



# Dynamics of renewable entry into electricity markets

Do cost fall faster than revenues?

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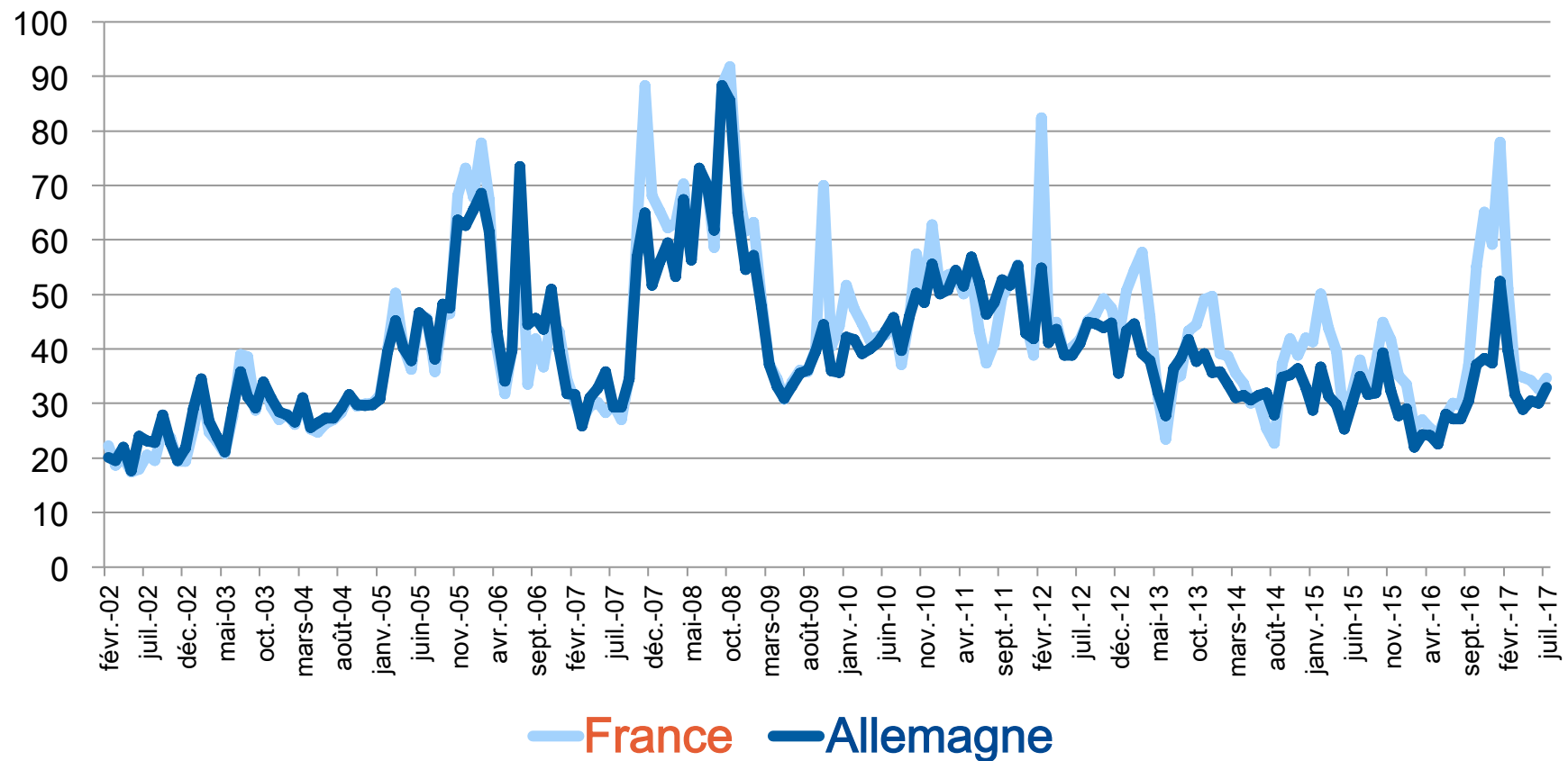


# Prologue

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# Low wholesale power prices in continental Europe ...

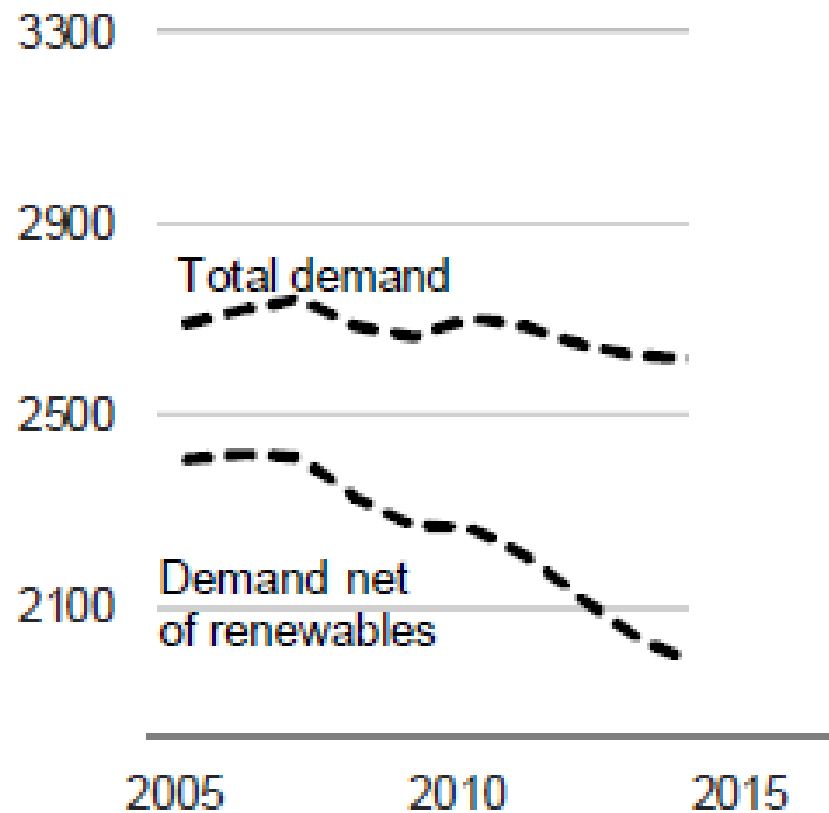
Wholesale spot prices, base, monthly average (€/MWh)



Source : EPEX

... caused by a reduction in residual demand ...

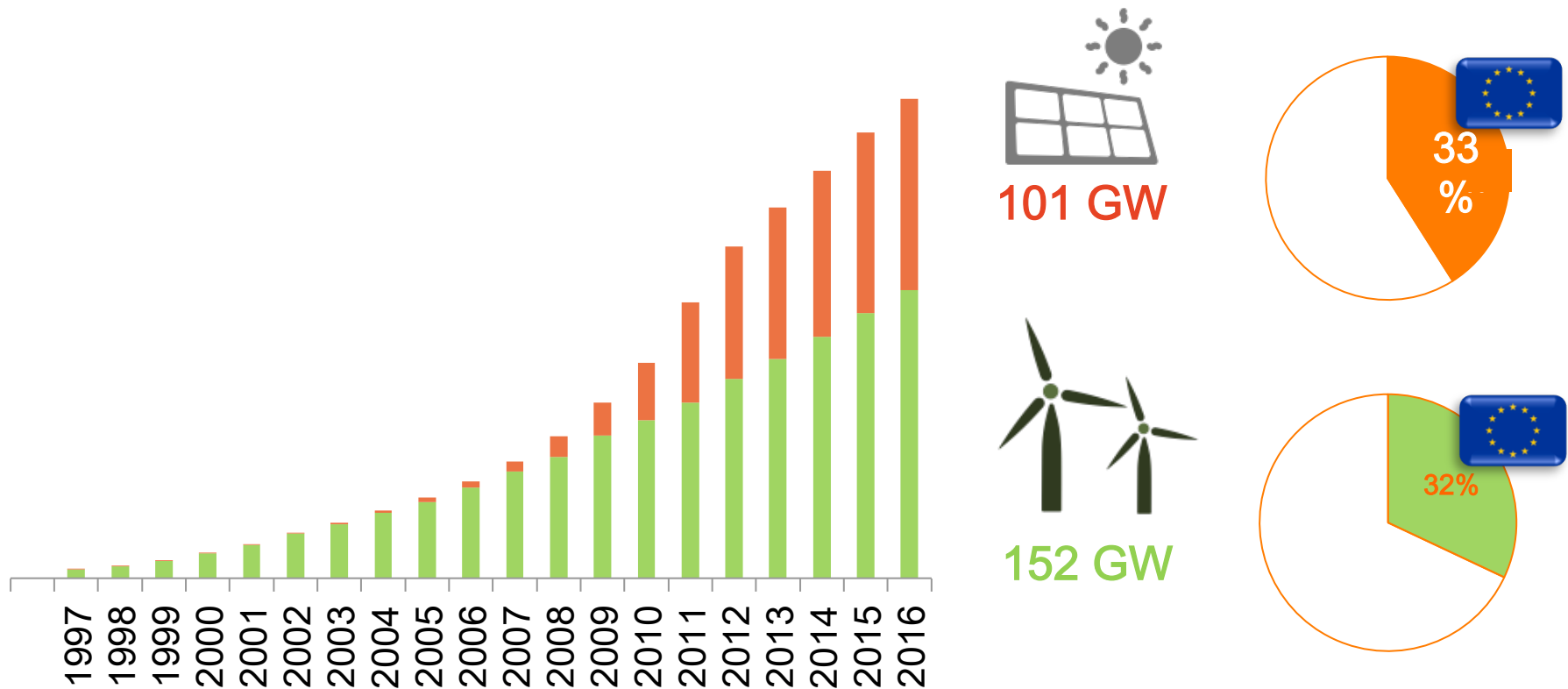
Electricity demand, continental Europe  
(TWh)



Source: présentation P. Torrion, EDF

# ... caused by massive RES entry

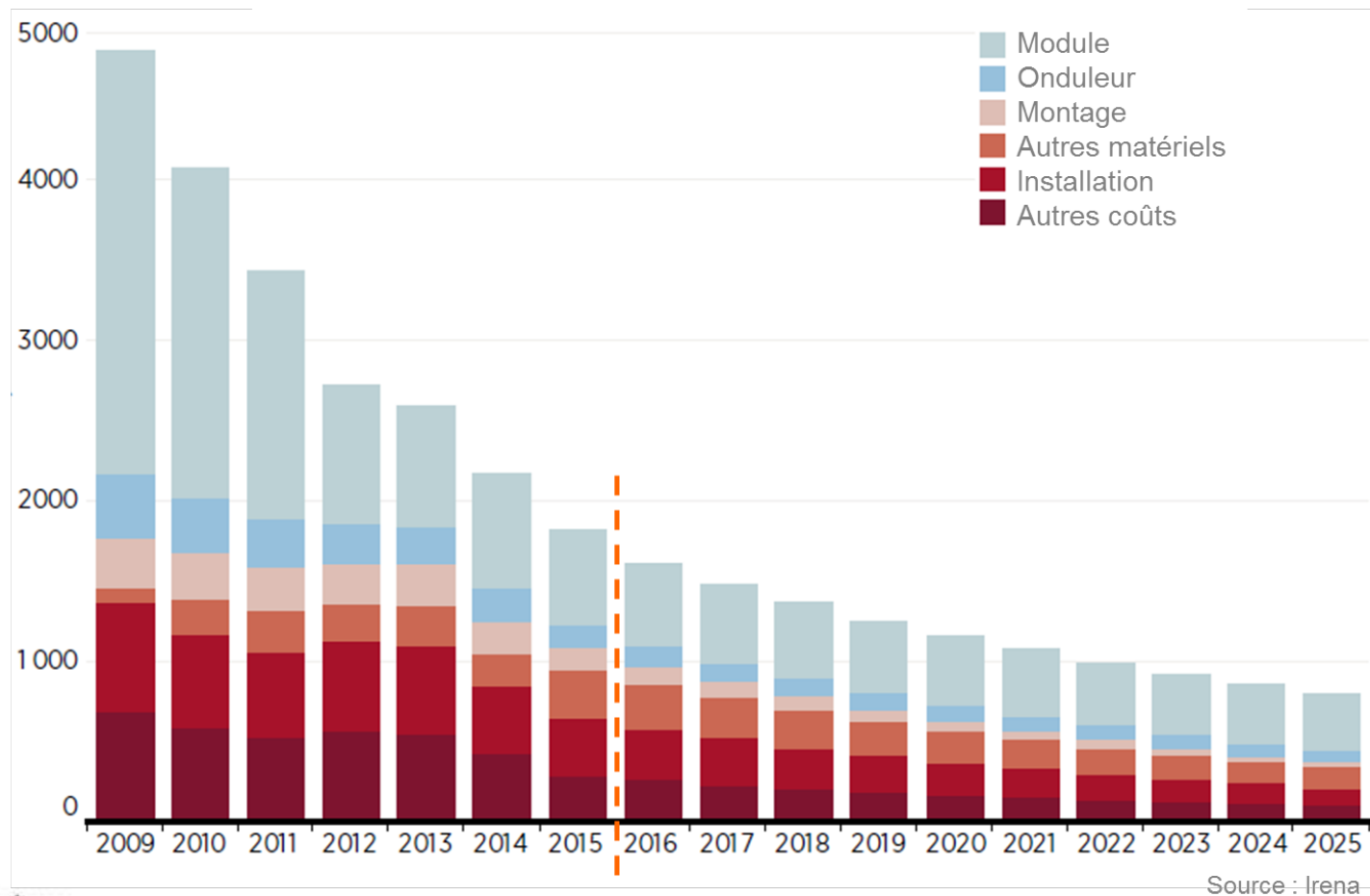
## Development of Renewable Energy Sources (UE; installed capacity MW)



Source : BP

# A technological revolution underway

Cost of a photovoltaic module  
(\$/kW)



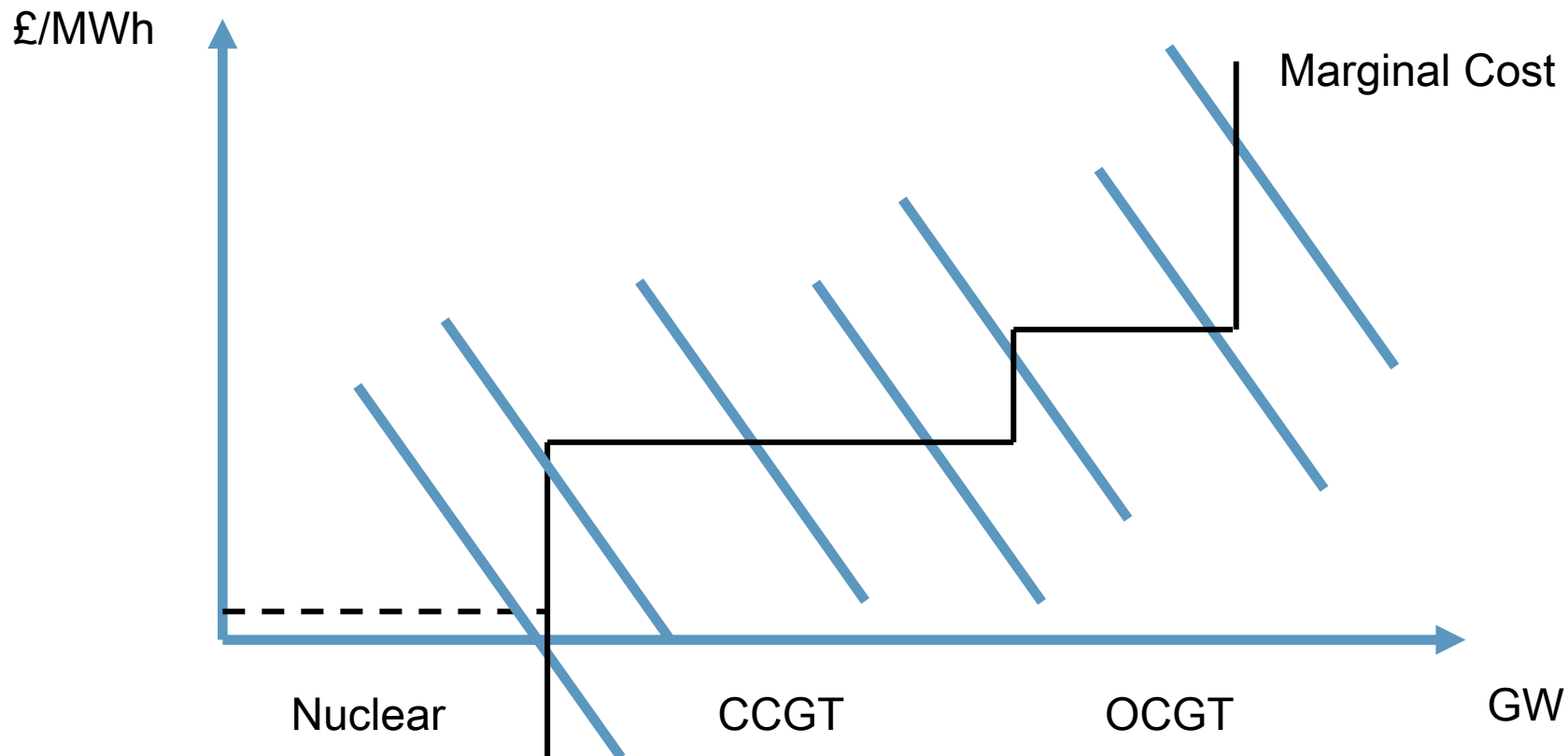
Source : Irena

# Summary of today's discussion

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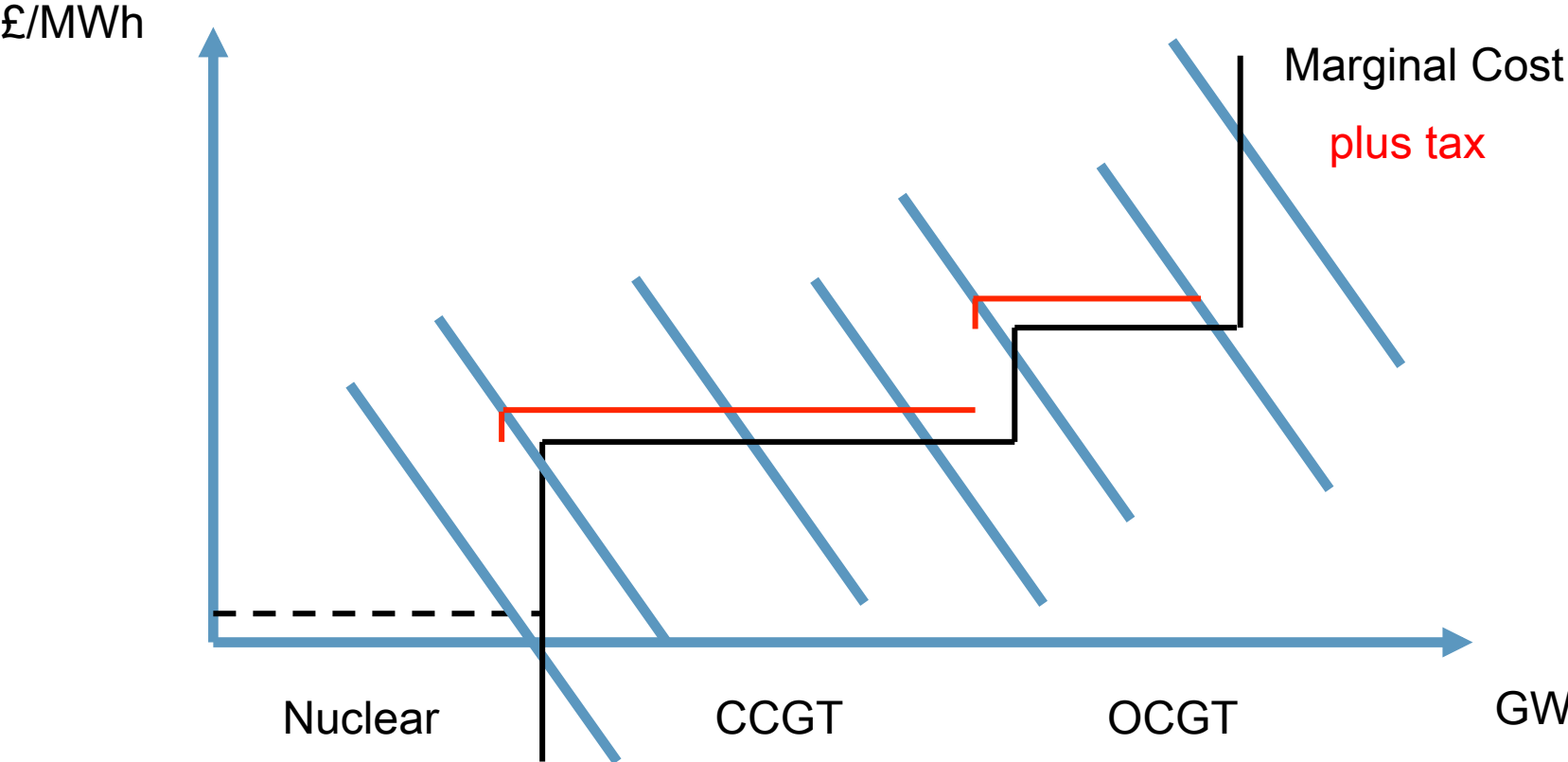
- Renewable entry has already had a profound impact on the generation mix and led to a high tax in Germany, and soon in other European countries
- This research project
  1. determines analytically the “laws of motion” of renewable entry, i.e., the dynamics of the generation mix, subsidy, and tax
  2. illustrates the analysis on the case of Great Britain
- It finds that
  1. massive wind entry in the UK under the current physical dispatch priority rule would push inflexible nuclear out of the market, and lead to a significant increase in the subsidy and tax
  2. replacing physical dispatch priority by financial dispatch priority would mitigate these negative effects without altering renewable economics

# Long-term generation mix: Marcel Boiteux forever





# Generation mix evolution as RES enter



## A bit of notation

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- $N$  incumbent technologies,  $c_n$  is variable cost (£/MWh),  $r_n$  fixed capacity cost (hourly, £/MWh),  $K_n$  cumulative capacity of first  $n$  technologies (ordered by MC, GW)
- $K^i_0$  installed capacity of renewable technology  $i$  (GW)
- $\theta$  is the state of the world
- $\alpha_i(\theta)$  is the availability of renewable technology  $i$  and  $u_n(\theta)$  the dispatch of technology  $n$  in state  $\theta$
- Inverse demand is linear with constant slope

$$P(Q, \theta) = a(\theta) - bQ$$

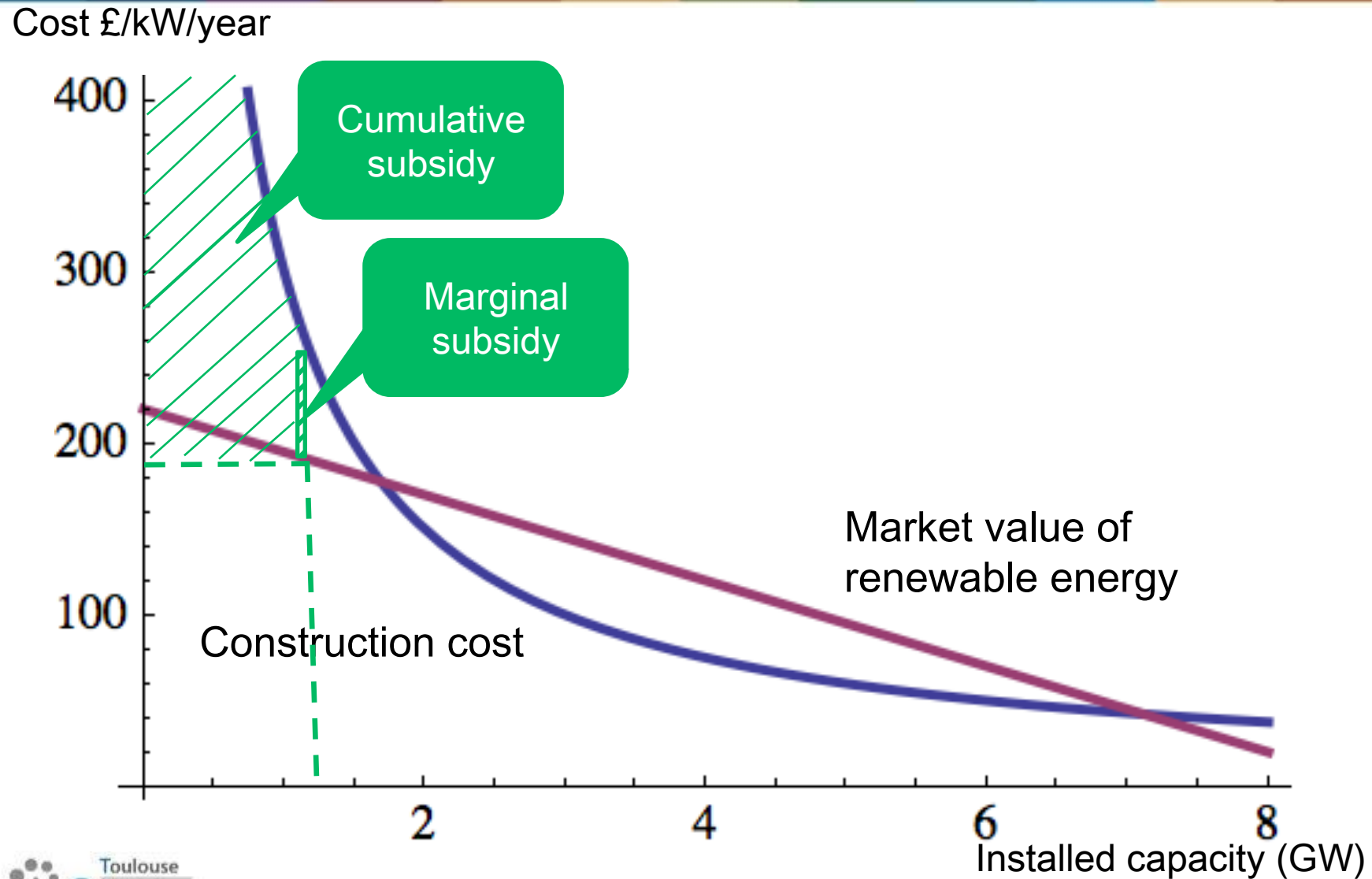
## Free entry in generation

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- Wholesale spot price is  $p(\mathbf{K}_0, \theta)$  (£/MWh)
- Free entry: expected hourly operating profit is equal to hourly fixed capacity cost for every technology

$$\mathbb{E} [(p(\mathbf{K}_0, \theta) - c_n) u_n(\theta)] = r_n, \text{ for } n \geq 1$$

# RES marginal and cumulative subsidy



# Subsidy and tax

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- Marginal subsidy for renewable technology  $i$  with marginal investment cost  $r_0(K_0^i)$

$$\varphi^i(\mathbf{K}_0) = \max(r_0^i(K_0^i) - \mathbb{E}[\alpha^i(\theta)p(\mathbf{K}_0, \theta)], 0)$$

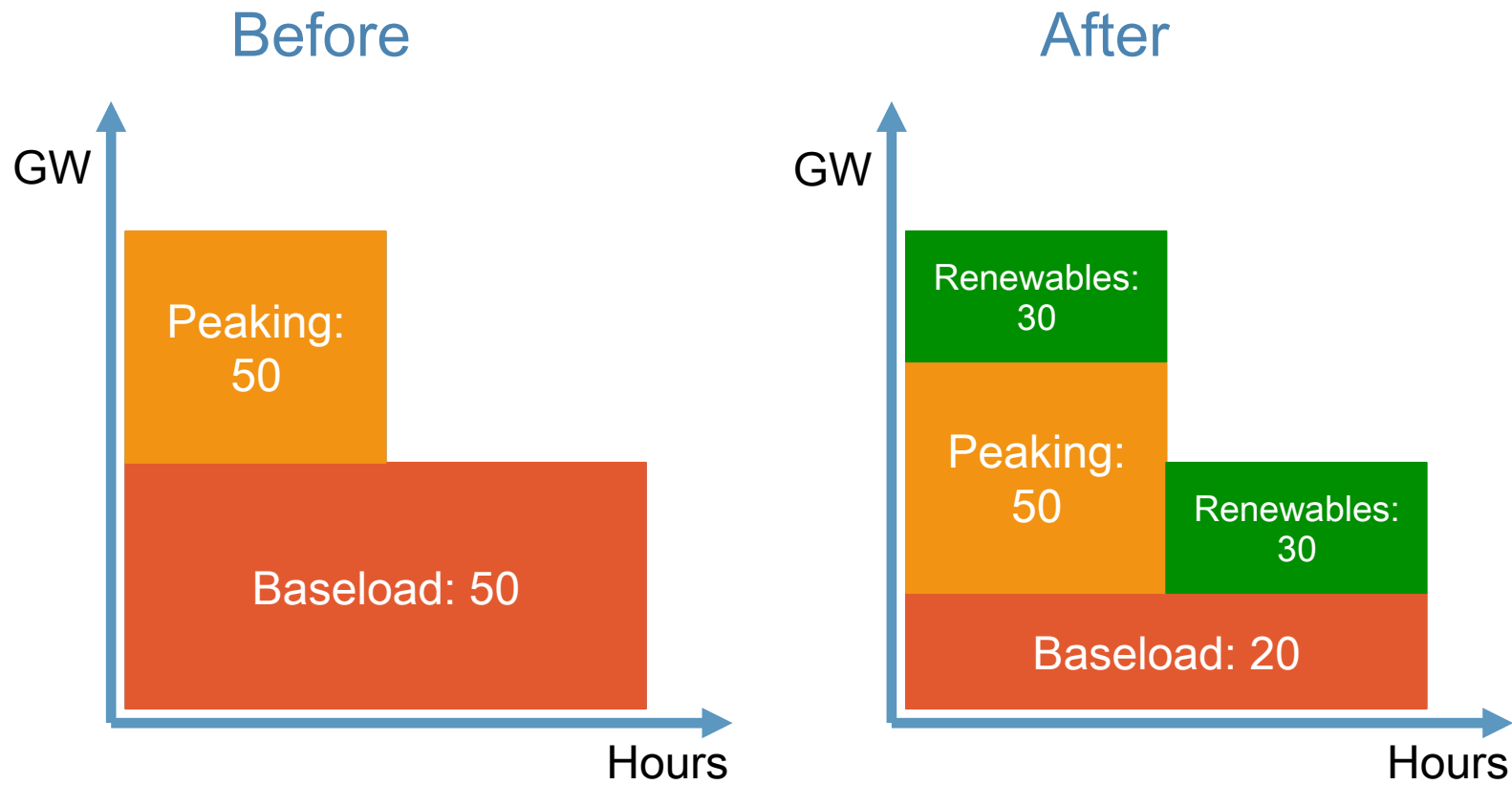
- Cumulative aggregate subsidy

$$\Phi(\mathbf{K}_0) = \sum_{i=1}^I \left( \int_0^{K_0^i} r_0^i(x) dx - \mathbb{E}[\alpha^i(\theta)p(\mathbf{K}_0, \theta)] K_0^i \right)$$

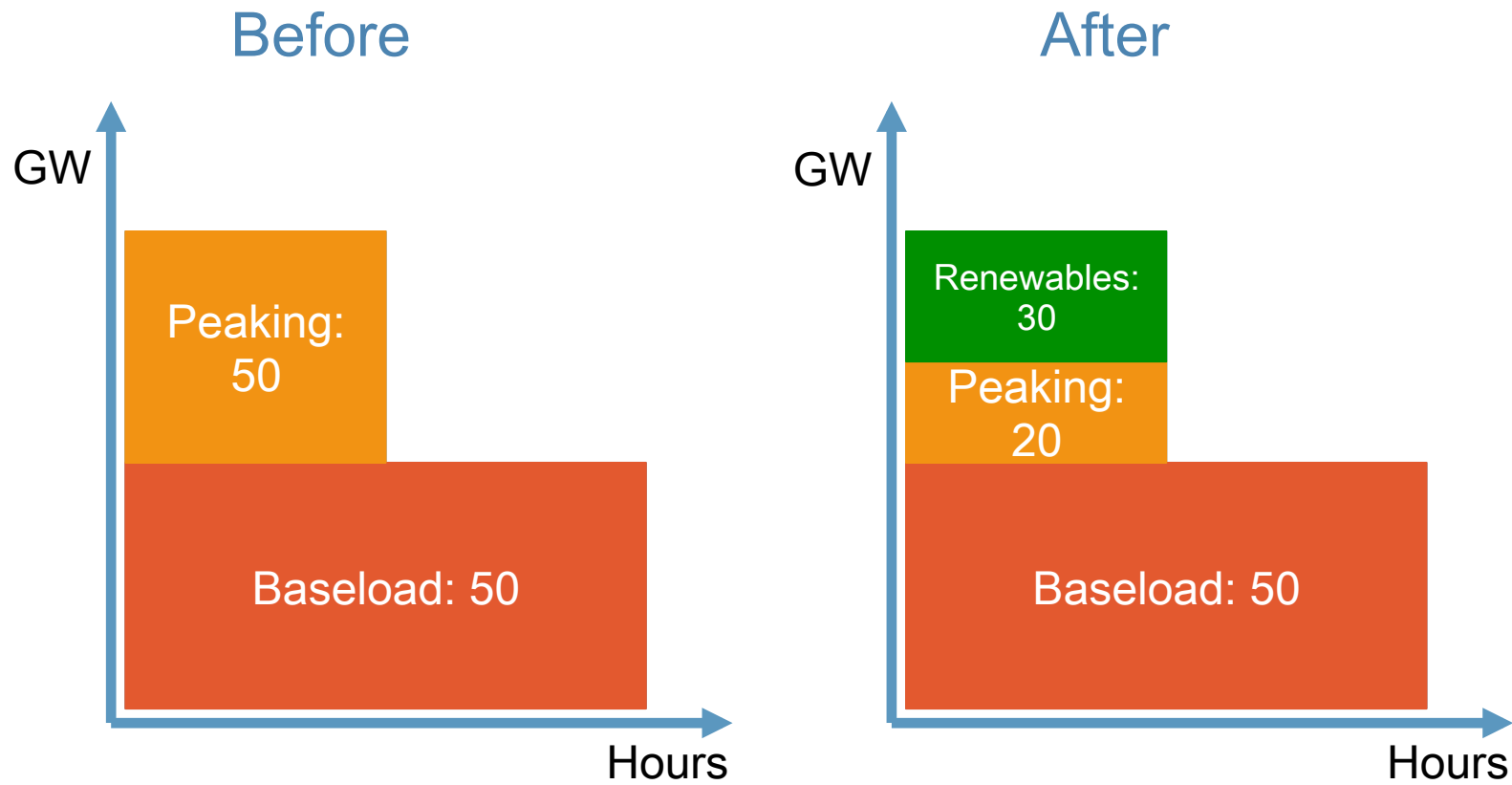
- Retail price is  $(p(K_0, \theta) + \tau)$  where  $\tau$  is the unit tax to finance renewables
- Total tax revenues

$$\tau(\mathbf{K}_0) \mathbb{E}[D(p(\mathbf{K}_0, \theta) + \tau(\mathbf{K}_0), \theta)] = \Phi(\mathbf{K}_0)$$

# Impact of renewables: no correlation with demand



# Impact of renewables: strong correlation with demand



## Dynamics of generation mix

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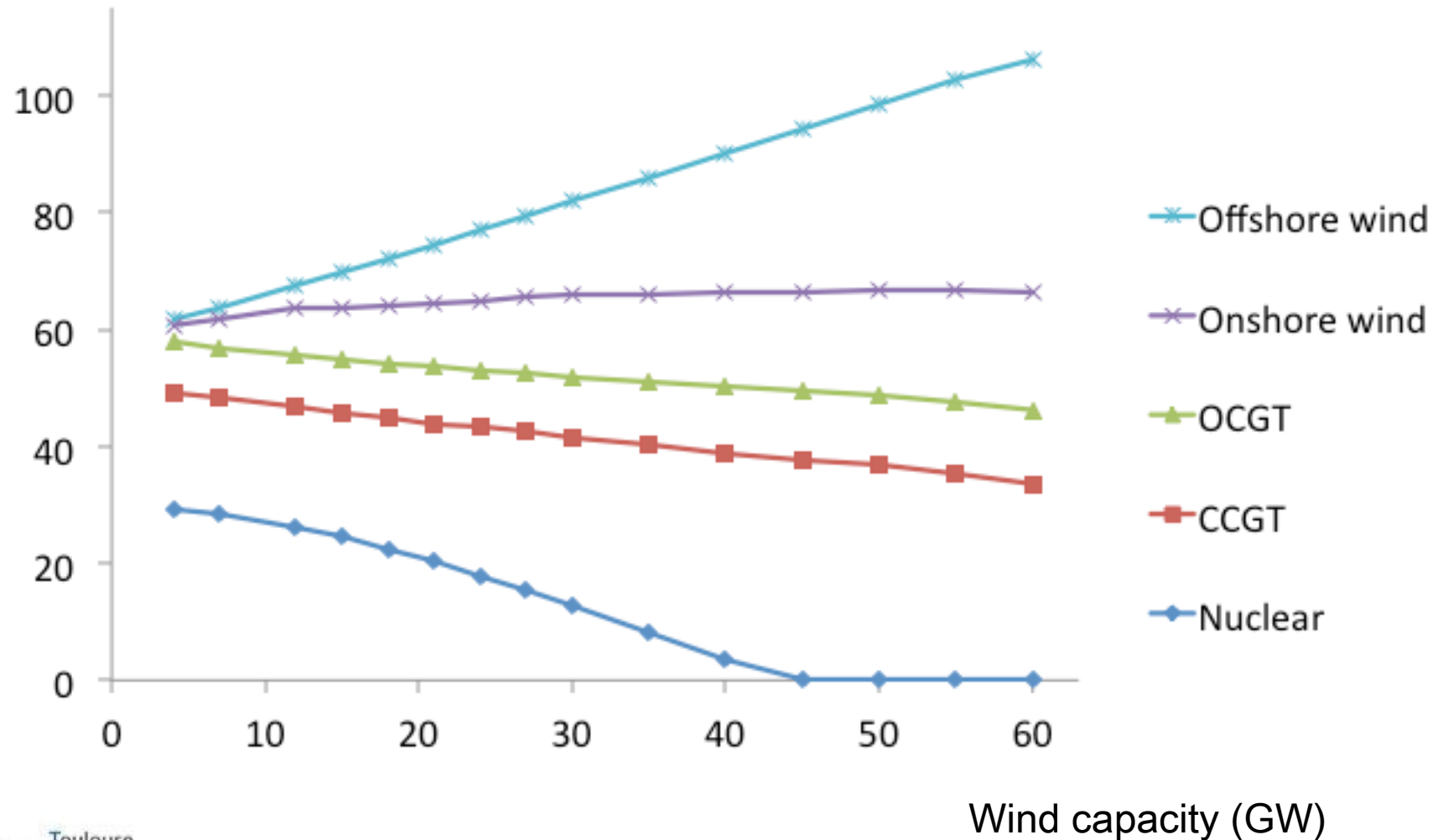
- $v_n$  is the vertical portion of the supply curve where technology  $n$  produces at capacity
- Long term equilibrium: conventional installed capacity is reduced as renewables capacity increases

$$\frac{\partial K_n}{\partial K_0^i} = -\frac{1}{b} \frac{\partial \tau}{\partial K_0^i} - \mathbb{E} [\alpha^i(\theta) | v_n]$$



# Resulting capacity mix in Great Britain

GW



# Dynamics of the marginal value of renewable capacity

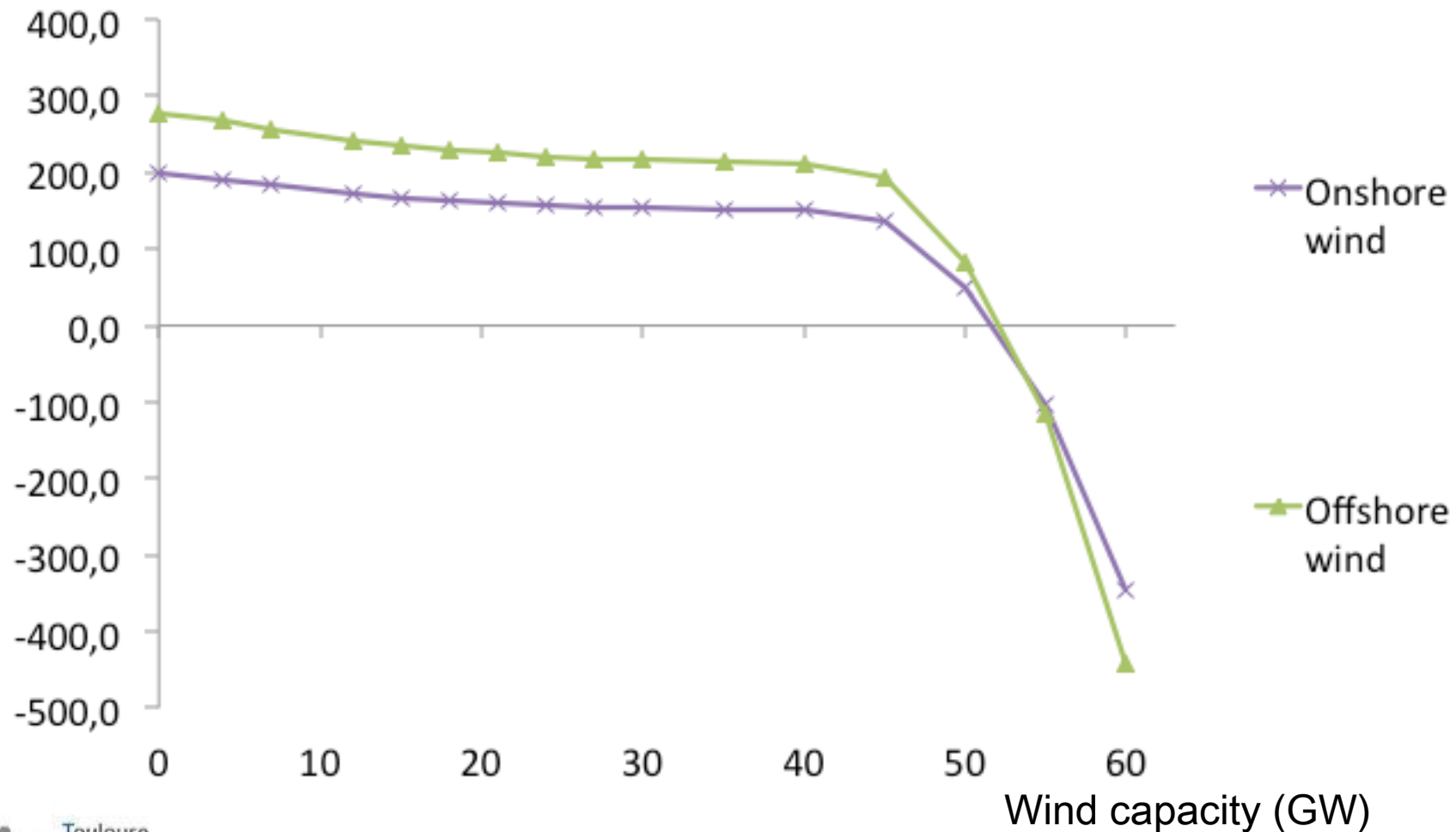
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The marginal impact of renewable technology  $i$  on the value of technology  $j$  is proportional to the covariance of availabilities

$$\mathbb{E} \left[ \alpha^j (\theta) \frac{\partial p}{\partial K_0^i} \right] = -b \widehat{cov}_{\mathbf{K}_0} [\alpha^i (\theta), \alpha^j (\theta)]$$

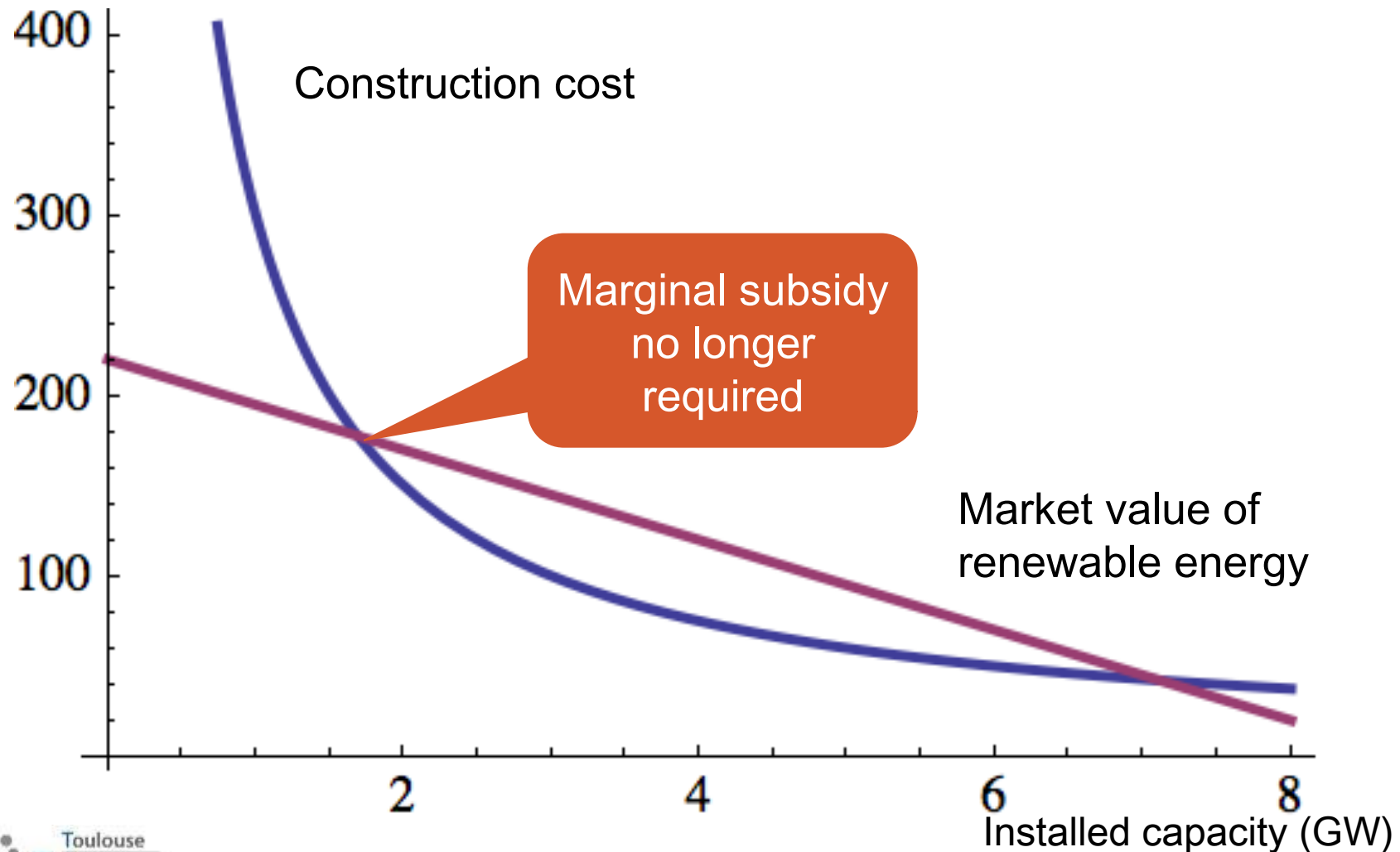
# Marginal value of wind turbines (status quo)

£ per kW per year



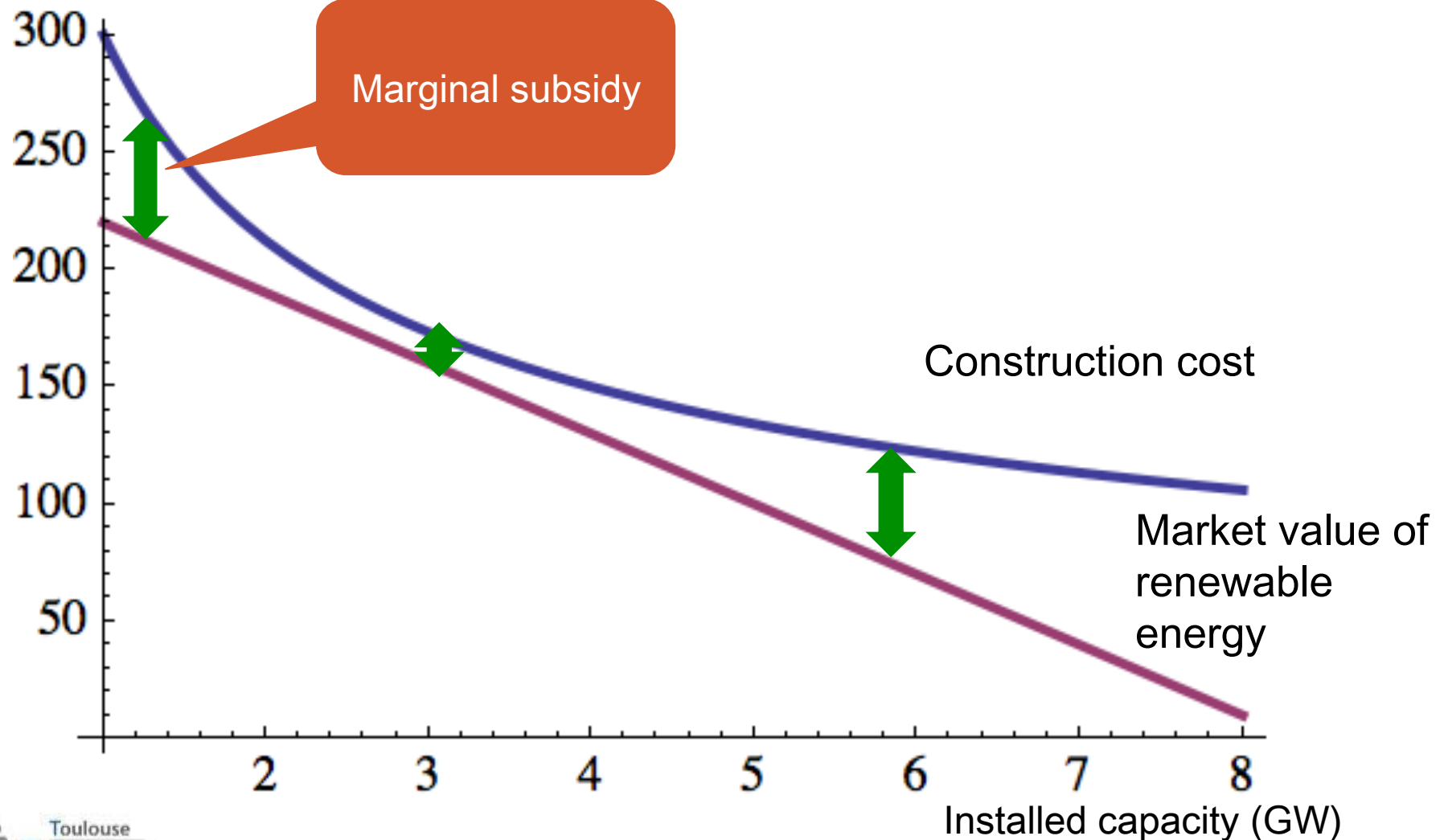
# Cost falls faster than the price: marginal subsidy ends

Cost £/kW/year



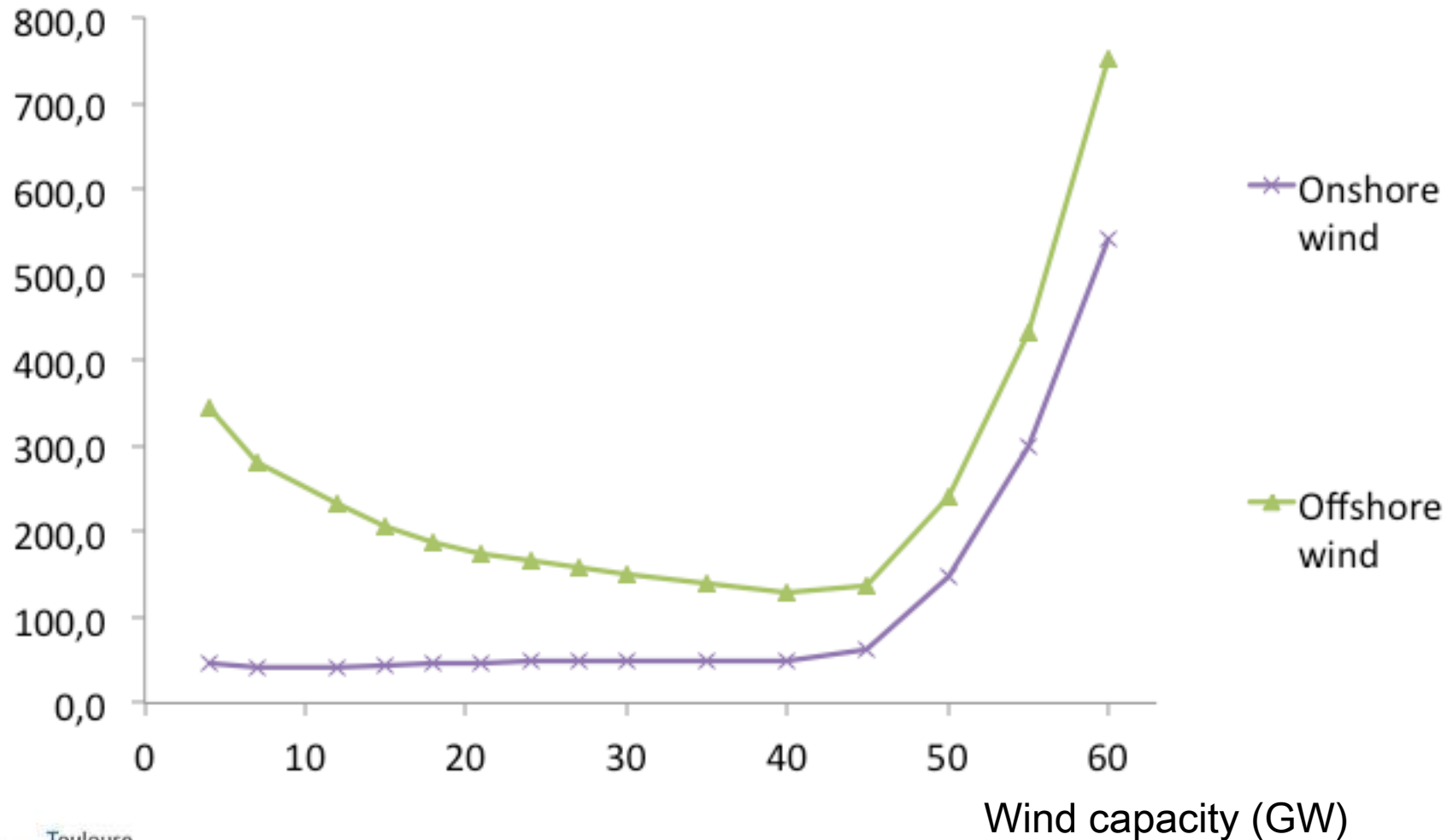
# Price falls faster than the cost: marginal subsidy required

Cost £/kW/year

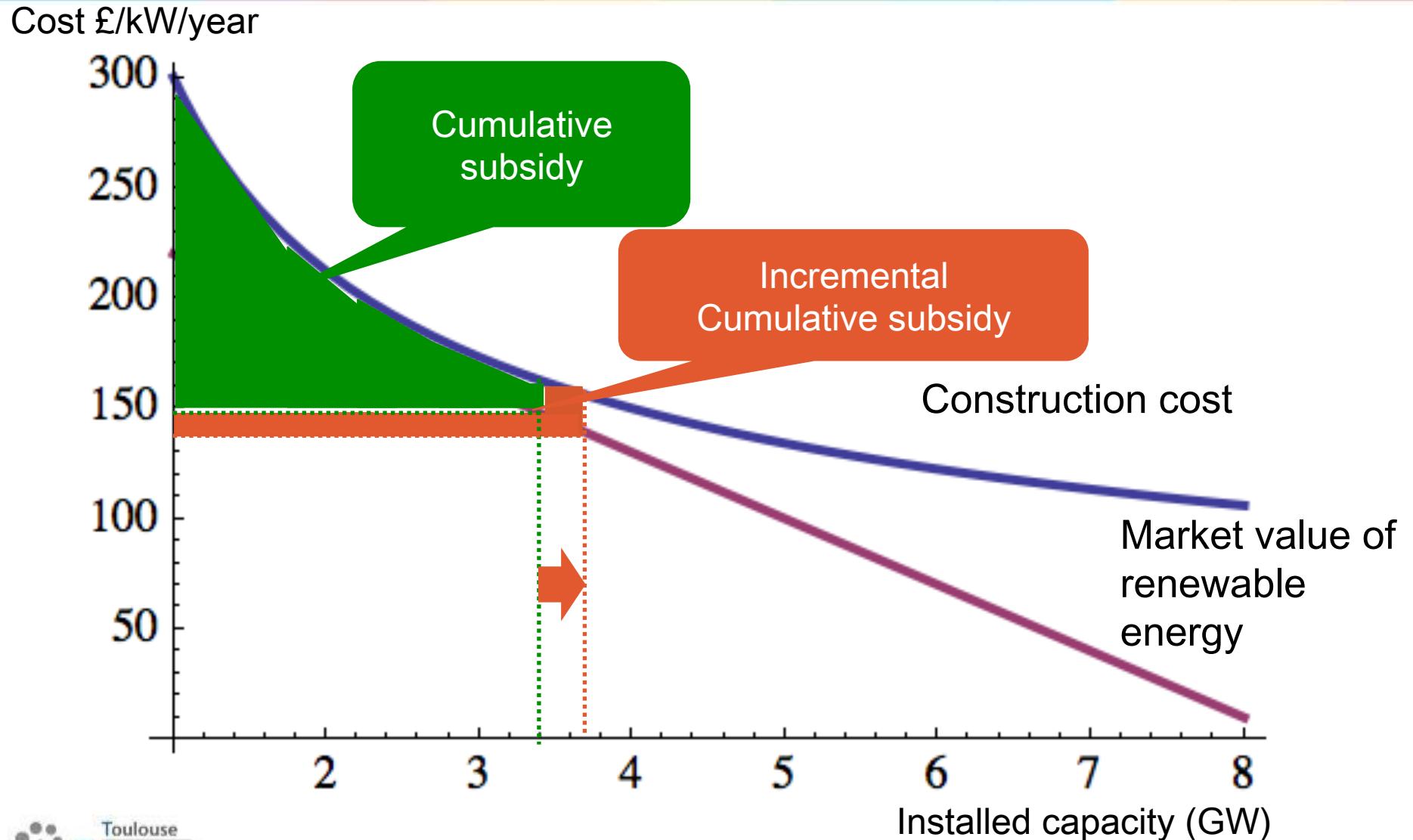


# Marginal subsidy to wind turbines (2015 data)

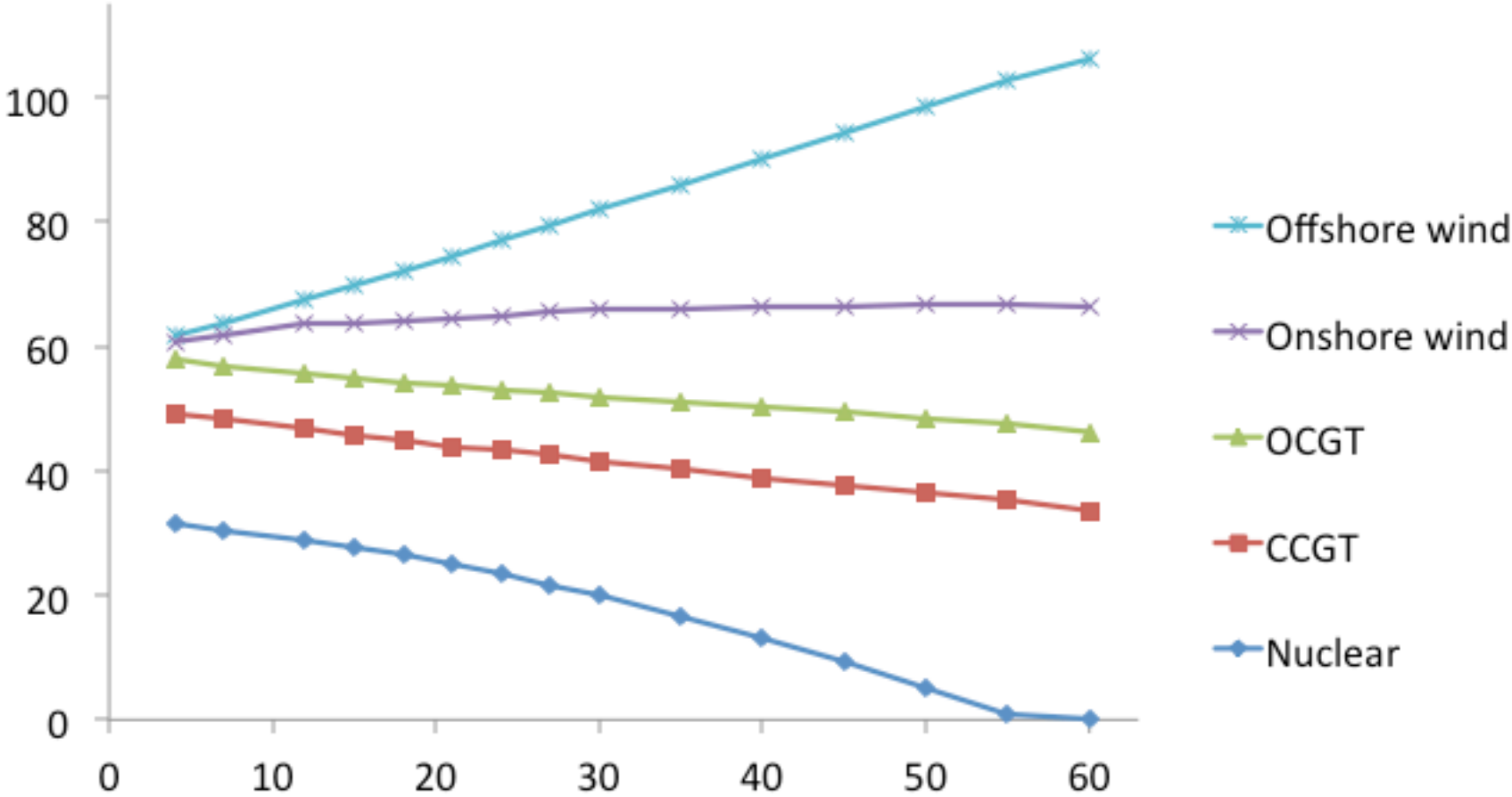
Subsidy (£ per kW per year)



# Evolution of cumulative subsidy

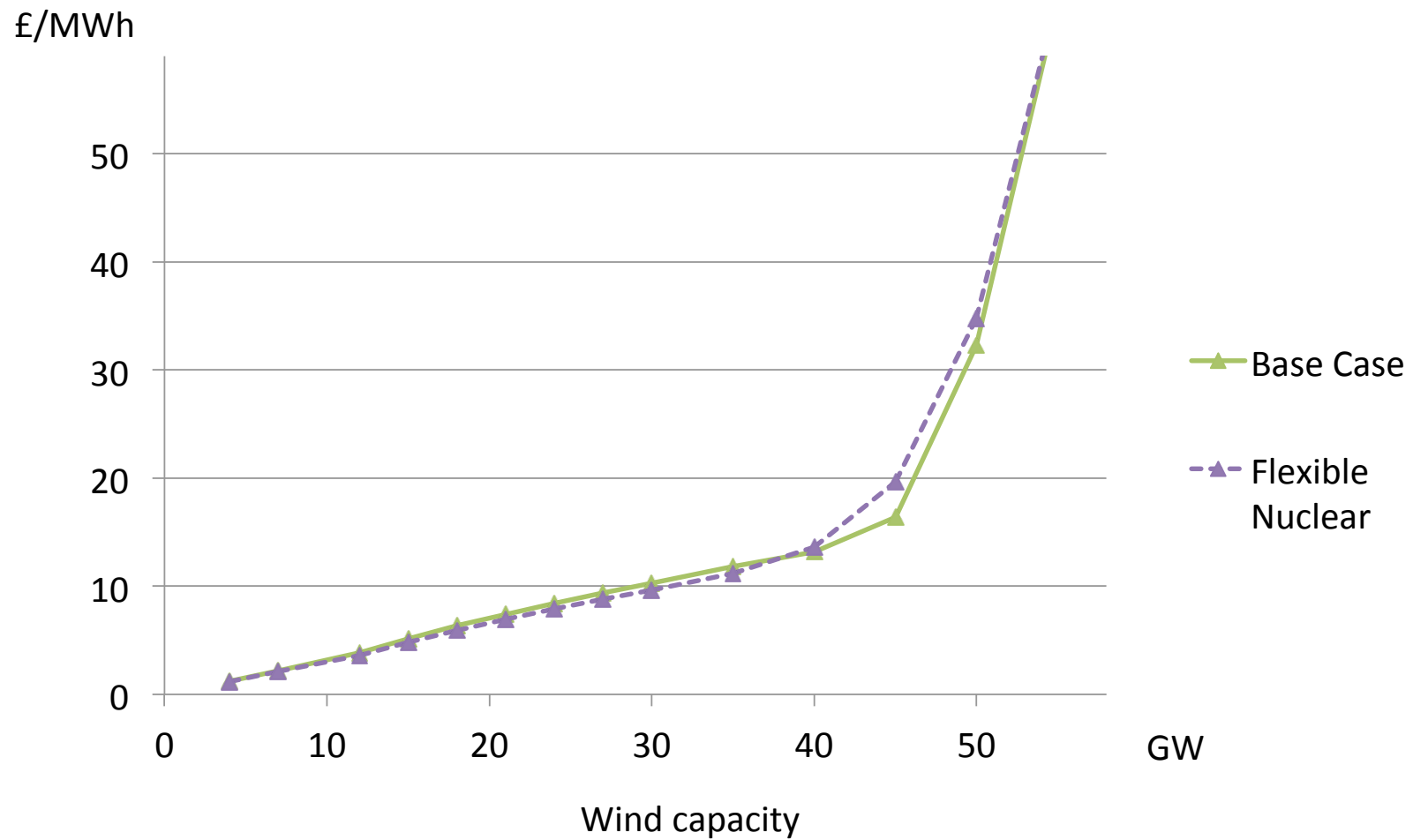


# What if nuclear was flexible?

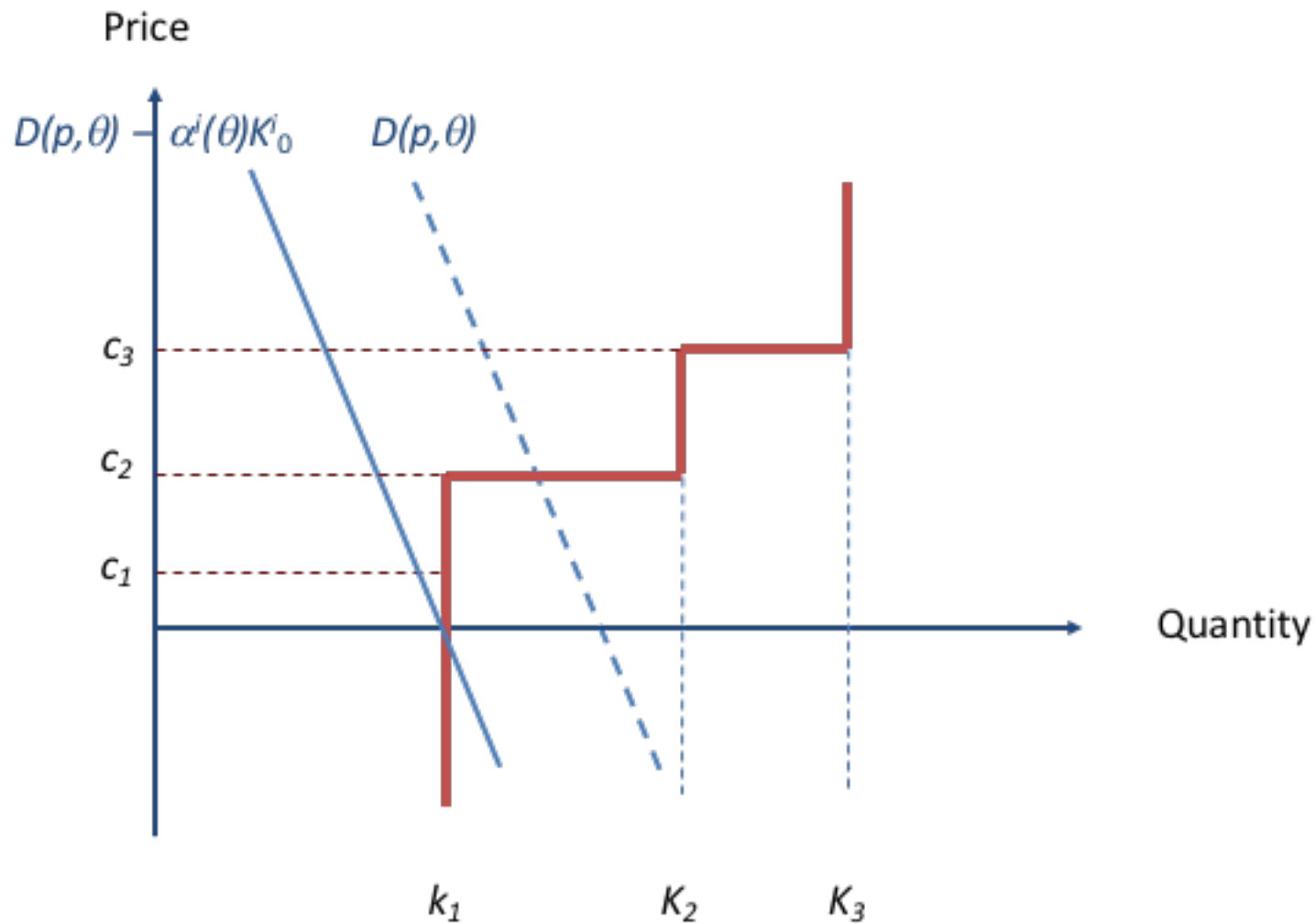




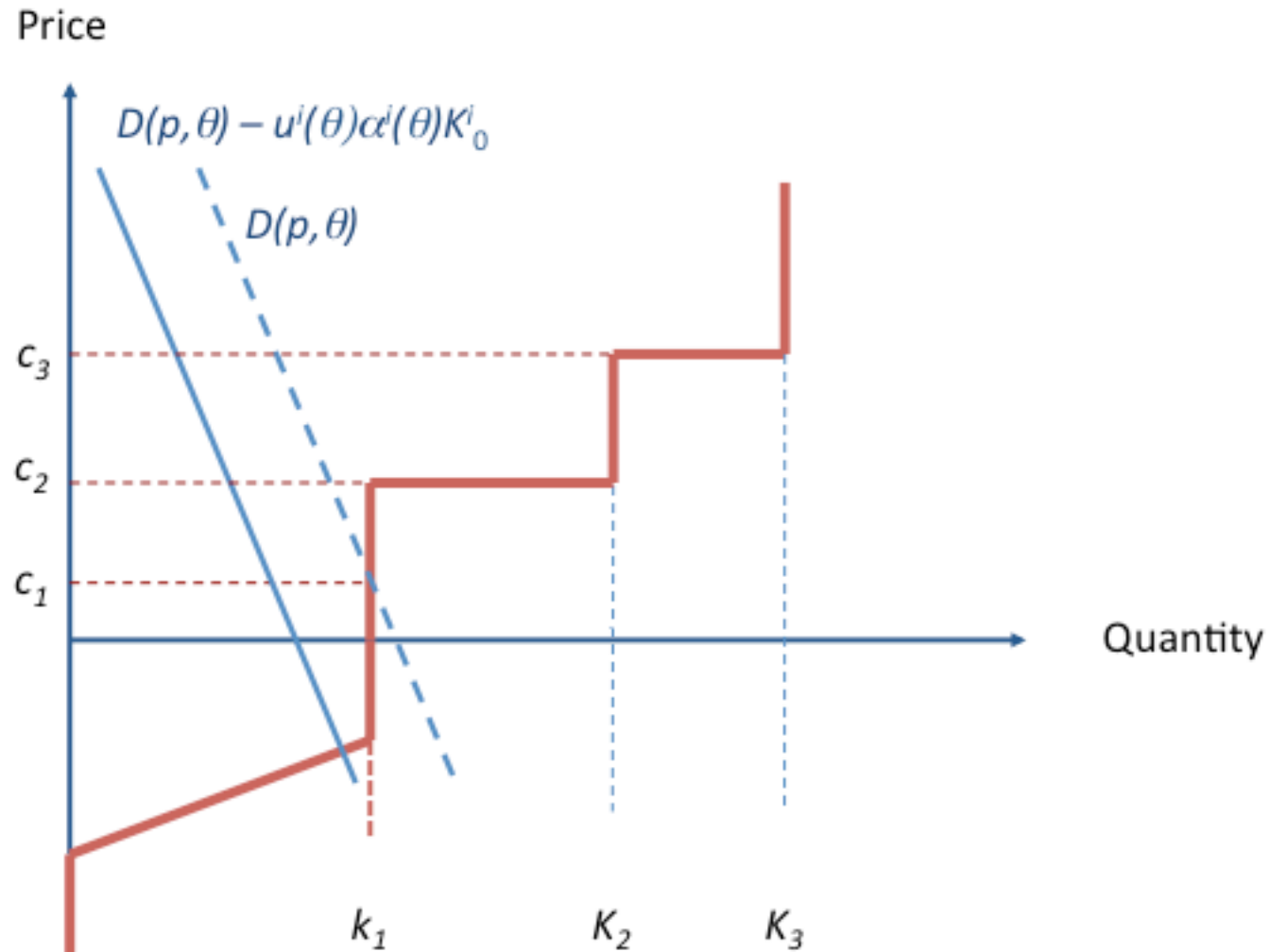
# Unit tax required



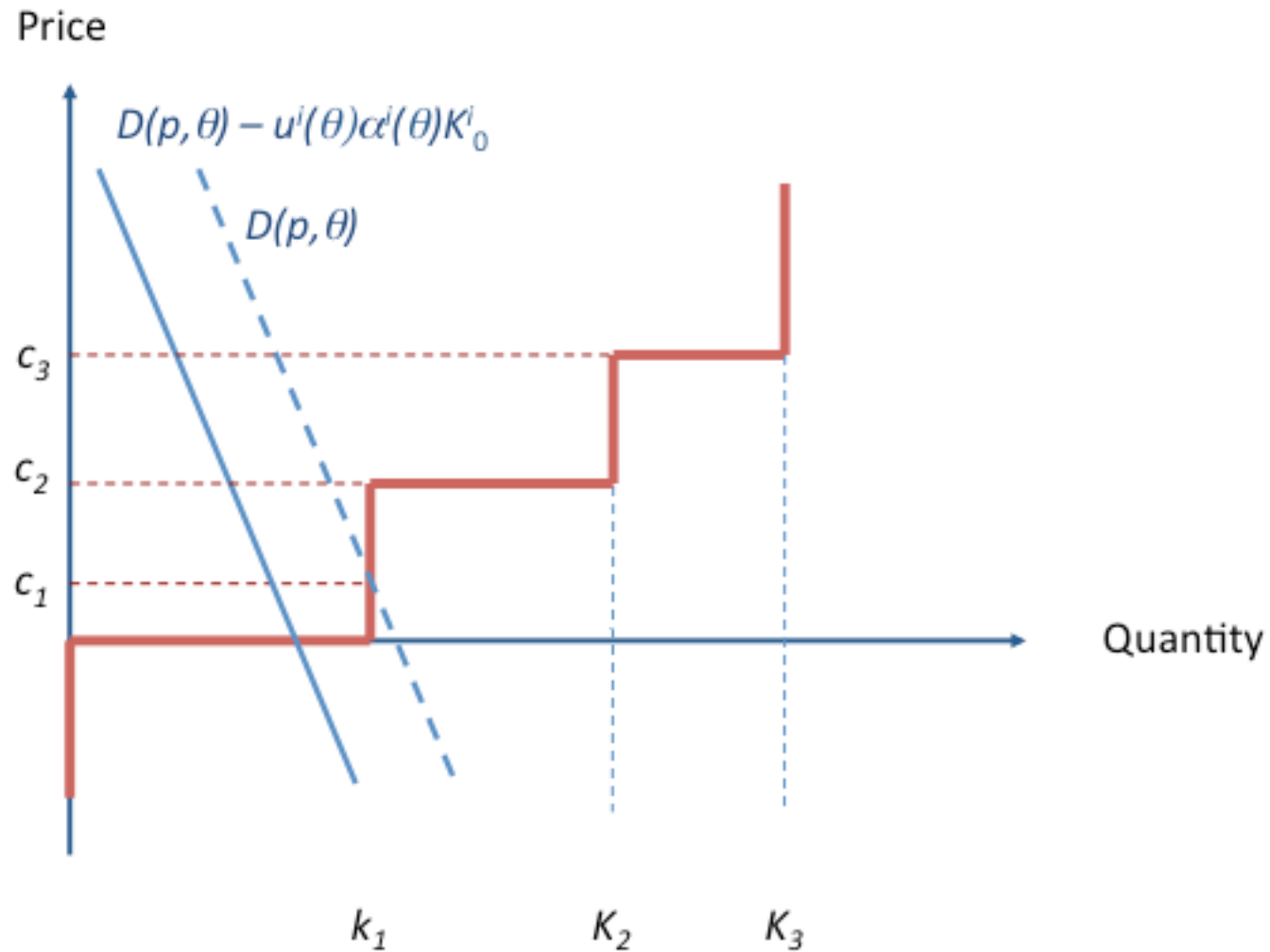
# Too many negative prices



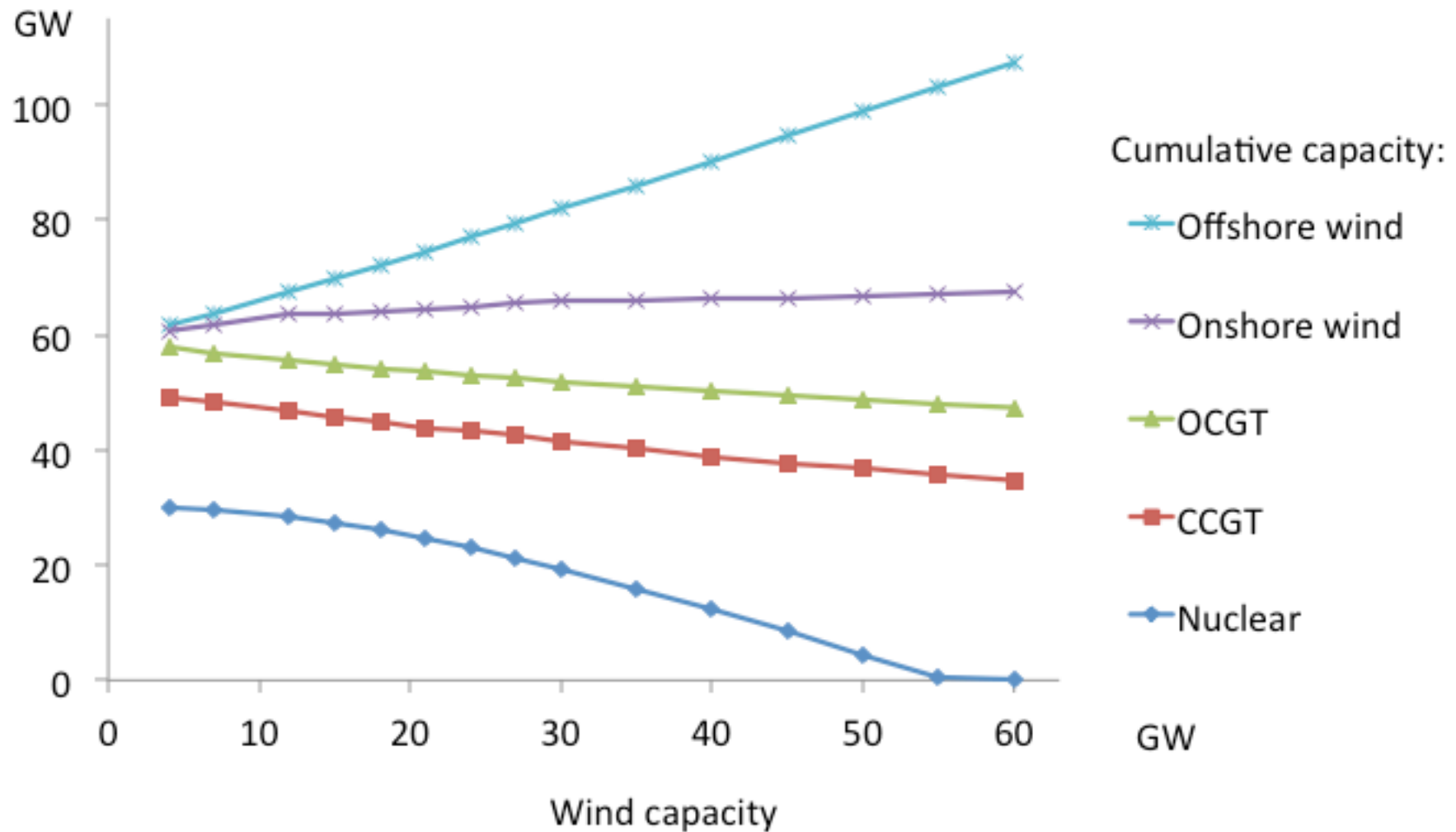
# What about a feed-in premium?



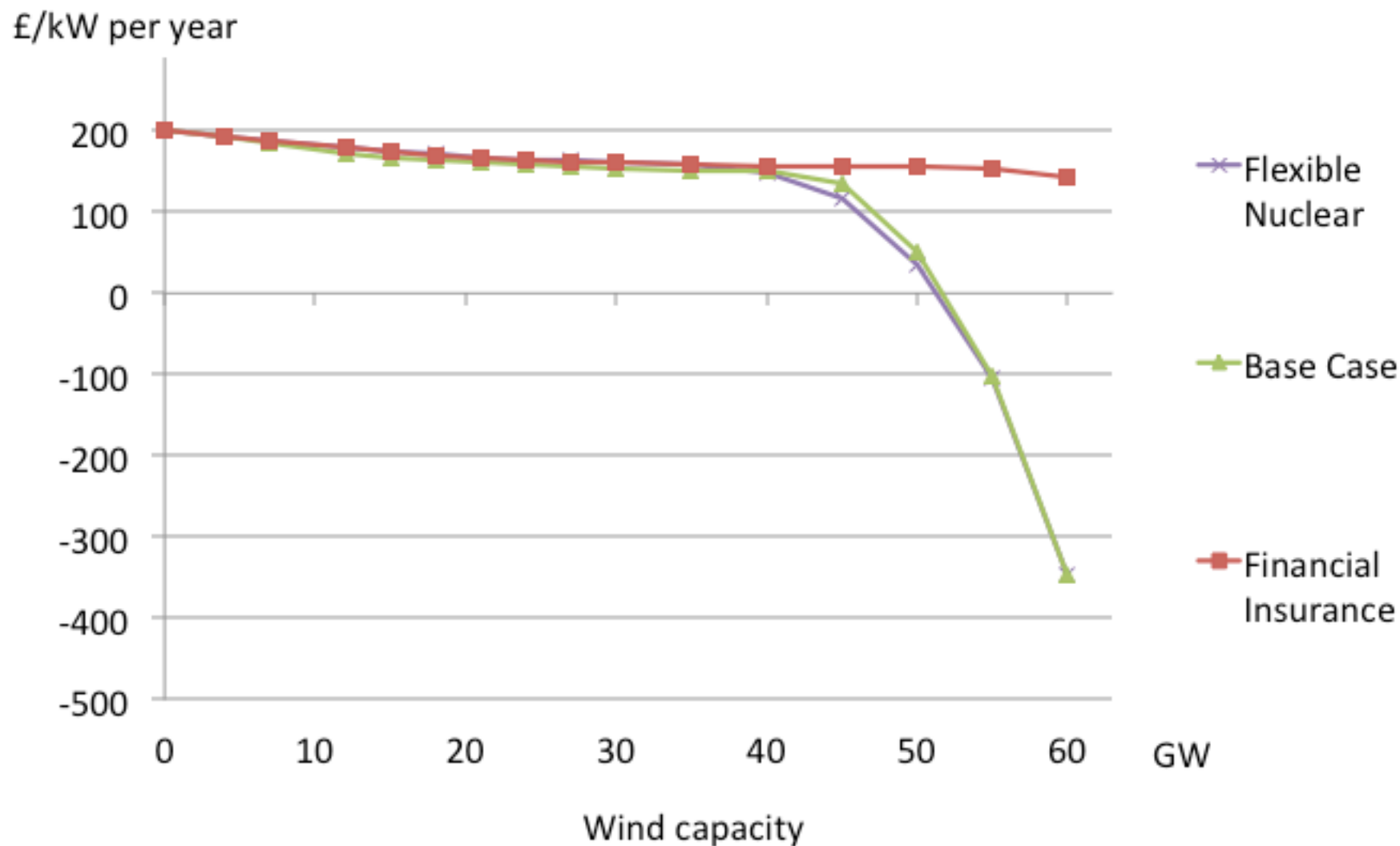
# What about financial distpatch insurance?



# Generation mix evolution under financial dispatch insurance



# Marginal value of on-shore wind for different scenarii



# Evolution of the unit tax

Tax (£ per MWh)

