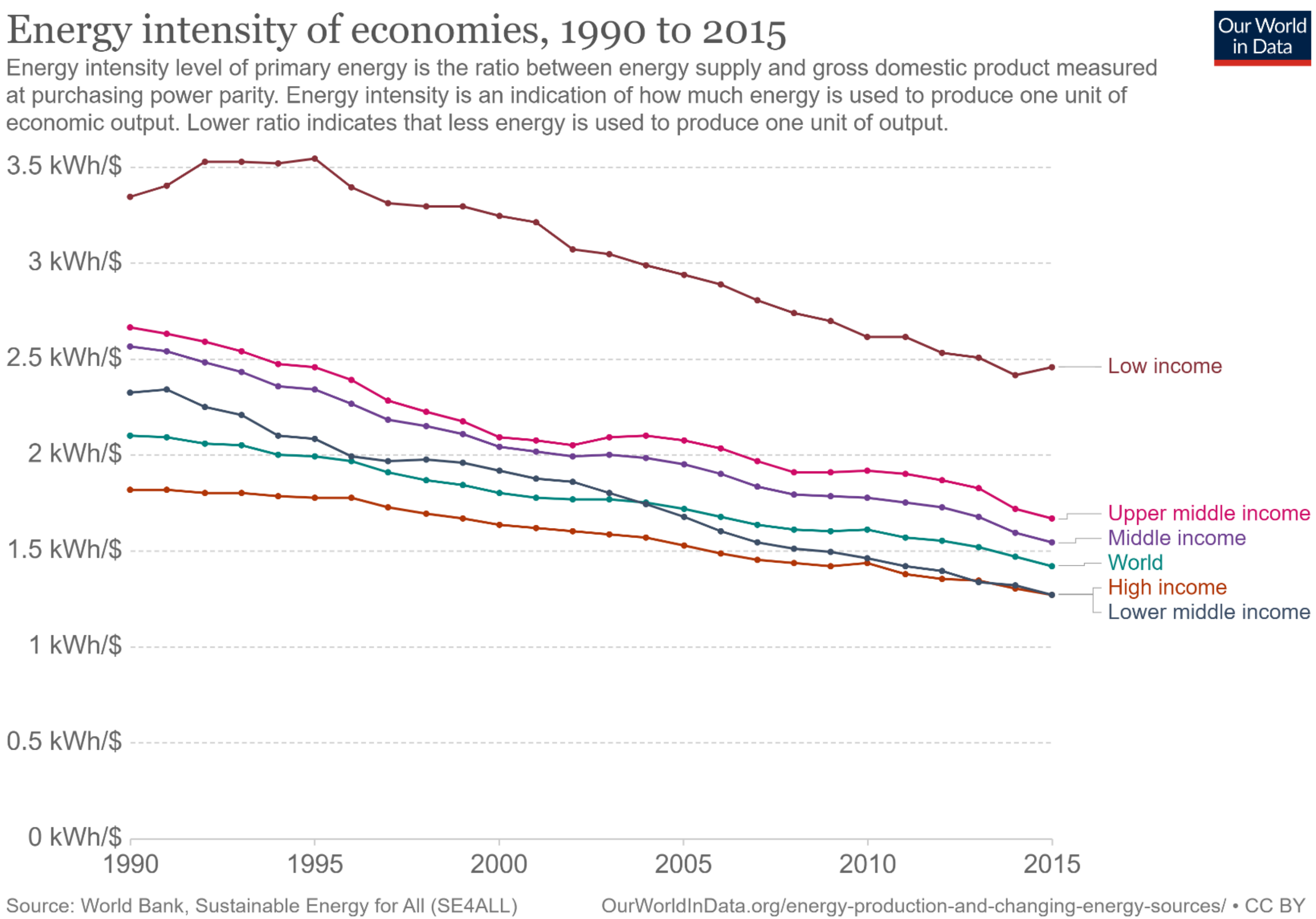


Renewable electricity

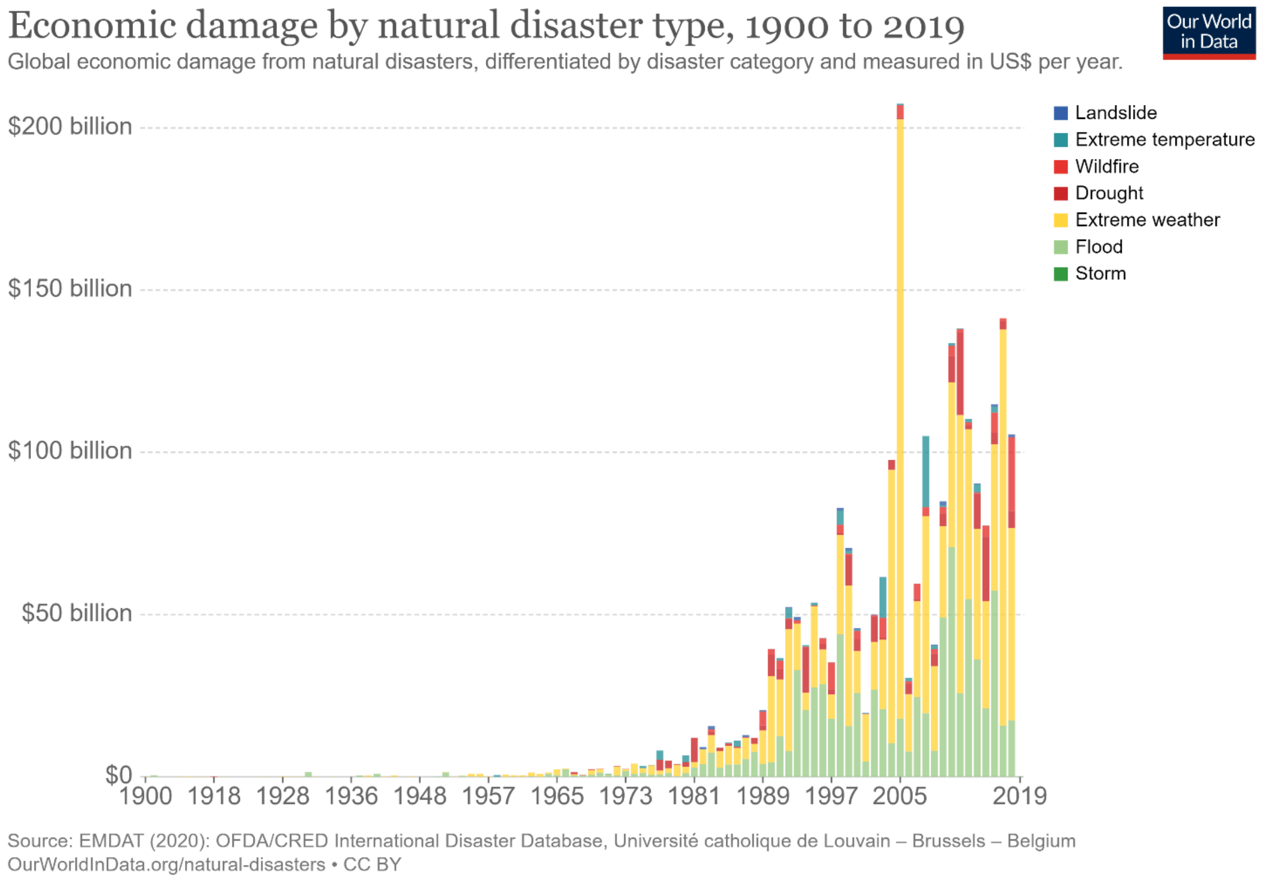


Scarcity not an issue

Thinking of Russia – Ukraine war?



… scarce environment is



→ Decarbonization → Sustainable development goals (SDGs)

Contemporary issues

Climate change

(Polluting) non-renewable resources important for production

- However: innovation and capital are increasingly substituting fixed resources such as land and non-renewable resources

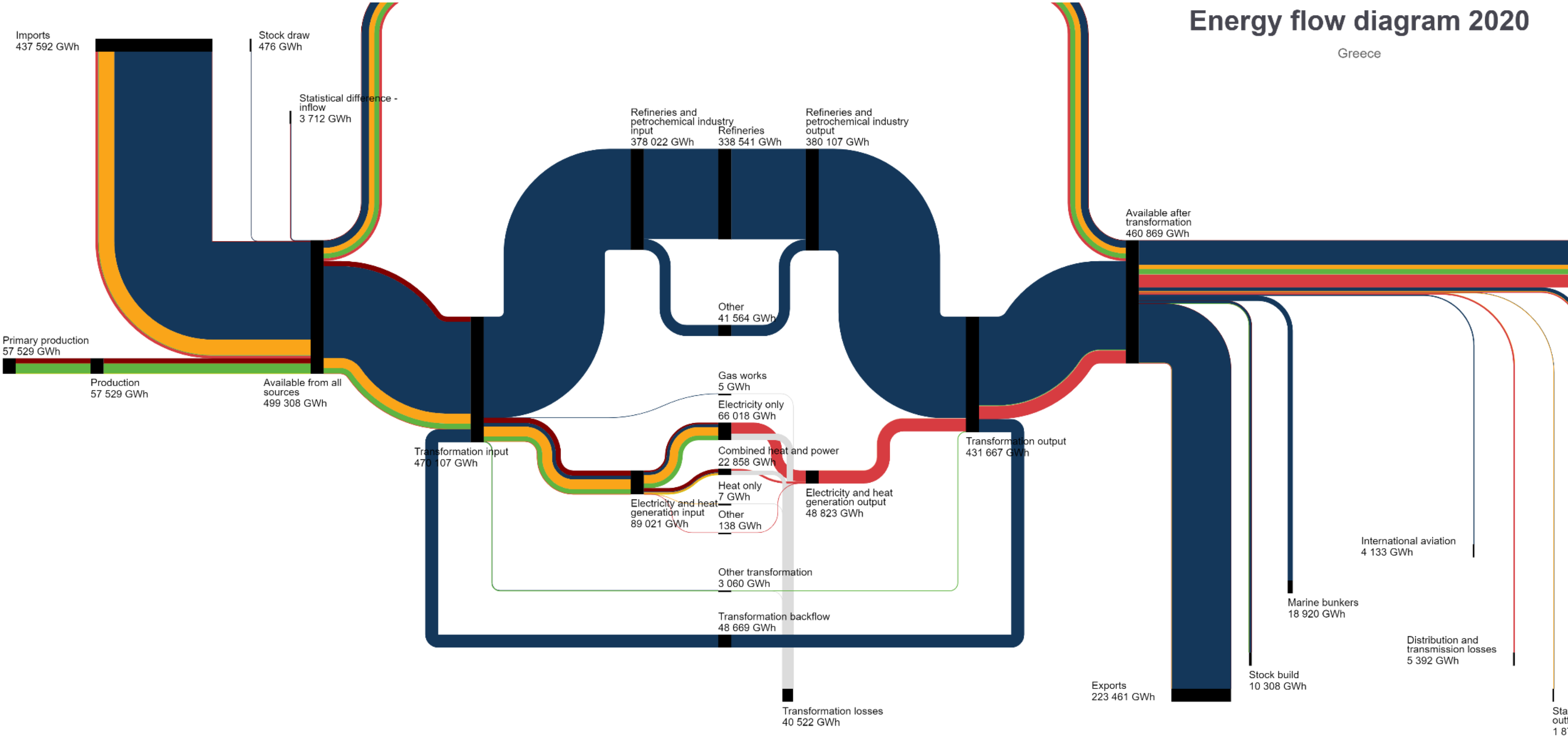
New problem: scarcity of clean environment - Climate change

- How can we correct the externality?
- Physical risks: drag on growth through natural disasters
- Transition risks: stringent environmental policy leads to stranded assets → financial stability impaired?

Policy – Energy transition

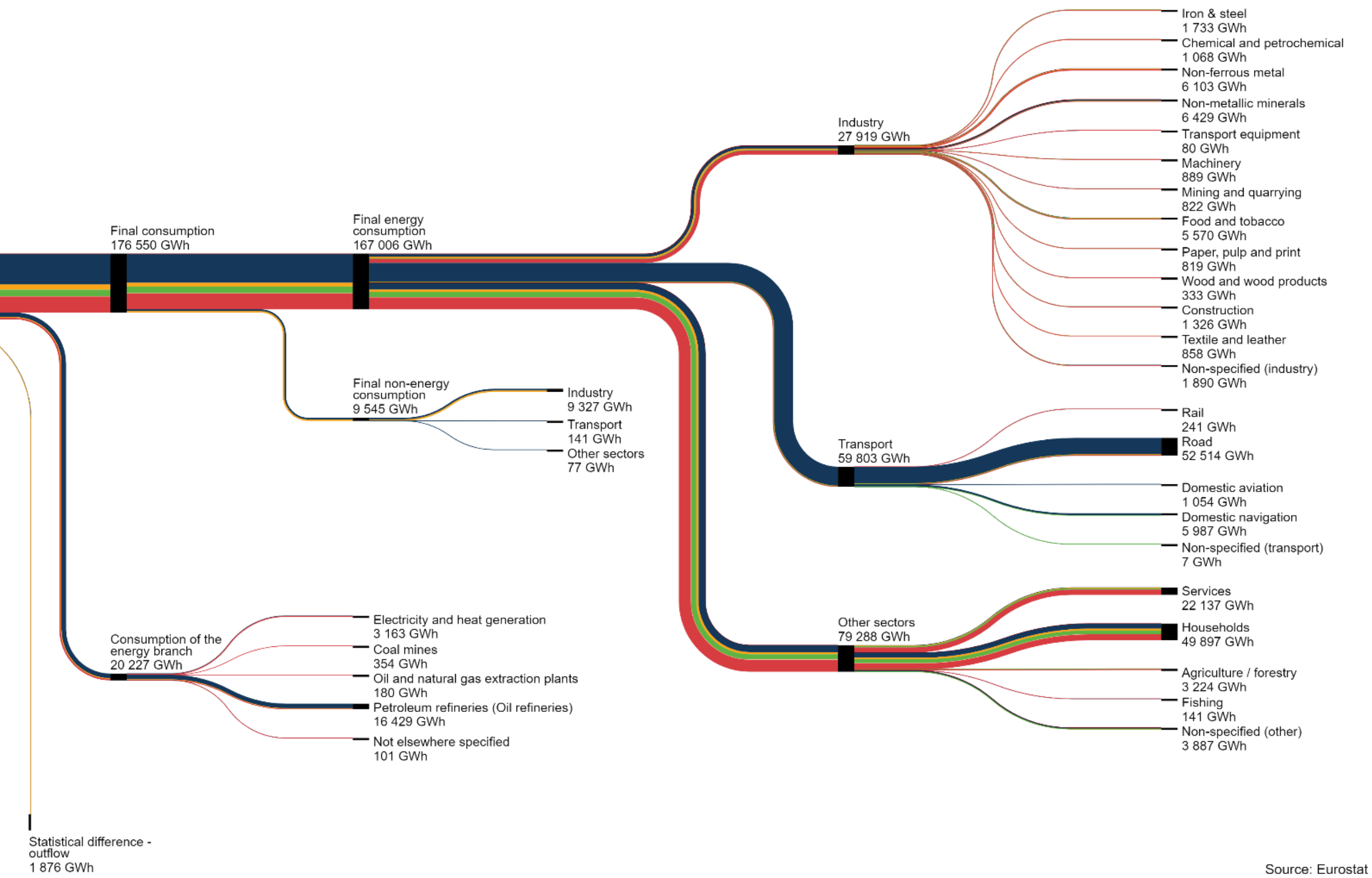
- Pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century
- Reduce energy-related CO_2 emissions to limit climate change
- Decarbonisation of the energy sector
- UN sustainable development goals

Situation in Greece



Source: Eurostat (link)

Situation in Greece



Source: Eurostat (link)

Greek targets

- Sustainable development pathways to 2030
- Quantifiable and goals, given time periods
- Energy transition in the most cost-effective way

Targets by 2030:

- **42% GHG emissions** reduction rel. to 1990 (or 55% relative to 2005) – **Lignite-free by 2028**. Ultimate goal: (Net-)Zero emissions by 2050
- Concrete **waste management** plans following principles of circular economy
- Energy consumption **35% renewables** (60% in electricity consumption) + Promotion of electromobility
- Promotion of **energy efficiency in buildings** and transportation

Greek targets

Μείωση εκπομπών αερίων θερμοκηπίου και περιβαλλοντικοί στόχοι

οι συνολικές εκπομπές ΑτΘ να μειωθούν κατά τουλάχιστον 40% σε σχέση με το 1990 (επιτυγχάνεται ποσοστό μείωσης >42%)

- να επιτευχθούν ισοδύναμοι στόχοι μείωσης εκπομπών στους επιμέρους τομείς εντός και εκτός του συστήματος εμπορίας δικαιωμάτων εκπομπών με τους αντίστοιχους κεντρικούς Ευρωπαϊκούς
- επίτευξη ποσοτικών στόχων για τη μείωση των εθνικών εκπομπών συγκεκριμένων ατμοσφαιρικών ρύπων
- **απόσυρση λιγνιτικών μονάδων ηλεκτροπαραγωγής έως το έτος 2028**

Αύξηση συμμετοχής ΑΠΕ στην κατανάλωση ενέργειας

το μερίδιο συμμετοχής των ΑΠΕ στην ακαθάριστη τελική κατανάλωση ενέργειας να ανέλθει τουλάχιστον στο 35%

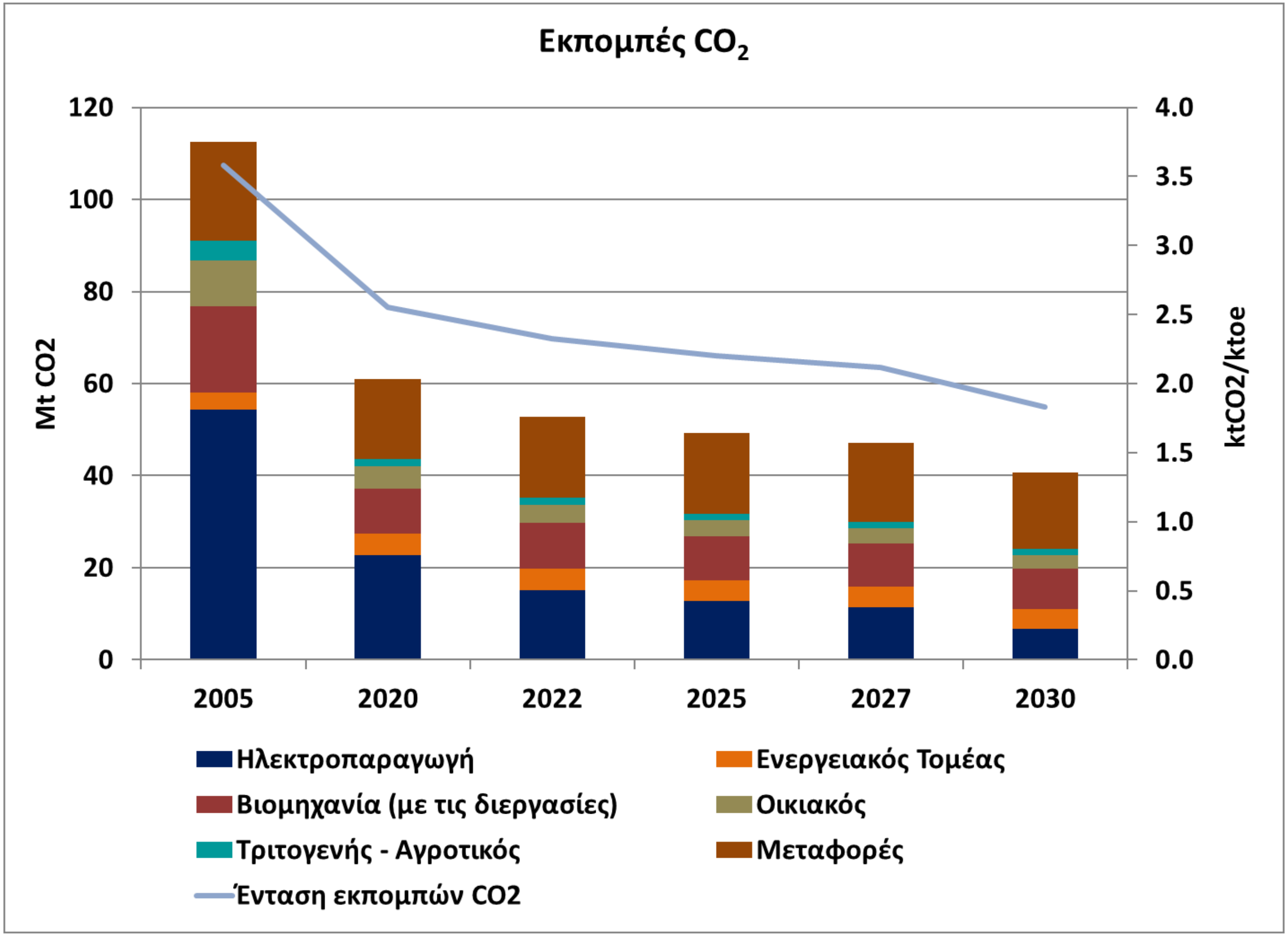
- το μερίδιο συμμετοχής των ΑΠΕ στην ακαθάριστη τελική κατανάλωση ηλεκτρικής ενέργειας να ανέλθει τουλάχιστον στο 60%
- το μερίδιο των ΑΠΕ για τις ανάγκες θέρμανσης και ψύξης να ξεπεράσει το 40%
- το μερίδιο των ΑΠΕ στον τομέα των μεταφορών να ξεπεράσει το 14% (επιτυγχάνεται 19%) σύμφωνα με τη σχετική μεθοδολογία υπολογισμού της ΕΕ

Επίτευξη βελτίωσης ενεργειακής απόδοσης

να επιτευχθεί βελτίωση της ενεργειακής απόδοσης κατά 38% σύμφωνα με την Ευρωπαϊκή μεθοδολογία

- η τελική κατανάλωση ενέργειας να μην ξεπεράσει τα **16,5Mtoe*** το έτος 2030
- η πρωτογενής κατανάλωση ενέργειας να μην ξεπεράσει τα 22,5Mtoe το έτος 2030
- να επιτευχθούν τουλάχιστον 7 Mtoe σωρευτικής εξοικονόμησης ενέργειας κατά την περίοδο 2021-2030**.
- να γίνει σε ετήσια βάση ενεργειακή ανακαίνιση του 3% του συνολικού εμβαδού της θερμικής ζώνης των κτιρίων της κεντρικής δημόσιας διοίκησης έως το έτος 2030

Greek targets



Challenges by renewable penetration

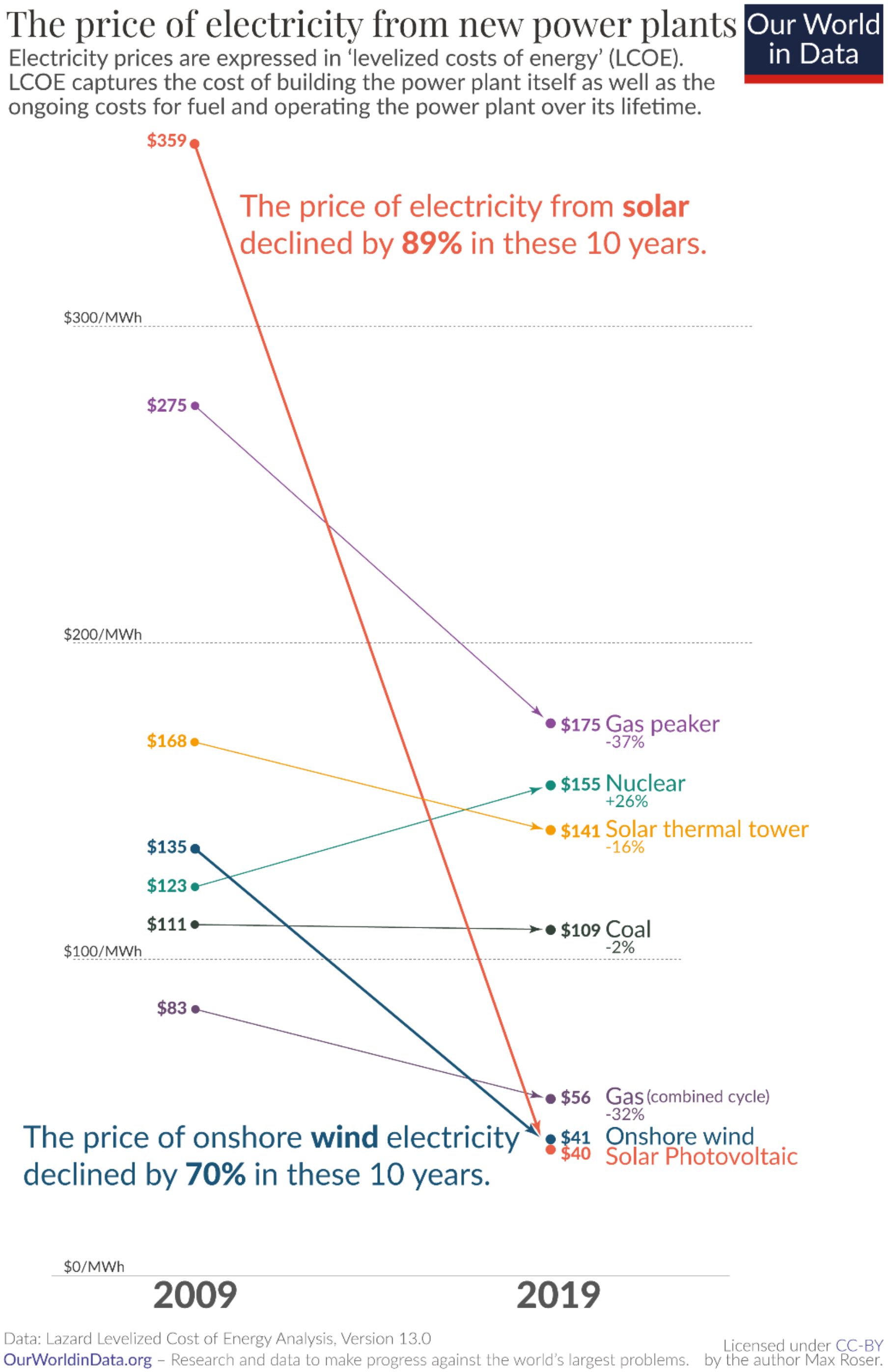
Characteristics of renewables

- Intermittency & variability
  - Need for backup capacity
  - Need for storage: hydro pump, batteries, hydrogen
  - Need for a diversified generation portfolio
  - Demand side management: smoothen the peak in demand

- Space issue
  - People hostile against wind turbines due to space, sight and sound

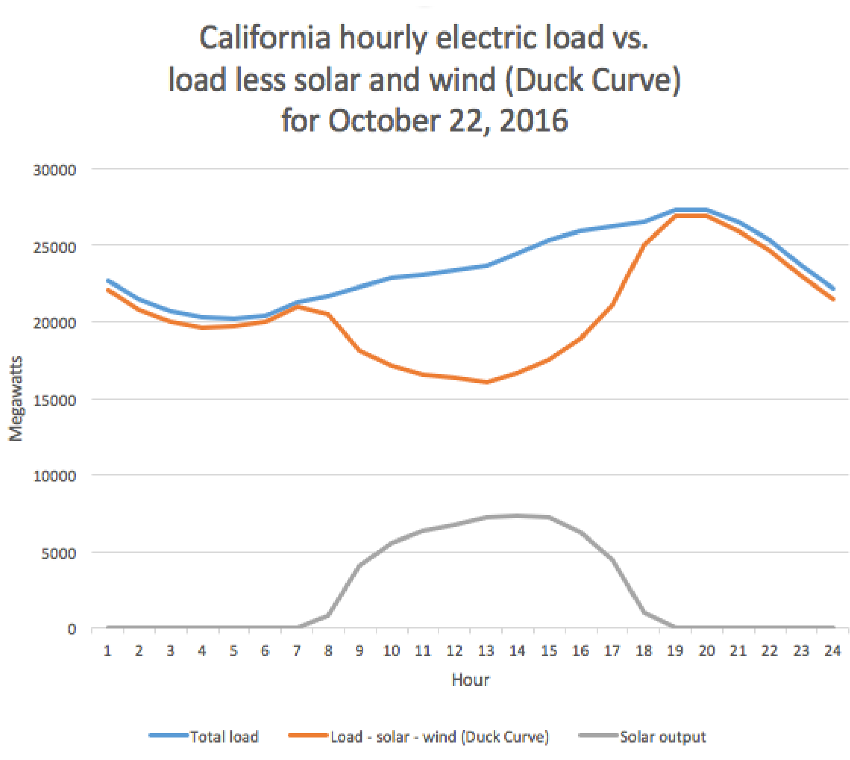
- Were expensive. Now they are not!
  - 20% reduction in PV cost for every doubling of cumulative capacity

→ Technical progress. Remember slide 16: with A increasing due to technology, same output Y can be produced with less inputs

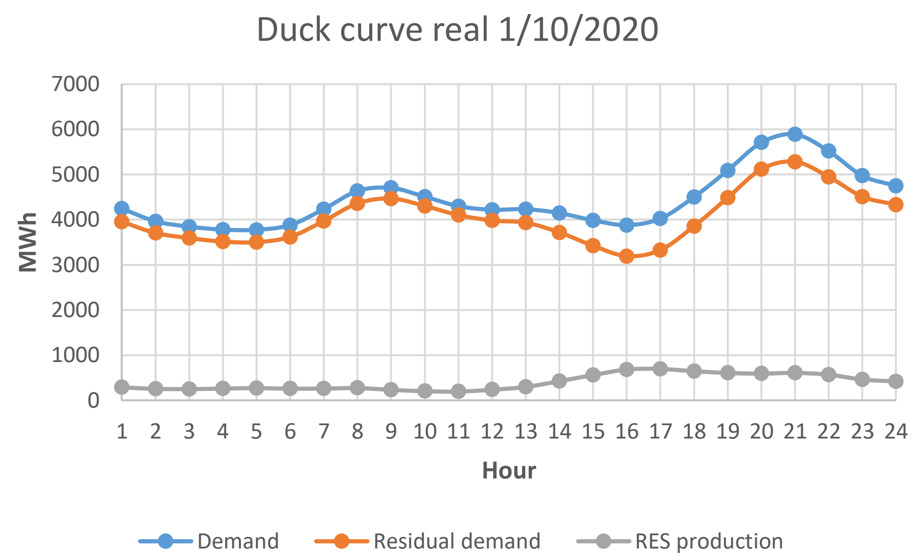


Challenges by renewable penetration

The “duck curve” of PV production

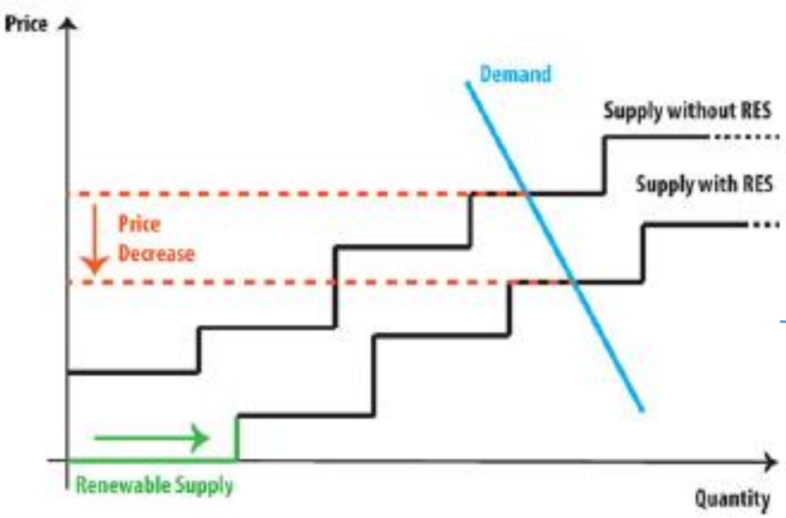


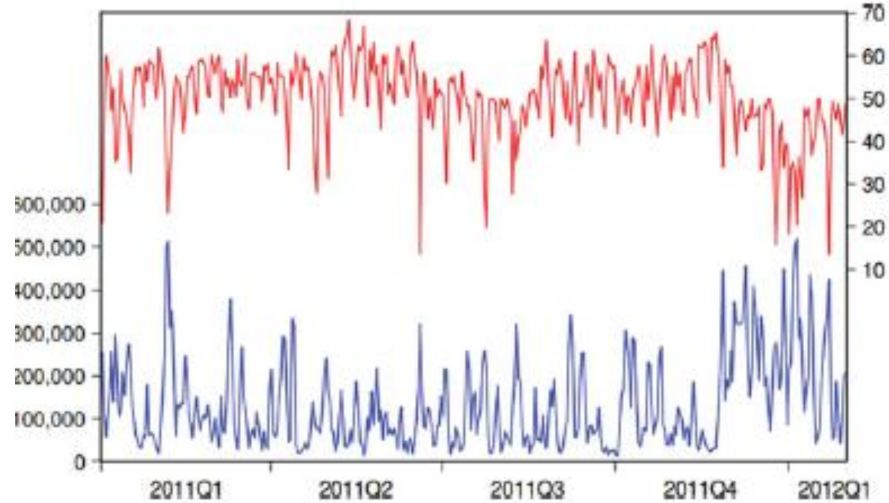
Greece



Challenges by renewable penetration

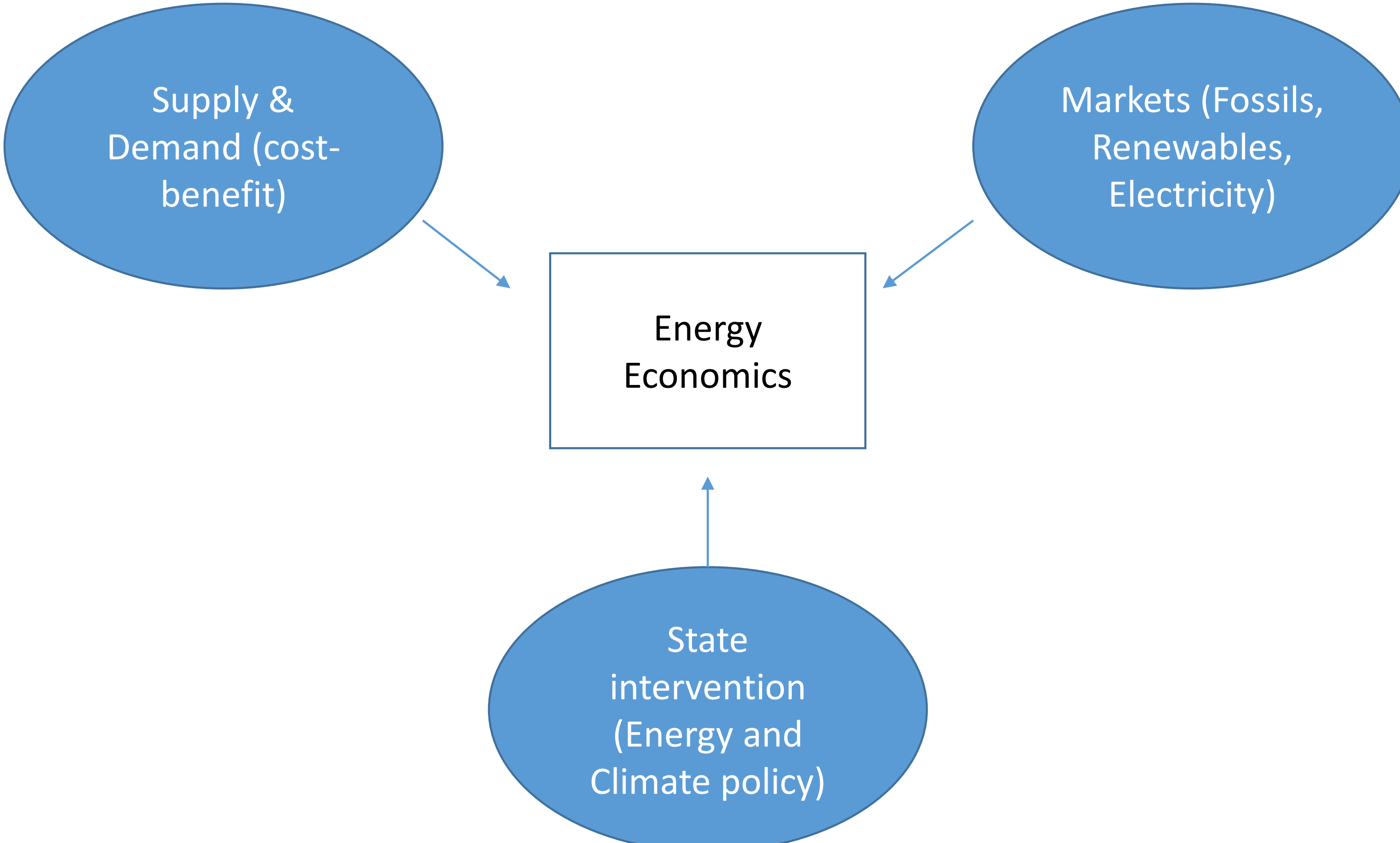
Variability leads to price fluctuations





Blue renewable production, red prices

Energy Economics - situation



Why all that? – Economic modelling

- What causes what in economic systems?
- At what level of detail shall we model an economic phenomenon?
- Which variables are exogenous (determined outside the model) and which are endogenous?

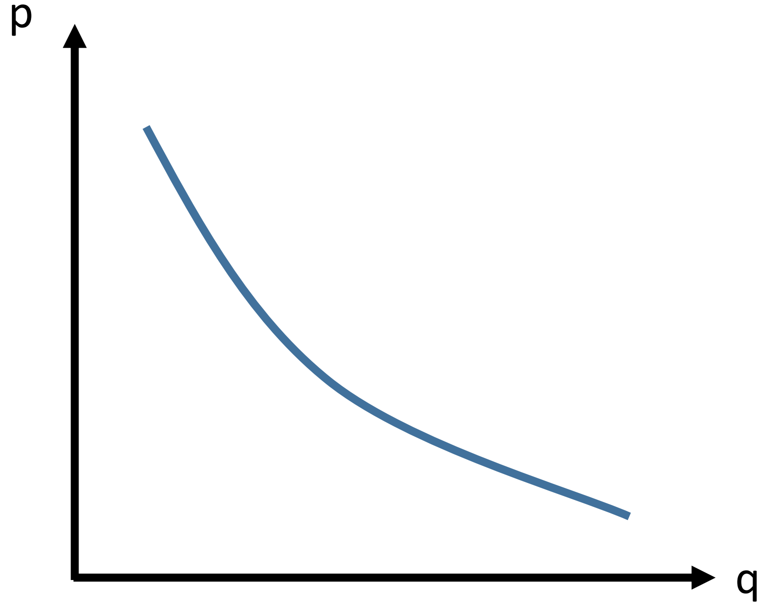
- **Example**: Modelling the short-run price of natural gas
- Things to consider
  - Substitutes – wood, electricity or warm clothes
  - The cost of alternatives are exogenous and known
  - Number of potential buyers and sellers (competition? monopoly?)
  - Supply demand curves (price vs quantity for sellers and buyers)

Economic modelling

- How much gas will be consumed? At what price?
- What if there is a shortage? A policy?
- Two basic assumptions:
  - **Rational Choice**: agents do their best depending on their options
  - **Equilibrium**: Market price adjust until quantity demanded = quantity supplied
- Demand: Suppose households (HH) receive a unit of gas or nothing
- In a given month the most a HH is willing to pay is 300 euro. Then p=300€/unit and q_D = 1.
- Suppose the price has to drop to 290 for a 2nd HH to subscribe. Then p=290€/unit and q_D=2.

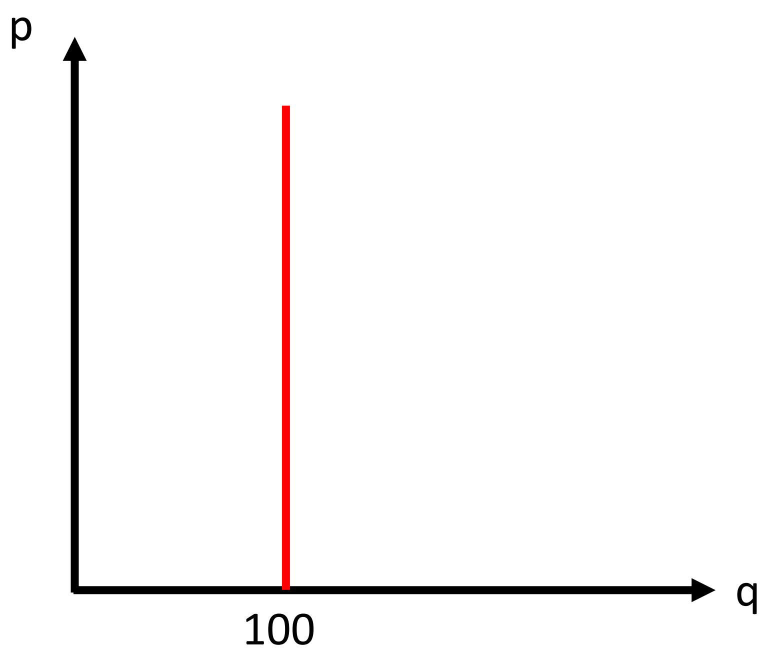
Demand for natural gas

- The lower the connection price p the larger the number of HH choosing to connect to the gas grid: p↓ then ↑q
- **Quantity demanded vs price = the market demand curve**
- Usually downward-sloping



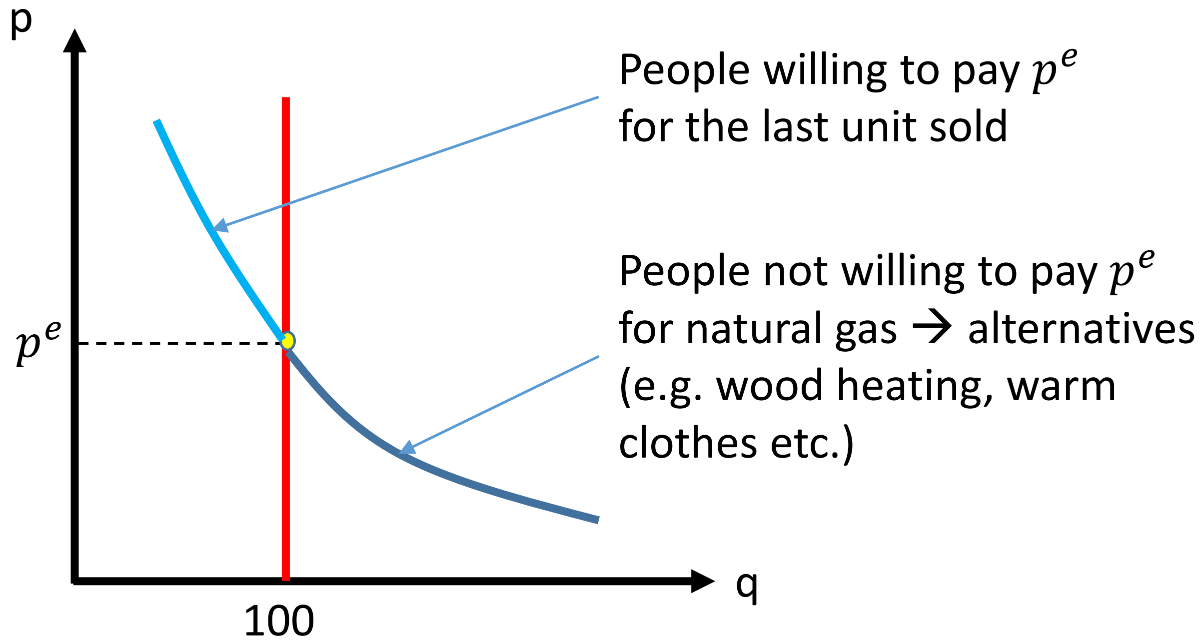
Supply of natural gas

- It takes time to build more gas storage capacity so in the short-run the quantity available is fixed (e.g. 100)
- **Quantity supplied vs price = the market supply curve**



Competitive market equilibrium

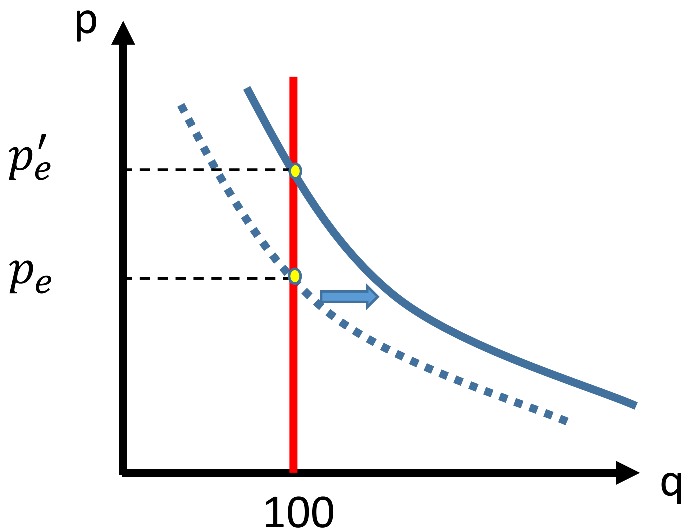
- "low" gas price → demand exceeds available → price will rise
- "high" gas price →demand is less than available → price will fall
- **Demand = Supply → Competitive Equilibrium**

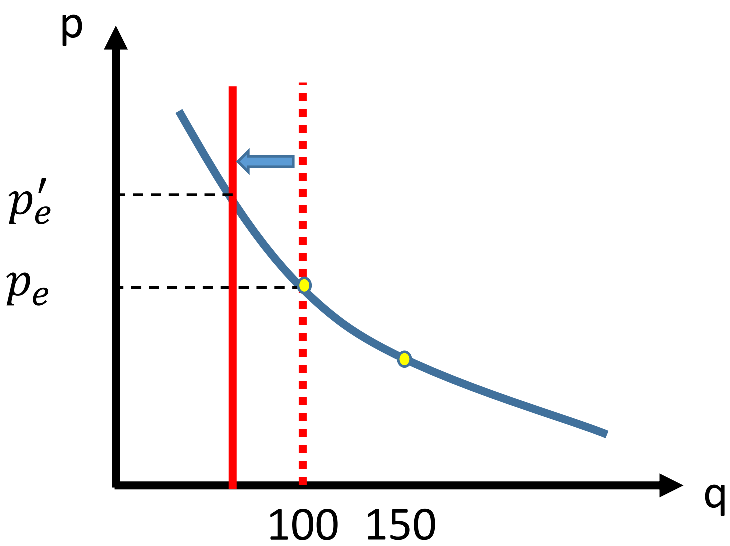


Comparative statics

- What is exogenous in the model?
  - Price / availability of alternative energy sources
  - Quantity of natural gas available for distribution
  - Customer incomes and responses to price changes
  - Policy …
- What happens if we challenge an exogenous variables?
- Suppose the price for wood increases
  - demand for gas increases
  - Rightward shift to the demand curve
  - higher market price for gas
- If gas shortage in the short-run
  - Supply decreases
  - supply curve will shift to the left
  - Price will increase
- **Exogenous shocks → shift in the demand and supply curves**

Competitive market equilibrium





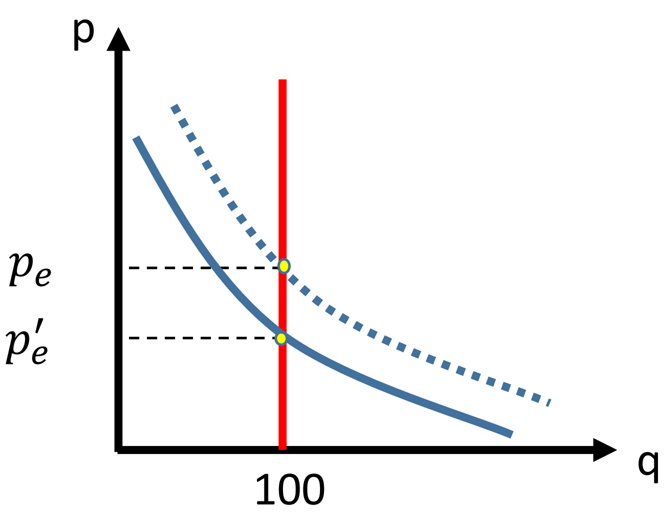
Left: Higher price for a substitute (e.g. fire wood) increases gas price
Right: Lower gas supply shifts supply curve to the left increasing market price

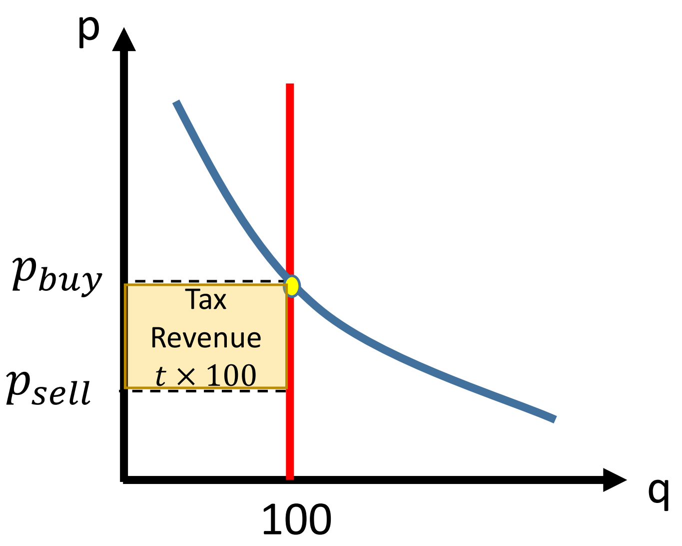
Comparative statics

Other issues

- Changes in consumer income – market economic activity
  - Lower income reduces willingness-to-pay
  - Lowers market price
  - Same in times of low market economic activity (corona times ☺)
- Policy (e.g. taxation, subsidies, quantity quota, price control)
  - Creates misbalance and changes the equilibrium
  - Reasons: raise government income, change people's spending/investing behavior, security in the energy market, increase the penetration of new technologies or reduce the use of old (energy transition)

Competitive market equilibrium





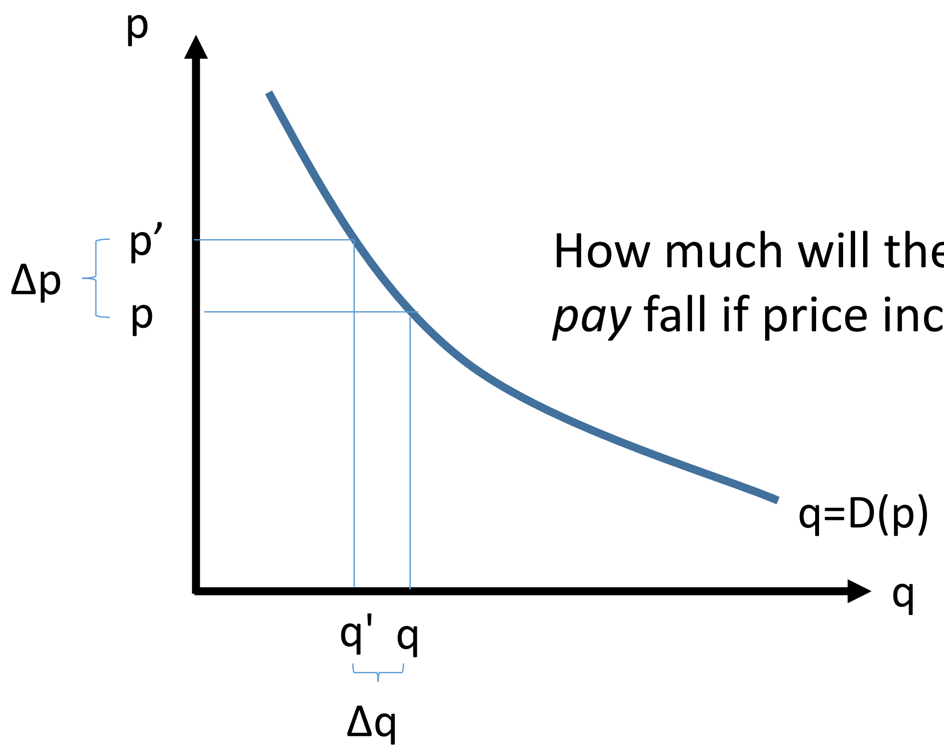
Left: Consumer income falls → downward shift of demand curve

Right: Taxing a commodity by t per unit

→ here tax is completely passed to producers (they receive p_{sell})

→ has to do with the elasticity of the supply vs elasticity of demand (more on that in a bit)

A bit on elasticities – Demand



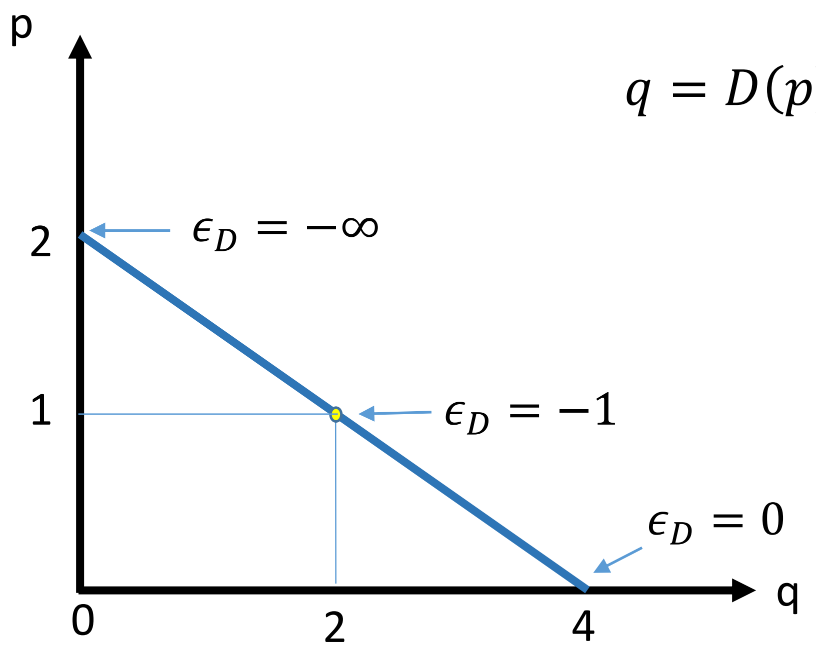
How much will the *willingness to pay* fall if price increases by 1%?

$$\epsilon_D = \frac{\%\ change\ in\ q\ (demanded)}{\%\ change\ in\ p} \approx \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}} = \underbrace{\frac{\Delta q}{\Delta p}}_{slope} \frac{p}{q} < 0$$

Elastic demand:	$\epsilon_D < -1$	(consumers respond a lot)
Inelastic demand:	$-1 < \epsilon_D < 0$	(consumers respond less)

Example: linear demand curve

$$q = D(p) = 4 \underbrace{-\,2}_{slope} p$$



- Elasticity depends on the slope but also on the point [quantity,price]
- Can vary along the demand curve
- There are also empirically-relevant curves with constant elasticity all along (isoelastic curves)

Other demand elasticities and estimation

Income elasticity: $\epsilon_I = \frac{\Delta q}{\Delta I}\frac{I}{q}$

As people get reacher (poorer) how is does the quantity demanded change?

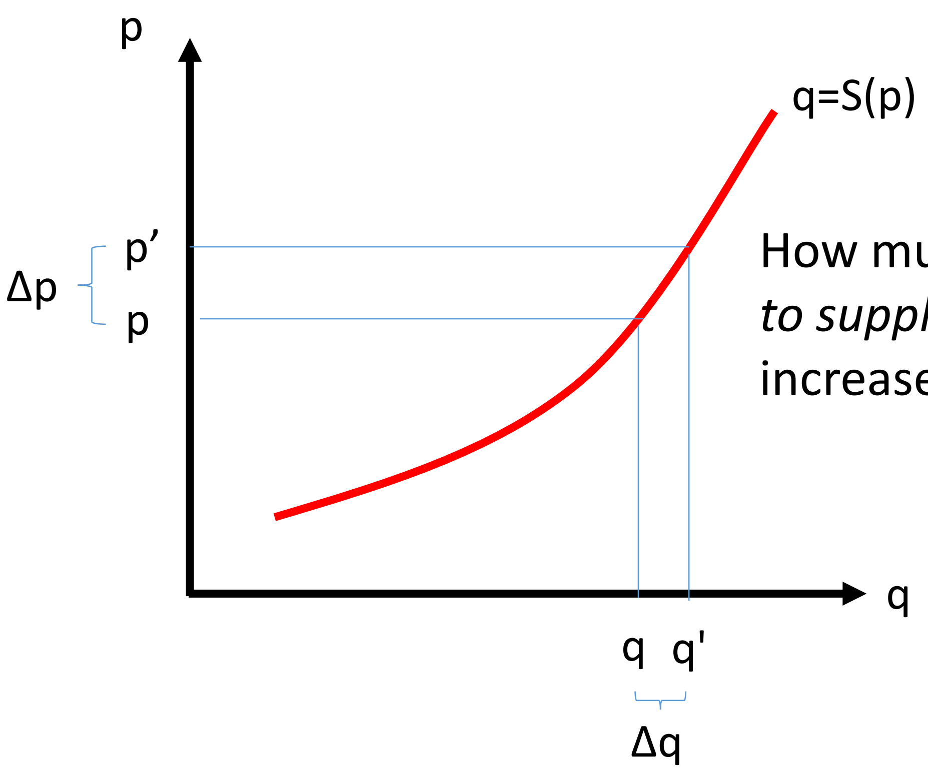
Cross-price elasticity: $\epsilon_{ij} = \frac{\Delta q_i}{\Delta p_j}\frac{p_j}{q_i}$

How does the price change in good j influence the quantity demanded of good i? Close substitutes tend to influence the price of one-another (e.g. butter vs margarine)

Estimation: $\log q_i = a + \epsilon_D \log p_i + \epsilon_I \log I + \epsilon_{ij} \log p_j + \cdots + error$

Using *econometric regressions* one can explain changes in a dependent variable (q_i here) using data from *independent variables* (p_i, I, p_j,...) (wait for 3rd lecture)

Elasticity of Supply

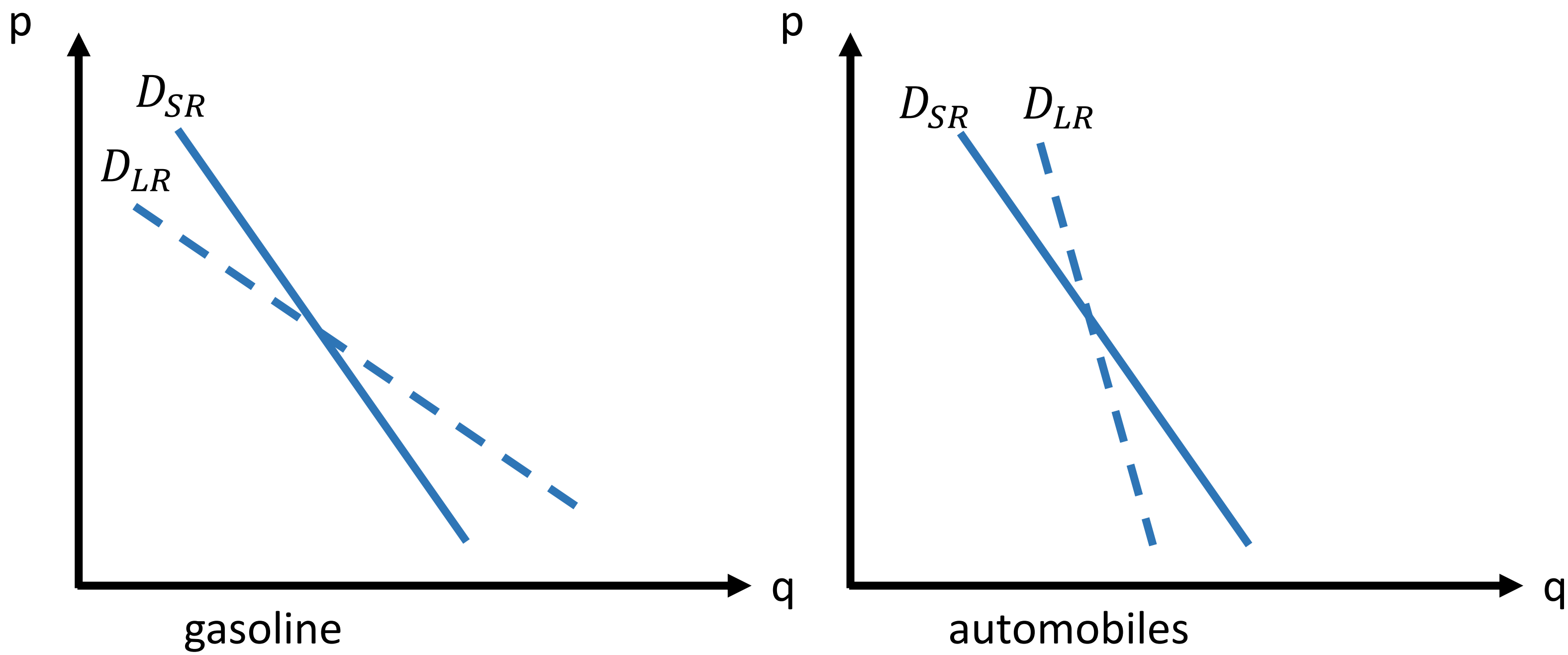


How much will the *willingness to supply* increase if price increases by 1%?

$$\epsilon_S = \frac{\%\ change\ in\ q\ (supplied)}{\%\ change\ in\ p} \approx \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}} = \underbrace{\frac{\Delta q}{\Delta p}}_{slope} \frac{p}{q} > 0$$

- In general supply curve is upward - sloping
- Other factors like interest rates, price of raw materials, price of other intermediate goods, the weather etc. can influence production and q supplied.

Short-Run (SR) vs Long-Run (LR) elasticities



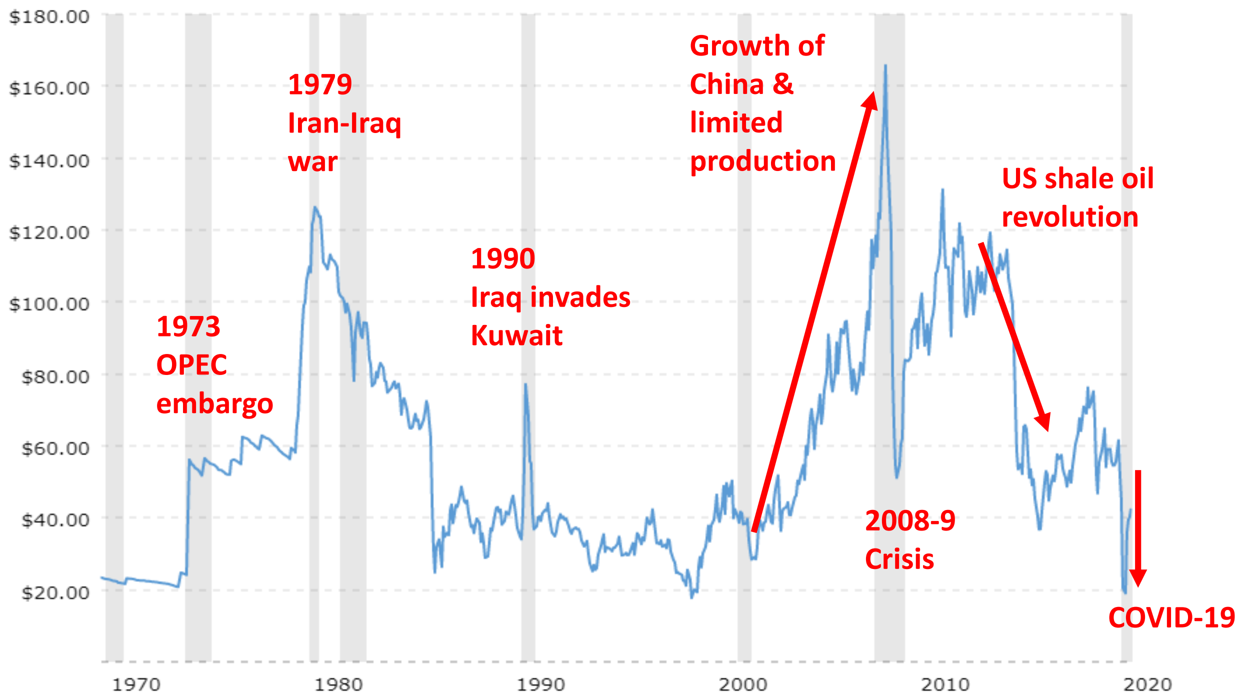
Left: An increase in the price has a small short-run effect and a larger long-run effect on the quantity demanded. E.g.: gasoline (non-durables)

Right: Opposite than above. E.g.: Automobiles (durable goods in general)

Short-run: within a year, Long-run: more than a year

Similar reasoning for the elasticity of supply.

Macro-shocks and the price of oil

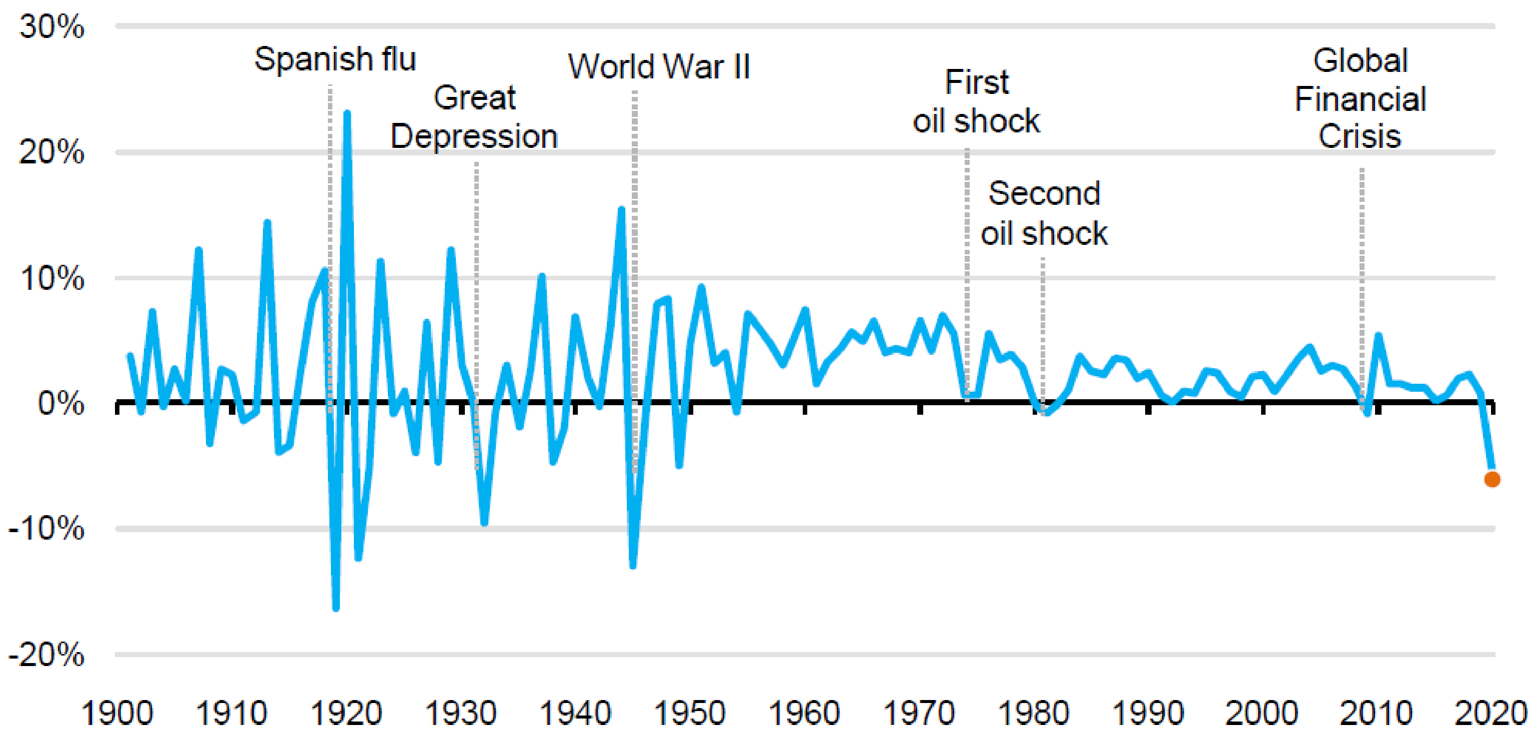


- 1973-1974: OPEC cartel cuts production
- 1979-1980: Production fell due to Iran-Iraq war
- …

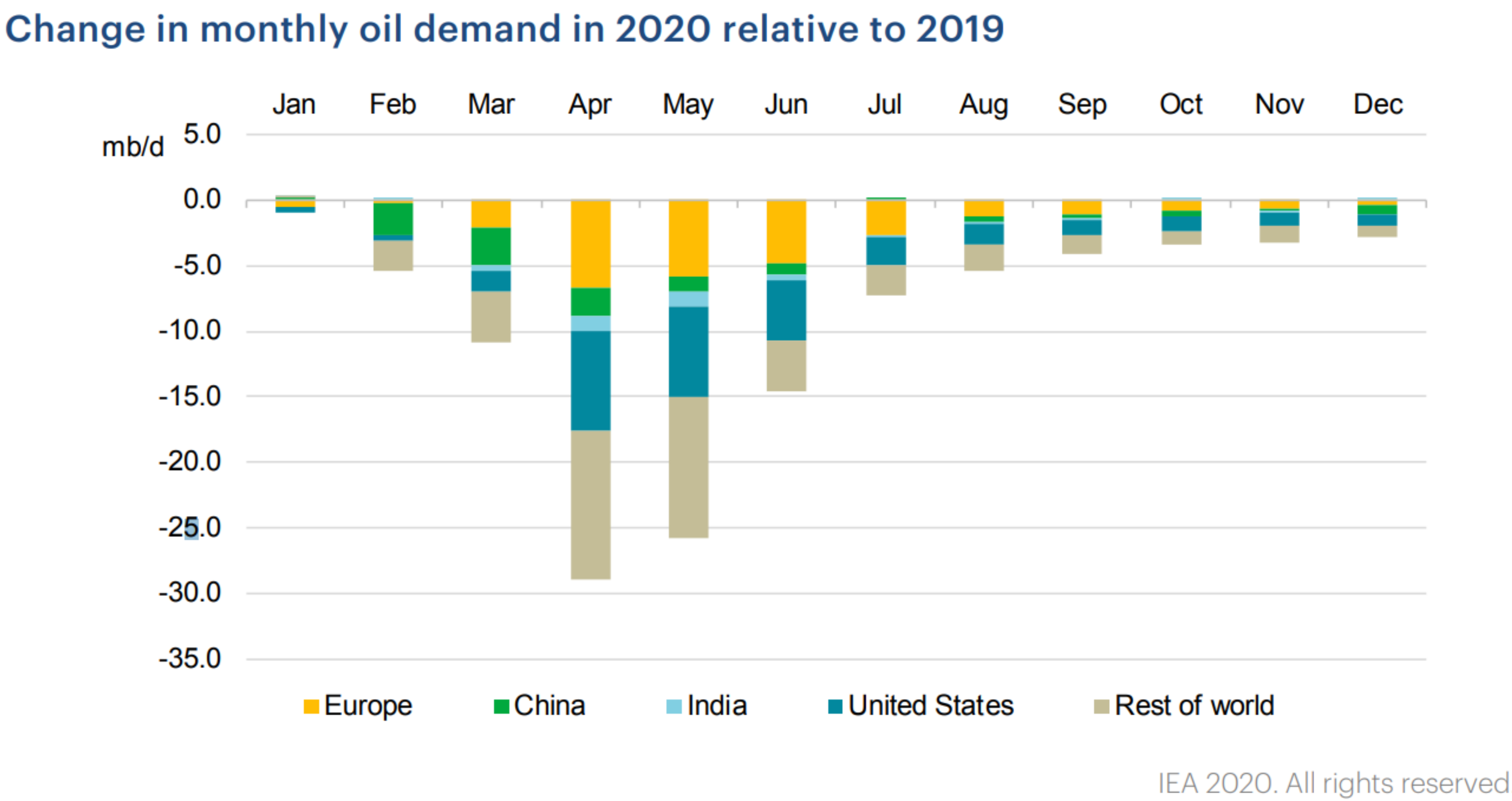
Question: short- and long-run response to oil prices from COVID-19

Pandemics and energy demand

Rate of change in global primary energy demand, 1900-2020



COVID-19 and the oil market

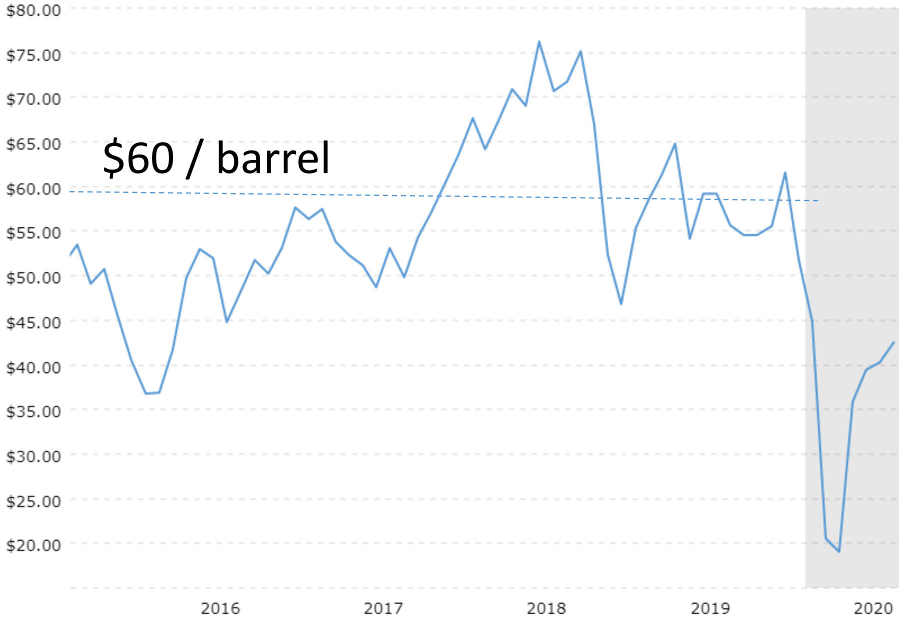


COVID-19 and the oil market

What drives fossil fuel prices?

- Supply – Demand
  - New discoveries
  - Political turmoil – e.g. embargoes, wars
  - Economic activity – economic cycle
- Consumer preferences
  - IC engine vs electric cars
- Technical progress
  - Lower exploration and extraction costs – shale oil and gas
  - Input substitution – Backstop technologies
  - Storage capacity – E.g. negative oil prices in April 2020?
- Market power
  - Monopoly – cartel (OPEC)
  - Privatization and competition
- Scarcity (intertemporal optimization)
- Policy (rationing, environmental taxation, energy transition,…)

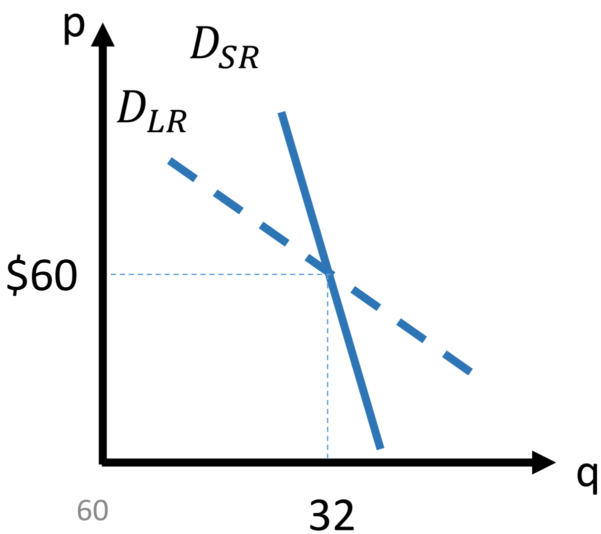
Example: COVID-19 and the price of oil

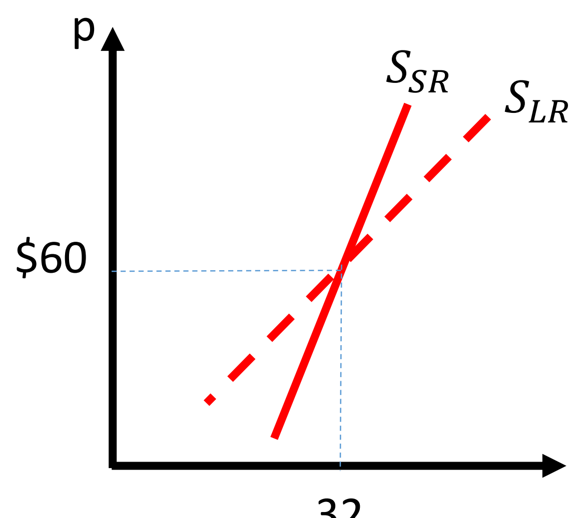


- 2017-2019 avg. price $60 / barrel
- World demand / supply = 32 bb/y
- OPEC supply = 14 bb/y
- Competitive supply = 18 bb/y

(bb = billion barrels)

Elasticities:	SR	LR
World demand (ϵ_D)	-0.05	-0.40
Competit. Supply (ϵ_S)	0.10	0.40





Example: COVID-19 and the price of oil

- Assume linear demand and supply curves (empirically relevant)
- For a linear curve we need a slope and a point. We use the elasticity for the slope and the market equilibrium (p_e, q_e) for the point:

$$\underbrace{q}_{S,D} = q_e + \underbrace{slope}_{S,D} \, (p - p_e)$$

- We have from sl. 50 and 53: $slope_D = \epsilon_D \frac{q_e}{p_e}$ and $slope_S^C = \epsilon_S \frac{q_e^C}{p_e}$.
- We then have for the demand and competitive supply:

$$D = q_e + \epsilon_D \frac{q_e}{p_e} (p - p_e)$$

$$S^C = q_e^C + \epsilon_S \frac{q_e^C}{p_e} (p - p_e)$$

Where total demand at $p_e = \$60$ is $q_e = 32$ while competitive supply is $q_e^C = 18$. Total supply is competitive supply + OPEC supply, such that total supply=demand.

Example: COVID-19 and the price of oil

Elasticities:	SR	LR
World demand (ϵ_D)	-0.05	-0.40
Competit. Supply (ϵ_S)	0.10	0.40

Short-Run demand: $\boldsymbol{D_{SR} = 33.6 - 0.0267\, p}$

Short-Run competitive supply: $S_{SR}^{C} = 16.2 + 0.03\, p$

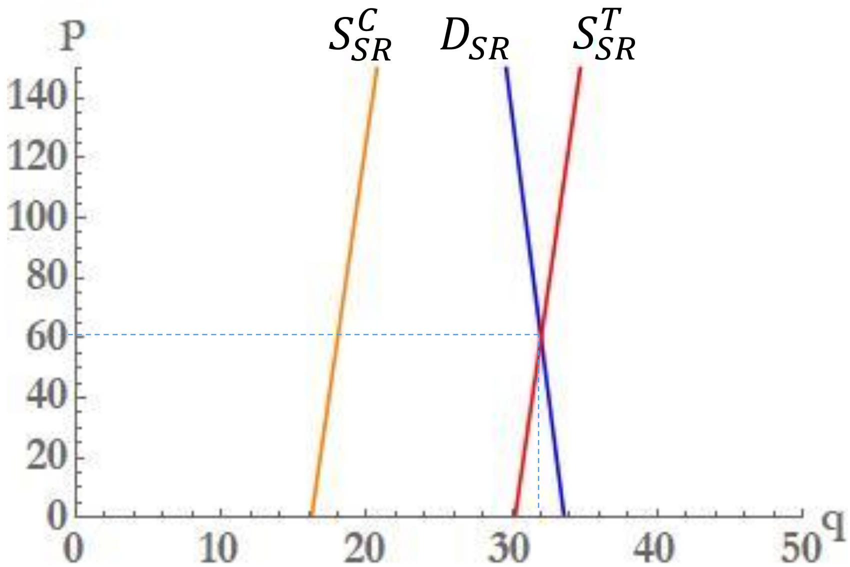
Short-Run total supply: $\boldsymbol{S_{SR}^{T} = \underbrace{30.2}_{16.2+14\,(OPEC)} + 0.03\, p}$

Long-Run demand: $D_{LR} = 44.8 - 0.2133\, p$

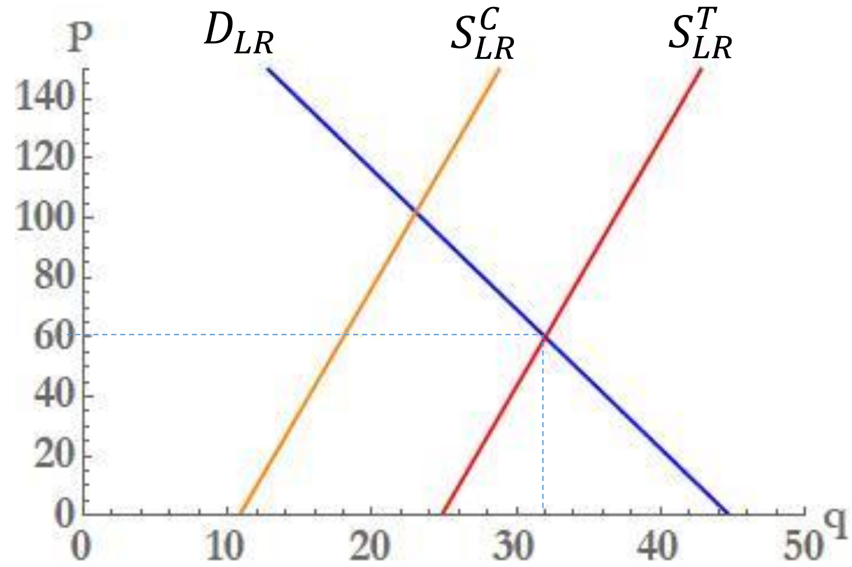
Long-Run competitive supply: $S_{LR}^{C} = 10.8 + 0.12\, p$

Long-Run total supply: $S_{LR}^{T} = \underbrace{24.8}_{10.8+14\,(OPEC)} + 0.12\, p$

Example: COVID-19 and the price of oil



Short-Run



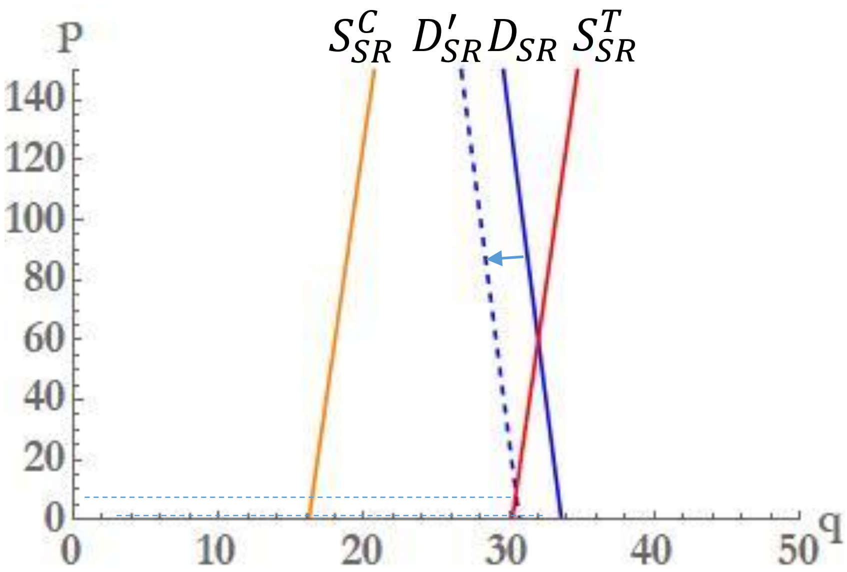
Long-Run

9% reduction in world oil demand 2020 vs. 2019:

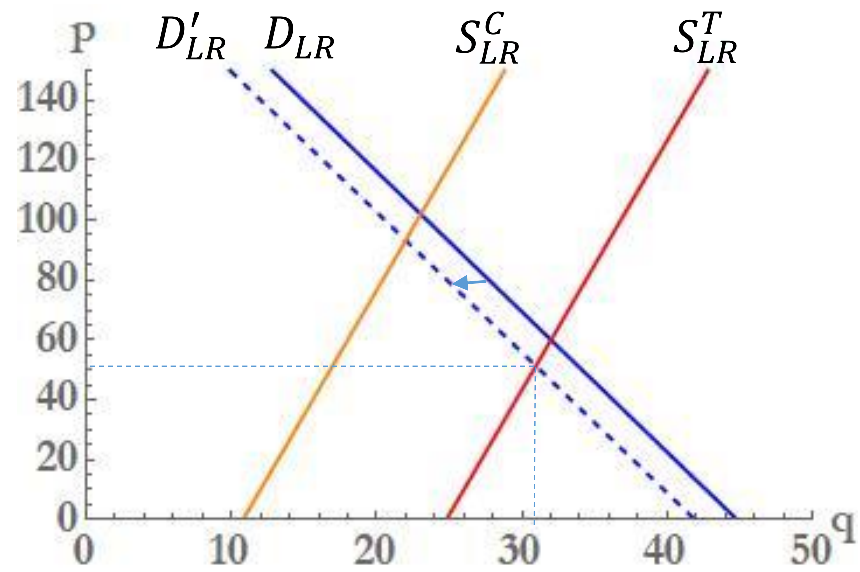
- Short-run demand curve changes to $D'_{SR} = 0.91 \times (33.6 \ - 0.0267\, p)$
- Long-run demand curve changes to $D'_{LR} = 0.91 \times (44.8 \ - 0.2133\, p)$

How should short-run and long-run price change?

Example: COVID-19 and the price of oil



Short-Run



Long-Run

- Short-run response: price drops to \$10/barrel, while q changes only a little
- Long-run response: price gradually climbs to \$50/barrel

Our model is very simplistic (other factors play a role for oil prices such as storage, the economic cycle, etc..) but gives us a way to predict how economic shocks can affect oil prices in the short- and «long-»run

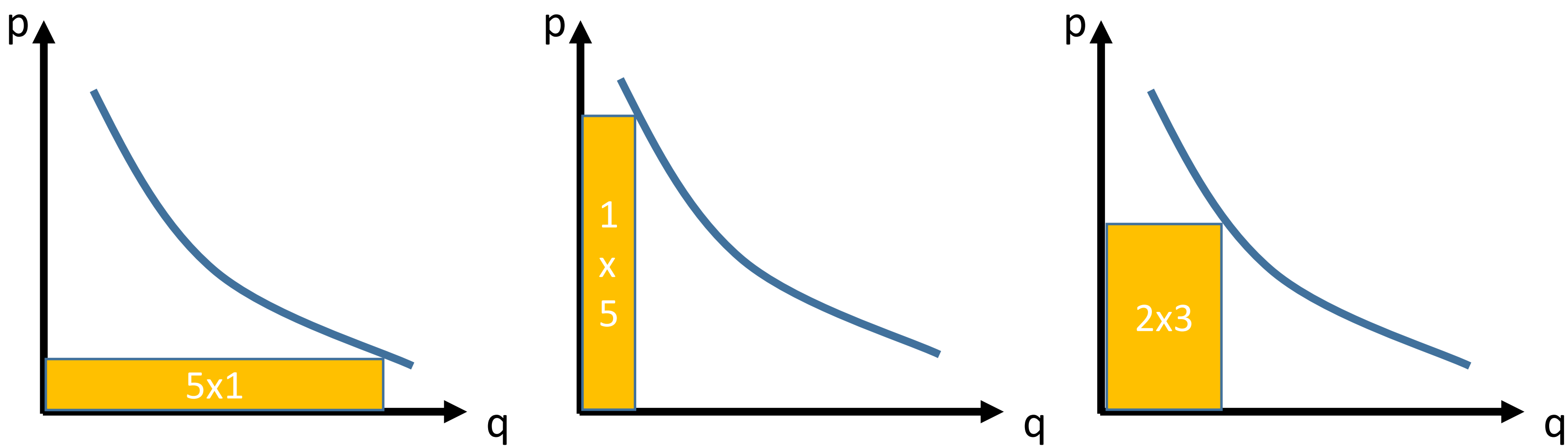
For the (really) long-run scarcity should play a role: Hotelling rule (lecture 6)

Natural gas again – Monopoly

A monopolistic supplier:

- Monopolist has market power and sets q and p at the same time
- When supplier sets a price p, he/she obtains D(p) customers
- Revenue = p D(p)
- Revenue is low if $p \approx 0$ or if p is high and $D(p) \approx 0$
- An intermediate value of p maximizes revenue

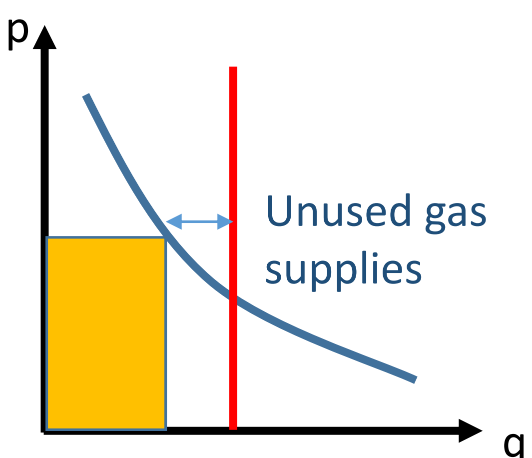
Monopolistic market equilibrium



low p high q
(low revenue)

high p, low q
(low revenue)

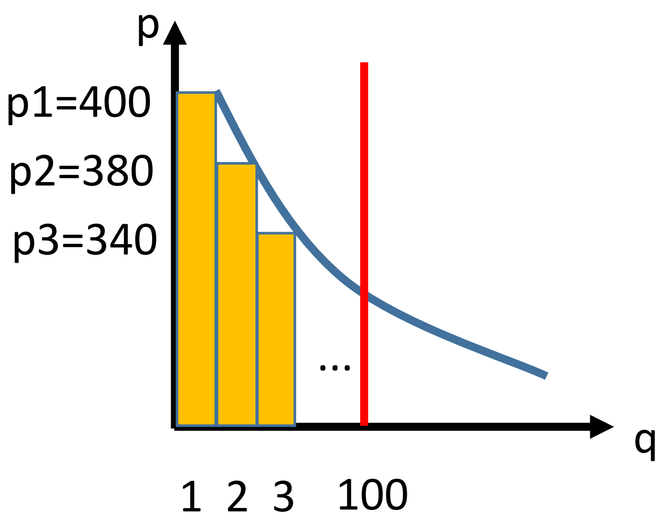
moderate p and q
(higher revenue)



moderate price × moderate quantity demanded = high revenue

Monopolist doesn't sell the entire supply (eventually he should! It is profitable to do so under intertemporal optimization. This will be discussed in lecture 6).

Perfectly discriminatory Monopolist

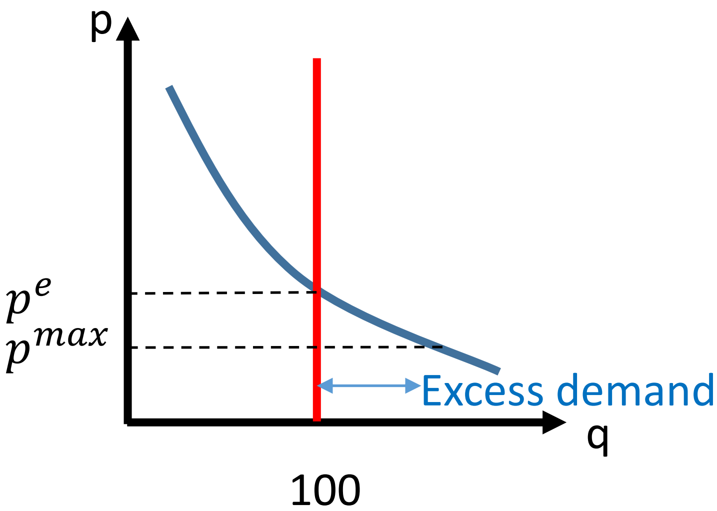


What if the monopolist knew everyone's willingness-to-pay?

- Charge 400 to the most willing-to-pay
- Charge 380 to the second most willing
- Charge 340 to the third, etc.
- ...

- Discriminatory monopolist charges the competitive market price to the last buyer, and sells the competitive quantity.
- Since it can capture the whole demand curve, revenues are at their maximum

Price control



The government imposes a maximum legal price $p_{max} < p_e$, the competitive price

In the short-run the 100 units are no longer allocated by willingness-to-pay

First-come-first serve? Lottery? Large families first?...

Which is better?

- Price control
- Perfect competition
- Monopoly
- Discriminatory monopoly

Next lecture

Microeconomics

- Supply, demand
- Policy incidence (tax, subsidy)
- Market power (monopoly, oligopoly, cartel)
- Cost-Benefit analysis, Interest rates, risk premia
- Externalities