Centre for Energy and Environmental Markets

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The Effects of Environmental and Renewable Energy Policies on the Existence Conditions for Distributed Generators in Electricity Markets.

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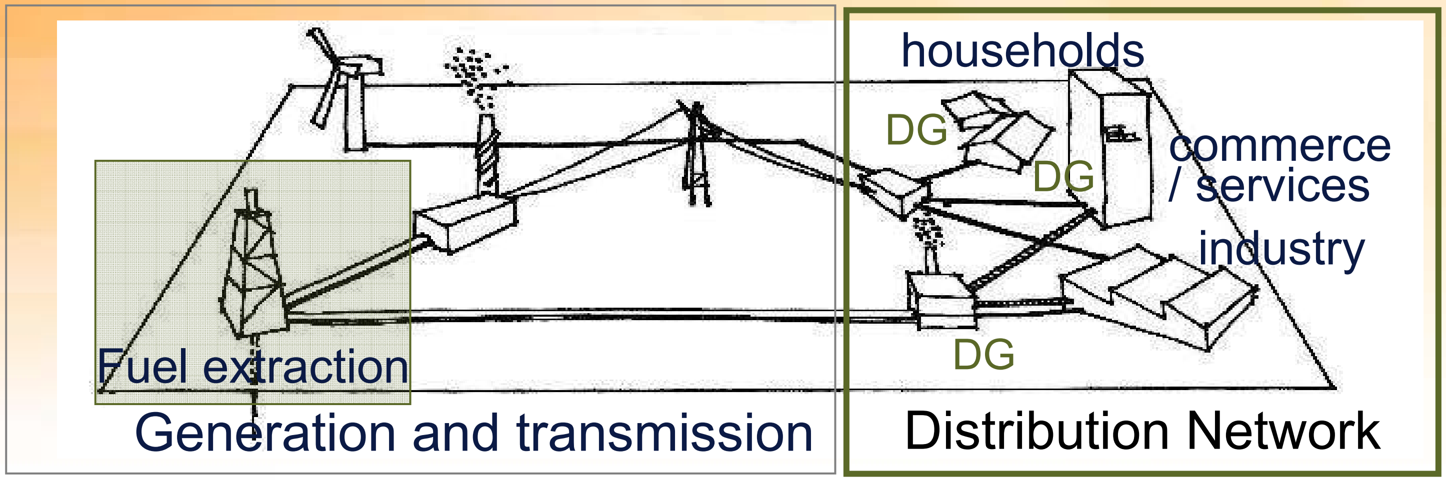
Background

- Electric power source which is connected directly to the distribution network or on the customer site of the meter (Ackermann, 2001).



Benefits of decentralised generation

- Structural benefits: avoided transmission costs, supply reliability (Gulli, 2006), (Firestone et al., 2006).
- In constrained areas: Avoided/deferred investment in capacity extension (Woo et al., 1995). Reduction of grid congestion (Firestone et al., 2006).
- CHP: lower-cost, higher efficiency, lower carbon footprint (Siddiqui, 2008).
- Decentralisation: transferring power and resources (Alanne, 2006). More direct decision making in planning, use of technologies (Winner, 1986).

Motivation

- Distributed Generation (DG) presents a number of benefits that support a more rational electricity supply in face of increasing market requirements in relation to demand growth and environmental degradation.

- **Existing models in relation to DG present :**
  - Economic feasibility in terms of project management
  - Case studies: specific sites and choice of technologies
  - ESM (CSIRO): diffusion of DG at the macro level (top-down)
  - Based on simulations of energy systems, operations research, real options analysis: requires good data, extense set of assumptions.

There is insufficient literature using economic models with focus on the adequacy of policy instruments in the field of distributed generation.

Research Scope

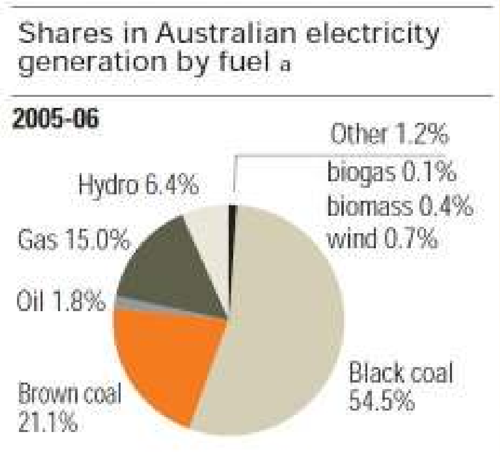
Identify requirements for the existence of Distributed Generation.

Australian context:

•ETS for carbon (postponed),

•State-based local pollution control measures (e.g. Load based Licensing in NSW)

•National markets for REC are in place (RE target: 45TWh by 2020).

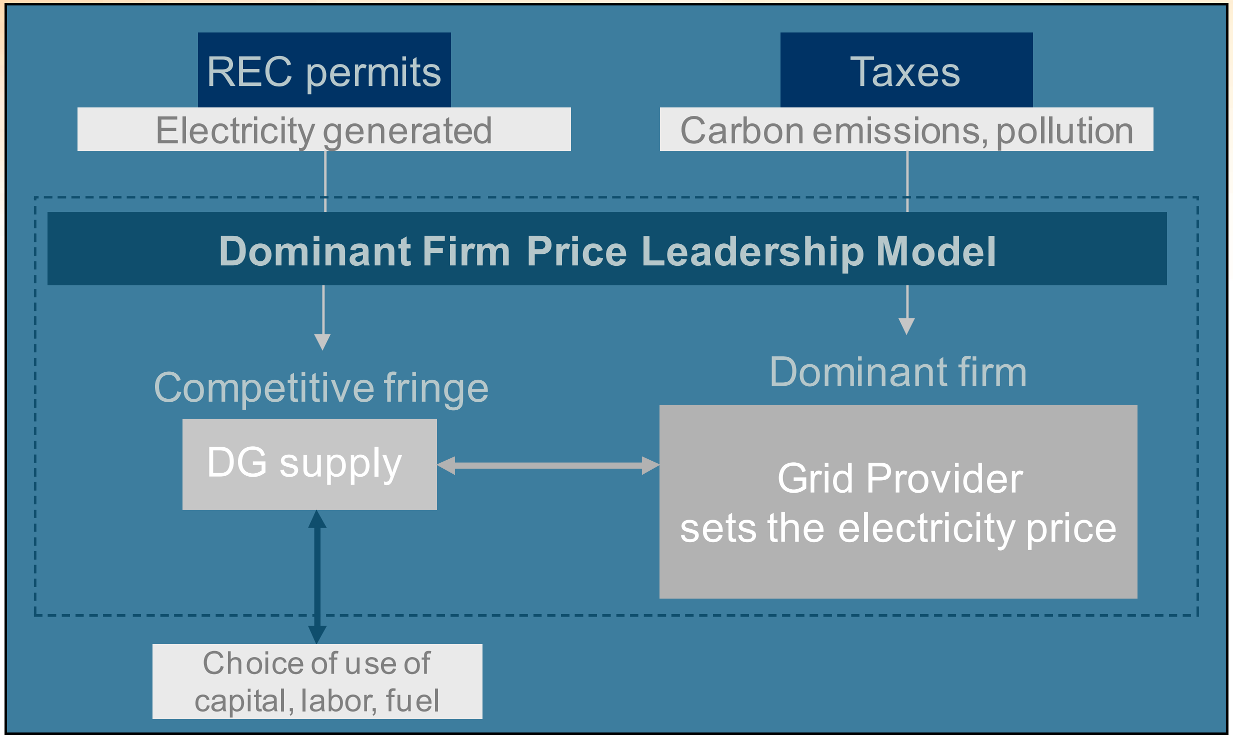


Research Questions

- What are the effects of taxing local pollution and greenhouse gases, together with subsidising electricity from renewable sources **on electricity prices**?
- What are the subsequent effects on the **market share of locally generated electricity**?
- What is the impact of taxes and the RET scheme **on the DG-mix** that is feasible in the current state of technology?

Theoretical Model

- Analysis: conditions in equilibrium for DG to exist embedded in the electricity network following the dominant firm price leadership model.
  - DG cost minimisation problem
  - Grid network provider's profit maximisation



Theoretical Model

1) Grid Provider: act as a monopoly

$$\max_{y^g} \Pi^g = P\left(y^g, \bar{y}^{DG}\right) y^g - C\left(y^g, x_E^g, x_P^g\right) \quad \text{subject to} \quad \begin{array}{l} x_E^g = \gamma_E^g y^g \\ x_P^g = \gamma_P^g y^g \end{array}$$

2) Distributed Generators: competitive fringe

$$\min_{x_K^{DG}, x_L^{DG}, x_F^{DG}} C\left(y^{DG}\right) = C\left(\vec{x}^{DG}, \vec{w}^{DG}\right) - \left(1 - \gamma^{DG}\right)^n \bar{p}_{rec} y^{DG} \quad \text{subject to} \quad y^{DG} = f\left(\vec{x}^{DG}\right)$$

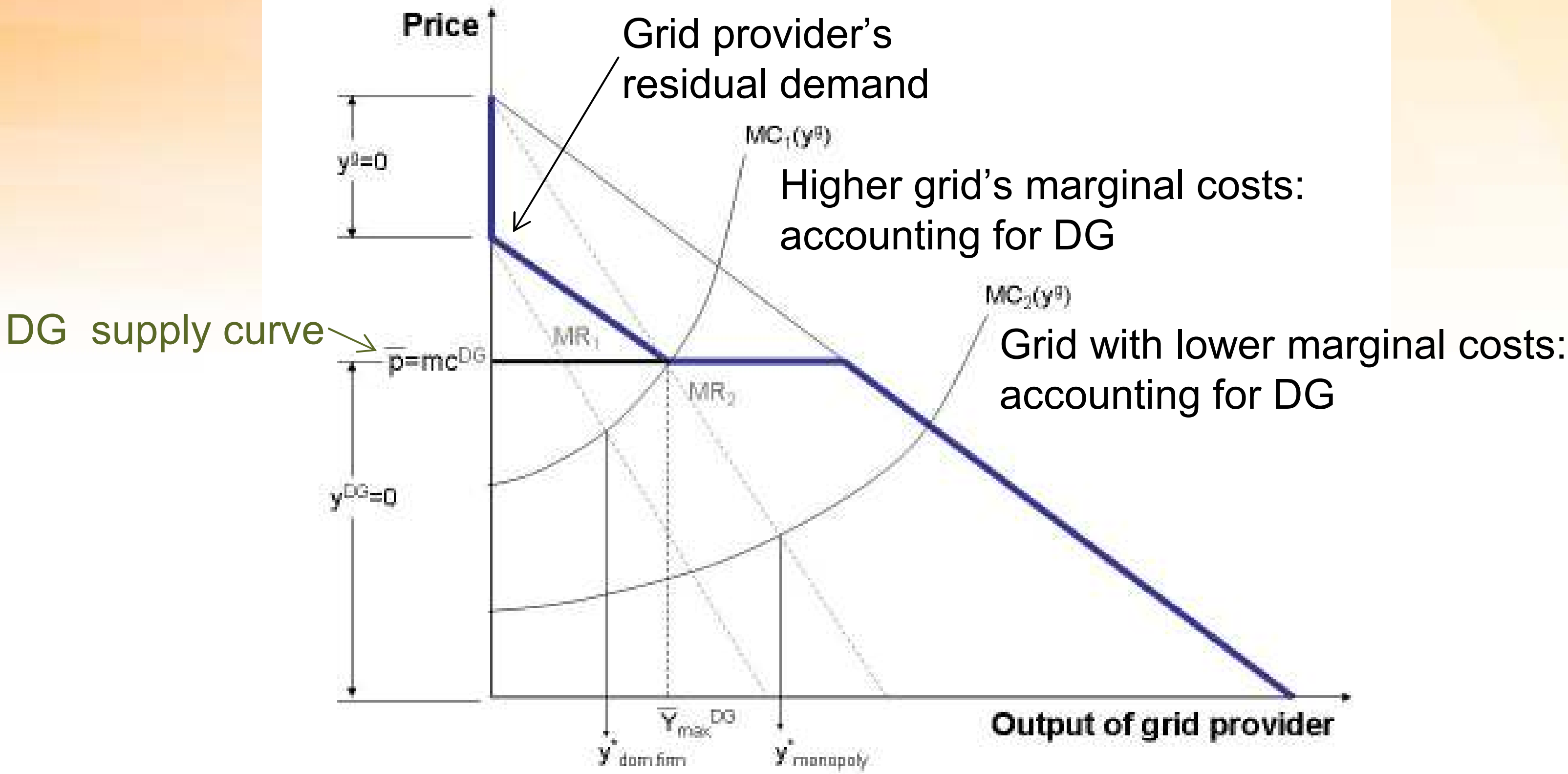
3) Market Clearing Condition: $y^g(p) + y^{DG}(p) = z(p)$

Assumptions

- The dominant firm knows the market's demand and the competitive fringe's supply curves.
- The inverse demand function of electricity is strictly positive, finite and strictly decreasing.
- Cost functions: convex function with C(0)=0, $C_y'>0$, $C_y''>0$ (weakly convex for DG).
- There is a common market for electricity, but only the centralised generator is liable for the associated emissions.
- Small DG firms do not affect prices of their input factors or any upstream market.
- DG firms exhibit constant returns of scale, but there is a capacity constraint.
- There is no market entry.

Market Interaction

- Equilibrium conditions for the interior solution: simultaneous generation from grid and DG



Optimality Conditions

- FOC for the DG fringe:

$$\frac{\partial C\left(y^{DG}\right)}{\partial x_i^{DG}} = 0 \quad \leftrightarrow \quad \frac{\partial y^{DG}}{\partial x_i^{DG}}\left(\lambda + \left(1-\gamma^{DG}\right)^n \overline{p}_{rec}\right) = w_i$$

- DG's factor demands:

$$x\left(\vec{w}, y^{DG}\right) = y^{DG}\frac{\partial MC(\vec{w})}{\partial w_i} \quad \text{or} \quad x(\vec{w}) = z^{DG}\left(MC(\vec{w}) - \left(1-\gamma^{DG}\right)^n \overline{p}_{rec}\right)\frac{\partial MC(\vec{w})}{\partial w_i}$$

- FOC for the grid provider:

$$\frac{\partial \Pi\left(y^g\right)}{\partial y^g} = 0 \quad \leftrightarrow \quad \frac{1}{\eta}\cdot\frac{p}{z}\left(y^g - \lambda\eta\frac{z}{p}\right) = MC^g\left(y^g\right) + \gamma_E^g\tau_E + \gamma_P^g\tau_P - \lambda - p$$

- SOC for the grid provider:

$$\frac{\partial \Pi^2\left(y^g\right)}{\partial {y^g}^2} < 0$$

Characterising the equilibrium

- There exists an equilibrium price p^* solving the grid provider's profit maximisation problem such that $p^* \geq MC^{DG}$ and $y^{g^*} < z(\bar{p}) - \bar{Y}_{\max}^{DG}$

  Assuming:

  a linear market demand $p = a - by$

  a cost function for grid provider $C(y^g) = k\frac{{y^g}^2}{2} + \gamma_E^g \tau_E y^g + \gamma_P^g \tau_P y^g$

  and a cost function for DG $C(y^{DG}) = \begin{cases} MC^{DG}(\vec{w})y^{DG} - (1-\gamma^{DG})^n \bar{p}_{rec} y^{DG} & \text{if } y^{DG} \leq \bar{Y}_{\max}^{DG} \\ \infty & \text{if } y^{DG} > \bar{Y}_{\max}^{DG} \end{cases}$

- It was found that the equilibrium condition is characterised by:

$$\frac{a - b\bar{Y}_{\max}^{DG} - (\tau_E + \tau_P)}{2b + k} < \frac{a - b\bar{Y}_{\max}^{DG} - \left(MC^{DG} - (1-\gamma^{DG})^n \bar{p}_{rec}\right)}{b}$$

  - high marginal costs of the grid network
  - large market size (higher price elasticity of demand)
  - high willingness to pay for electricity

Market interaction

- In the interior solution: if the market demand is fixed, augmenting the capacity of distributed generation will decrease the equilibrium price of electricity.

Source: www.usgbc-centraltexas.org

- Given a market with the characteristics mentioned previously and in the presence of DG, the grid provider will maximise its profits by setting the electricity price p^* that simultaneously will create profits for the industry of the smaller firms:

Electricity price: $$p^* = \frac{MC\left(y^g\right) + \gamma_E^g \tau_E + \gamma_P^g \tau_P}{\frac{1}{\eta} \cdot \frac{y^g}{z} + 1} > MC^{DG}\left(\vec{w}\right) - \left(1 - \gamma^{DG}\right)^n \bar{p}_{rec}$$

↑ environmental taxes, ↑ electricity prices, ↓ grid's output, which ↑ DG

Effects of environmental and RE policies

- Effect of environmental and renewable energy policies:
  - <u>Taxes on carbon emissions or pollution</u>:

    Increase electricity price and share of DG along with their mark up.
    Minimum tax levels for DG into the market:

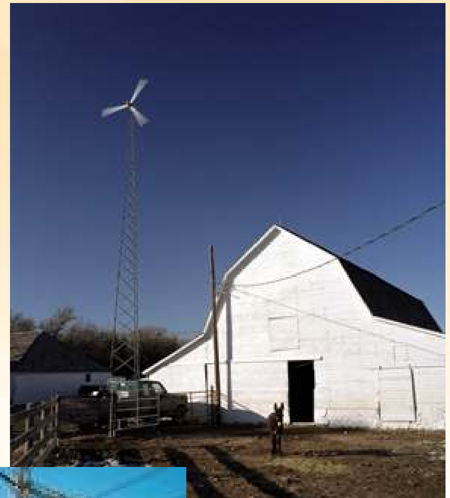
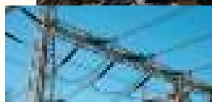
$$\tau_E \geq \frac{MC^{DG}\left(\frac{1}{\eta}+1\right)-\mathrm{MC}^{g}\left(y^{g}\right)}{\gamma_E^{g}}$$

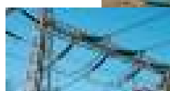
  - <u>Subsidy to renewable generation</u>:

    Electricity prices and share of DG remain unchanged.

  - <u>Combining both policies</u>: electricity prices increase according to emission factors of the dominant firm, which allows DG firms to increase their share and market profit.

Numerical simulation of heterogeneous DG firms




- Simulation associated with different DG technologies
  - Mix of existing DG options: natural gas, biomass, wind, solar
  - Substantial differences in terms of use of inputs, marginal costs and capacity load utilisation.
  - A nested CES production function for DG :

$$f(\vec{x}) = \left(\beta_1 \left(\alpha_1 x_K^{\rho_1} + \alpha_2 x_L^{\rho_1} \right)^{\frac{\rho_2}{\rho_1}} + \beta_2 x_F^{\rho_2} \right)^{\frac{1}{\rho_2}}$$

  - The marginal costs function can be derived:

$$MC^{DG}(\vec{w}) = \left(\beta_1^{1-\varphi_2} \left(\alpha_1^{1-\varphi_1} w_K^{\varphi_1} + \alpha_2^{1-\varphi_1} w_L^{\varphi_1} \right)^{\frac{\varphi_2}{\varphi_1}} + \beta_2^{1-\varphi_2} w_F^{\varphi_2} \right)^{\frac{1}{\varphi_2}} \qquad \varphi_i = \frac{\rho_i}{\rho_i - 1}$$

  - Task: compare the impact of DG forms on electricity prices when REC are valued at $30-50 AUD/MWh and taxes are set as: $20USD/ton CO2, $240AUD/ton NOx, $8.5 AUD/ton SOx, $480AUD/ton FPM, $70AUD/ ton CPM

Conclusion

- Local generation embedded in the electricity grid network can be adequately modelled with the price-dominant leadership model.
- A market with high willingness to pay, large size and relatively high marginal costs of the grid provider are required to obtain simultaneous participation of the dominant firm and the DG fringe.
- Environmental taxes are set to internalise the effect of pollution and carbon emissions of centralised generation. However, at a certain level they can also support the integration of small scale DG.
- Renewable energy subsidies reduce the marginal costs of DG, but in the short run does not affect the price setting process.
- Future work: complete numerical simulations to account for heterogeneity among DG technologies.
  Extension for market entry following DG's positive profit.

Acknowledgements

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