March 2017

Electricity system modelling

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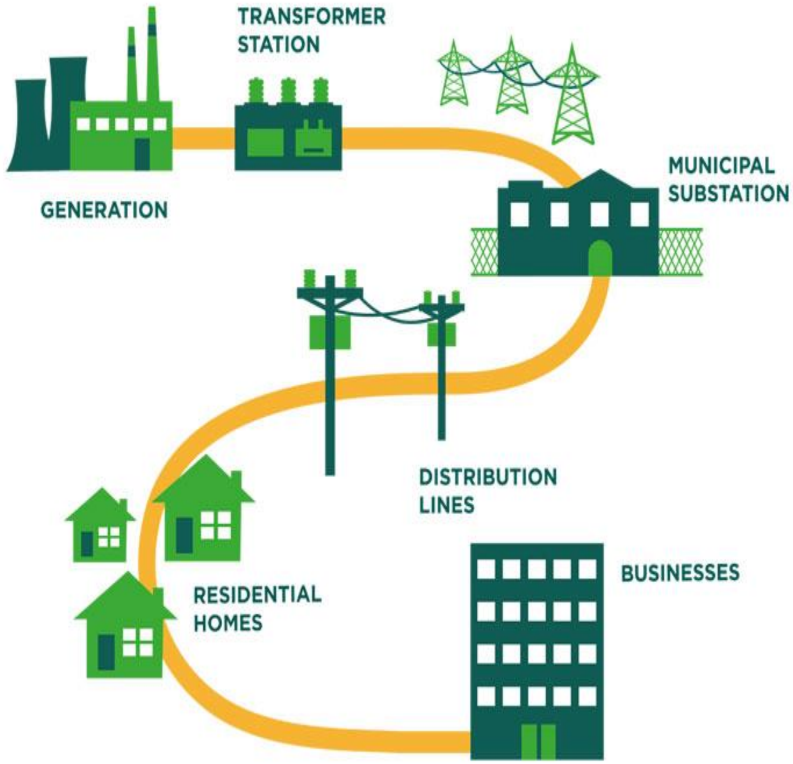
From energy to electricity system analysis

- The electricity system is a heavily intertwined subpart of the comprehensive energy system
- We focus this training on modelling the electricity system,
- More specifically: finding the least-cost sustainable electricity system development.



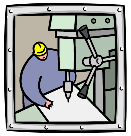
Electricity system

Complex system involving: extraction and/or import facility, power plants, transmission and distribution lines, storage, transport, industrial uses, residential uses, transportation, and others.



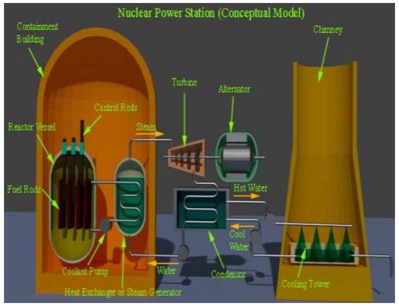






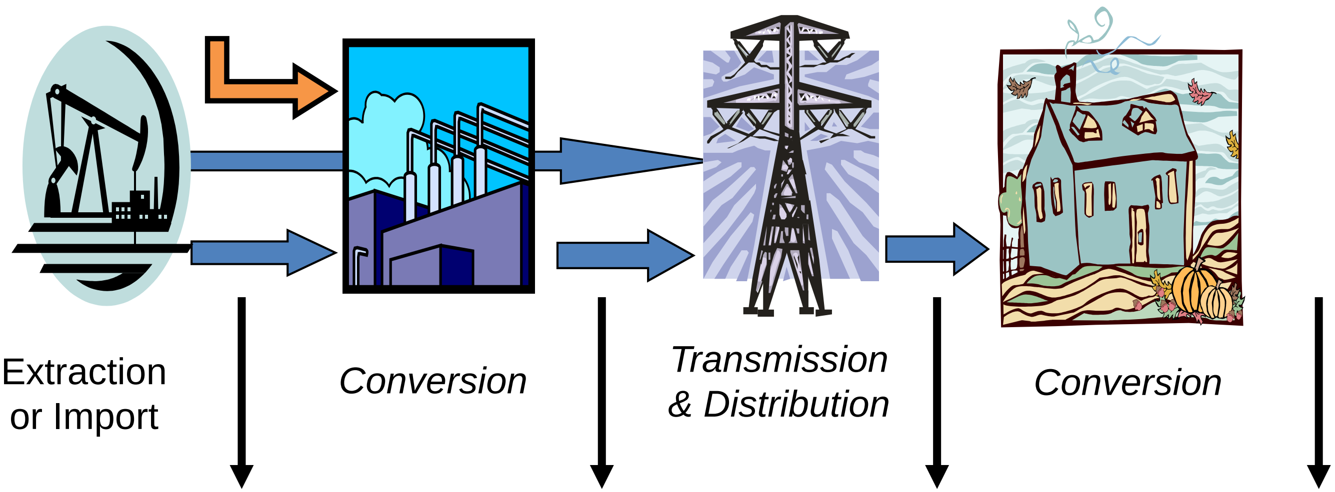






Elements of an electricity system model

The complexity of electricity systems requires a well-organized **model structure**.



PRIMARY
-Oil
-Gas
-Coal
-Uranium
-Hydro
-*Wind*
-*Solar*

SECONDARY
- Diesel
- Kerosene
- Gas
- Electricity
- Coal

FINAL
- Diesel
- Kerosene
- Gas
- Electricity
- Coal

USEFUL
- Heating
- Lighting
- EVs
- Ind. Uses
- Cooling
- Etc.

Demand

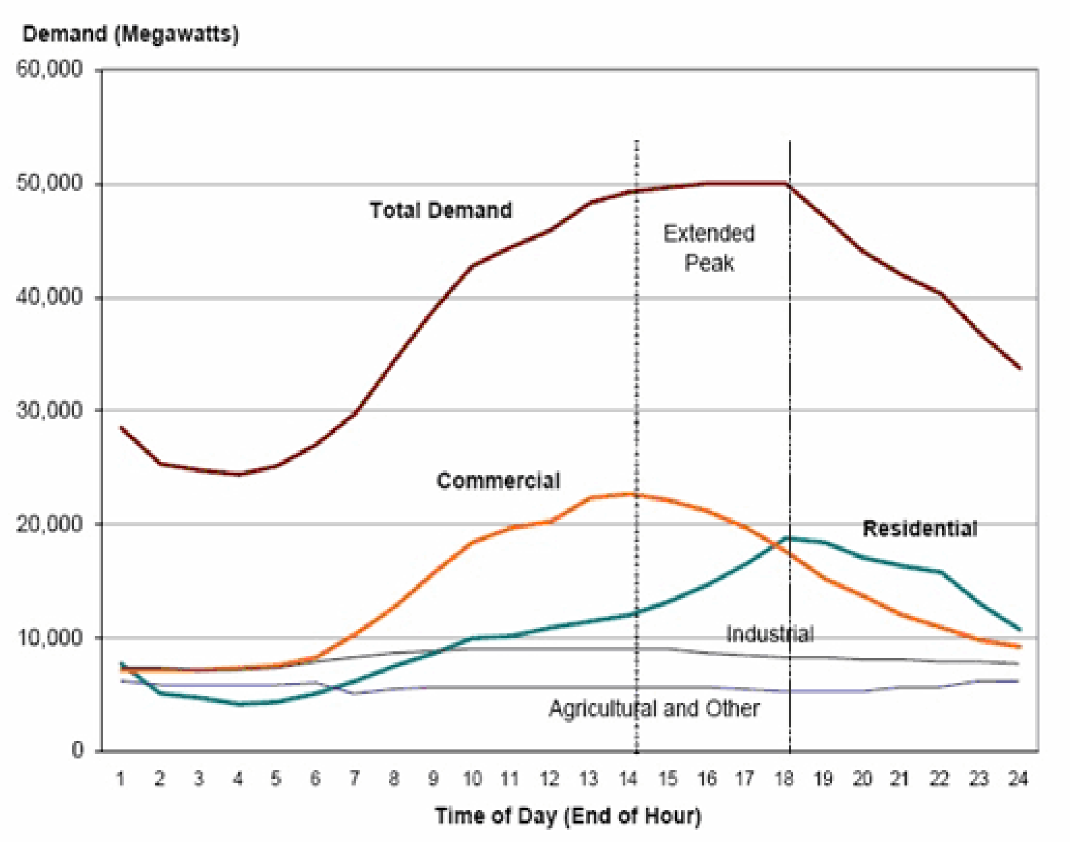
The demand for electricity has to be met instantly when it arises.

Where does demand come from?

- ✓ Industry
- ✓ Tertiary
- ✓ Residential
- ✓ And others

Why not simply aim to satisfy the average annual demand?

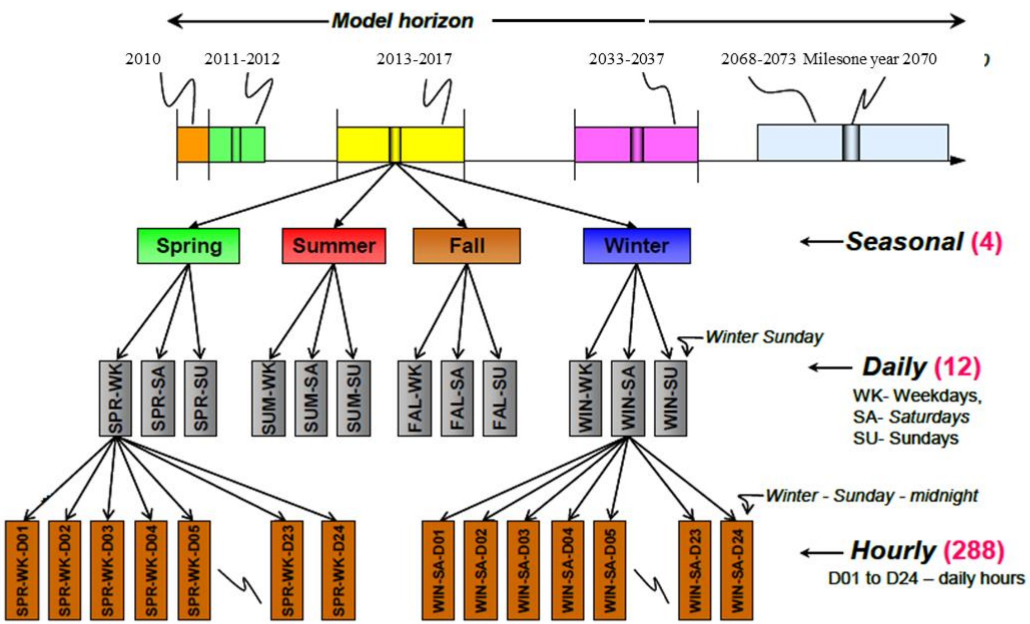
- ✓ Consumers activities are different during the day/year.
- ✓ Accordingly, electricity demand varies over time.
- ✓ Average or total annual demand can not capture the daily and yearly variations.



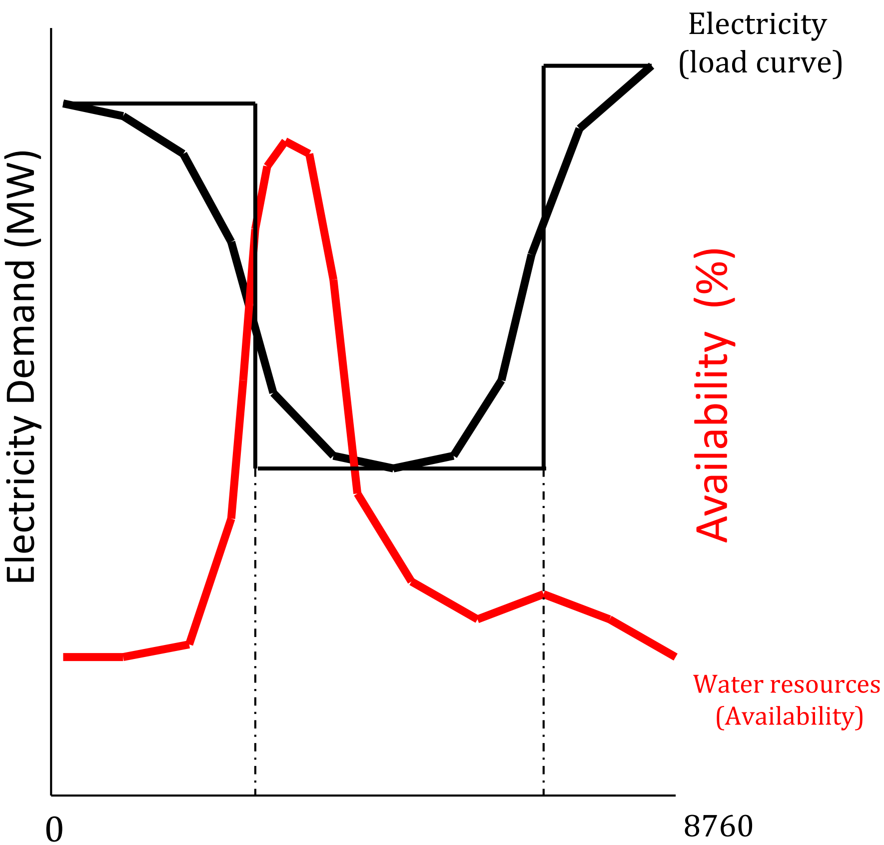
Time slices

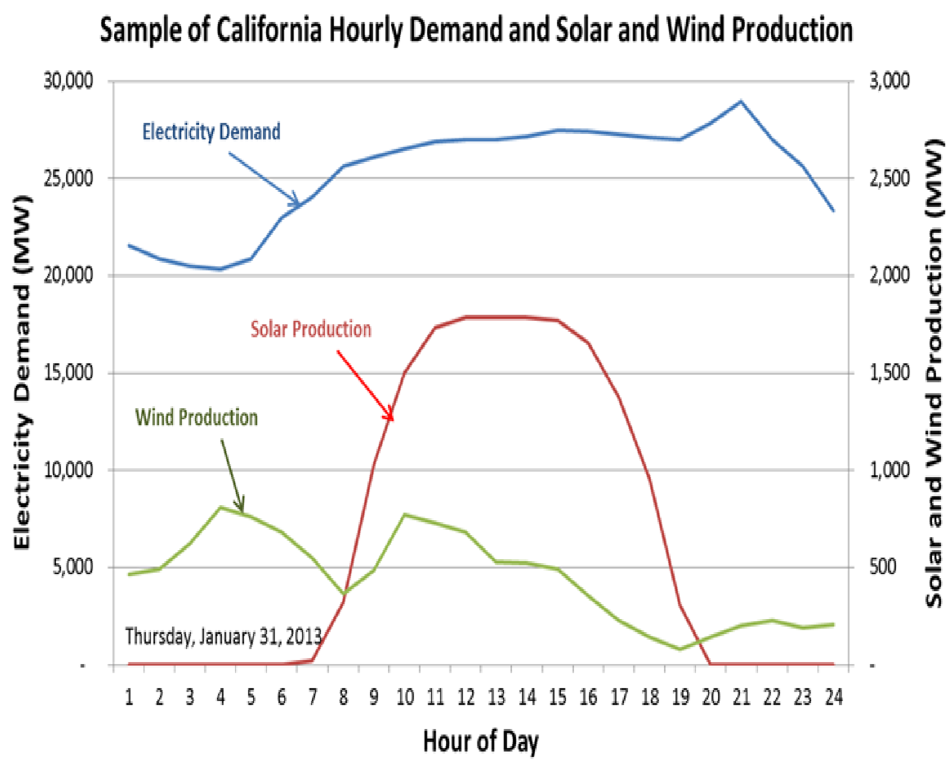
- All characteristics of the system vary over different time scales (days, weeks, seasons). Think for instance of:
  - Electricity demand;
  - Rainfall patterns;
  - Irrigation needs and duration of the daylight.
- The year is therefore broken down into representative pieces called **time slices.**

Both demand and supply (especially intermittent renewables!) are therefore studied at the scale of the individual time slices



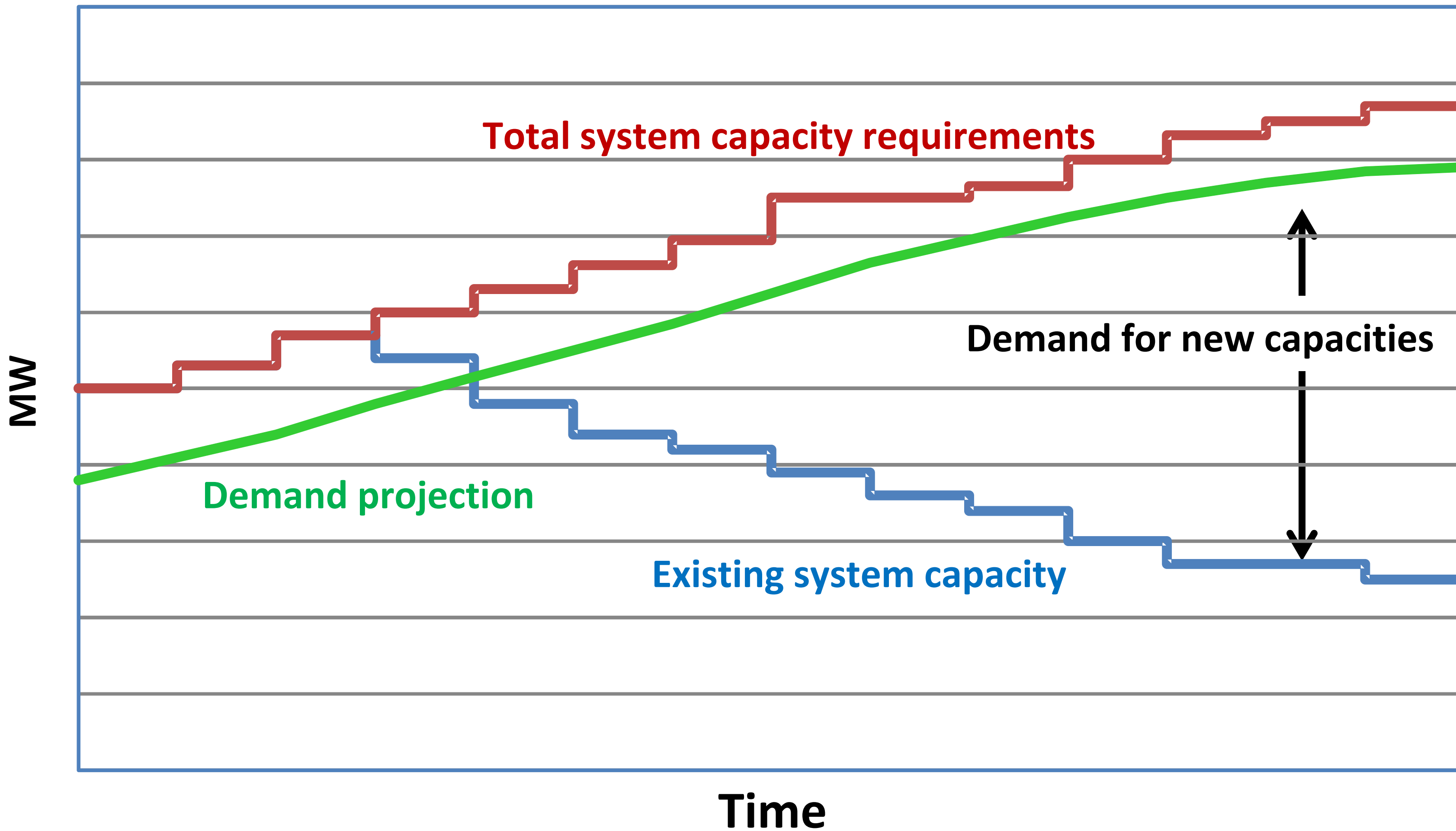
Why are time slices important ?





Planning the electricity system

Type and schedule of new capacity additions for an uncertain future



Levelised Cost of Electricity (LCOE)

Investment and fixed costs **Variable and fuel costs** **Decommissioning**

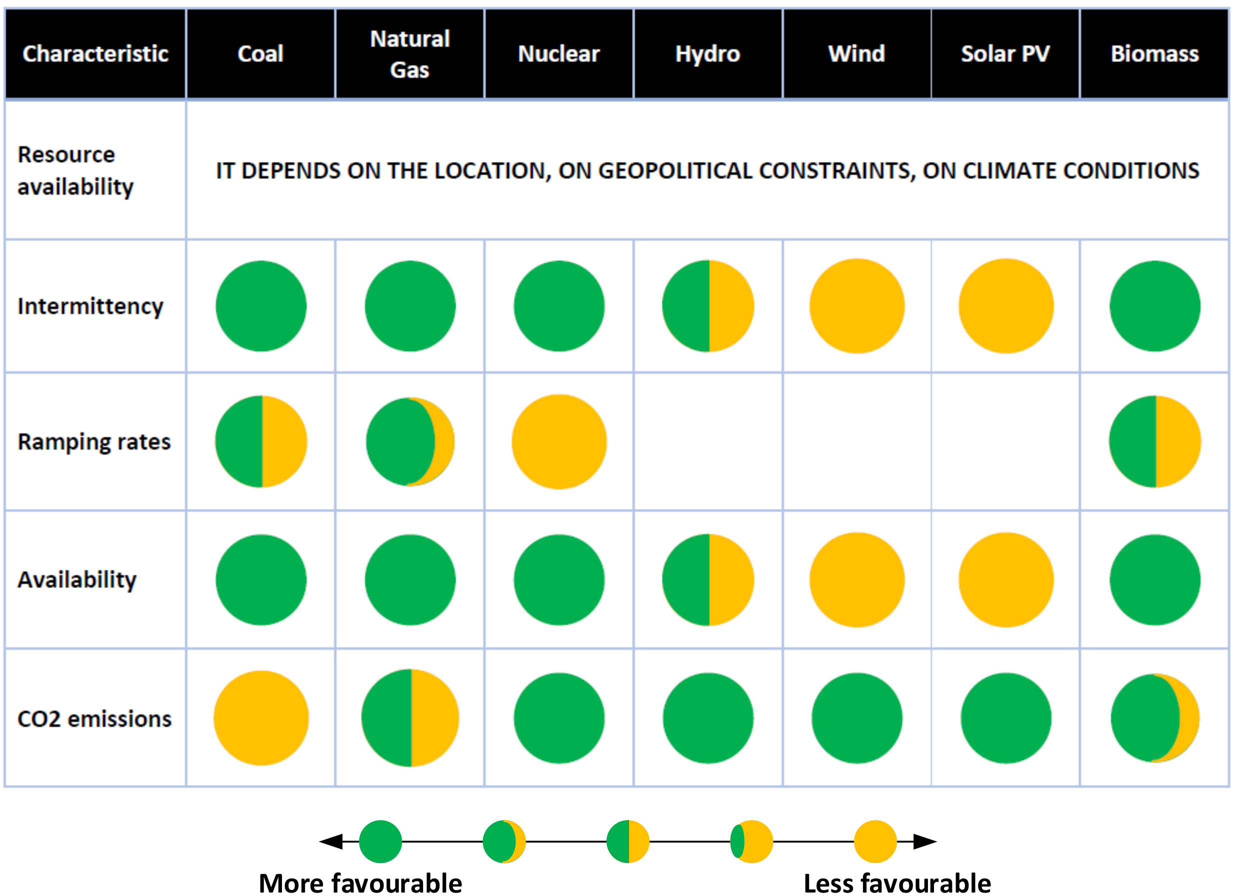
$$LCOE = \frac{\left(\frac{INV \times CRF + FOM}{PLF}\right)}{8760} + VOM + \frac{P_{FUEL}}{\eta} + \frac{\left(\frac{DECOM}{PLF} \times (1+i)^{-(PLT+T)}\right)}{8760}$$

LCOE, in \$/kWh of electricity output

INV – Overnight investment costs per kW of installed capacity, $\$/kW_e$
CRF – Capital recovery factor (annuity)
DECOM - Decommissioning costs per kW of installed capacity, $\$/kW_e$
FOM - Fix operating and maintenance costs per year, $\$/kW_e$
VOM Variable operating costs, \$/kWh
P_{FUEL} - Fuel price per kWh, in \$/kWh input
PLF - Plant factor, i.e., full load hours of plant operation per year, fraction of year
PLT - Plant life time, years
η - Plant thermal efficiency, in %
i - Discount rate, in %

Is LCoE the only decision criterion?

Technologies compete to gain a share in the energy supply, based on their techno-economic characteristics (e.g. **Levelized Cost of Electricity)**, but also on a number of other constraints – **e.g. resource availability, intermittency of production, ramping rates**, etc.



Basic technology characterization

Expansion / replacement options	**CCGT**	**GT**	**Coal PP**	**Coal CCS**	**Diesel**	**Hydro**	**Wind PP**	**Solar PV**	**Solar thermal (CSP)**	**Nuclear**
Technical data										
Unit size (MWe)	400	50	1 000	1 000	25	150	3	2	100	1 000
Efficiency (%)	54	34	39	35	30	-	--	-	-	35
Fuel	Gas/LFO	Gas / LFO	Coal	Coal	Diesel	-	--	-	-	UO_2
Load factor %	60	20	80	80	8	90	35	25	40	85
Operational life time (years)	30	30	40	40	20	50	20	20	25	50
Construction time (years)	3	2	4	4	1	4	2	1	2	6
Economic data										
Investment cost ($/kW overnight)	950	500	2 200	4 100	450	2 000	1 600	2 500	4 500	5 000
Fixed O&M cost ($/kW/yr)	15.4	7	28.15	52	7	12	25	20	40	63
Variable O&M cost excl. fuel ($/MWh)	3.6	12	5	9	8	1.5	1.2	0.8	2	2.1
Fuel costs ($/GJ)	6	6	3	3	12					2
Fuel costs ($/MWh)	21.6	21.6	10.8	10.8	43.2	0	0	0	0	7.2
Interest/discount	5	% per year								
Calculation of LCOE										
Annuity	0.0651	0.0651	0.0583	0.0583	0.0802	0.0548	0.0802	0.0802	0.0710	0.0548
Investment	0.0118	0.0186	0.0183	0.0341	0.0515	0.0139	0.0419	0.0916	0.0911	0.0368
Fix O&M	0.0029	0.0040	0.0040	0.0074	0.0100	0.0015	0.0082	0.0091	0.0114	0.0085
Varibale O&M	0.0036	0.0120	0.0050	0.0090	0.0080	0.0015	0.0012	0.0008	0.002	0.0021
Fuel cost	0.0040	0.0064	0.0028	0.0031	0.0144	0	0	0	0	0.0021
LCOE $/kWh	0.0223	0.0409	0.0301	0.0536	0.0839	0.0169	0.0512	0.1015	0.1045	0.0494
LCOE $/MWh	**22.3**	**40.9**	**30.1**	**53.6**	**83.9**	**16.9**	**51.2**	**101.5**	**104.5**	**49.4**

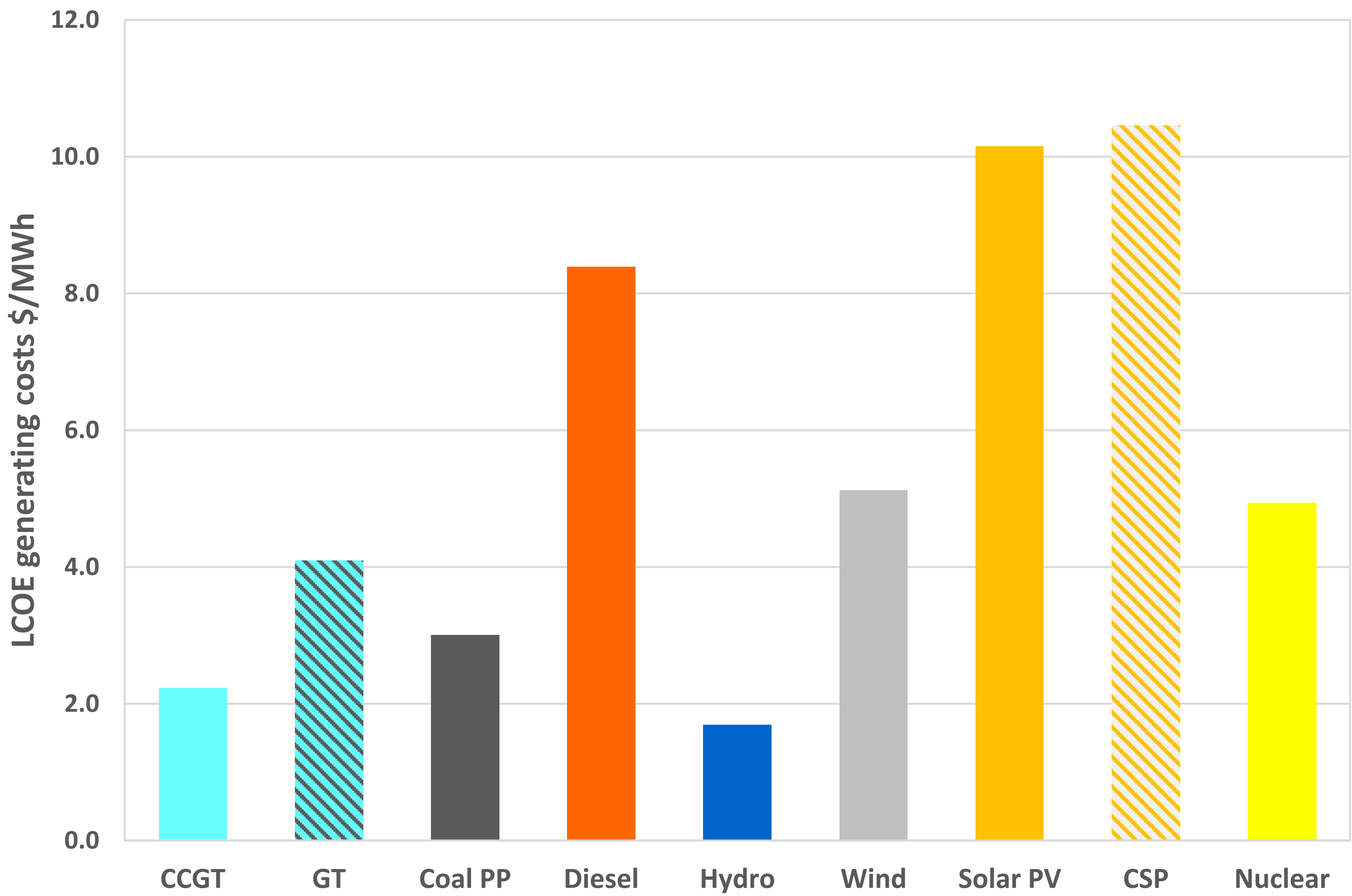
Exercise 2

Comment in 5 bullet points the graphs shown in slide 27 of this presentation.

Answer the following guiding questions:

- Which are the main features of each of the technologies plotted?
- Why one needs to look at LCOE to compare technologies and decide which one minimizes costs?
- Besides what is included in the LCoE calculations, what other criteria need to be taken into account select technologies for an electricity system?

LCOE with realistic load factors



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OpTIMUS.community, 2017. Electricity system modelling, OpTIMUS.community. Available at: http://www.osemosys.org/understanding-the-energy-system.html. [Access date]