



## **Exercises and assignments for Risø DTU course 45003: Energy Resources, Markets, and Policies**

**Jacobsen, Henrik; Hansen, Lise-Lotte Pade; Schröder, Sascha Thorsten**

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# Exercises and assignments



Risø DTU course 45003:  
Energy Economics, Markets, and Policies

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## Energy Economics background: Markets, Definitions, Properties and Assumptions

### Exercise A1: Producers

A firm produces a good  $q$  for which it incurs production costs of

$$C(q) = 12q^3 - 270q^2 + 2700q.$$

The market price for each unit of the product sold is  $p = 2439$ .

Which output level  $q$  does the firm choose to maximize profit?

Derive the first and second order conditions.

What is the firm's marginal revenue?

What are the firm's marginal and average cost functions?

Graphical representation:

- 1) plot profit in one graph;
- 2) plot marginal cost, price and average cost in 2nd graph;
- 3) plot total cost and revenue in a third graph

### Exercise A2: Profit Maximization

An electricity producer faces a cost of  $C(q) = 1.5 q^2 + 15 q$ . For each MWh of electricity sold, the electricity producer receives the market price of 45 €.

Which output level  $q^*$  does the power producer choose to maximize profit?

Define the producer's profit function.

What are the firm's marginal and average cost functions? What is the firm's marginal revenue?

Derive the first and second order conditions.

What is the profit maximizing output level  $q^*$ ?

What is the producer's profit and his revenue?

## Demand and supply curves

### Exercise B1:

Let the market price for a good be 120 €.

A producer incurs total cost of  $C(q) = 100q + q^2$ . Find the profit maximizing quantity  $q^*$ , profit  $\pi^*$ , marginal cost and marginal revenue. What is the total cost incurred at profit maximum? Use Excel to plot the graph.



Exercise B2:

An electricity producer faces generation cost of  $C(q)=q^3-9q^2+60q+80$ . The power price amounts to 60€/MWh. What are the marginal cost and the marginal revenue functions? Which output level  $q^*$  does the electricity producer choose? What is his profit  $\pi^*$ ?

Exercise B3:

Demand is given by  $q^D(p)=1200-p$ . The supply function is  $q^S(p)=300+2p$ .

Use Excel to plot the demand and supply curves on a graph, and indicate the market equilibrium.  
Determine the market equilibrium by calculating it (using algebra).

## Market equilibrium and shift in demand and supply

### Exercise C1: Equilibrium and different price levels

Demand is given by  $q_D(p) = 1200 - p$ .

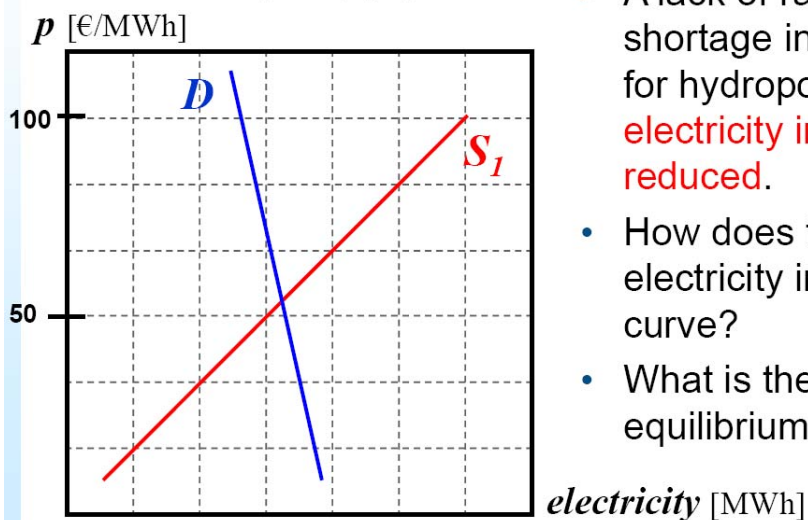
The supply function is  $q_S(p) = 300 + 2p$ .

Determine the market equilibrium by using algebra.

What happens at the price of 5 €? What at the price of 10 €?

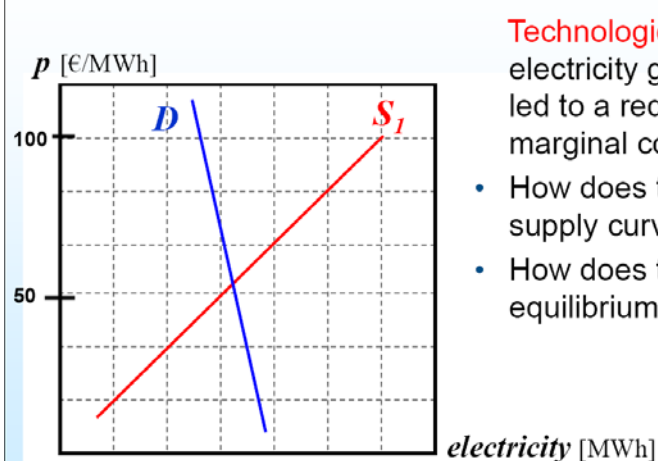
## Exercise: Shift in Supply I

On an electricity market, demand  $D$  is met by electricity supply  $S$ .



- A lack of rainfall caused a shortage in water reservoirs for hydropower so that **total electricity industry supply is reduced**.
- How does this shift the electricity industry supply curve?
- What is the effect on the equilibrium price?

## Exercise: Shift in Supply II



**Technological progress** in electricity generation has led to a reduction in marginal cost of production.

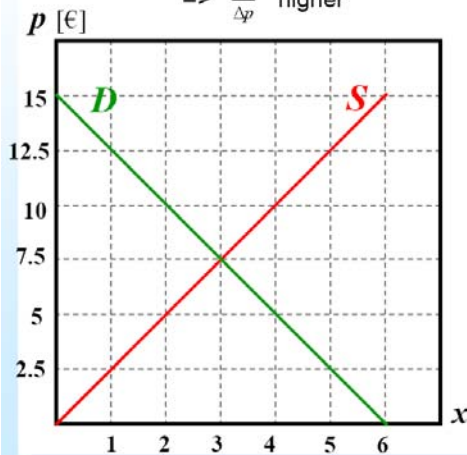
- How does this affect the supply curve?
- How does this affect the equilibrium price?

Exercise C3: Shift in demand and elasticity

## Elasticity of Demand – Exercise I

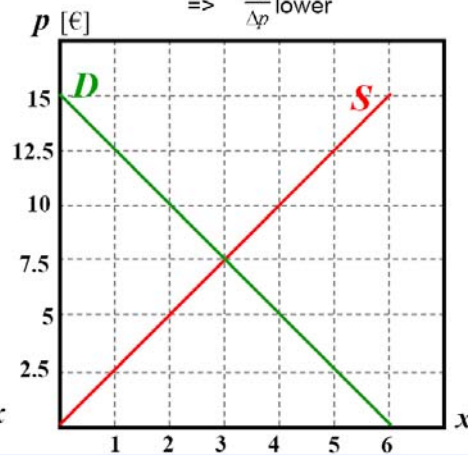
- $D'$  has higher demand elasticity than  $D$ :  $q$  reacts more to  $p$

=>  $\frac{\Delta q}{\Delta p}$  higher



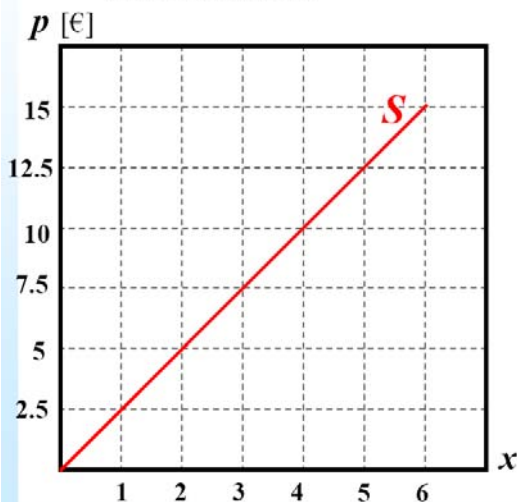
- $D'$  exhibits lower demand elasticity than  $D$ :  $q$  reacts less to  $p$

=>  $\frac{\Delta q}{\Delta p}$  lower

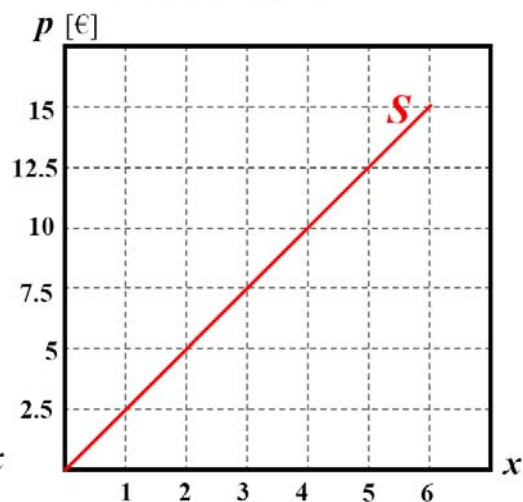


## Elasticity of Demand – Exercise II

- Perfectly elastic demand: if  $p$  rises, quantity demanded decreases to zero



- Perfectly inelastic demand: quantity demanded completely insensitive to price



## Market structure and competition

### Exercise D1: Monopolist example

A monopolist faces production cost of  $C(q) = 0.25 q^2$ . The electricity producer acts as a monopolist, i.e., there are no competitors in the market. The monopolist faces demand, given by the inverse demand function  $p(q) = 100 - 2q$ .

- Find the profit maximizing quantity  $q^*$  and the corresponding price  $p^*$ .
  - Find the solution by solving the profit function for  $q$ .
  - Solve instead the problem by maximizing profit with respect to  $p$ .
  - Compare the solutions of the profit maximization problem (duality).
  - Plot the graphs of demand, MC, MR and the solution.

## Exercise: Profit Maximization Monopolist

A large electricity producer faces a production cost of  $C(q) = 1.5q^2 + 15q$ . The electricity producer acts as a monopolist, i.e., there are no competitors in the market. The monopolist faces demand, given by the inverse demand function  $p(q) = 90 - 4.5q$ .

- Which output level  $q^*$  and price  $p^*$  does the monopolist choose to maximize profit?
  - Define the producer's marginal revenue and marginal cost as a function of  $q$ . Solve for quantity  $q^*$  and determine the price  $p^*$ . Plot the graphs by using Excel.
  - Alternatively, we can formulate the same demand function as a function of price:  $q(p) = 20 - \frac{2}{9}p$   
Use  $q(p)$  to formulate profit as a function of price, and solve the problem by maximizing  $\pi(p)$ . Find  $p^*$  and then  $q^*$ .

Exercise D3: Game theory example: OPEC

## Exercise: OPEC Example

- Find the dominant strategy for each player and the resulting Nash equilibrium ( market outcome).
- Which market outcome would maximize collective profits for both players?
- How does the result impact consumers?

		Strategy Other OPEC Countries (OPEC*)	
		Keep price (Cooperate)	Lower price (Defect)
Strategy Saudi-Arabia (OPEC*)	Keep price (Cooperate)	<p>OPEC* 600 Mio. \$/day</p> <p>Saudi Arabia 600 Mio. \$/day</p>	<p>OPEC* 750 Mio. \$/day</p> <p>Saudi Arabia 300 Mio. \$/day</p>
	Lower price (Defect)	<p>OPEC* 300 Mio. \$/day</p> <p>Saudi Arabia 750 Mio. \$/day</p>	<p>OPEC* 400 Mio. \$/day</p> <p>Saudi Arabia 400 Mio. \$/day</p>



## Energy commodities, energy balance, intensity indicators and input-output calculations

### Exercise E1: Energy commodities:

List at least 5 energy commodities?

- Try to sort by economic importance?
- Try to sort by environmental harmful importance? (how much does it contribute to global pollution)
- Consider if economic importance matches environmental importance

Exercise E2: EU energy balance and energy commodities:

**EU energy balance: Individual exercise**

Energy balance- EU27- 2004

ktce	Solidfuels	Crudeoil	Oil products	Gas	Hydro, Nud.	Elec.	Heat	Biomass	Total
PRIMARY PRODUCTION	20300	14574		20296	30088		1340	8098	98400
Imports	15542	65891	27043	29554		2413		1610	140604
Exports	-2552	-9137	-26250	-6630		-2477		-1170	-46970
Marine bunkers			-4905						-4905
Stock variations	-19	-283	139	-282				-70	-453
PRIMARY CONS.	32871	71045	-3973	43504	30088	-64	1330	8136	181689
Refineries	-40	-7574	76032	-13					268
Power plants	-24370	0	-3140	-12040	-30088	28279	4945	-2541	-38904
Own use, losses	-1836	4673	-885	-2458		-4844	455	-346	-13251
FINAL CONSUMPTION	6627		60026	28994		23371	5533	5253	129804
industry	5434		4773	10404		9669	1194	1745	32180
transport	10		35860	47		627		200	36735
households, services	1072		984	17146		13076	4339	3308	46280
non-energy uses	119		9710	1397					11225

1. What is the import share in natural gas
2. Which sector consumes the largest share of fossil fuels
3. Why is the primary consumption of heat less than the final consumption
4. What is the input composition in heat production
5. Is the EU a net exporter of electricity
6. Which type of energy is dominating the non-energy use

### Exercise E3: Compare energy balances for countries

Group Exercise: Compare structure of 2 countries for given year based on file: 5balan.xls

Examine energy balance and extract/illustrate the following if possible with data:

1. Composition of primary consumption in 2 countries
2. Self sufficiency in oil products
3. Total efficiency of heat and power conversion
4. Renewable share in electricity generation
5. Composition of final demand on sectors

### Exercise E4: Compare energy indicators for countries

Data from Campusnet (data indicators.xls)

Group exercise: Groups upload to Campusnet 1 slide with one graph indicator comparison and one observation/conclusion

- Compare three countries and energy intensity.
- Choose at least one high growth and low growth country
- Examine for example: Growth of energy demand, transport energy and electricity demand
- Compare indicators based on: (GDP, GDP/Cap, Cap?)

What is the link between GDP and energy intensity for different types of energy?

Exercise: Additional questions

1. Is it the same countries that have high energy intensity relative to GDP as relative to population?
2. Can You compare electricity intensity and oil products intensity within one country?
3. Which energy types have increasing intensity and which ones are declining?
4. Which intensities are most volatile?
5. What is the interpretation of indicator development and the link between growth and energy resource use?

## Energy and input-output techniques

### Exercise F1: Input-output tables Examples and exercise

Access the excel file from campusnet: IO-data and exercise: Sheet Exercise A

Illustrative steps and tables in excel file

1. Flows of goods and services between producers
2. Imports for production inputs
3. Primary inputs
4. Final demand
5. Coefficient matrix
6. Leontief inverse and production
7. Combining energy intensities and IO matrices

#### Flows of goods and services

For each producing sectors rows represents supply of the sector output to other sectors and final demand  
Columns represent input to production of that sector

	Agriculture	Manufacturing	Services	Final demand	Production
Agriculture	50	10	10	200	270
Manufacturing	25	100	20	300	445
Services	25	30	10	150	215
Imports	5	50	10	250	
Primary inputs	165	255	165		
	270	445	215	900	

## Primary inputs

Three categories of primary inputs (or value added) are now included in the table

	Agriculture	Manufacturing	Services	Final demand	Production
Agriculture	50	10	10	200	270
Manufacturing	25	100	20	300	445
Services	25	30	10	150	215
Imports	5	50	10	250	
Employees	<b>65</b>	<b>150</b>	<b>120</b>		
Capital owners	<b>100</b>	<b>100</b>	<b>25</b>		
Indirect taxes		<b>5</b>	<b>20</b>		
	270	445	215	900	

## Imports

The import row can be divided as a matrix on import goods or

divided on goods produced in the same sectors as the domestic ones

	Agriculture	Manufacturing	Services	Final demand	Production
Agriculture	50	10	10	200	270
Manufacturing	25	100	20	300	445
Services	25	30	10	150	215
Agricul. Imports		<b>5</b>	<b>5</b>	100	
Manuf. Imports	<b>5</b>	<b>40</b>	<b>5</b>	100	
Services imports		<b>5</b>		50	
Primary inputs	165	255	165		
	270	445	215	900	

## Final demand

Four categories of final demand are now included in the table

	Agriculture	Manufacturing	Services	Private consumption	Government consumption	Investment	Export	Production
Agriculture	50	10	10	100	10		90	270
Manufacturing	25	100	20	100	25	50	125	445
Services	25	30	10	120	10		20	215
Imports	5	50	10	125	25	50	50	
Primary inputs	165	255	165					
	270	445	215	445	70	100	285	

## Coefficient matrix

The coefficient matrix is given by the element-wise dividing the inputs in each sector with total production for that sector

	Agriculture	Manufacturing	Services
Agriculture	0.19	0.02	0.05
Manufacturing	0.09	0.22	0.09
Services	0.09	0.07	0.05
Imports	0.02	0.11	0.05
Primary inputs	0.61	0.57	0.77
	1	1	1

That means 19% of inputs in agriculture is agricultural products and only 2% is imports

What about the interpretation related to rows?

## Leontief inverse

The Leontief inverse matrix  $(I-Ag)^{-1}$  is the inverse matrix of an identity matrix  $I$  minus the coefficient matrix  $Ag$  (the red part of the table in the previous slide)

	Agriculture	Manufacturing	Services
Agriculture	1.24	0.04	0.06
Manufacturing	0.16	1.31	0.14
Services	0.13	0.10	1.06
Total	1.54	1.44	1.26

What is the interpretation of the first element in this inverse matrix?



Exercise F2: Replicate the Inverse matrix with the excel file 'IO-data and exercise raw'

**Energy matrix**

Energy matrices can be combined with input output matrices  
 An energy matrix could look as the following with numbers in some common measure (TJ, TOE)

Energy matrix final use

	Electricity	Natural gas	Diesel	Other fuels
Agriculture	50	0	30	30
Manufacturing	400	30	100	100
Services	150	5	200	100
Production input	600	35	330	230

Energy coefficients/intensity

	Electricity	Natural gas	Diesel	Other fuels
Agriculture	<b>0.19</b>	0.00	0.11	0.11
Manufacturing	<b>0.90</b>	0.07	0.22	0.22
Services	<b>0.70</b>	0.02	0.93	0.47

**Energy multiplier calculation example**

Electricity consumption associated with manufactured exports	Share of total electricity in production
156.2	26.0%

- Load worksheet "io exercise raw" and replicate calculations for electricity associated with manufacturing exports
- Make calculation element wise

### Exercise F3: Energy multiplier calculation exercise

Use the simple structure from the Excel file of 3x3 activities. Exercise A

In sheet exercise B

Expand the basic activity: manufacturing into two activities:

1. high energy intensity
2. low energy intensity

Assume they have equal share of total manufacturing output and their input structure is similar:

Then assume that their production is differently distributed on the final demand components.

high intensity: For export 25 (increase the other final demand components proportionally)

low intensity: For export 100 (reduce the other final demands proportionally);

so that production in the two sectors remain the same

Then calculate the new input coefficients:

Check coefficients – How?

Assume electricity intensity:

high energy intensity 1.4

low energy intensity 0.4

Now calculate the electricity associated with total manufacturing exports. The sum of electricity use in all sectors as a consequence of exports of both high and low electricity intensive manufacturing goods

Compare with the original calculation

Is this difference in electricity intensity realistic?

## Competition, Liberalization and Internationalization

### Exercise G1: Producers and isolated markets

An energy market is regulated by authorities by setting price caps equal to marginal production costs. No new producer entry to the market is allowed. It is assumed that the regulator has full information about costs and demand.

Two producers are granted access to the market.

Producer East has costs of  $C(q) = 20 + 2q + 1.5q^2$

Producer West has costs of  $C(q) = 1.5q$

Producer West has a maximum production capacity of 20 units.

The market demand is given by  $D(p) = 40$

- Find the equilibrium price and quantity for the market.
- Calculate profits for each of the two producers.

### Exercise G2: Market solution in another region

Another region (country) has a market for the same energy good also with two producers. Prices here are also regulated so that  $MC = \text{price}$ .

Producer North has costs of  $C(q) = 1 + 0.5q + 3q^2$

Producer South has costs of  $C(q) = 3q + 2.25q^2$

The market demand is given by  $D(p) = 200 - 2p$

- Find the equilibrium price and quantity for the market.
- Find the output for each producer
- Calculate profits for each of the two producers.

### Exercise G3: Integrating markets

Consider the two markets: Qualitative answers are fine.

Q1: What would happen at market 1 if the authorities liberalize the price setting at the market but do not give free access to foreign companies?

Q2: What would happen at market 2 if the authorities liberalize the price setting at the market but do not give free access to foreign companies?

Q3: What if producer East is publicly owned and maximize welfare and not profits;? would the market outcome with liberalized prices be different from the situation in Q1?

Exercise G4: Now the EU enforces liberalization of these two markets.

That include access to both markets for all 4 producers. The price setting is totally free and we assume that competition is strong enough to secure competitive market pricing already with the 4 producers.

- Try to guess the effect on price and for producers
- Then calculate to:
- Find the market prices on the two markets?
- Calculate the output of all 4 producers
- Compare the prices and the marginal production costs of the producers
- Is the situation with liberalized markets better than before?
- Who benefits and who loose from liberalization?

## Power Economics

### Exercise H1: Price determination at an electricity spot market

You represent the power exchange „Central European Spot“. For one hour of the following day, you have received the following supply bids:

Company	Amount (MWh)	Bid price (€/MWh)
Red	100	25
Red	100	30
Blue	200	10
Blue	50	80
Purple	100	40
Yellow	50	70

1. Build the supply curve.
2. First, let's assume a price-independent demand. What are the market prices at a demand of 380 and 540 MW? What are the revenues of the different companies?
3. Now, let's assume that demand is price-dependent. The following customers buy the amounts up to their cut-off price:

Customer	Amount (MWh)	Cut-off price (€/MWh)
Utility 1 (repr. households+offices)	180	infinite (price-independent)
Utility 2 (repr. households+offices)	100	infinite (price-independent)
Industry 1	250	200
Industry 2	50	60

Build the demand curve.

4. What are the market price and traded amount?
5. For the following hour, the bid situation remains unchanged with regard to supply and demand – except one new supply bid after sunrise. PV and wind enter the picture as follows:

Company	Amount (MWh)	Bid price (€/MWh)
Green	100	0

What are the market price and traded amount now?

6. Discuss how PV and wind affect the other market participants.

## Exercise H2: Load duration curve and prices (hourly data)

Examine the Danish West area load and price data in the Excel file. Time series is 2006-2009.

Compare the load of a winter weekend day and a working day from the same month. (choose a year and month)

- What is the difference?
- Who do You think is responsible for the peak load in the system?

Match the load data with the corresponding price

- What can be concluded about the relationship between load and price?
- How is this related to the supply and demand functions and price variation
- What possible “noise” explanations for the deviations from the load - price relationship could you suggest?



### Exercise H3: Construct annual load duration curves and compare the years

Use the load data to construct a load duration curve for one of the years.

- Is the curve smooth without sudden changes in slope?
- What is the peak requirements of the system?
- Try to guess if the duration curve would change over the years and how.

Then compare the duration curve of two years. For example compare 2008 with 2009.

- Is the shape of the duration curve different?
- Is the size of the peak load changed?
- How much do you think duration curves change shape in time and how much level?

Additional:

Compare the load duration curve with price series. Is there a general relationship?

#### Exercise H4: Market arbitrage? Day-ahead and regulating/balancing

Consider 3 generators:

A: Fuel costs 7 €/MWh

B: Fuel costs 18 €/MWh

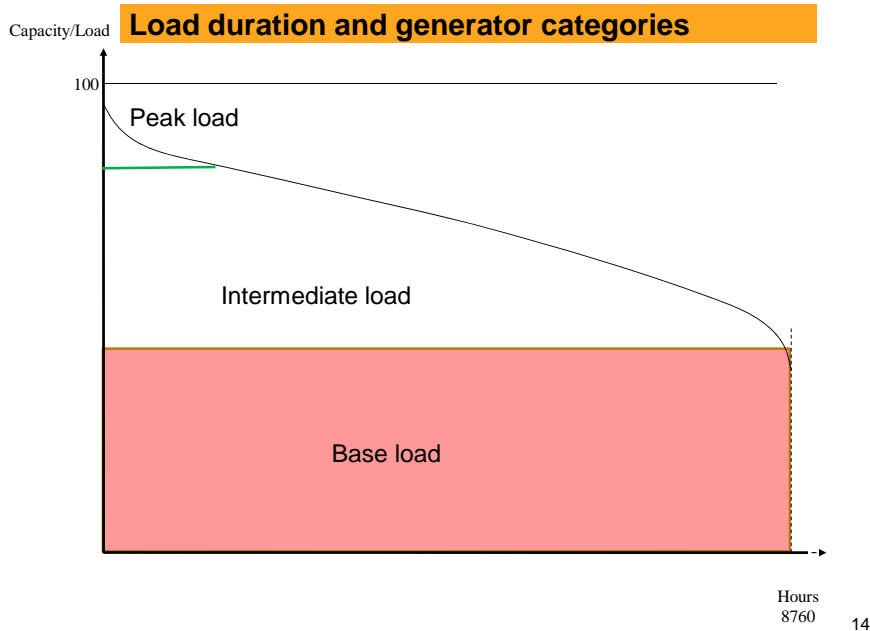
C: Fuel costs 24 €/MWh

Expected price on day ahead market with competitive prices: 25 €/MWh

For the hour 13:00 to 14:00 next day the probability for up regulation is 75% and for down regulation 25%. The generator will only receive revenue if activated.

- a) What will each generator bid on the regulating market given that the generators should be indifferent to supplying each market – what is the level of expected price on regulating markets relative to day ahead?
- b) Which generators will supply each market?

## Exercise H5: Duration curve and generation technologies



a) Base load: How many hours will base load generate?

b) Which technologies will be base load?

Intermediate load:

Peak load:

### Load curve properties and dynamics

c) Price change ? Is there an effect on the duration curve?

d) What will happen to duration curve if higher prices?

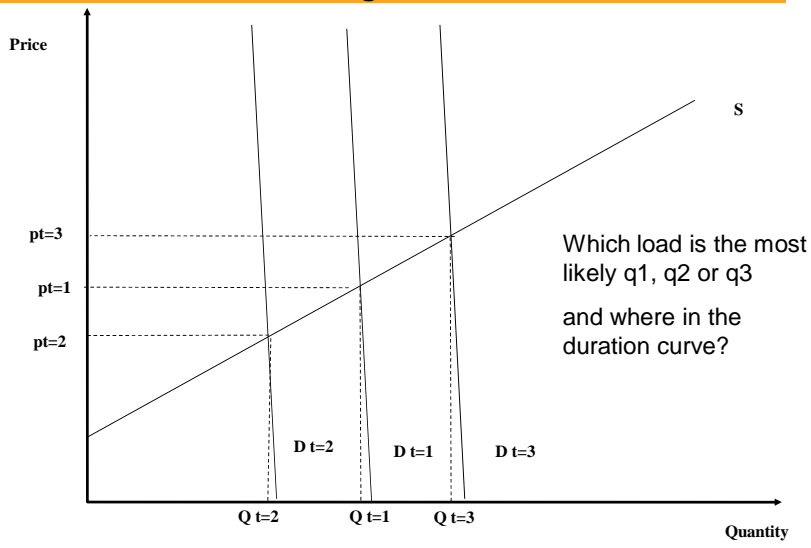
e) What will happen to duration curve if population increases

f) Is the shape of duration curve similar for different countries

g) What happens if there is a reduction in industrial output?

a. What will happen if a new generation technology is introduced

### Exercise A: Demand changes and duration curves



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- Argue which technologies will be generating in the three situations D1 to D3 given the equilibrium price and demand
- Draw the duration curve and place the demand D1 to D3 in intervals on the curve.

## Exercise H6: Increased variable costs and the optimal technology composition

- Two technology case again
- Variable costs increased by 20%; compared to original figures in table below:

**Table 2-2.1** Costs of Available Technologies

Technology	Fixed Cost per MWh	Variable Cost per MWh
Peaker	\$6	\$30
Baseload	\$12	\$18

- Use screening curves to determine duration of peak and base load
- Calculate base load capacity
- Calculate flat part of demand curve duration (K)
- What will optimal peak capacity and base load capacity be?

## Market failure, public goods and externalities

### Exercise I1: Social optimum with damage costs

A competitive market is characterized by producers that are profit maximizing.

They have production costs of  $C(q) = 4.5q$

The market demand is given by  $D(p) = 100 - 2.5p$

- a) Find the equilibrium price and quantity for the market.
- b) Calculate profits for the producers.

The producers are aware that their production using diesel as input results in emissions of particles that have negative environmental impacts on the local inhabitants in the neighborhood.

The authorities have estimated the cost of emissions at 0.8 per output unit  $q$  (diesel input is proportional to output  $q$ , and particles emissions proportional to diesel input).

- c) Find the social optimal output level taking into account the externality
- d) Calculate the corresponding price and compare the solution with the market outcome
- e) Calculate profits and calculate emission (damage) costs and compare these two
- f) Compare the producer and consumer surpluses in the two situations and identify the losers and the winners from market intervention (graphical is ok)

### Exercise I2: Monopoly and externality costs

In this case we are dealing with the same market but characterized by a profit maximizing monopoly.

$$C(q) = 4.5q$$

The pollution effect is slightly different by that externality costs are characterized by rising marginal damage costs of emissions.

$$C_e(q) = 0.04q^2$$

- a) Find the optimal output and corresponding price for the monopoly
- b) Find the optimum with perfect competition assumptions
- c) Find the social optimal output level
- d) Calculate the corresponding price and compare the solution with the monopoly and the perfect competition situation
- e) Compare the surpluses in the three situations and identify the losers and the winners from market intervention; the social optimum (graphical is ok)

Which situation is the most welfare decreasing: the monopoly or the externality with market failure in a competitive market?

## Local and global pollution problems

### Exercise J1: Pollution problems, solutions and challenges

- Mention some differences between local and global pollution problems
- How does the problem of acidification and global warming differ?
- Which of these is the most difficult to address with regards to externality costs
- Is the CFC emissions and ozone depletion more similar to acidification than to global warming
- What is the link between energy sector liberalisation and the enforcement of international environmental agreements?
- If the mixing of the pollutants is uniform for each greenhouse gas what does that imply for the mitigation options to undertake by different countries regarding global warming?
- Why is that difficult to establish in a global agreement?



## Externalities and health costs

### Exercise K1: Externalities and health costs

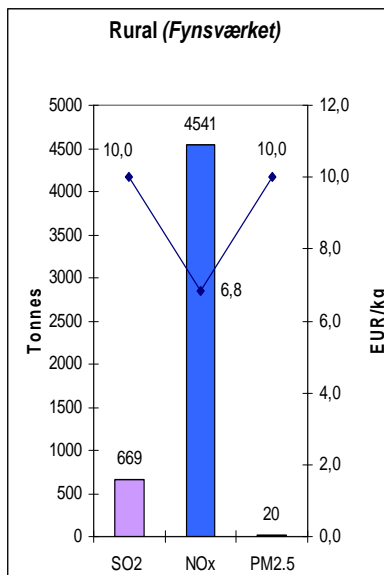
1. Use the data to calculate

- total health (local) external costs of the three power plants due to health damage
- health external costs per electricity unit produced by three plants (e.g. Euro cent/kWh)
- the marginal Danish electricity production emits 779 kg/MWh of CO<sub>2</sub> in average. The Danish Energy Agency recommends to use CO<sub>2</sub> cost of ~ 32 EUR/t in the socioeconomic studies.

2. Calculate the total global external CO<sub>2</sub> costs of electricity production in the fossil fuel-based plants using the numbers for the marginal electricity production. Compare the local and global external costs.

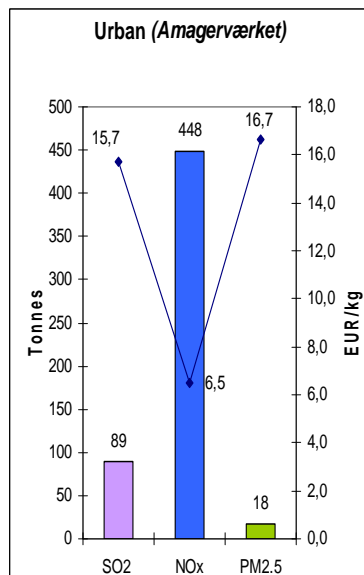
3. Prioritise electricity production in the three plants based on local external costs due to health damage.

4. Discuss what other factors/costs can change the prioritisation of production in the plants? How? (E.g. imagine that the plants are to be built)



Coal (60%) and natural gas (40%)

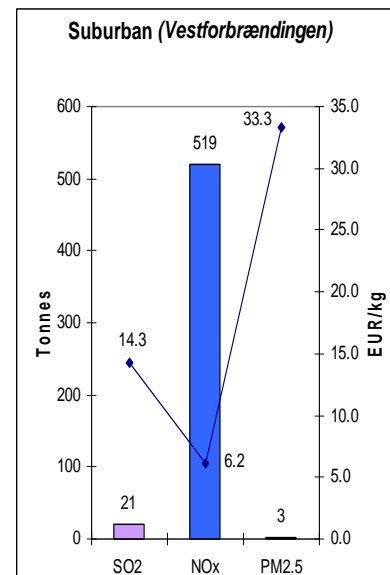
Electricity production: **1808 GWh**



Coal (95%) and bio waste (5%)

Electricity production: **1450 GWh**

Desulphurisation and de-NO<sub>x</sub>

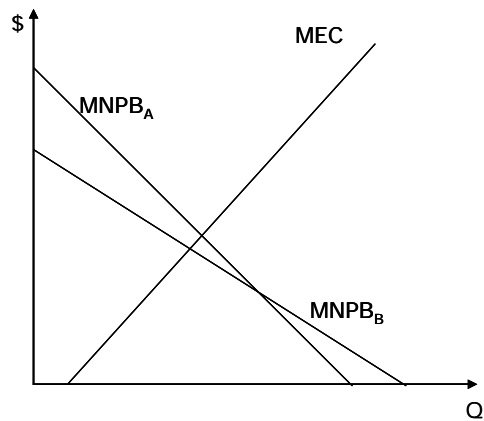


Municipal waste

Electricity production: **83 GWh**

## Regulation and economic instruments for environmental protection

### Exercise L1: Two cases of Marginal Net Private Benefits



Consider firm A:

- constant MC
- downward sloping demand

What is the optimal production level:

- private
- social

Is there any scope for public regulation?

Is there any possibility for socially inefficient production?

How could the production level be regulated?

Consider firm B

- constant MC
- downward sloping demand

Is the optimal production levels changed:

- privately
- socially

Is the optimal tax higher or lower than in Case A?

Does consumers preferences for consumer goods affect the optimal production level?

### Exercise L2: Abatement costs and regulation efficiency

- Comparison of direct regulation (command and control) with a tax (market based)

Consider two producers:

- using comparable fuels
- one type of emission:

They can reduce emission at given costs. Abatement costs reflect the emission reduction

They can both reduce max 12

A: Abatement costs

$MAC = 2 + \frac{1}{2}q_a$  ; for  $q_a \leq 7$  ;  $MAC = 8$  for  $q_a > 7$  ;  $q_a(\max) = 12$

B: Abatement costs

$MAC = 7$  ;  $q_b(\max) = 12$

Reduction of emissions => total abatement  $Q = 10$

Assume both have to reduce equally:

- what would be the total abatement costs?

Imagine a tax on emission:

- what should be the optimal level to achieve the total desired reduction?

What is the total cost of emission reduction in the tax case?

How is the distributional impact of a tax?

How could the difference be eliminated?

### Exercise L3: Optimal emission tax and welfare loss

Consider two representative energy producers

Producer A

produce electricity based on natural gas

marginal abatement cost:  $MAC_A = 1/2q_A$

Producer B

produce electricity based on coal

marginal abatement cost:  $MAC_B = q_B$

Abatement:  $Q = q_A + q_B$

The optimal abatement level  $Q^* = 8$

1. What is the total MAC of the industry?

We introduce command and control regulation and assume that both producers emit equally:

2. What is the abatement costs of producer A?

3. What is the abatement costs of producer B?

Instead we introduce economic incentive based regulation

4. What is the optimal tax level,  $t^*$ ?

5. How much does producer A abate,  $q_A^*$ ?

6. How much does producer B abate,  $q_B^*$ ?

7. What are the abatement costs of producer A?

8. What are the abatement costs of producer B?

Comparison of regulatory means:

9. What is the welfare loss from command-and-control regulation compared to economic incentive based regulation?

10. What is the welfare effect of a lump sum redistribution of the tax revenue?

11. Why is it more efficient to setting a tax compared to setting a fixed abatement level corresponding to their optimal abatement level ( $q_A^*$  and  $q_B^*$ )?

## Exercise L4: Tradable quotas compared to standard quotas

INFO:

2 Firms (power generators)

Total emission quota: 400 tonnes (e.g. CO<sub>2</sub>). Each have 200 tonnes emission quota allocated. Quotas has been allocated for free

Generator 1

- use coal
- conversion efficiency = 0.41;
- capacity unlimited

Generator 2

- use natural gas.
- conversion efficiency = 0.47
- capacity unlimited

- gas price 43 /GJ
- coal price 32 /GJ
- emission coefficient:
  - coal: 1 tonnes per GJ
  - nat gas: 0.66 tonnes per GJ
- Demand curve:  $p = 800 - 2Q$ 
  - Q is demand in MWh

A: No permits trade case

Given the allowed quota – calculate:

- marginal costs per MWh
- generation

B: Introduce tradable permits

Compare the two situations: No-trade and trade

What will be the effect on:

- profits
- the generation
- price of quotas

Will both generators prefer a situation with trade or do they have different preferences?

- what about the consumers?



### Exercise L5: Renewable support schemes and electricity markets

A renewable project investor has erected wind capacity of 2 MW. He receives a production subsidy of 3.4 cent/kWh on top of the spot market price and incurs zero marginal cost for production (since this is a short-term perspective, we do not consider investment cost).

- Calculate the investor's hourly profit with the power prices from Thursday 19.11.2009 (excel sheet). Then calculate the average profit (i.e., the mean profit) of that day.

(To abstract from the impact of the intermittency of wind on profits, let us assume on the day of calculation, there are good wind conditions so there is always full production utilizing total capacity.)

- In a neighbouring country, feed-in tariffs are applied. There are two kinds of tariff: a high initial tariff of 9.2 ct/kWh for the first five years and a lower tariff of 5.02 ct/kWh thereafter. To see how his profit would have differed under this system, the wind project developer calculates what his hourly profit would have been under a fixed feed-in tariff.
- In another country, a green certificate system has been adopted. Using the certificate prices from that country (excel sheet), the wind investor calculates what his hourly profit and the mean profit would have been under a green certificate system with these certificate prices for that day.
- To compare the impact of the different support schemes, plot the investor's hourly profits for the price premium, feed-in tariff (initial and regular) and the green certificate system in one graph.
- How would a rise/decline in electricity prices influence the investor's profit in the case of feed-in tariffs, premiums and green quotas?

## Energy demand components and instruments for final energy demand

### reduction

#### Exercise M1: Energy savings – Heating of residential houses

Calculate energy savings based on insulation implemented in building codes

Old houses (older than 30 years): average roof insulation of 100mm

New initiative: 300mm mandatory when replacing roof on old houses

Assume:

Average old house have annual consumption of 50 GJ for heating purposes

By insulating (100 to 300 mm of roof insulation) 20% of consumption can be saved

Savings are based on a temperature of 20 degree Celsius indoor and 100 m<sup>2</sup> heated area on average.

For the national energy savings plan this initiative is estimated to contribute to reducing energy consumption by 1% in 5 years.

Question 1:

Heating price: 30 €/ GJ

**How much is the annual savings for each house replacing roof?**

Question 2:

Then you have to consider consumer behaviour:

Price elasticity for residential heating is -0.2

**What happens to heating demand?**

How can that be interpreted? – what is the *purpose* of the “new” heat demand?

Question 3:

Now assume that there exist 350 000 old houses.

Assume that 5% of the initial stock of old houses have replaced roof every year.

**What is the annual energy savings in heat demand after 5 years?**

Question 4:

**What is total consumption before introduction of the new initiative compared to the consumption 5 years later?**

Question 5:

Consider what happens to the household consumption budget:

Assume 80% of the *gross savings* (*what does that mean?*) are used to pay for the additional insulation costs.

The remaining *net savings* are used for additional consumption (goods and service).

On average the direct and indirect domestic energy content in total consumption of (goods and services) is 5% in value terms.

Assume: price on energy is 30 €/GJ for all energy types.

**How much will the savings result in increased energy demand?**

Question 6:

Compare gross national annual energy savings after 5 years with the adjusted energy savings taking into account the consumer response of households:

**What is the reduction in the savings?**

Question 7:

**Which part(s) of increased energy consumption left out in this simplified calculation?**

## Assignment for 45003 Fall 2009

The assignment is individual and you must hand in your own version, but you are free to discuss with others. The assignment should be about 7-10 (max 10) pages and the deadline is Tuesday November 3 in my mail [jhja@risoe.dtu.dk](mailto:jhja@risoe.dtu.dk). If there are questions or you want clarifications, please send me a mail no later than October 20 and I will collect and answer collectively.

**1:** Compare energy intensity indicators for your home country and the US. Provide indicator time series for at least 15 years and comment. Discuss the difference between development for electricity intensities and for total energy. If you have problems finding relevant data for your country, please choose another.

Which factors contribute to explaining the change in intensity over time?

How does a change in the structure of an economy affect the intensities?

**2:** Energy market types

Consider two energy related markets:

- Hard coal
- District heating

How are the basic preconditions for establishing a competitive market for these two products fulfilled?

**3:** Equilibrium price in competitive market with 3 producers:

Producer 1: Cost  $C(q) = 2.5q + 4$ ;  $q_{\max} = 6$

Producer 2: Cost  $C(q) = 2q + 3$ ;  $q_{\max} = 4$

Producer 3: Cost  $C(q) = 1.5q + 1$ ;  $q_{\max} = 2$

Demand is inelastic in case A

$D("p") = 5$

What will the equilibrium price be on this market?

What is the profit for each producer?

Is this a long term equilibrium and will the market be characterised with the same producers in the long term?

Assume now that demand becomes more elastic

$$D(p) = 12 - 4.5 p^{0.3}$$

What is the new equilibrium, with this demand curve?

Does this change the profits for producers ?

What could make the demand curve shift outwards in time?

Is there in general a difference for a monopolist that face an inelastic demand curve or a more elastic demand curve as the last one used in this question.

**4:** Discuss how the price of bioethanol is related to

- other energy prices
- technological progress
- competing uses for its raw materials
- macroeconomic growth

If cross price elasticity with gasoline is 3.5 and world market gasoline prices increase 10% while bioethanol only 3%, what will be the effect on bioethanol demand.

**5:** In wholesale day ahead power markets the prices on an hourly basis vary a great deal.

Is the size of volatility caused by:

- demand changes?
- changes in supply?
- composition of generation technologies?
- the size of the market?
- fuel price changes?

For each option explain how it affects volatility or why if it does not:

For demand changes and supply changes make illustrative drawings of changing curves. Illustrate the effect on prices. They can be drawn linear. Discuss how the shape of the demand and supply curves affects price volatility. Which property of electricity markets demand and supply curves are especially challenging.

Discuss if price volatility is an advantage or a drawback for generators and compare between the classes of generators: peak, intermediate and base load.

## Assignment for 45003 Fall 2010

The assignment is individual and you must hand in your own version, but you are free to discuss with others. The assignment should be about 7-10 (max 10) pages and the deadline is Friday October 15 in the campusnet assignment module. You are free to allocate pages for the different questions. They are of different size. If there are questions or you want clarifications, please send me a mail no later than October 7 and I will collect and answer collectively.

**1:** Compare energy intensity indicators for your home country and the US. Provide indicator time series for at least 15 years and comment. Discuss the difference between development for electricity intensities and for total energy. If you have problems finding relevant data for your country, please choose another.

Some possible sources are:

<http://www.eia.doe.gov/emeu/iea/>

<http://data.un.org/Data.aspx?d=SNAAMA&f=grID%3a102%3bcurrID%3aUSD%3bcFlag%3a0%3bitID%3a24>

Others: OECD, IEA, EUROSTAT

For some of the sources comparable numbers are converted using PPP. These can be used, but be aware that the levels for intensities are different from intensities based only on currency conversion.

- Which factors contribute to explaining the change in intensity over time?
- How does a change in the structure of an economy affect the intensities?
- If GDP energy intensity is projected constant for the next 10 years and we assume GDP growth of 3% annually what does that imply for the energy consumption ?

**2:** Energy market types

Consider two energy markets: The two markets should be considered separate.

- Crude oil
- Natural gas

- a) How are the basic preconditions for establishing a competitive market for these two products fulfilled?
- b) Which kind of structural changes could contribute to fulfilling the competitive preconditions

- c) If we could make crude oil markets a perfect competition market how would the environment be affected relative to a oligopoly situation?

**3: Equilibrium price in competitive market with 3 producers:**

The market we are examining is assumed to be competitive even though there are only three producers that make up the supply side. This means we assume there will be no strategic behavior from producers.

Producer 1: Cost  $C(q) = 0.75q^2 + 2q + 2$  ;

Producer 2: Cost  $C(q) = 2q + 3$ ;  $q_{\max} = 4$

Producer 3: Cost  $C(q) = 1.5q + 1$ ;  $q_{\max} = 2$

Demand is inelastic in case A

$D("p") = 5$

- What will the equilibrium price be on this market?
- What is the profit for each producer?
- Is this a long term equilibrium and will the market be characterised with the same producers in the long term?

Assume now that demand becomes more elastic

$D(p) = 12 - 4.5p^{0.3}$

- What is the new equilibrium, with this demand curve?
- Does this change the profits for producers?
- What could make the demand curve shift outwards in time?
- Is there in general a difference for a monopolist that face an inelastic demand curve or a more elastic demand curve as the last one used in this question?
- Explain how the need for regulation of markets with market power (oligopoly) is related to the characteristics of demand curves. Is the need for public regulation most important if demand is elastic or inelastic?

**4: Discuss how the price of LNG (Liquefied Natural Gas) is related to**

- other energy prices
- technological progress
- competing uses for its raw materials
- macroeconomic growth
- storage capacities

If cross price elasticity with natural gas (piped) is 5 and natural gas price increase 10% while LNG only 6%, what will be the effect on LNG demand. (You don't have to consider the own price elasticity.)

5: Examining a load curve illustrated in fig 1.

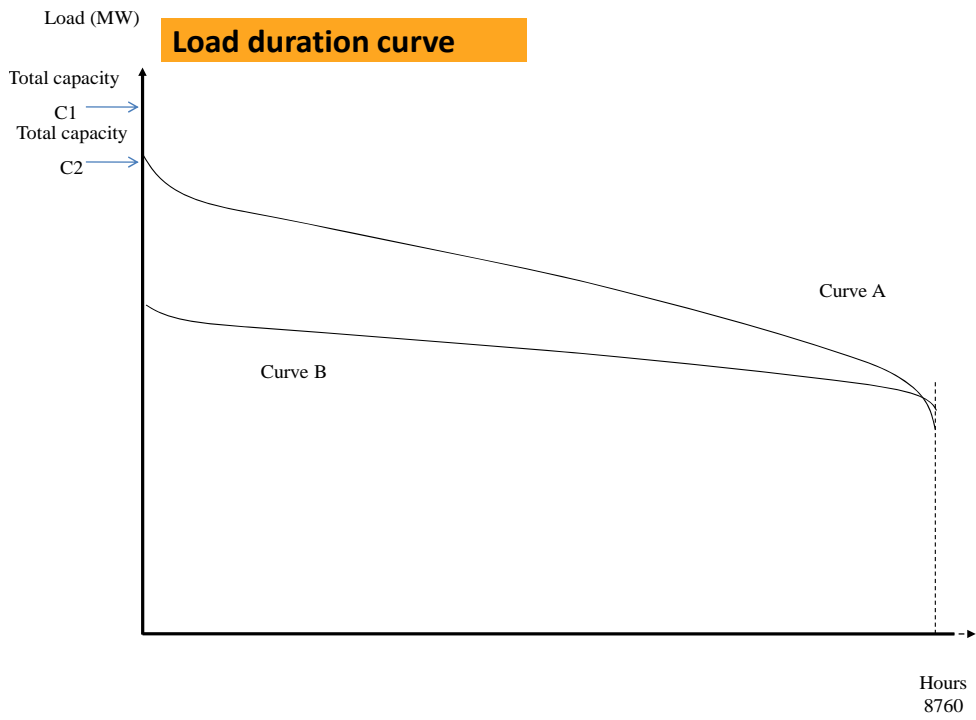
How are power prices corresponding to the hours in duration *curve A* related to the total generation capacity represented by C1 and C2.

- Discuss how peak load, base load and intermediate load power plants are affected if capacity is reduced permanently from C1 to C2 by decommissioning of old power plants. The decommissioning of plants does not change the composition of plants on peak, intermediate and base load types.

Compare two duration curves A and B from fig 1.

- Which one is representing the largest system?
- Could the introduction of wind power be the reason for a shift from A to B?
- Would the change from A to B affect the composition of peak, intermediate and base load plants in the long term?
- How would volatility of electricity prices be affected by a shift from A to B?
- Would average power prices in the long run be highest with duration curve shape like A or B?
- Where would You place the hours in the duration curve that a large CHP coal based plant in Denmark is generating?
- Draw a load profile for the 24 hours of a day in the middle of the week and note to which part of the load duration curve the different parts of the profile belongs to





- Figure 1gs to

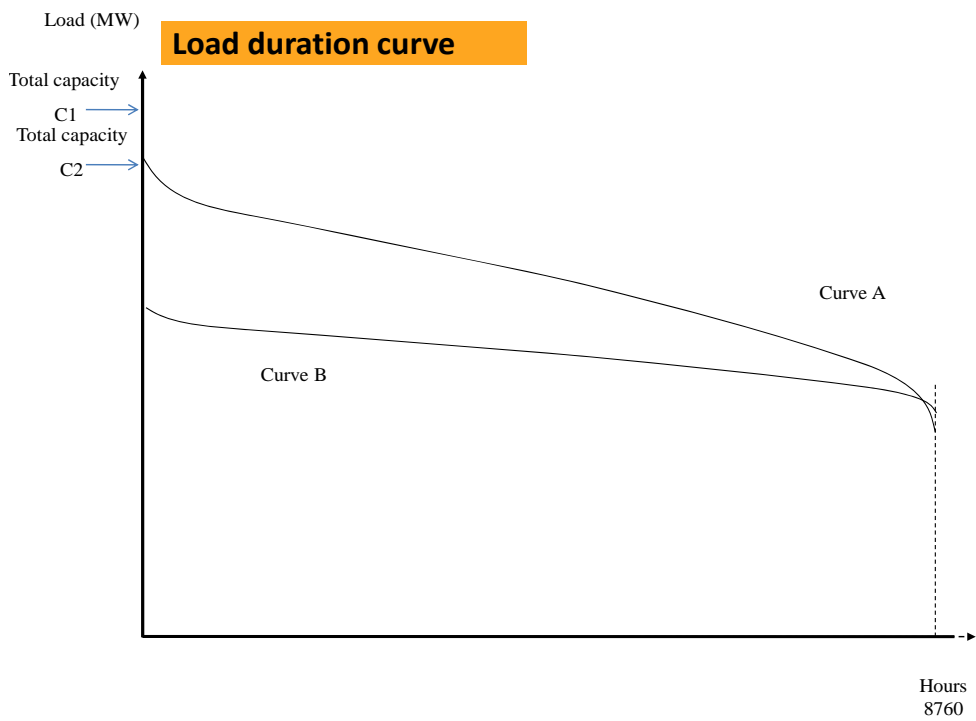


Figure 2 Load duration curves and total power capacity

