Overview of past work and recent advances in assessing the full costs of electricity provision

Components of total costs

**Internal Costs**

**External Costs**: A cost is external when it is not paid by those who have generated it.

**Total Costs**: Internal + External + (System effects)

Negative externalities are **internalised** when they are passed on to those who generate them.

Total costs may serve as an **aggregated measure of performance** and as a basis for **cost-benefit analysis**.

Total costs have been proposed as a measure of **sustainability performance** of technologies.
Costs & Purposes

• Marginal technology costs are used for system operation (electric system dispatch, oil/gas production, etc.)

• Average technology costs (e.g. average generation cost) are often used for planning (i.e. production or capacity factors are often assumed - it’s better to model)

• System expansion planning should be based on the total system cost per unit (e.g. kWh) of service provided (to allow for both supply and demand side options, system costs, and load growth uncertainty).
Approaches to internal cost estimation

**Bottom Up** - Detailed, design-specific costing (component basis)
- Major effort, suitable for vendors
- Still contains many uncertain assumptions

**Top Down** - back of the envelope approximation (order of magnitude)

**Intermediate** - based on *similar* units, adjusting for
- Size (economies of scale)
- Time (Learning curves for state-of-the-art)
- Component costs (e.g. materials, labor and component cost shifts)
Historical nuclear costs

Nuclear Capital Costs by Region

Challenge: NPP investment cost uncertainty

Overnight capital cost range by region (US $/kW)

North America: 42
Europe: 64
Asia: 44
Middle East: 8

Note: Data collected from various publications and studies to keep track of nuclear power plants investment costs, since 2008 (updated August 2014), all data in 2013 USD

Source: Dr. N. Barkatullah, World Nuclear Association 2014 Symposium
Recent Nuclear Cost Overruns

**Challenge: Construction risk**
Investment Cost over time by Site ($/kW) - 2013 prices

Source: Dr. N. Barkatullah, World Nuclear Association 2014 Symposium
Capital costs (new plants, Swiss conditions)

Source: PSI/Hirschberg et al., 2010
Generation costs (new plants, Swiss conditions)

Source: PSI/Hirschberg et al., 2010
Cost Sensitivities – EPR 2030

Source: Hirschberg et al., 2012

1 CHF = 0.83 EUR
1 Swiss cent = 0.83 euro cent
Deep geothermal energy: Sensitivity curves for model inputs

Source: Hirschberg et al., 2015
Nuclear & Renewables – System Effects

• Focus is on the interplay between nuclear and renewables
• Recognizes all major system costs & externalities, but only quantifies grid-related costs (5 categories)
• System problems caused by stochastic generation with zero marginal costs are due to subsidized penetration of solar/wind
• Damage to fossil and nuclear generators is due to “market competition,” but ultimately caused by renewables.
• Nuclear has a big role as swing capacity, but low capacity factors are a problem for recovering high capital costs, and hence a big problem for future nuclear construction
The Polish case

Capital investment (at 7%) USD per MWh (electric) produced over lifetime USD/MWh

- Natural gas OCGT: 2.5
- Natural gas CCGT: 4.46
- Hard coal: 6.89
- Nuclear power: 17.15
- Wind on shore DE: 25.6
- Biomass IRENA: 28.1
- Wind on shore PL: 36.6
- PV – large: 51.5
- Biomass: 52.5
- Wind off shore: 58.4

Source: Strupczewski 2016
The Polish case

Source: Strupczewski 2016
Impacts

- Impacts on human health, crop yields, buildings, land, ecosystems, ...

Dispersion & Chemical Reactions

- E.g. change of pollutant concentrations

Impacts

- Impacts on human health, crop yields, buildings, land, ecosystems, ...

Valuation

- Monetary valuation: External costs

Life Cycle Assessment

- Other flows: Land use, Resource use

Emissions

- Emissions from operating plant

- Emissions from rest of chain
Development of external cost modeling

Example:
Projected coal power plant, South Germany, parameters of power plant are constant. Only emissions from plant operation. ExternE method. CO2 costs not included.

E-R funct.: Exposure-Response function
Total costs (2050)

- **Generation cost**
- **Land use**
- **Pollution**
- **GHG low**
- **GHG high**

### Nuclear
- Gen III: EU Pressurised Reactor
- Gen IV: EU Fast Reactor

### Fossil
- Coal:
  - Pulverised Coal (PC)
  - PC & Post comb. CCS
  - PC & Oxyfuel CCS
  - Integrated Gasification
  - Int. Gasification & CCS
- Nat gas:
  - Combined Cycle (CC)
  - CC & Post comb. CCS
- Nat gas cogen:
  - Internal Comb. <1MW
  - MC Fuel cell <1MW
- Biomass cogen:
  - SRC Poplar 9MW
  - Waste straw 9MW
- Solar:
  - PV, Thin-film, 3kWp
- Wind:
  - Offshore 24MW

### Renewables

Source: PSI/Schenler & Hirschberg, 2009
China Energy Technology Program
Internal and External Costs for Power Plant Options in Shandong Province

Source: Hirschberg et al., 2003
Different estimates of external costs of CO$_2$

- With 3% discounting, simple sum (Tol 2005)
- With 1% discounting, equity weighting (Tol 2005)
- Stern Review (Stern 2006)
- Abatement costs EU (ExternE 2004)
- Willingness-To-Pay Swiss Referenda (Heck 2004)
- Very low estimate (Downing et al. 2005)
- Very high estimate (Downing et al. 2005)
- Germany BMU (Krewitt et al. 2006)
- Damage costs, no equity weighting
- Damage costs, equity weighting
- Abatement costs

Based on impact assessment and damage costs
Based on abatement costs
Based on referenda
Study of uncertainties
Governments
EU NEEDS 2009 final
Examples of controversial/difficult to estimate external effects

- Severe accidents, terrorism, risk aversion
- Visual intrusion
- Resource depletion
- Nuclear proliferation
- Biodiversity losses
- Security of supply

Serious attempts to estimate the corresponding costs mostly lead to low estimates, but this does not resolve the controversy!
In spite of the limitations, there is general acceptance of the concept of externalities, of the internalisation of external costs and of most results, but…

Coal and oil technologies have the highest external costs

Natural gas technologies have quite low external costs due to low air pollution and moderate external costs due to GHG emissions

Renewable technologies have mostly low external costs

Nuclear energy has low external costs

Source: Faberi et al., 2007
Cost-Benefit Analysis for Selected Electric Sector Simulation Scenarios
Province Shandong, China in Year 2020

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost</th>
<th>Benefit (avoided external damages)</th>
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<tbody>
<tr>
<td>Coal, FGD</td>
<td>0.5</td>
<td>10.2</td>
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<tr>
<td>Clean Coal-Technology + Diversification</td>
<td>0.9</td>
<td>15.4</td>
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</table>

Source: Hirschberg et.al., 2003

incl. LCA
## Sustainability Criteria

**Source:** Hirschberg et al., 2007&2008

<table>
<thead>
<tr>
<th>Criterion</th>
<th>RESOURCES</th>
<th>CLIMATE CHANGE</th>
<th>IMPACT ON ECOSYSTEMS</th>
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<th>IMPACTS ON CUSTOMERS</th>
<th>IMPACTS ON OVERALL ECONOMY</th>
<th>IMPACTS ON UTILITY</th>
<th>SECURITY/RELIABILITY OF ENERGY PROVISION</th>
<th>POLITICAL STABILITY AND LEGITIMACY</th>
<th>SOCIAL AND INDIVIDUAL RISKS</th>
<th>QUALITY OF RESIDENTIAL ENVIRONMENT</th>
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<tbody>
<tr>
<td><strong>RESOURCES</strong></td>
<td>Energy Resources</td>
<td>Mineral Resources (Ores)</td>
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<td>Special Chemical Wastes stored in Underground Depositories</td>
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Effects on the utility/operator: 8%
Effects on the national economy: 7%
Electricity production costs: 13%
Waste: 8%
Ecosystem quality: 11%
Security of power supply: 7%
Political stability & legitimacy: 5%
Social & individual risks: 7%
Local effects on residential areas: 5%
Climate change: 18%
Resources: 11%
Economy aspects: 27%
Social aspects: 24%
Environment: 49%

Source: PSI/Schenker & Hirschberg, 2009
Total costs and MCDA ranking

Source: Schenler & Hirschberg, 2009
Technology ranks and stakeholder weighting

Source: PSI/Hirschberg et al., 2010
Conclusions

• Most basic distinction between generation technologies is in fixed v. variable costs, i.e. capital cost v. dispatch costs.

• Common features of “good” NPPs include: turn-key delivery contract, not first-of-its-kind, short construction time, clear licensing regime with no major changes during the construction, reasonably low interest rates, and high load factors with minimum unplanned interruptions of operation.

• External environmental costs may be substantial but large variety between technologies and sites. Good technologies including advanced fossil have rather low pollution costs.

• External costs of nuclear and renewables are low; external costs of natural gas are moderate; external costs of coal and oil are highest.

• Social aspects of energy systems are represented to limited extent by current estimates of external costs.

• Internalisation of external costs is economically and socially justified. It leads to more efficient overall economy.

• Total costs are attractive as an aggregated measure of performance and as a basis for cost-benefit analysis.

• Total costs remain to be controversial as a measure of sustainability performance of technologies.

• Total cost approach favours nuclear.
Thank you!