Real Options Approach to Energy Investments

Overview

- Modeling Electric Power Expansion
- A Case Study from Turkey
Real Options Approach to Energy Investments

Stochastic Optimization

- Electric Power Expansion - standard

**The Traditional Case**

Minimize total cost

\[
\text{Minimize } \quad \text{total cost} = \sum_{j=1}^{J} \sum_{v=1}^{T} f_{c_{jv}} X_{jv} + \sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{v=0}^{t} \sum_{s=1}^{S} v_{c_{jtv}} L_{jtv_{s}} \theta_{s}
\]

Subject to

\[
\sum_{j=1}^{J} \sum_{v=0}^{t} a_{jv} X_{jv} \geq D_{ts} (1+m) \quad s = 1, \quad t = 1, \ldots, T
\]

\[
\sum_{j=1}^{J} \sum_{v=0}^{t} L_{jtv_{s}} \geq D_{ts} \quad s = 1, \ldots, S \quad t = 1, \ldots, T
\]

\[
L_{jtv_{s}} \leq a_{jv} X_{jv}
\]

**Technological + Regulatory Constraints**
Stochastic Optimization

- Electric Power Expansion - stochastic

\[
E_t(NPV) = \sum_{j=1}^{J} \sum_{\tau=t}^{T} \sum_{v=0}^{\tau} \sum_{s=1}^{S} E_{z_{\tau}}(P_{\tau}) \cdot L_{j_{\tau} vs} \cdot \theta_s
\]

\[
- \sum_{j=1}^{J} \sum_{v=1}^{T} f_{c_j v} \cdot X_{j v} - \sum_{j=1}^{J} \sum_{\tau=t}^{T} \sum_{v=0}^{\tau} \sum_{s=1}^{S} E_{z_{\tau}}(v_{c_{j v}}) \cdot L_{j_{\tau} vs} \cdot \theta_s
\]

S. to

\[
\sum_{j=1}^{J} \sum_{\tau=0}^{\tau} L_{j_{\tau} vs} \geq E_{z_{\tau}}(D_{\tau s}) \quad s = 1, ..., S \quad \tau = 1, ..., T
\]

\[
v_{c_{j,\tau}} = \alpha_0 + \sum_{i=1}^{p} \alpha_i v_{c_{\tau-i}} + \sum_{i=0}^{q} \beta_i \epsilon_{\tau-i}
\]

\[
\sum_{j=1}^{J} \sum_{v=0}^{\tau} a_{j v} X_{j v} \geq E_{z_{\tau}}(D_{\tau s}) \cdot (1 + m) \quad s = 1, \tau = 1, ..., T
\]

\[
L_{j_{\tau} vs} \leq a_{j v} X_{j v} \quad , \quad \sum_{s=1}^{S} L_{j_{\tau} vs} \theta_s \leq b_j X_{j v}
\]

& other constraints
A real options evaluation model for the diffusion prospects of new renewable power generation technologies

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Real Options Approach to Energy Investments

Outline

- Introduction

- Theoretical Background
  - The Real Options Approach
  - Learning Curves and RET Adoption

- Model Description

- Empirical Analysis
  - The Turkish Electricity Supply Industry
  - Model Calibration
  - Results

- Conclusions
Introduction

- Turkey on the way to EU membership
  - Recently ratified the UNFCCC, Kyoto in line
  - Great renewable energy potentials

- Uncertain prospects for the diffusion of RETs
  - High investment costs of RETs
  - Uncertainty due to electricity market restructuring

- Technology Adoption Modeling
  - Challenges on traditional investment planning OR models
  - Real Options approach to deal with uncertainty
  - Learning Curve theory to reflect RET cost reductions
Theoretical Background

➢ The Real Options Approach

➢ *Dixit/Pindyck, 1994*
➢ Resolution of uncertainty over time, dynamic programming
➢ *Crystal Ball®* software (*Mun, 2002*)
➢ Variety of applications to energy industry issues
  e.g. *Ronn (2003), Frayer/Uludere (2001), Keppo/Lu (2003)*

➢ Learning Curves and RET Adoption

➢ Reduction in cost as a function of cumulative production
➢ Progress ratios, learning rates
➢ Global progress ratios (*Junginger et al., 2005*)
➢ Many empirical studies on learning curves in energy research
Model Description

Maximizing the Net Present Value (\(NPV\))

\[
NPV_t(X_{i,v=t}) = \max \left\{ \sum_i \sum_{z=t+lt(i)+el(i)} p_z (1+r)^{(z-t)} L_{i,z,v=t} \theta_{i,z,v=t} \right. \\
- \left\{ \forall \sum_i L_{i,z,v} \theta_{i,z,v} \geq d_z \mid \sum_i \sum_{z=t+lt(i)+el(i)} p_z (1+r)^{(z-t)} \left\{ L_{i,z,v=t} \theta_{i,z,v=t} - d_z \right\} \right. \\
- \sum_i \sum_{z=t+lt(i)} vc_{i,z,v=t} (1+r)^{(z-t)} L_{i,z,v=t} \theta_{i,z,v=t} \\
- \sum_i fc_{i,v=t} X_{i,v=t} \\
+ \frac{1}{1+r} E_t \left( NPV_{t+1}(X_{i,v=t+1}) \right) \right\}
\]

**Variables/parameters:**
- \(d\) ... peak power demand
- \(p\) ... el. price
- \(r\) ... real interest rate
- \(L\) ... load
- \(\theta\) ... duration hours
- \(vc\) ... var. cost
- \(fc\) ... fixed cost

**Indices:**
- \(i\) ... plant type
- \(z\) ... year
- \(v\) ... vintage
- \(t\) ... time

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Model Description

- Meeting peak load demand

\[ \sum_{i} \sum_{v=\text{z-}lt(i)-el(i)} L_{i,z,v} \theta_{i,z,v} \geq d_{z} (1 + m) \]

\[ \forall \ t + lt(i) + el(i) \geq z \geq t \]

- Price-elastic demand for electricity (elasticity increases with degree of market opening)

\[ d_{z}(p_{z}) = \alpha p_{z}^{\varepsilon z} \]
Model Description

- Considering capacity availability

\[ L_{i,z,v} \leq a_i X_{i,v} \]

\[ L_{i,z,v} \frac{\theta_{i,z,v}}{8760} \leq c_{f_i} X_{i,v} \]

\[ \forall \ t + lt(i) + el(i) \geq z \geq t + lt(i) , \ v \leq t \]
Model Description

- Introducing uncertainty

\[ \delta p_z = p_{z-1} \left( \mu \delta z + \sigma \varepsilon \sqrt{\delta z} \right) \]

\[ \delta v c_{i,z,v} = v c_{i,z-1,v} \left( \mu \delta z + \sigma \varepsilon \sqrt{\delta z} \right) \]
Real Options Approach to Energy Investments

Model Description

- Integrating technological learning

\[ f_{c_{i,v}} = f_{c_{i,v=2000}} \cdot C C^{-li} \]

\[ PR = 2^{-li} \]
Empirical Analysis

➢ The Turkish Electricity Supply Industry

Figure 1. Development of electricity generating capacity in Turkey, 1984-2001 (Source: TEIAS, 2002)
Table 1. Renewable electricity potentials and current and expected RET installations in Turkey

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Theoretical potential</th>
<th>Technical potential</th>
<th>Economic potential</th>
<th>Current (2001) installation</th>
<th>Expected contribution / Policy goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>49 GW 430 TWh</td>
<td>216 TWh</td>
<td>35 GW 125 TWh</td>
<td>11.6 GW 24 TWh</td>
<td>14.8 GW 48 TWh 65 - 85 TWh Goal: 100% of potential 29 - 35 GW 98 - 110 TWh</td>
</tr>
<tr>
<td>Wind power</td>
<td>88 GW &gt; 400 TWh</td>
<td>83 GW-124 - 166 TWh</td>
<td>10 - 20 GW</td>
<td>18.9 MW 62.4 TWh</td>
<td>643 MW 0.6 - 4 GW 1 GW</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>4.5 GW&lt;sub&gt;e&lt;/sub&gt; tot.</td>
<td>2.0 GW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>17.5 MW 89.6 GWh</td>
<td>0.04 - 0.15 GW&lt;sub&gt;e&lt;/sub&gt; 22 TWh</td>
<td>0.3 - 0.5 GW&lt;sub&gt;e&lt;/sub&gt; 44 TWh 1 GW&lt;sub&gt;e&lt;/sub&gt; 96 TWh</td>
</tr>
<tr>
<td>Solar</td>
<td>102 TWh proven</td>
<td>102 TWh</td>
<td>1.5 TWh</td>
<td>Goal: 40 MW&lt;sub&gt;e&lt;/sub&gt; (PV)</td>
<td>9 TWh</td>
</tr>
<tr>
<td>Biogas</td>
<td>12 - 23 TWh</td>
<td></td>
<td>5.4 MW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>10 MW&lt;sub&gt;e&lt;/sub&gt; (Biogas-Waste)</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>197 - 372 TWh</td>
<td></td>
<td>91 MW</td>
<td>86 TWh 87 TWh</td>
<td></td>
</tr>
<tr>
<td><strong>Total RET</strong></td>
<td></td>
<td></td>
<td>104 TWh</td>
<td>25 GW 30 GW</td>
<td></td>
</tr>
</tbody>
</table>

Data sources: see paper
Empirical Analysis

- Model Calibration

**Figure 2.** Variable cost projections for existing power generation technologies, 2001-2025
Empirical Analysis

- Model Calibration

Figure 3. Electricity price projections, 2001-2025
Real Options Approach to Energy Investments

Table 3. Candidate power generation technologies: costs, assumed availability, learning rates and construction lead times

<table>
<thead>
<tr>
<th>Technology</th>
<th>Inv. cost ($/kW)</th>
<th>Annual fixed O&amp;M cost ($/kW)</th>
<th>Availability factor</th>
<th>Capacity factor</th>
<th>Learning rate</th>
<th>Construction lead time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal FBC CHP plant</td>
<td>3600</td>
<td>144</td>
<td>0.80</td>
<td>0.70</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td>Pulverised coal power plant</td>
<td>1488</td>
<td>44.4</td>
<td>0.75</td>
<td>0.80</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td>Integrated coal gasif. power plant</td>
<td>1260</td>
<td>64.8</td>
<td>0.75</td>
<td>0.80</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td>Oil fired power plant</td>
<td>1032</td>
<td>28.8</td>
<td>0.75</td>
<td>0.80</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>Natural gas CC power plant</td>
<td>972</td>
<td>25.2</td>
<td>0.75</td>
<td>0.65</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>Gas turbine CHP plant</td>
<td>912</td>
<td>13.2</td>
<td>0.80</td>
<td>0.60</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>Lignite fired power plant</td>
<td>1728</td>
<td>44.4</td>
<td>0.75</td>
<td>0.75</td>
<td>0.01</td>
<td>4</td>
</tr>
<tr>
<td>Integrated lignite gasif. power plant</td>
<td>1920</td>
<td>37.2</td>
<td>0.75</td>
<td>0.45</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td>Nuclear LWR power plant</td>
<td>2928</td>
<td>64.2</td>
<td>0.75</td>
<td>0.95</td>
<td>0.01</td>
<td>6</td>
</tr>
<tr>
<td><strong>Renewable</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass gasifier dedic. STAG (NH)</td>
<td>2448</td>
<td>240</td>
<td>0.75</td>
<td>0.80</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Biomass gasifier SOFC*</td>
<td>3120</td>
<td>312</td>
<td>1.00</td>
<td>0.80</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Biomass gas turbine CHP</td>
<td>2040</td>
<td>51</td>
<td>0.80</td>
<td>0.80</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Solar PV</td>
<td>6000</td>
<td>24.6</td>
<td>0.90</td>
<td>0.15</td>
<td>0.20</td>
<td>2</td>
</tr>
<tr>
<td>Large onshore wind turbine</td>
<td>1140</td>
<td>21.6</td>
<td>0.90</td>
<td>0.25</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Large onshore wind turbine storage</td>
<td>1632</td>
<td>26.4</td>
<td>0.90</td>
<td>0.25</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Large offshore wind turbine storage</td>
<td>2340</td>
<td>37.2</td>
<td>0.90</td>
<td>0.25</td>
<td>0.08</td>
<td>2</td>
</tr>
<tr>
<td>Low head hydro</td>
<td>3420</td>
<td>30</td>
<td>0.80</td>
<td>0.47</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Medium and high head hydro</td>
<td>2280</td>
<td>22.8</td>
<td>0.85</td>
<td>0.34</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Hydro pumped storage</td>
<td>3420</td>
<td>45.6</td>
<td>0.92</td>
<td>0.40</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Geothermal power plant</td>
<td>1236</td>
<td>31.2</td>
<td>0.70</td>
<td>0.90</td>
<td>0.1</td>
<td>2</td>
</tr>
</tbody>
</table>
Empirical Analysis

Model Calibration

Table 4. Scenario assumptions

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Upper bound on capacity addition per technology</th>
<th>Price elasticity (2020 → 2025)</th>
<th>Technology adoption restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLEX</td>
<td>2 GW p.a.</td>
<td>-0.01 → -0.05</td>
<td>No restriction</td>
</tr>
<tr>
<td>NF1</td>
<td>1 GW p.a.</td>
<td>-0.01 → -0.02</td>
<td>No restriction</td>
</tr>
<tr>
<td>NF2</td>
<td>1 GW p.a.</td>
<td>-0.01 → -0.02</td>
<td>Natgas/Total Cap. ≤ 40%</td>
</tr>
<tr>
<td>NF3</td>
<td>1 GW p.a.</td>
<td>-0.01 → -0.02</td>
<td>Wind Turbine Licensing</td>
</tr>
<tr>
<td>NF4</td>
<td>1 GW p.a.</td>
<td>-0.01 → -0.02</td>
<td>Draft Law (8% Renew.)</td>
</tr>
</tbody>
</table>
Empirical Analysis

Results

Figure 4. Composition of annual capacity additions, 2008-2025
Empirical Analysis

- Results

Figure 5. Percentage share of renewables among new capacity additions, 2008-2025
Conclusions

- RO dynamic programming formulation & learning curve integration for power generation investment planning

- The Case of Turkey
  - Diffusion of renewable energy technologies other than geothermal occurs only if targeted policies/promotion exists
  - Long lead times discourage hydropower investments under uncertainty
  - Natural gas CC remains the most attractive option
  - Draft renewable energy law under discussion induces technological learning and can significantly affect the evolution of the technological structure in the power sector
  - Opportunities for technological learning via Kyoto flexibility mechanisms