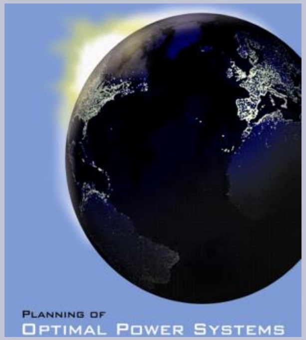


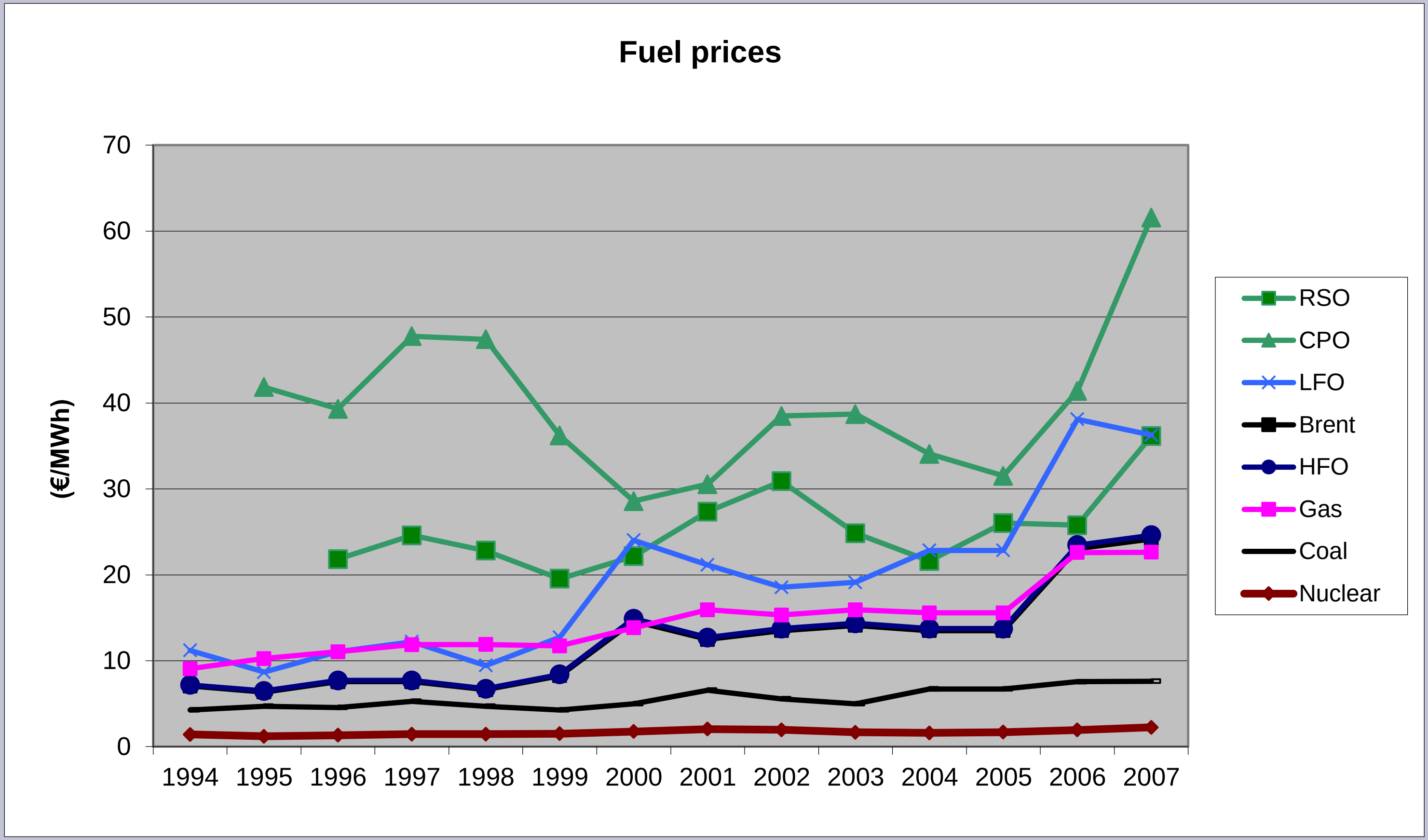
3. PLANNING OF NATIONAL POWER SYSTEMS

Asko Vuorinen

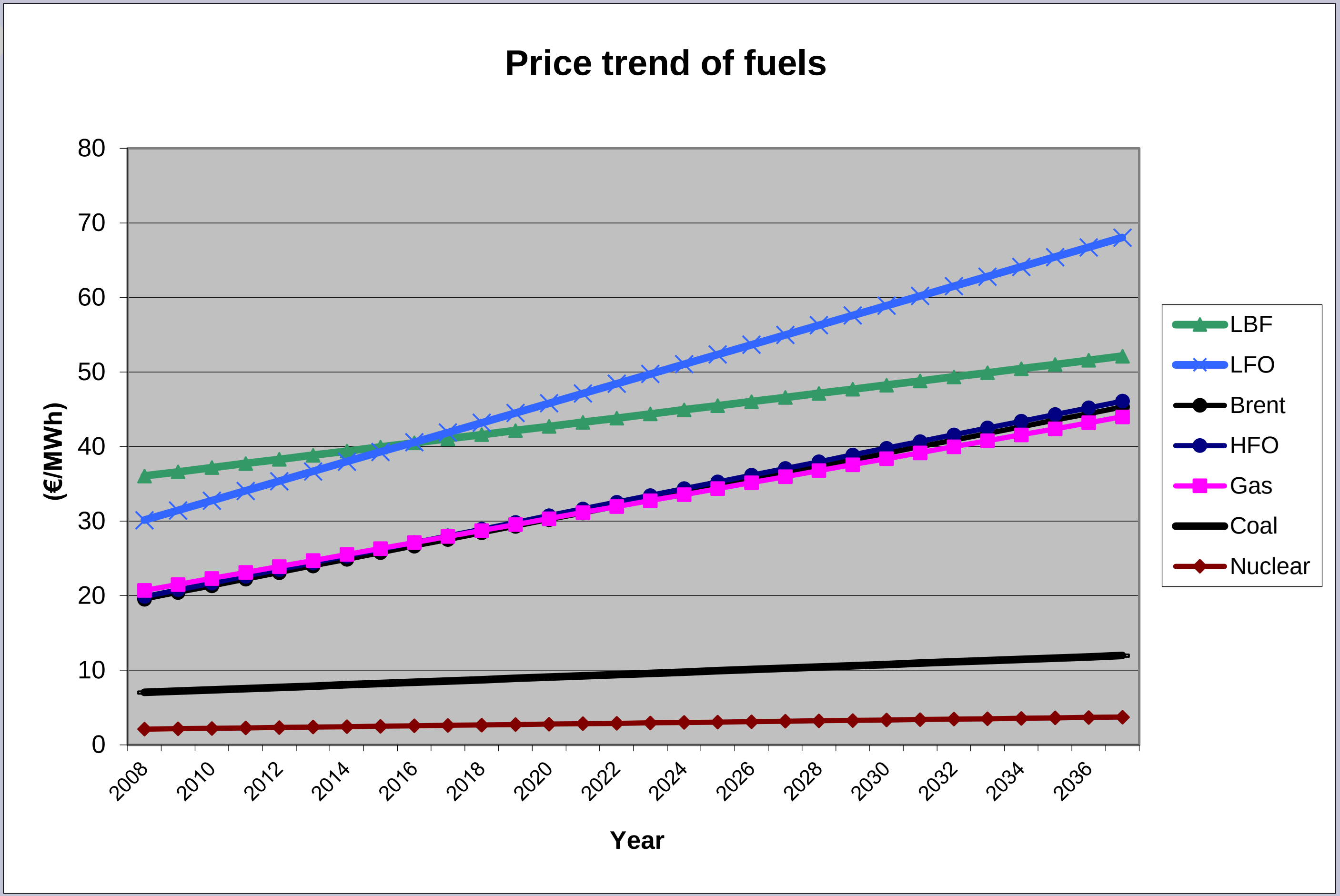
System conditions

Site	South-Europe
Site temperature	$+30\ ^{o}C$
Site elevation	200 m
Peak load of power system	10 000 MW

Historical prices of fuels



Future prices of fuels by regression analysis



Levelised prices of fuels

Calculated by discounting future prices to first year of operation (2011):

$$FI = \frac{\sum (f(i)/(1-r/100)^i)}{\sum (e(i)/(1-r/100)^i)}$$

where
FI = levelised price
f(i) = fuel price in year i
e(i) = energy generation in year i
r = discount rate (=8 %)

Levelised prices of fuels,
(eur/MWh lhv)

	2013 price	levelised price
Liquid biofuel (lbf)	38,8	43,4
Light fuel oil (lfo)	36,7	47,4
Heavy fuel oil (hfo)	24,4	31,8
Natural gas*	24,4+2	31,3+2
Coal	7.9	9.3
Nuclear	2,4	2,8

* Natural gas has variable and fixed (2) components

Cost estimates of power plants

- Power plant options
- Capital costs
- Operation and maintenance costs
- Fuel costs
- Tariff formulas

Alternative power plants

- Oil-fired plants
- Gas-fired plants
- Other plants

Oil-fired power plants

Plant	Concept
DE-160 hfo*	10 x 16 MW diesel engines
DE-160 lfo**	20 x 8 MW diesel engines
ADGT-160 lfo	4 x 40 MW gas turbines
Ind.GT-110 lfo	1 x 110 MW gas turbine
DE-160 lbf***	10 x 16 MW diesel engines

*hfo = heavy fuel oil

**lfo = light fuel oil

***lbf= liquid bio fuel (palm oil/rape seed oil)

Oil-fired power plants, Performance

Plant	Net efficiency (%)	CO2-emission (g/kWh)
DE-160 hfo	43 %	654
DE-160 lfo	41 %	644
ADGT-160 lfo	36 %	712
Ind.GT-110 lfo	31 %	860
DE-160 lbf	41 %	-

Oil-fired power plants, Capital costs

Plant	Investment €/kW	Capital costs €/kWa
DE-160 hfo	991	93,6
DE-160 lfo	756	71,5
DE-160 lbf	980	92,6
ADGT-160 lfo	857	80,9
Ind.GT-110 lfo	635	60,0

Oil-fired power plants, Fixed O&M costs (FOM)

Plant	Personnel €/kWa	Other €/kWa	Total €/kWa
DE-160 hfo	12.5	5.9	18,4
DE-160 lfo	2.9	4.9	7.8
DE-160 lbf	6.5	5.8	12.2
ADGT-160 lfo	3.0	5.3	8.4
Ind.GT-110 lfo	4.5	5.4	9.9

Oil-fired power plants, Variable O&M costs (VOM)

Plant	Maintenance €/MWh*	Materials €/MWh	Waste** €/MWh	Total €/MWh
DE-160 hfo	6.0	3.5	16.7	26.3
DE-160 lfo	4.8	3.3	16.1	24.2
DE-160 lbf	6.0	3.1	-	9.1
ADGT-160 lfo	4.8	7.4	18.0	30.2
Ind.GT-110 lfo	4.8	17.8	21.5	44.1

*Includes start-up costs lfo plant run 2 h/startup (gas turbines conume 5 eq.hours/start-up)

** includes CO_2 costs (23 eur/ton CO_2)

Oil-fired power plants, Tariff formulas

Plant	Fixed costs €/kWa	Variable costs €/MWh	Gen. costs at 500 h/a €/MWh
DE-160 hfo	113.5	102.5	330
DE-160 lfo	81.5	138.7	**<u>302</u>**
DE-160 lbf	106.9	113.9	328
ADGT-160 lfo	91.8	158.1	342
Ind.GT-110 lfo	72.8	197.3	343

Gas-fired power plants, Concepts

Plant	Concept
GTCC-500 gas	300 MW GT+ 200 MW ST
GTCC-330 gas	2 x 110 MW GT + 110 ST
DF-160 gas	10 x 16 MW dual-fuel engines
GE-160 gas	20 x 8 MW gas engines
ADGT-160 gas	4 x 40 MW gas turbines
Ind.GT-110 gas	1 x 110 MW gas turbine
CHP-160 gas	20 x 8 MW gas engines or 110 GT and 50 MW ST

Gas-fired power plants, Performance

Plant	Net efficiency (%)	CO_2-emission (g/kWh)
GTCC-500 gas	58 %	350
GTCC-330 gas	49 %	414
DF-160 gas	43 %	474
GE-160 gas	42 %	482
ADGT-160 gas	38 %	529
Ind.GT-110 gas	31 %	646
CHP-160 gas*	42 %(86%)	238

* Combined heat and power (CHP) plant has 86 % total efficiency

Gas-fired power plants, Capital costs

Plant	Investment (€/kW)	Capital costs (€/MWh)
GTCC-500 gas	1316	124,4
GTCC-330 gas	1244	117.5
DF-160 gas	984	92.9
GE-160 gas	915	86.4
ADGT-160 gas	1036	97.9
Ind.GT-110 gas	752	71.0
CHP-160 gas	999	94.4

Gas-fired power plants, Fixed O&M costs (FOM)

Plant	Personnel (€/kW)	Other (€/kW)	Total (€/kW)
GTCC-500 gas	8.3	5.9	14.2
GTCC-330 gas	11.6	5.9	17.5
DF-160 gas	6.8	5.9	12.6
GE-160 gas	6.7	5.6	12.2
ADGT-160 gas	6.7	6.0	12.7
Ind.GT-110 gas	9.9	5.8	15.8
CHP-160 gas	6.7	5.9	12.6

Gas-fired power plants, Variable O&M costs (VOM)

Plant	Maintenance €/MWh	Materials €/MWh	Waste* €/MWh	Total €/MWh
GTCC-500 gas	3.6	3.5	8.8	15.9
GTCC-330 gas	3.6	3.7	10.5	17.8
DF-160 gas	4.8	1.6	11.9	18.3
GE-160 gas	4.8	1.6	12.1	18.5
ADGT-160 gas	4.8	5.9	13.4	24.0
Ind.GT-110 gas	4.8	4.5	16.3	25.6
CHP-160 gas	4.8	1.2	5.9	11.9

* Includes CO_2-costs at price 23 €/t CO_2

Gas-fired power plants, Tariff formulas

Plant	Fixed costs €/kWa	Variable costs €/MWh	Gen.costs at 2000 h/a €/MWh
GTCC-500 gas	155.9	66.7	**145**
GTCC-330 gas	155.8	78.6	157
DF-160 gas	130.4	87.1	152
GE-160 gas	122.6	88.5	150
ADGT-160 gas	137.1	101.5	170
Ind.GT-110 gas	119.1	120.3	180
CHP-160 gas	130.8	49.0	**114**

Other power plants

Plant	Concept
Nuclear-1500	1500 MW (Evolutionary PWR)
Coal-500	Superctritical steam plant
Biomass-150	150 MW wood chip fired plant
Wind-150	30 x 5 MW wind park

Other power plants Performance

Plant	Efficiency (%)	CO_2-emission (g/kWh)
Nuclear-1500	35 %	-
Coal-500	40 %	858
Biomass-150	34 %	-
Wind-150	-	-

Other power plants
Capital costs

Plant	Investment costs (€/kW)	Capital costs (€/kWa)
Nuclear-1500	3205	302.8
Coal-500	1794	169.5
Biomass-160	1812	171.2
Wind-160	1440	136.1

Other power plants
Fixed O&M costs (FOM)

Plant	Personel costs €/kWa	Other costs €/kWa	Total costs €/kWa
Nuclear-1500	15.2	13.0	28.2
Coal-500	11.5	7.8	19.3
Biomass-160	25.6	9.2	34.9
Wind-160	7.4	7.9	15.3

Other power plants Variable O&M costs (VOM)

Plant	Maintenance €/MWh	Materials €/MWh	Waste €/MWh	Total €/MWh
Nuclear-1500	4.8	2.0	0	6.8
Coal-500	3.6	3.0	21.4*	24.7
Biomass-160	2.0	1.0	-	3.0
Wind-160	10.0	1.0	-	11.0

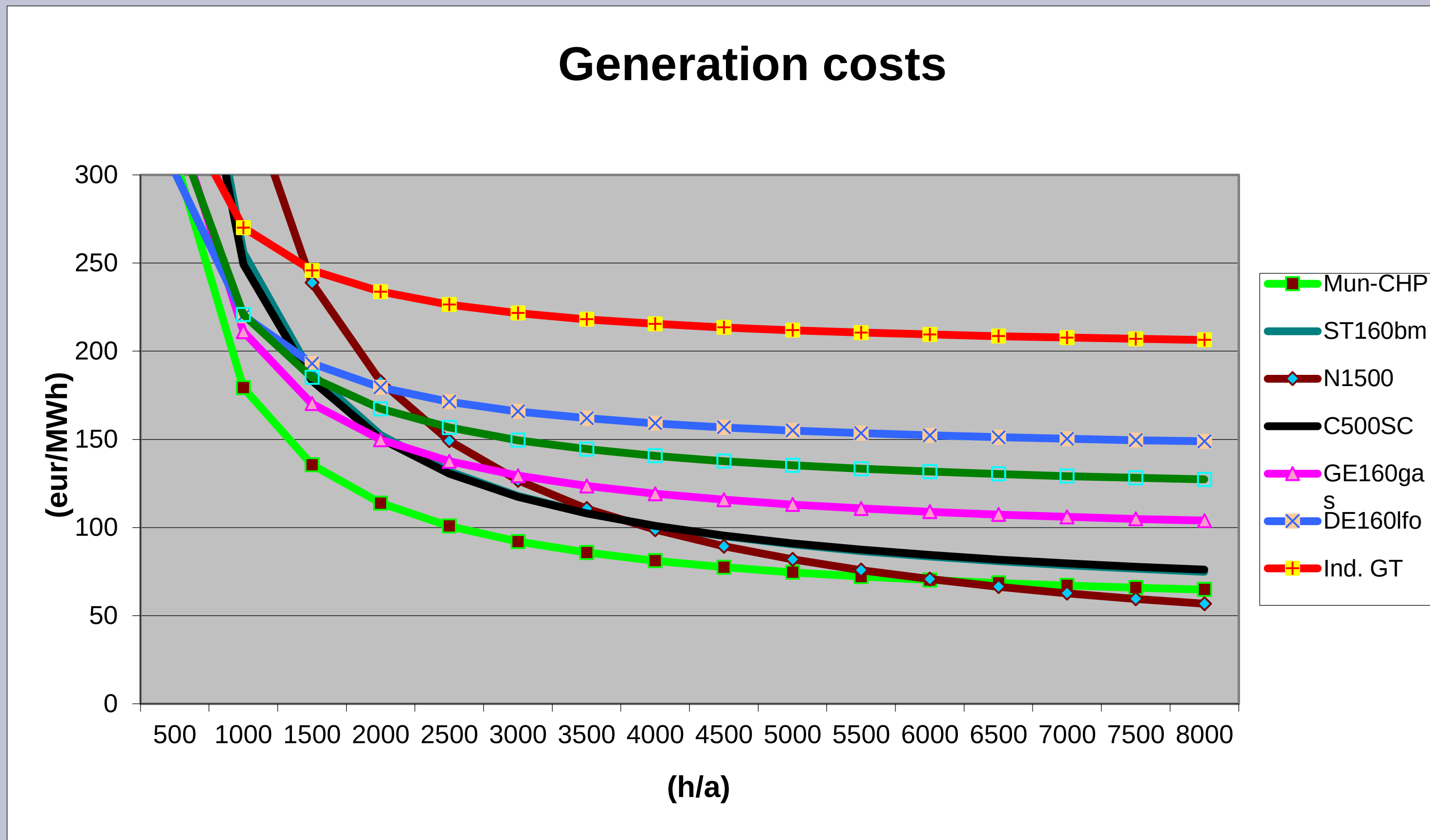
* includes CO_2 costs

Other power plants Tariff formulas

Plant	Fixed costs €/kWa	Variable costs €/MWh	Gen. costs at 7000 h/a €/MWh
Nuclear-1500	336.1	14.7	**62.7**
Coal-500	197.8	51.4	79.7
Biomass-150	206.9	49.0	78.6
Wind-150	151.4	11.0	**61.7***
CHP-160 gas	130.8	49.0	67.1

* At 3000 h/a

Generation costs



Break even costs

Full power hours (t) when the alternative power plants have the same generation costs

$$VC_1 \times t + FC_1 = VC_2 \times t + FC_2$$

Then

$$t = (FC_2 - FC_1)/(VC_1 - VC_2)$$

Break even costs

1) <149 h/a Ind. GT cheapest (LFO)
2) >149 h/a diesel engine is cheaper than GT
3) >820 h/a gas engine is cheaper than DE
4) >1530 h/a GTCC-500 is cheaper than GE
5) >2740 coal plant is cheaper than GTCC
6) >3770 h/a nuclear plant cheaper than coal
7) between 770 - 5800 h/a CHP plant is cheaper than others

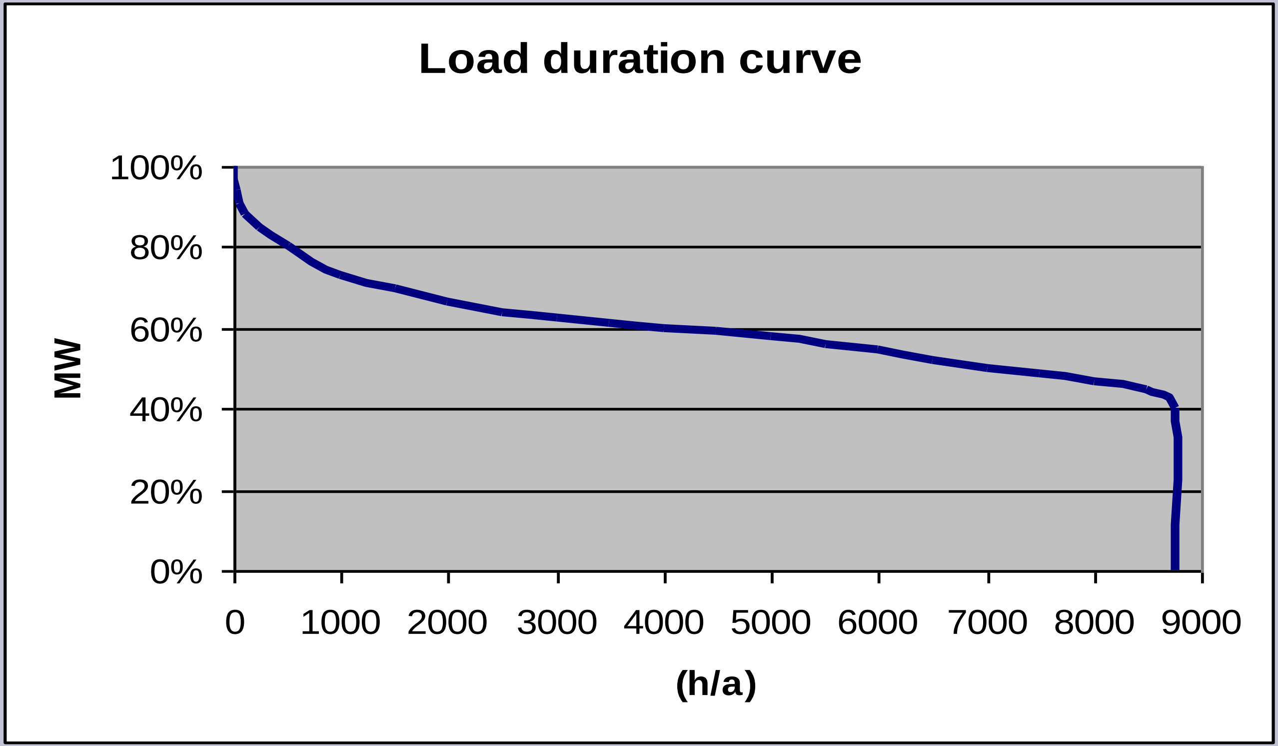
If nuclear and coal plants are not accepted

4) GTCC plant is cheapest 1530-8766 h/a

Renewable plants

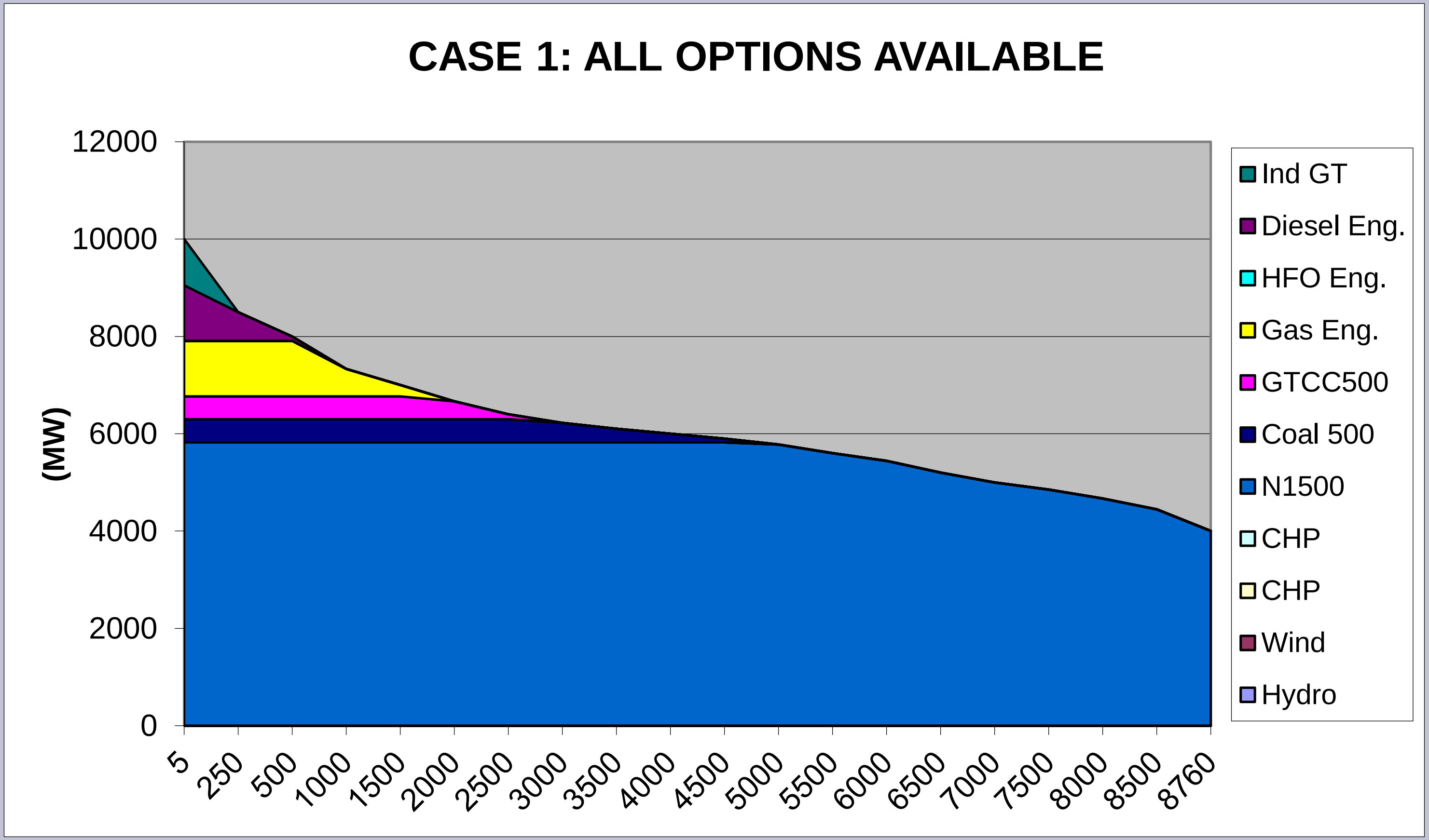
1) < 1125 h/a LBF diesel plant
2) > 1125 h/a biomass plant and wind plants

Minimizing of the total costs



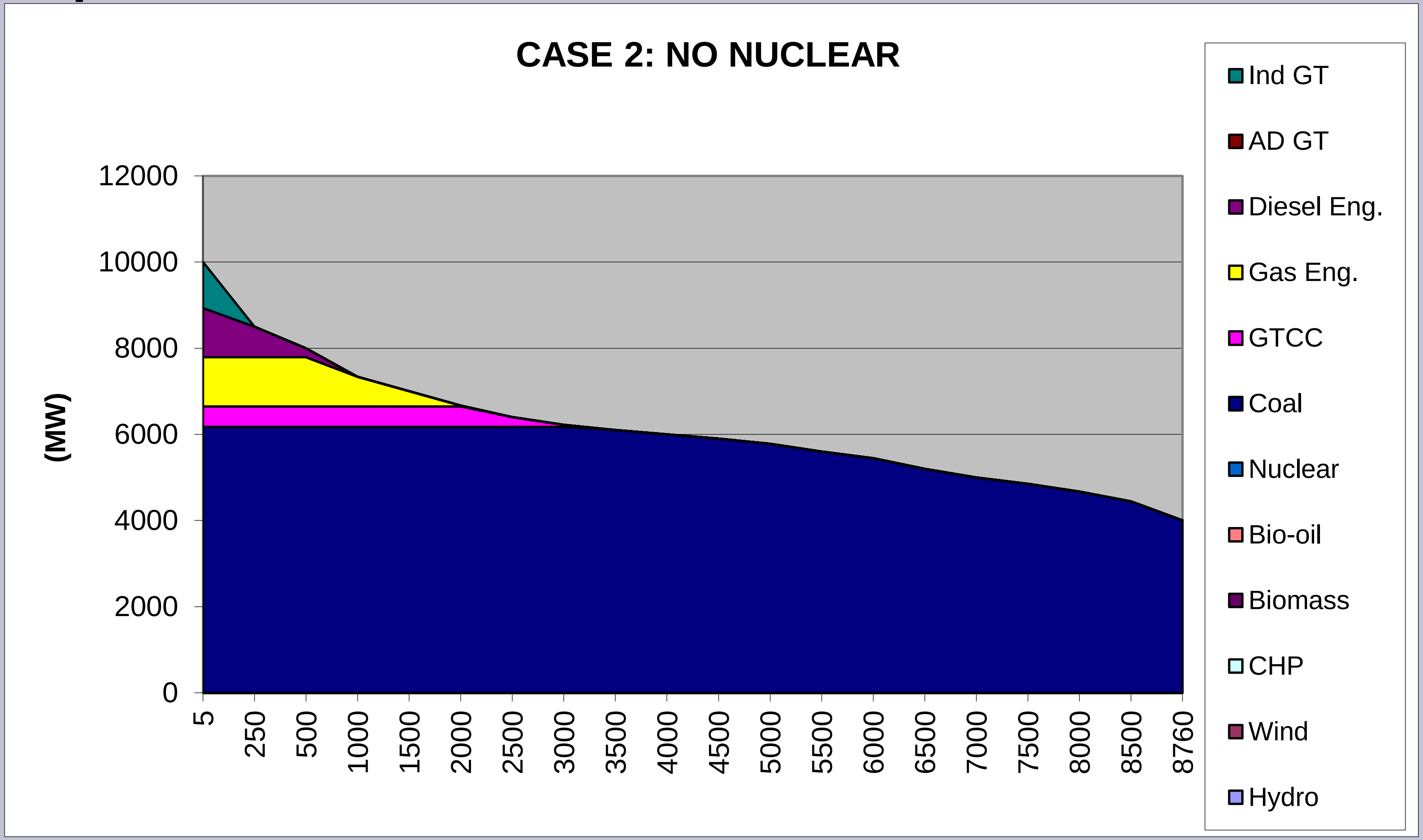
- Fill the load duration curves using the least cost alternatives

Case 1) All options available



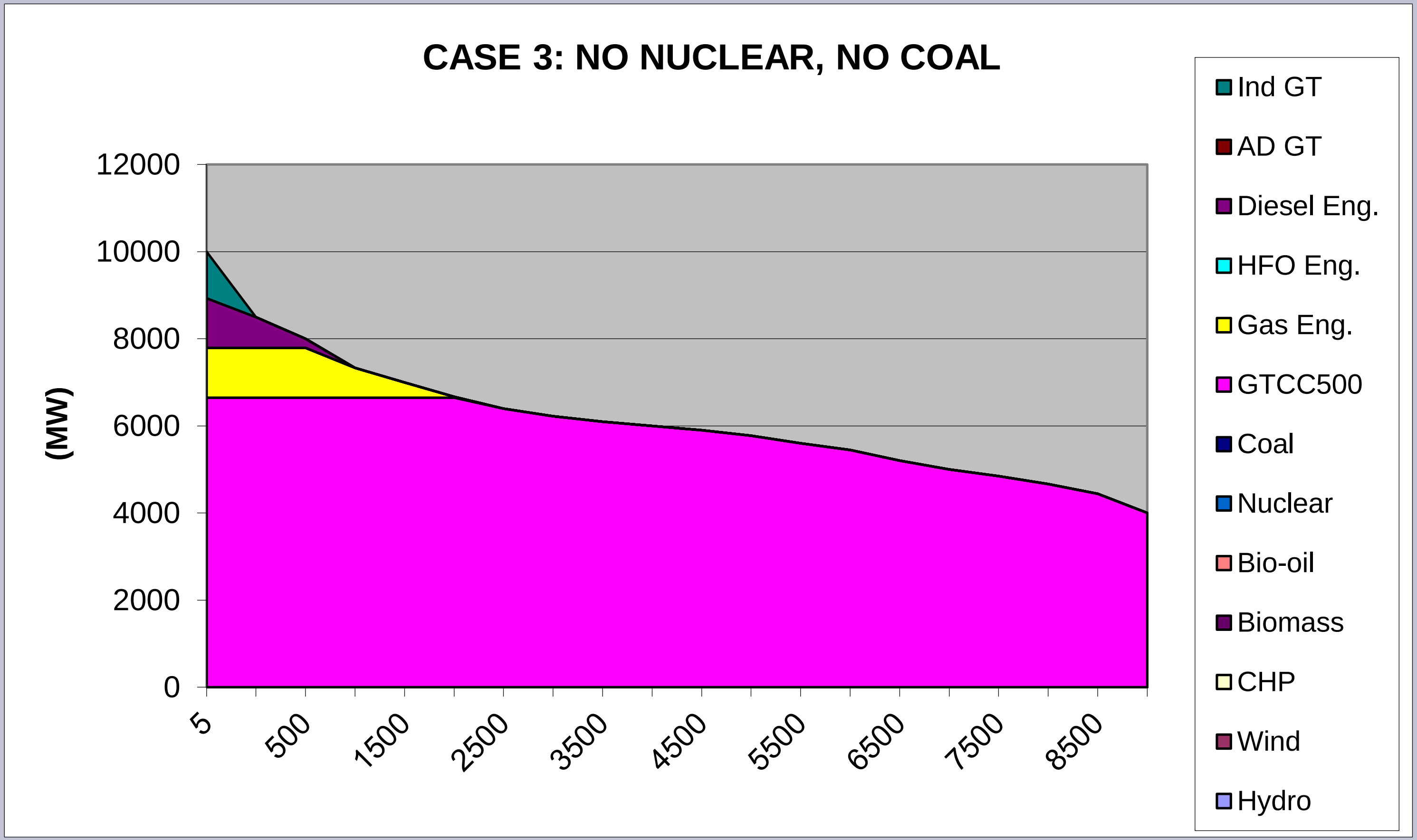
Case 2) No nuclear

Note: coal replaces nuclear



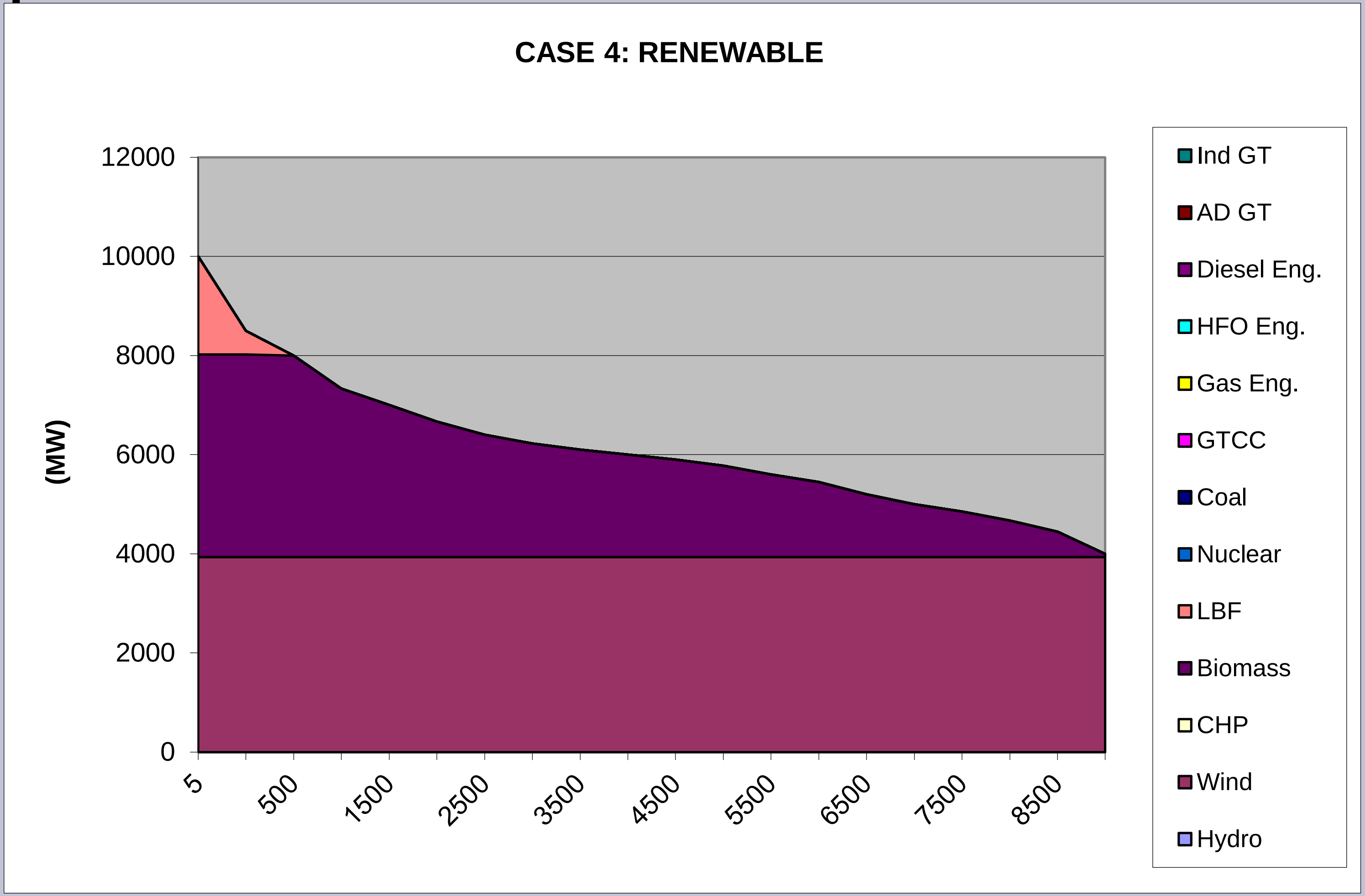
Case 3) no nuclear, no coal

Note: GTCC plant replaces nuclear and coal



Case 4) Renewable

Wind in the base and LBF-diesel in the peak load



Total system costs and CO_2-emissions

Alternative	Cost €/MWh	Emissions g/kWh
1) All options	69.6	53
2) No nuclear	86.8	834
3) No nuclear/coal	96.0	421
4) Renewable	86.9	0

Pofitablity of alternatives

In the new electricity markets the price of electricity equals the variable costs of marginal plant (MC)

Profits = Revenues - Costs

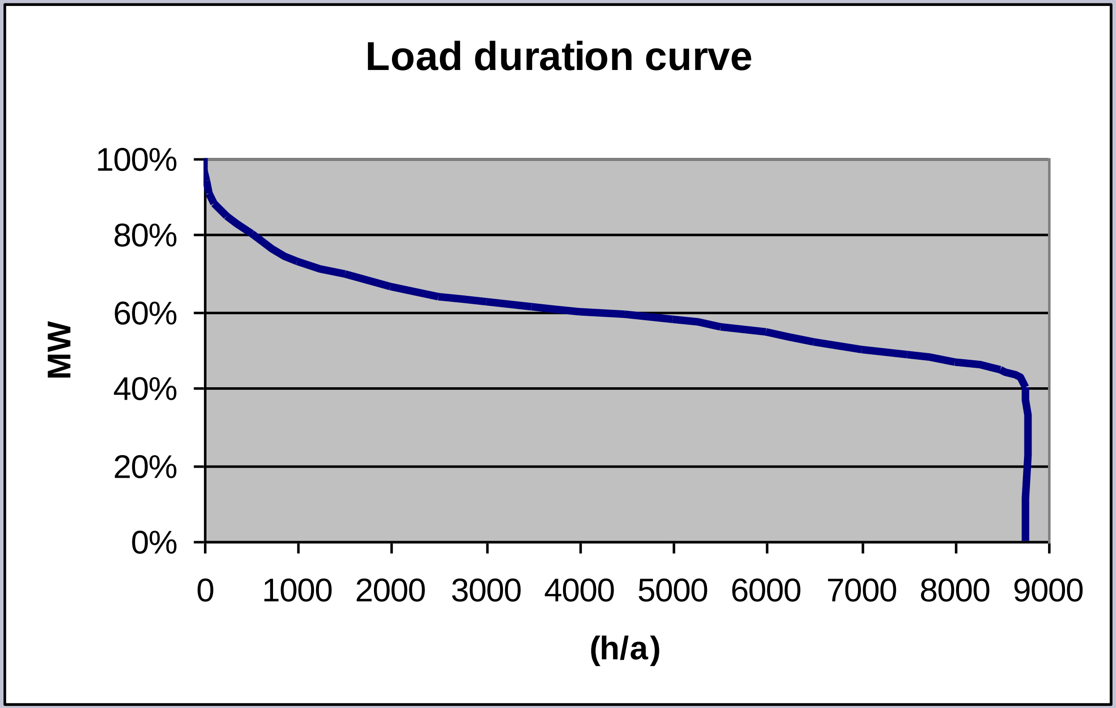
where

Revenues = $\sum (MC(t) \times E(t))$

MC(t) = marginal costs at hour (t)

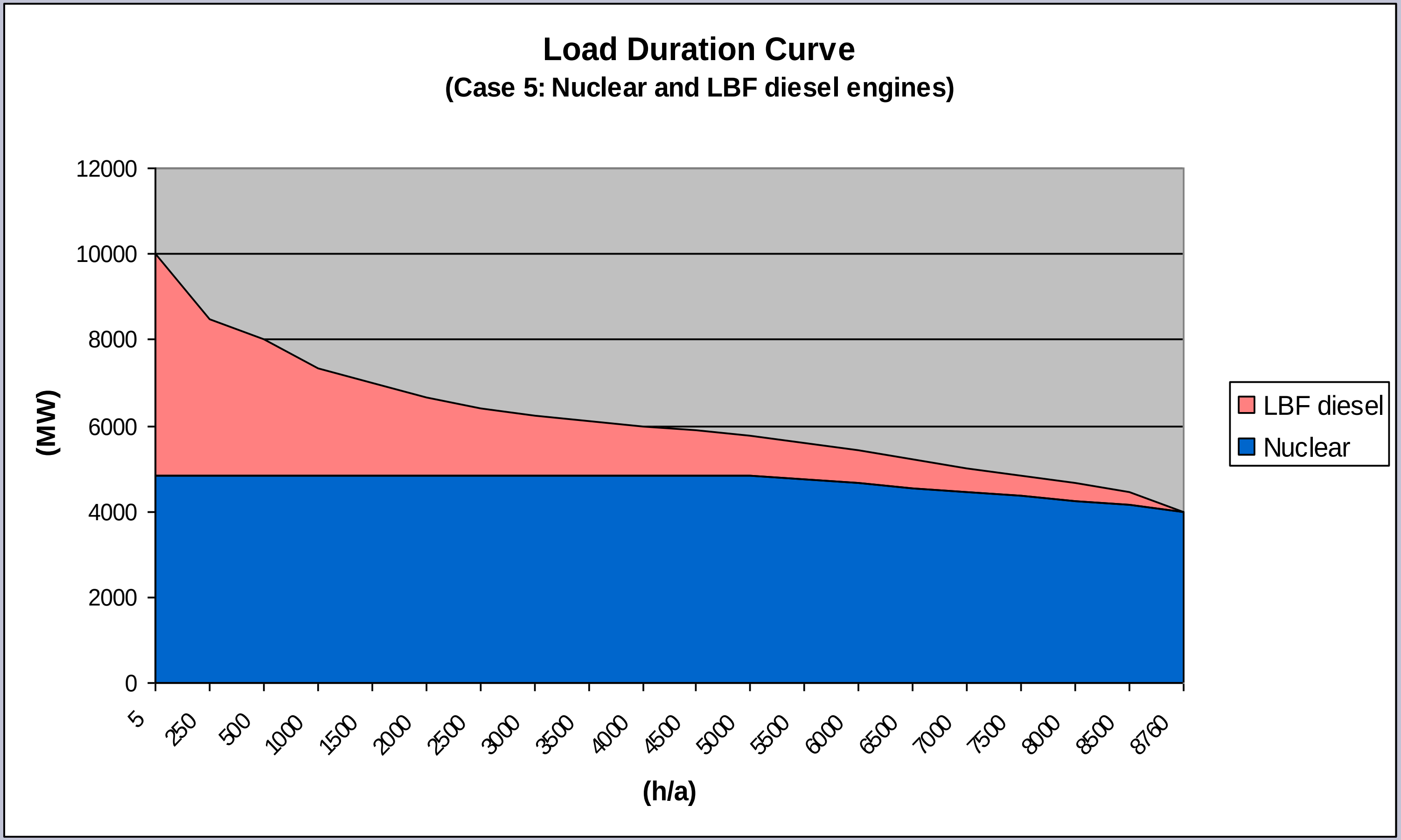
E(t) = energy generation during hour (t)

Maximization of profits

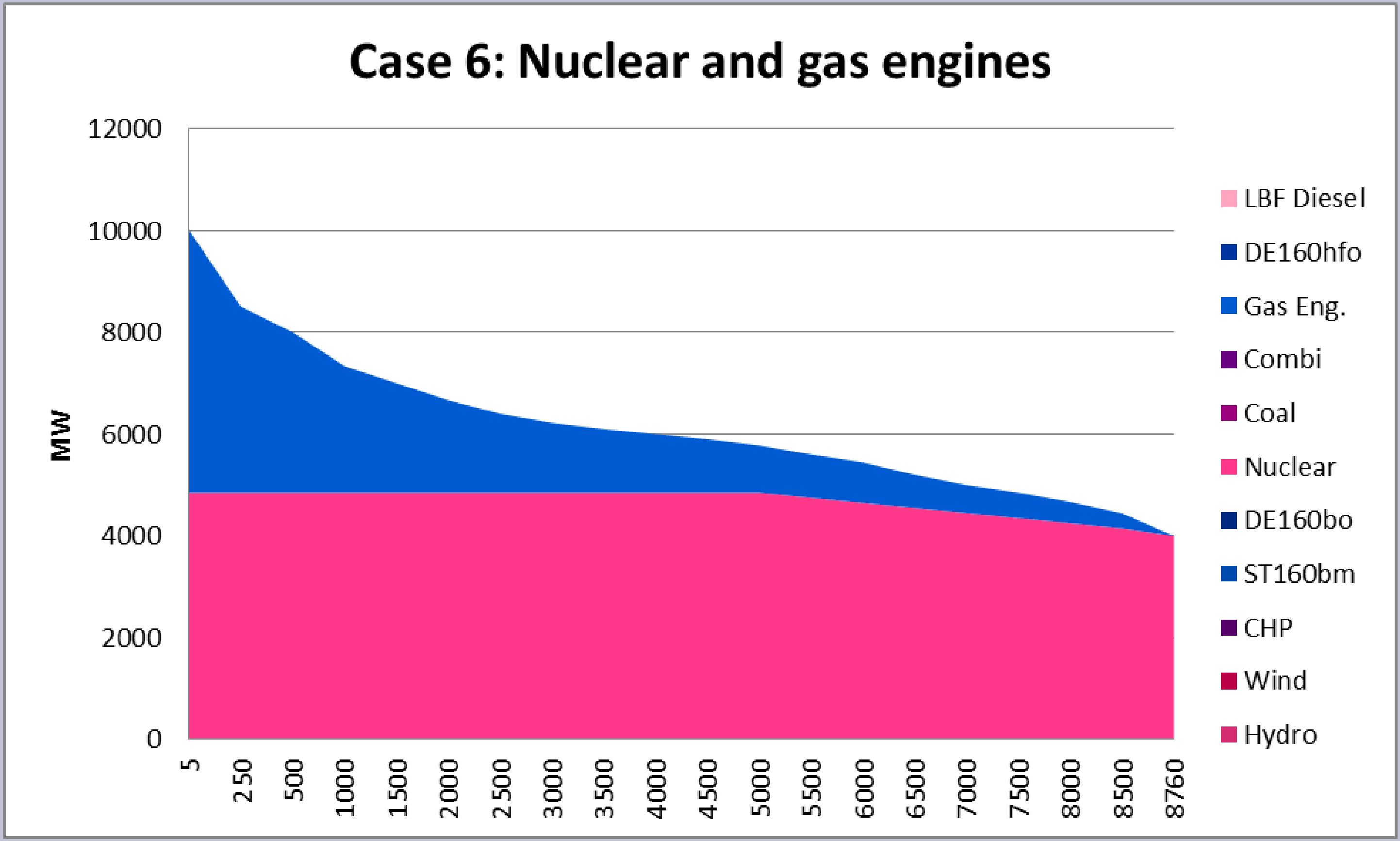


Fill the load duration curve so that the highest variable cost plant is operating in the peak and intermediate load and the lowest variable cost plant in the base load

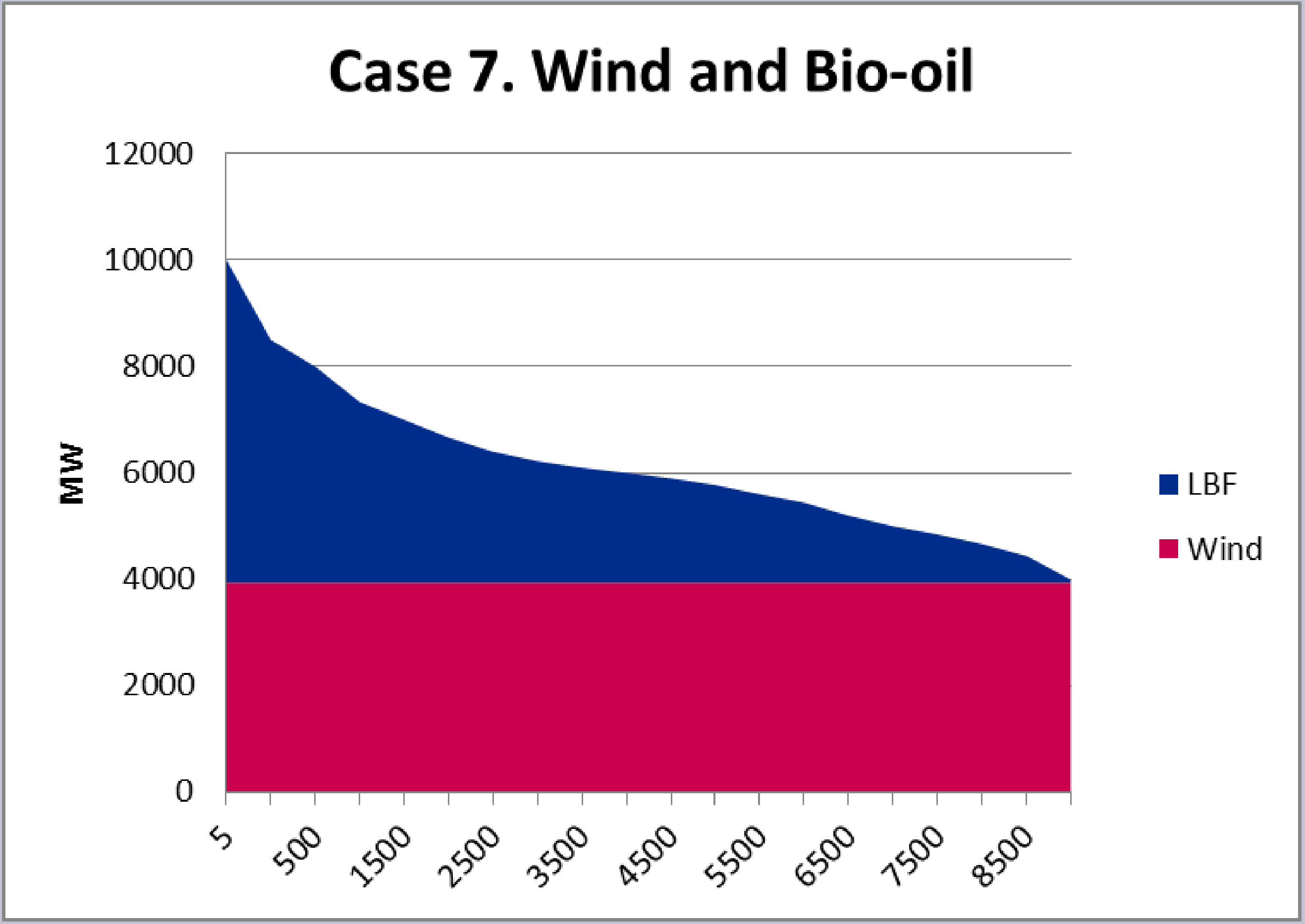
Case 5) Nuclear in base load and LBF diesel plant in peak load



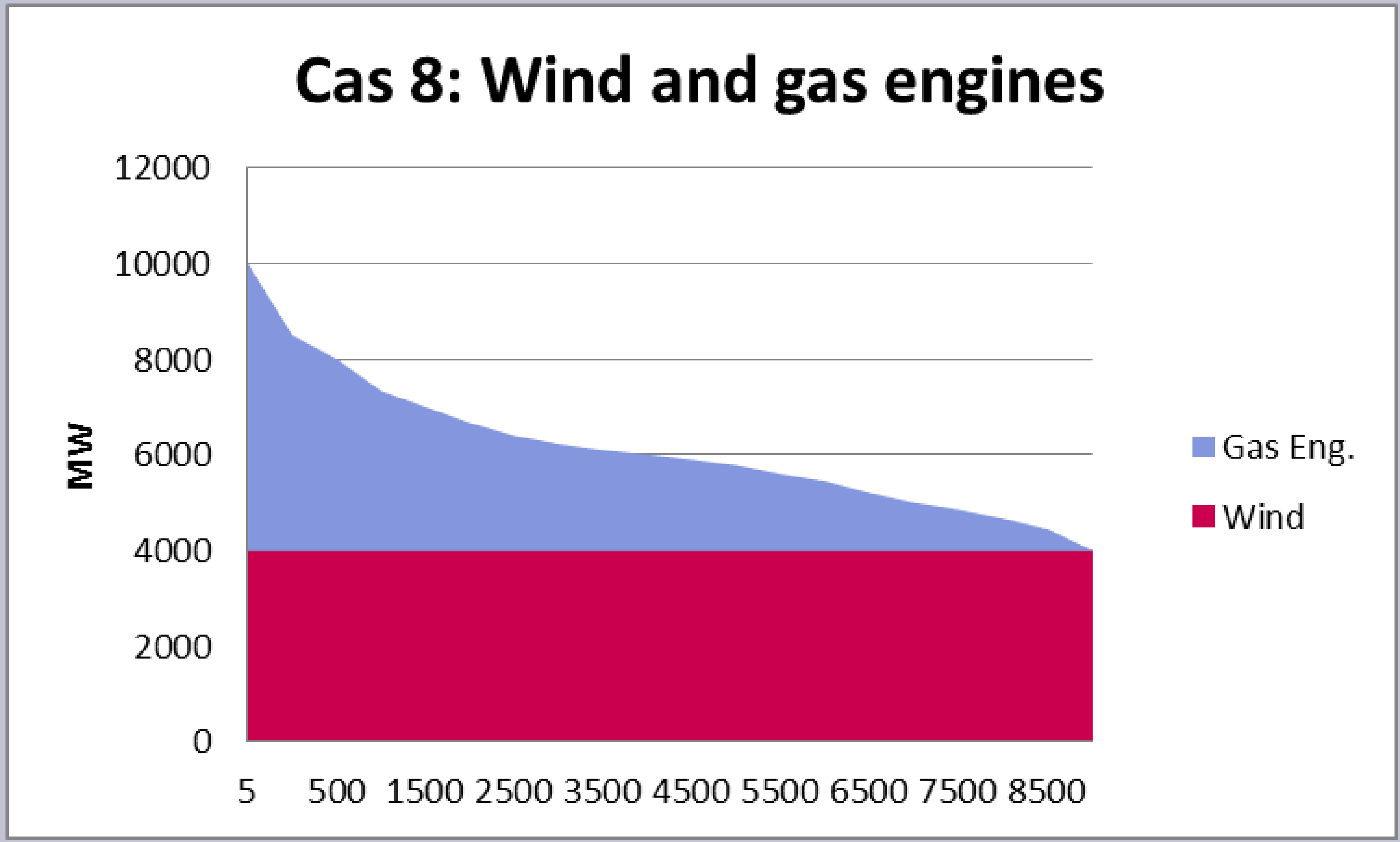
Case 6) Nuclear in base load and Gas engine plant in peak load



Case 7) Wind in base load and LBF diesel plant in peak load



Case 8) Wind in base load and Gas engine plant in peak load



Pofitablity of alternative case systems

Case		Profits M€/a	Electricity price
1)	All options	- 785	50.7 €
2)	No nuclear	- 768	69.5
3)	No nucler/coal	- 791	79.0
4)	Renewable	-1830	51.8
5)	Nuclear/LBF diesel	+1730	114.5
6)	Nuclear/Natural gas	+ 601	89.0
7)	Wind/LBF diesel	+ 668	114.5
8)	Wind/Natural gas	- 655	89.0

Recommendations

1) Maximize the use CHP-plants because they have the lowest generation costs in the base and intermediate load

2) Fill the base load then with wind and nuclear plants up to 6000 h/a

3) Use gas fired plants in the intermediate load

4) Use LFO and LBF plants in the peak load

Recommendations, continued

5) Select actual power plants only after studying the need of

- ancillary services
- reserve power requirements

The largest plant has largest need for ancillary services and reserves

Recommendations, continued

6) The peak and intermediate load plants should

- be able to start-up in 5 - 10 min
- be able to participate in Automatic Generation Control (AGC)
- have high ramp rate

Recommendations, continued

7) Build the power plants near the consumption centers to avoid transmission losses and need of reactive reserves

Summary

- Power system can be optimised to give minimum costs or maximum profits
- The boundary conditions may be target to reduce CO_2-emissions
- Optimal system has low variable cost plants in base load and flexible plants in the peak load

For details see reference text book **”Planning of Optimal Power Systems”**

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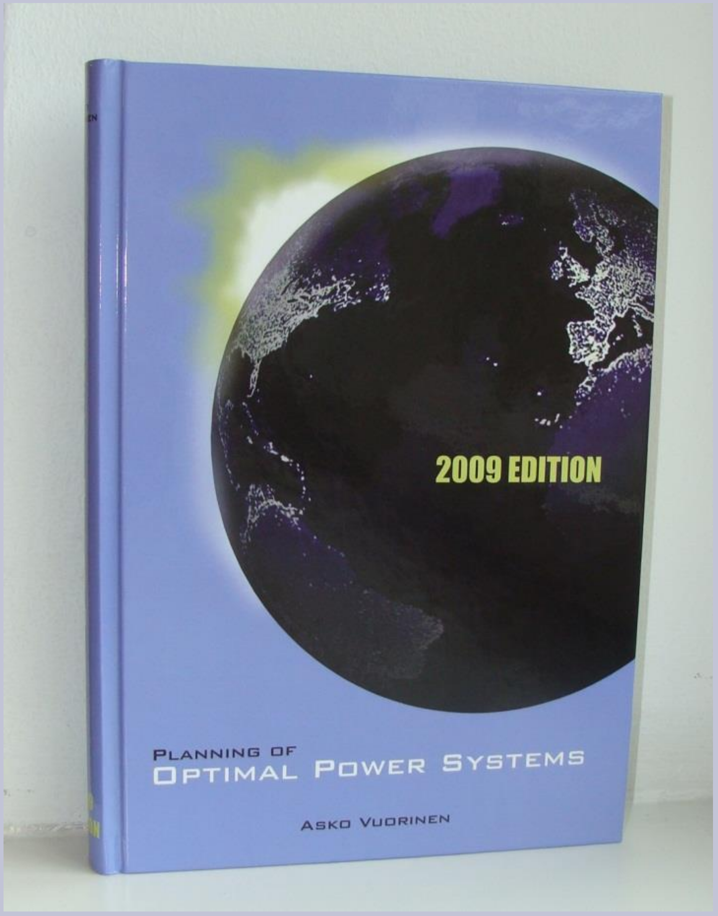

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