An Analysis of Long Run Power-Emissions Markets Interactions Under Alternative Emissions Allocation Rules

Benjamin F. Hobbs
The Johns Hopkins University

Jinye Zhao and Jong-Shi Pang
Rennselaer Polytechnic Institute

Atlantic Energy Group, 3 Nov. 2006

Thanks to NSF, Energieonderzoek Centrum Nederlands for support

Outline

I. Background

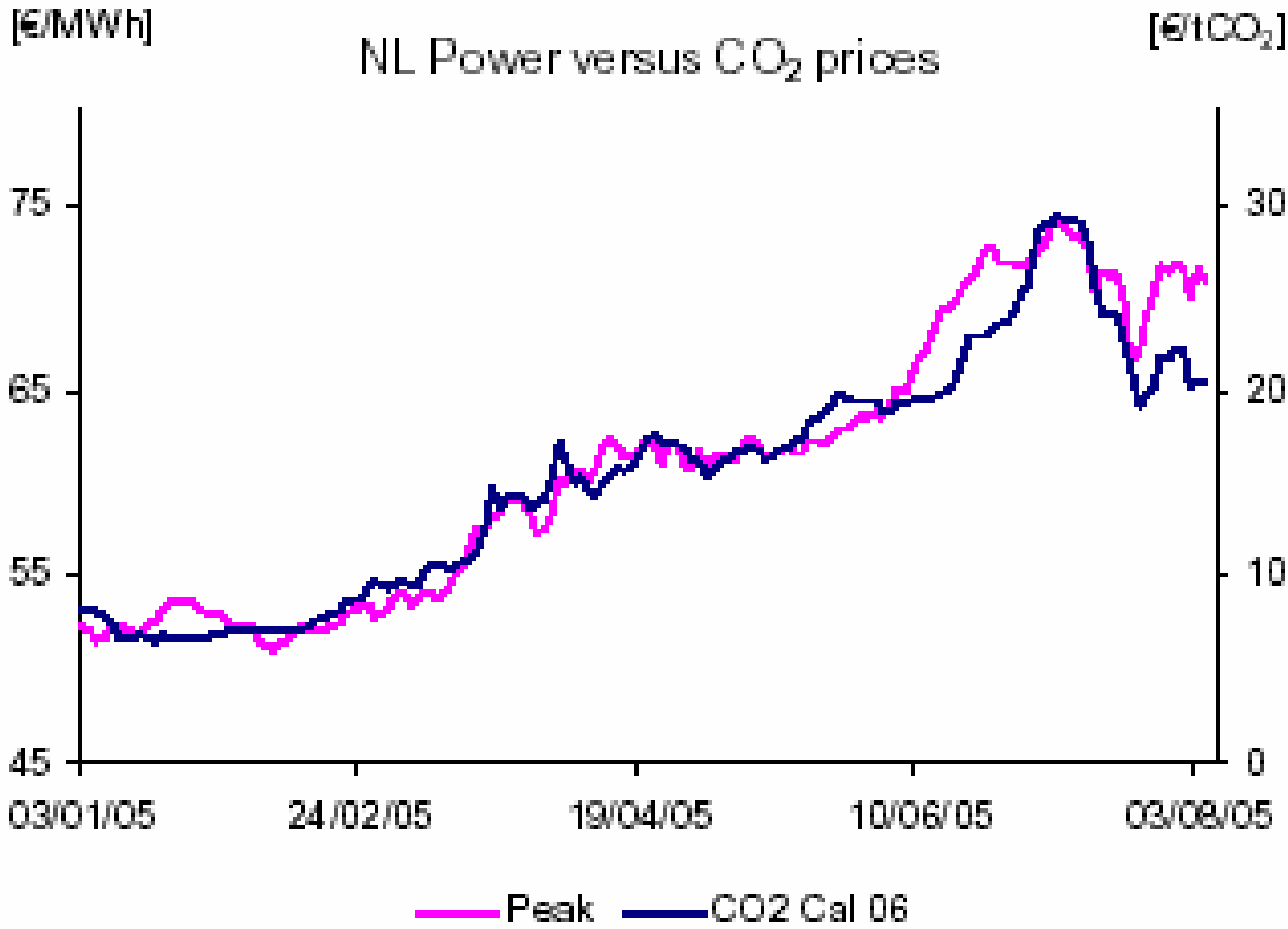
II. Model Structure & Computation Approach

III. Application: CO_2 Emissions allowances allocation
   - Effect of Grandfathering vs. giving allowances to new investment
   - Interaction with capacity markets

I. Background

CO_2 and Dutch Power (APX) Prices

(Source: Sijm et al., CO2 price dynamics:The implications of EU emissions trading for the price of electricity, ECN, 2005)



Long Run Energy & Emissions Market

- **Alternative allocation schemes:**
  - ***Auction***
  - ***Grandfathering***
  - ***Free allocation by formula***
  - ***Mix and timing***
- **How might alternative allocation schemes affect market outcomes?**
  - ***Generation mix***
  - ***Costs***
  - ***Consumer costs***

Debate over Price Impacts of CO_2 Trading in EU

- ***"However, if the expansion of the generation park (by incumbents or newcomers) is associated with a free allocation of emission allowances, then players will base their long-term investment decisions on the long-term marginal costs, including the costs of the CO_2 allowances, but by subtracting the subsidy that lowers the required mark-up for the fixed costs … On balance, the power price will not be increased (ceteris paribus)."***

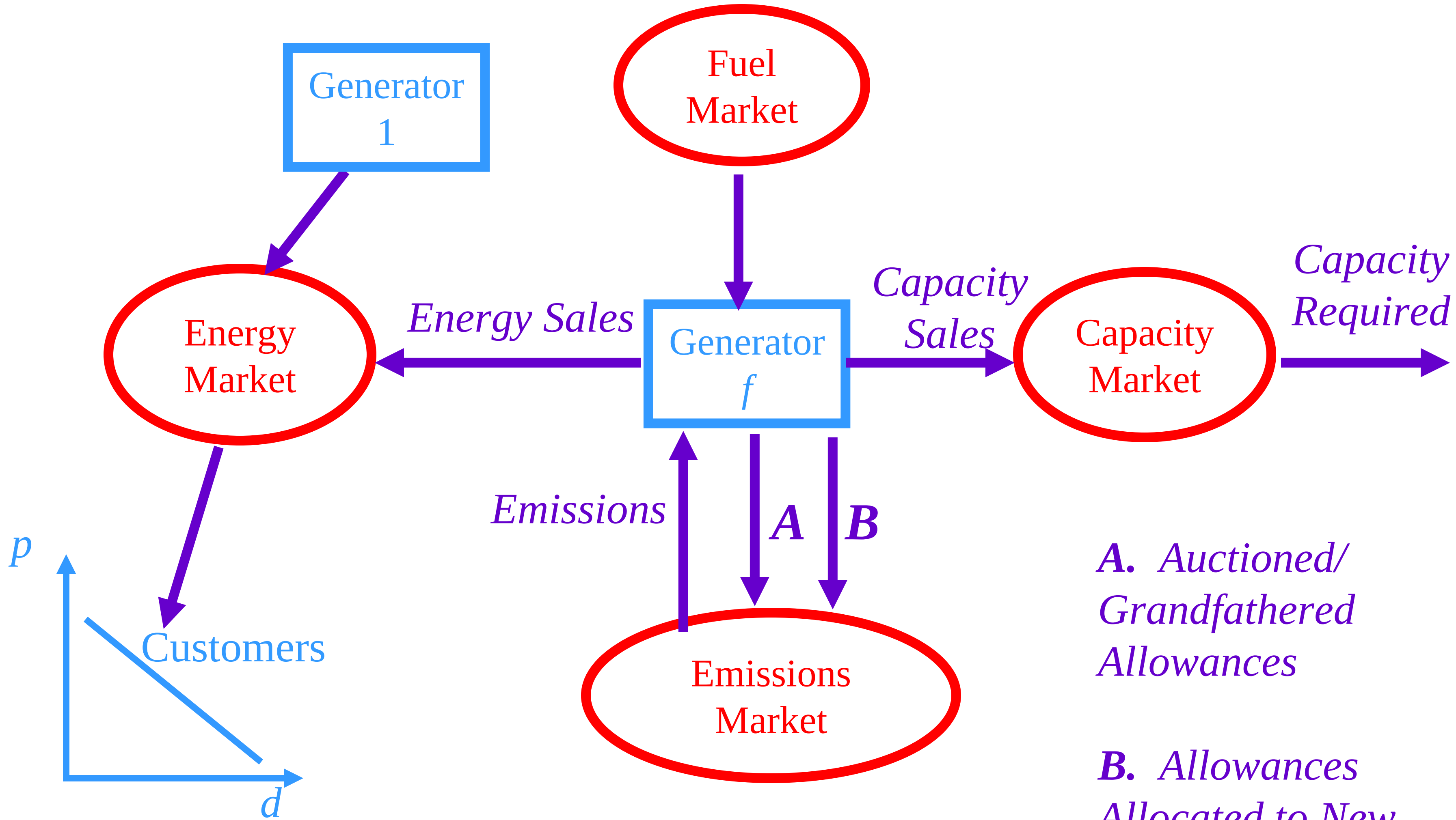
  "Explanation of CPB Vision on Relationship Emissions Trading - Power Prices," Aug. 2005, Netherlands Bureau for Economic Policy Analysis, Ministry of Economic Affairs

- **Is this true in an industry with time varying demand, no storage, and a mix of technologies?**
  - **Will the least-cost generation mix still result, and all the allowances rent returned to consumers?**

II. Model of Long Run Energy & Emissions Market

- **Compare:**
  - ***Complete grandfathering (or auction)***
  - ***Mix of grandfathering & partial allocation to new investment***
    - ***Lowers net investment cost***
- **Assume:**
  - ***Free entry long run equilibrium***
  - ***Spot market and long run contracts market arbitraged***
  - ***No market power, no scale economies, no random generation outages***
  - ***Alternative cases:***
    - ***Capacity market***
    - ***Unit commitment (min run) constraint***

Model Structure



A. *Auctioned/ Grandfathered Allowances*

B. *Allowances Allocated to New Capacity*

Long Run Energy & Emissions Market

With emissions allowances allocation to new investment

Equilibrium problem: Find $\{p_t^*, pe^*, pcap^*, \alpha_i^*, s_{it}, cap_i\}$ that solve:

Profit Maximization, Generator *i*:

Given $\{p_t^*, pe^*, pcap^*, \alpha_i^*\}$:

$$MAX \quad \Sigma_t (p_t - MC_i - pe^* E_i) s_{it} + (pcap^* + \alpha_i^* \, pe^* - F_i)\, cap_i$$

$$\text{s.t.:} \quad 0 \le s_{it} \le cap_i, \ \forall t$$

Market clearing:

Energy Market: $\Sigma_i s_{it} = d_t(p_t^*), \ \forall t$

Emissions Market: $0 \ge \Sigma_{i,t} E_i s_{it} - \bar{E} \ \perp \ pe^* \ge 0$

Emissions Rights Allocation: $\Sigma_i \alpha_i^* cap_i + E_{GF} = \bar{E};$

$\alpha_i^*/\alpha_1^* = R_i, \ \forall i \ne 1$

Capacity Market: $\underline{CAP} \le \Sigma_i cap_i \ \perp \ pcap^* \ge 0$

NCP Statement

Given constants {$\underline{CAP}_i$, MC_i, E_i, , R_i, $\forall i$; $\underline{CAP}$, $\bar{E}$, E_{GF}} and $d_t(p_t^*)$, find {p_t^*, $\forall t$; pe^*, $pcap^*$; α_i^*, cap_i, $\forall i$; s_{it}, μ_{it}, $\forall i,t$ } solving:

<u>For all generators *i*:</u>

$$0 \le s_{it} \perp (p_t - MC_i - pe^* E_i) - \mu_{it} \le 0, \qquad \forall t$$

$$0 \le cap_i \perp (pcap^* + \alpha_i^* pe^* - F_i) + \Sigma_t \mu_{it} \le 0$$

$$0 \le s_{it} - cap_i \perp \mu_{it} \ge 0, \qquad \forall t$$

<u>Market clearing:</u>

Energy Market: $\Sigma_i s_{it} = d_t(p_t^*)$, $\forall t$

Emissions Market: $0 \ge \Sigma_{i,t} E_i s_{it} - \bar{E} \perp pe^* \ge 0$

Emissions Rights Allocation: $\Sigma_i \alpha_i^* cap_i + E_{GF} = \bar{E}$;

$\alpha_i^* / \alpha_1^* = R_i$, $\forall i \ne 1$

Capacity Market: $\underline{CAP} \le \Sigma_i cap_i \perp pcap^* \ge 0$

Note: More generally, $\Sigma_i \alpha_i^* (W_{cap} cap_i + \Sigma_t W_{si} s_{it}) + E_{GF} = \bar{E}$ for the first Emissions Allocation condition, with constants W_{cap}, $W_{si} \ge 0$.

Model Properties and Solution

- **Under mild conditions, a solution exists**
- **Computation**
  - ***Rearrange and linearize NCP to obtain (a provably feasible) LCP***
    - **α_i*cap_i term requires linearization**
  - ***Iterate until convergence; converged solution solves the original problem***

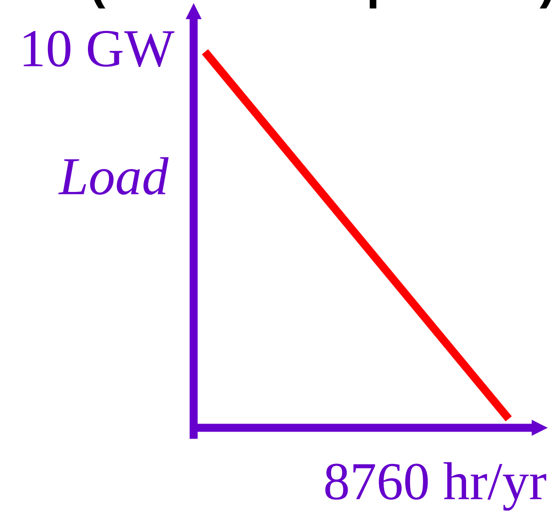
Example Analysis: 3 Gen Types

- **Emissions limit: 20 or 40 MT/yr**
  - ***94%, 47% of unconstrained emissions***
- **Elastic demand**
  - ***Price intercept of $1000/MWh***
    - $\Rightarrow \varepsilon$ ***= -0.11 @ P=$100/MWh***
- **No capacity market**
  - ***Sensitivity case:*** **Capacity market (11 GW)**
- **Generator assumptions:**

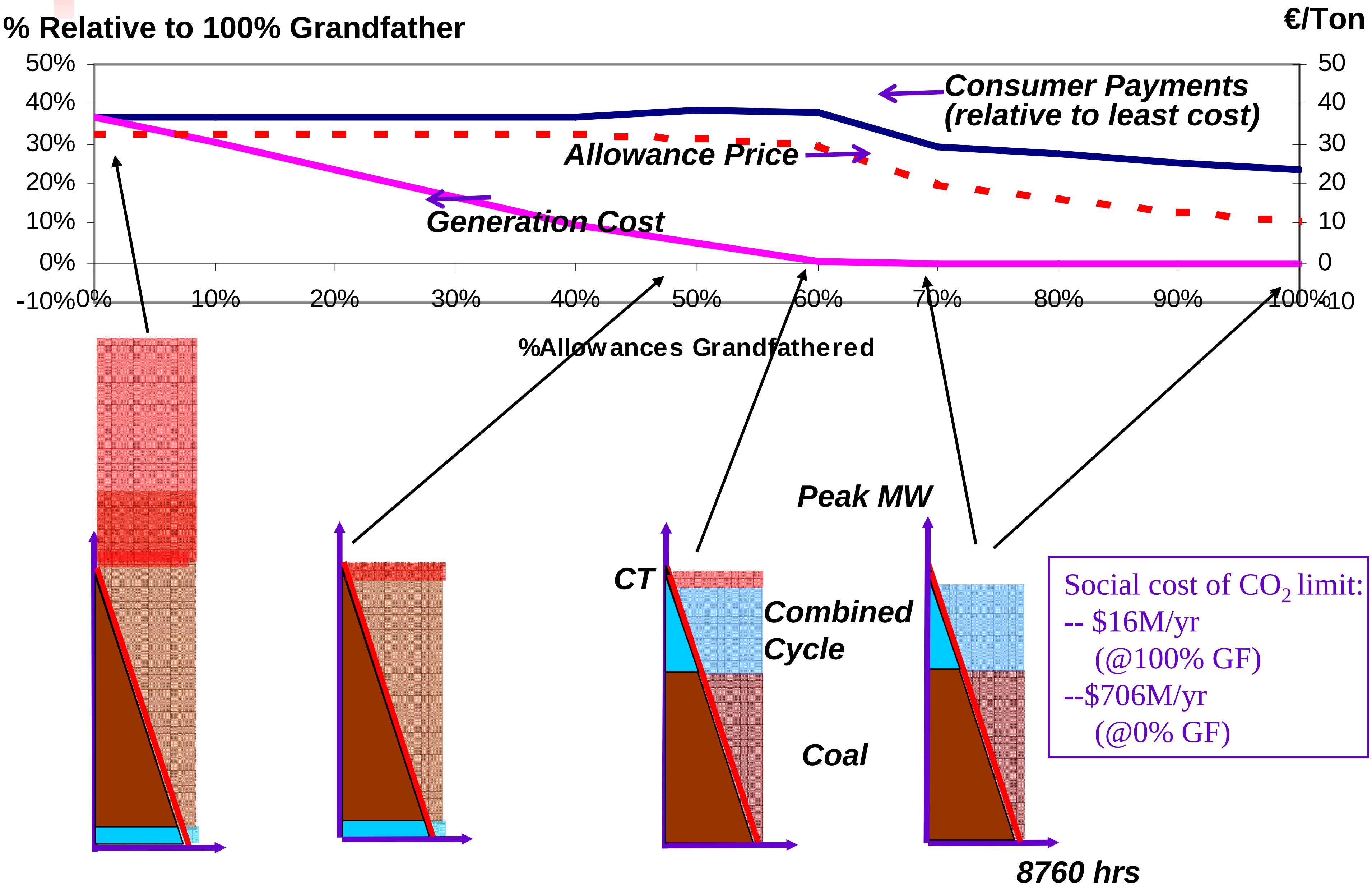
Technology	Fixed Cost (€/kW)	Var Cost (€/MWh)	CO2 (Ton/MWh)	Allocation of Allowances to New Investment (relative) (1/MW)
Combustion Turbine	50	80	0.6	0.35
Combined Cycle (Gas)	75	40	0.35	0.35
Pulverized Coal	120	20	1	1

  - ***Sensitivity case:*** **Coal has 35% Min Run constraint**

Load Distribution @*p* = $0/MWh (20 x 436 hr periods)

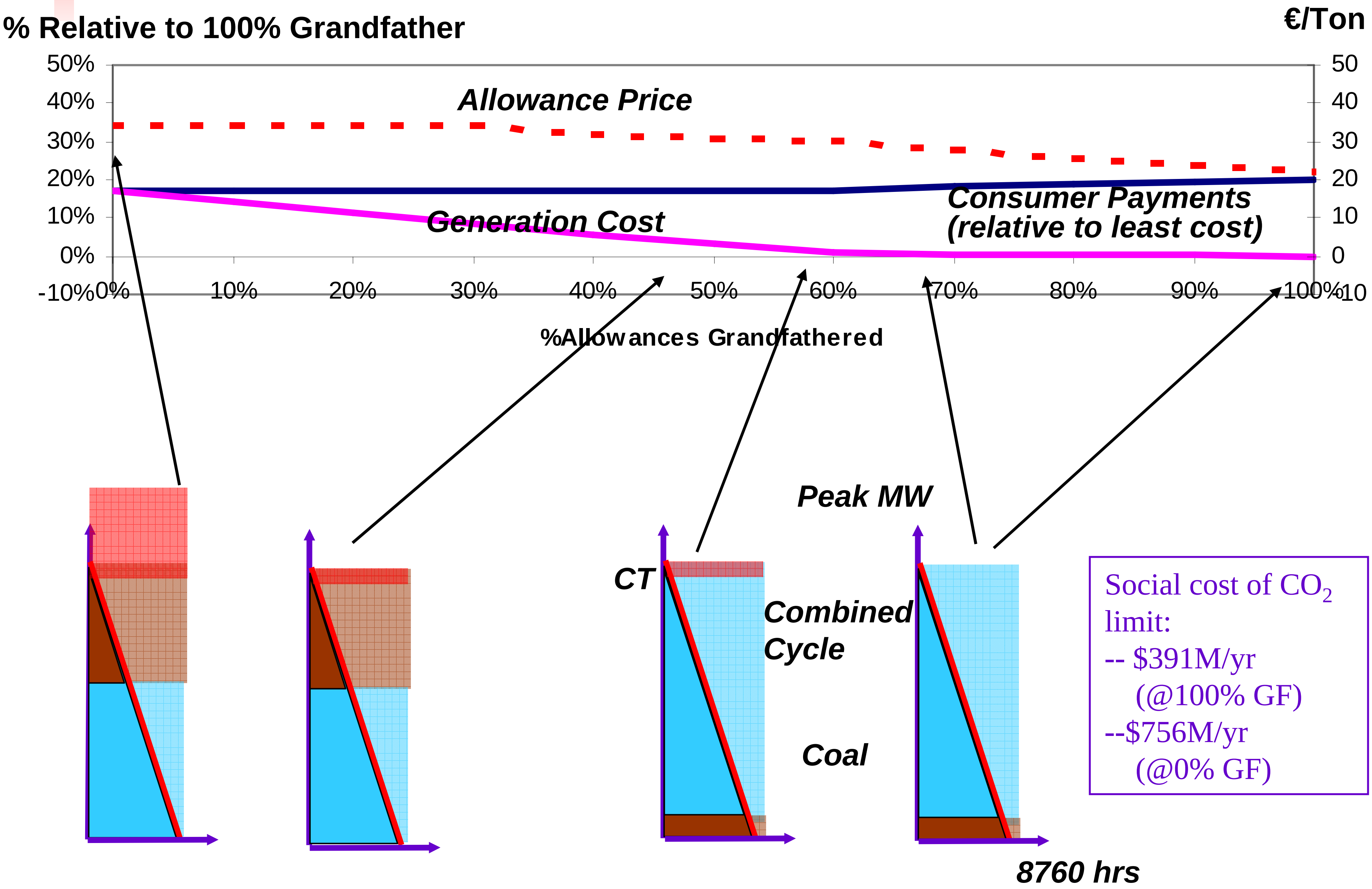


Results: 6% Emission Reduction



Social cost of CO_2 limit:
-- \$16M/yr
(@100% GF)
--\$706M/yr
(@0% GF)

Results: 53% Emission Reduction

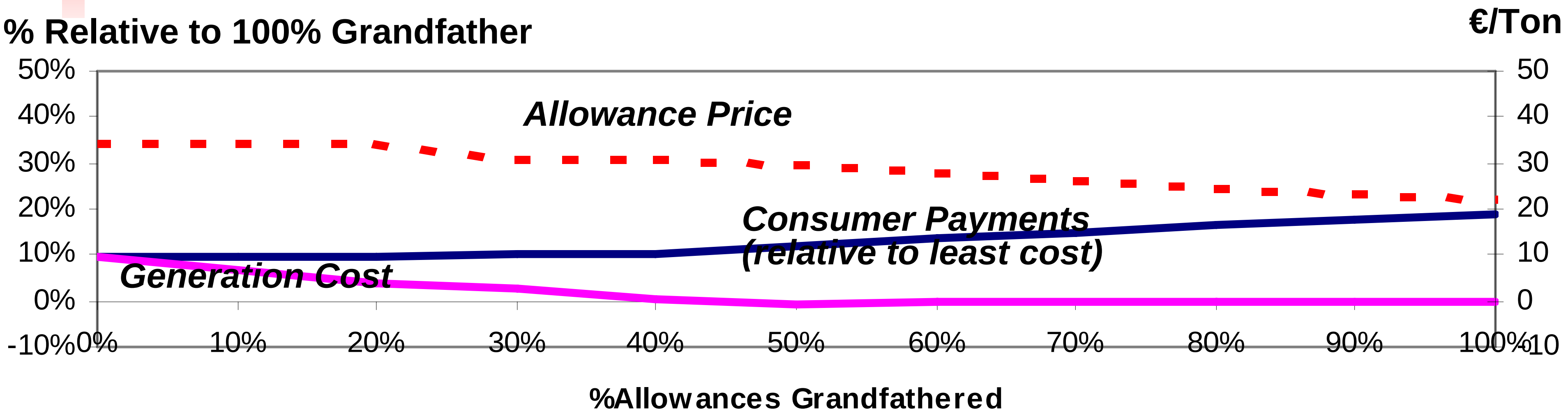


Social cost of CO_2 limit:
-- $391M/yr (@100% GF)
--$756M/yr (@0% GF)

Effects of Giving Away Allowances

- Increases effective demand for allowances
  - so price ↑
  - distorts dispatch order
- Investment distortion
  - For %Grandfather > 60%: minor (slight changes in mix)
  - For %GF < 50%: major (overinvest--generation built to get allowances)
- Increases social cost of CO_2 control
  - At least doubles (under %GF = 0)
  - Distortion worse at <u>smaller</u> levels of CO_2 reduction
  - Power prices may not change; instead most of cost is loss of government allowance rent

Add Capacity Market @53% CO_2 Reduction

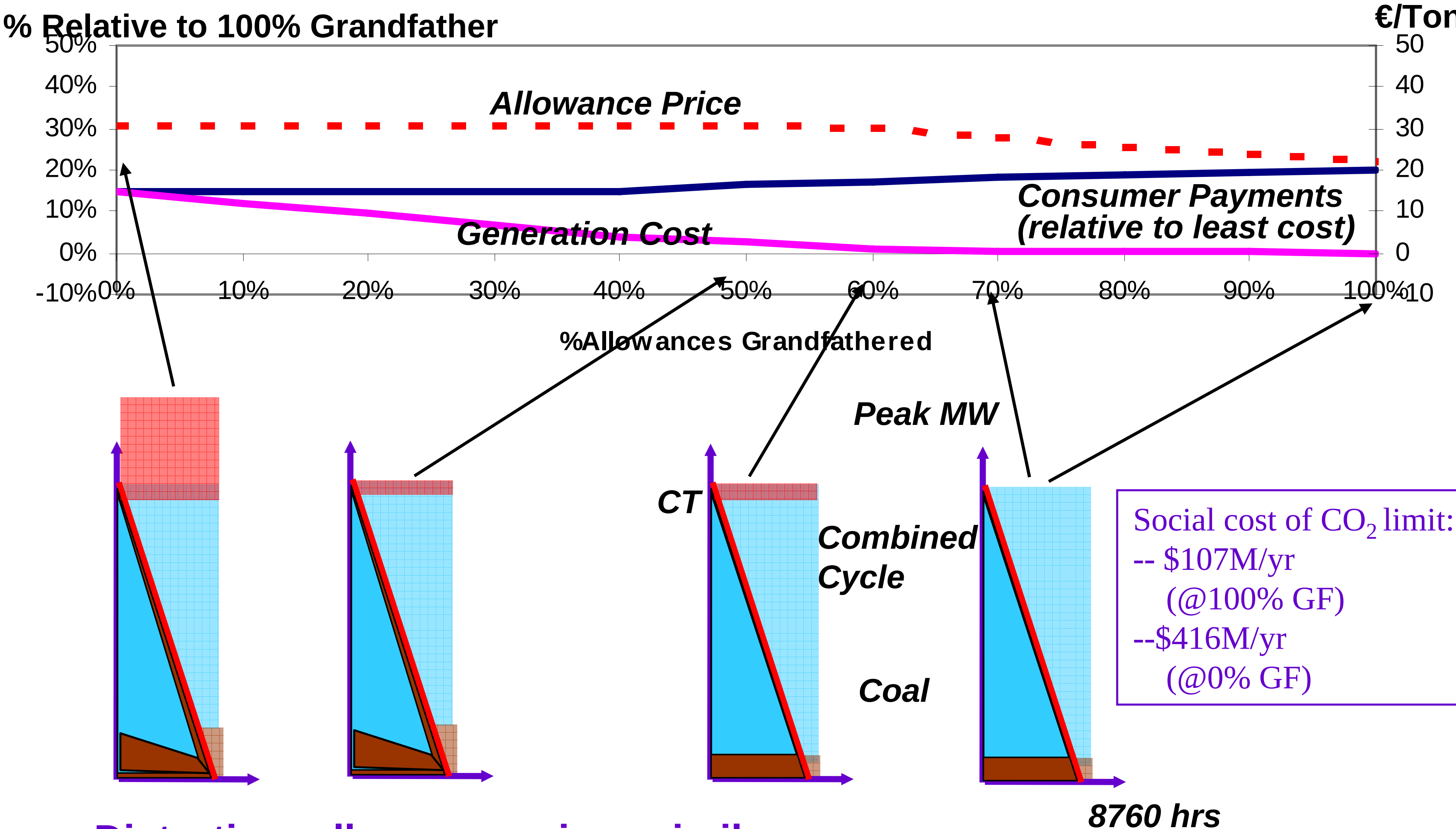


Social cost of CO_2 limit:
-- $395M/yr (@100% GF)
--$647M/yr (@0% GF)

Effect of capacity market:

- **Cost & investment distortion lessened**
  - **Occurs only for smaller %GF**
- **None on emissions allowances**

With Coal MinRun Constraint & Lowest CO_2



Social cost of CO_2 limit:
-- $107M/yr
(@100% GF)
--$416M/yr
(@0% GF)

- Distortion, allowance prices similar
- Cost of CO_2 compliance (@100%GF) less because baseline emissions lower (due to coal constraint)

Conclusions

- **Original questions: "*Will the least-cost generation mix still result, and all the allowances rent returned to consumers if allowances are given to new investors?*"**
  - **Yes, investors compete away the allowance rents**
  - **But deadweight losses occur:**
    - ***Inefficient dispatch orders***
    - ***Changes in mix and amounts of investment***
- **Capacity markets dampen losses, but recognition of operating constraints does not**
- **Issue:**
  - **Efficiency: ought to grandfather or auction**
  - **Equity: unfair that only existing plants get rents?**
- **Next:**
  - **Other allocation rules**
  - **Wider range of generation and control technologies**
  - **Parameterize for realistic markets**