Environmental Impact Assessment


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EIA methodology continued

- Weighted checklists and environmental grades
- The Battelle Evaluation System
- Multi-Attribute-Utility theories
  - Utility functions
  - Environmental Quality Index
  - The AHP ("The Analytic Hierarchy Process" by Thomas Saaty)
- A Case Study. The 685 MW Kárahjnúkar Power Plant and ALCOAs aluminium smelter in Reyðarfjörður
Weighted average of environmental impacts

- Sondheim (1978) uses weighted checklists (weighting panels constituted for each EIA)

- Yapijakis (1983) uses an adaption of Sondheim methods
  - Permanent national weighting panels with members from academia, industry and government
  - In a trial project (river alteration, water supply), the national panels of Greece and the former Yugoslavia (Macedonia) produced similar weights
  - \( \text{PROALT} = w_{\text{BCR}} \cdot \text{BCR} + w_{\text{CO}} \cdot \text{CO} + w_{\text{EI}} \cdot \text{EI} + w_{\text{SI}} \cdot \text{SI} + w_{\text{MTL}} \cdot \text{MTL} \)
    - PROALT is the project alternative ranking or grade
    - BCR is the benefit/cost ratio of the alternative
    - CO is the total capital outlay for the alternative
    - EI is the quantified total environmental impact of alternative
    - SI is the social impact of alternative
    - MTL is the manageability and technology level of alternative
    - \( w_i \) are the weights, decided by the weighting panels
Evaluation of alternatives

*Certain basic steps*

- Determine an appropriate set of environmental factors to be considered (for example, wildlife habitat)

- Determine the environmental impact index for each factor
  - Define the units of measurement for each environmental factor (e.g., hectares preserved)
  - Collect data on the environmental factor (e.g., 10,000 hectares preserved)
  - Decide on a common interval/index scale for each environmental factor (e.g., 0 – 1, 1 – 5, or 0 – 10, sometimes 1 – 9 only)
  - Convert data for the environmental factor to an environmental factor index (this is usually done by normalizing all values over a maximum or minimum value)

- Determine a weight (importance), $w_{EF}$, for each environmental factor EF

- Decide on the method of aggregation across all factors (usually additive)
Weighting and scaling techniques

Consider two environmental factors: wildlife habitat (hectares preserved) and employment increase (jobs created). EF’s are scaled to an index (0 is worst and 1 is best). Two different approaches: a) simple addition of factor indices, EF’s equally weighted; b) Wildlife habitat, weight 0.2, employment increase, weight 0.8.

Comparison result

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weights</th>
<th>Alternative One</th>
<th>Alternative Two</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw Data</td>
<td>Scaled</td>
<td>Weighted</td>
</tr>
<tr>
<td>Wildlife habitat (ha)</td>
<td>5000</td>
<td>0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Employment increase (jobs)</td>
<td>5000</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Wildlife habitat index</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Employment increase index</td>
<td>1</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Wildlife habitat weighted index</td>
<td>0.2</td>
<td>0.01</td>
<td>0.2</td>
</tr>
<tr>
<td>Employment increase weighted index</td>
<td>0.8</td>
<td>0.8</td>
<td>0.48</td>
</tr>
<tr>
<td>Grand index</td>
<td>NA</td>
<td>1.5</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Scaling: 10,000 ha = 1.0; 5000 jobs = 1.0
The Battelle Evaluation System

The Battelle Environmental Evaluation System (BEES) was developed by an interdisciplinary research team at Battelle Columbus Laboratories, Ohio (Dee et al., 1972, 1973). It is based on a hierarchical assessment of environmental quality indicators.

- Human Concern is separated into four main categories.
  - Ecology (nature and natural habitats)
  - Physical/chemical
  - Aesthetics (visual impacts and more)
  - Human interest/social interest (f.inst. jobs and recreation possibilities)

- Each category is broken down into number of environmental components.

- For each component, an index/grade of environmental quality, normalized to a scale ranging from 1 to 10, is developed, using value or utility functions.

- Environmental indicator defined as difference in environmental quality between "before" and "after" impact states.

- Each environmental component has a weighting factor (relative importance).

- Weights are fixed, and overall impact of project alternative is calculated by summing the weighted impact indicators.
Value or Utility Functions

The Battelle Procedure for creating utility functions

- **Step 1**: Obtain information on the relationship between the parameter, EF, and quality of the environment.
- **Step 2**: Order the parameter scale (abscissa x) so that the lowest value is zero.
- **Step 3**: Divide the quality scale (ordinate y) into equal intervals between 0 to 1, and determine the appropriate value of the parameter for each interval. Continue the process until a curve can be drawn.
- **Step 4**: Ask several different specialists to repeat Steps 1 to 3 independently. Average/smooth the curves to obtain a group curve. (For parameters based solely on value judgements, use a representative cross-section of the population.)
- **Step 5**: Show curves to all participants, and ask for a review if there are large variations. Modify the group curve as appropriate.
- **Step 6**: Repeat Steps 1-5 with a separate group of specialists, to test for reproducibility.
- **Step 7**: Repeat Steps 1-6 for all the selected parameters
Utility functions (Nytjaföll)

Utility functions, enviromental ranking on a scale 0-10

Terrestrial carrying capacity for browsers and grazers (beitiðland fyrir grasbíta)

Hypothetical utility function $U_i(x)$ showing environmental ranking of percentage loss of salmonid populations in a river
Battelle Evaluation System (Pros and Cons)

- **Pros**
  - Has high capability for identification and prediction of impacts, and good replicability of results.
  - Provides high level of detail for assessment and documentation purposes.
  - Basis for the development of environmental indicators, and associated weights is fully documented.
  - Objectivity is high in terms of comparison between alternatives or different project options.

- **Cons**
  - System is applicable only to projects for which it was designed; development of additional indicators is demanding.
  - System has no mechanism for estimating or displaying interactions between environmental components.
  - System does not link impacts to affected parties or to dominant issues.
  - The system has very high resource requirements (money, time, manpower skills).
Environmental Quality Indices
(Umhverfisgæðavísitölur)

*Environmental indices*

- Environmental Media Indices
  - Air quality (weighted average content of pollutants). Bad and good ozone ($O_3$), Mexico City example.
  - Water quality (weighted average content of pollutants)
  - Noise

- Ecological sensitivity and diversity
  - to evaluate the relative sensitivity to perturbations of the ecosystems in a region

- Archeological resources
  - 19 parameters studied to evaluate the best waterway navigation route through an archeologically sensitive region

- Visual quality

- Quality of life Index (QOL-vísitölur)
Multi-Attribute-Utility-Theories
(Margfeldisáhrifa-nytjafræði)

Morgenstern and Neumann (1953), Keeney and Raiffa (1978)

- Multi-Attribute-Utility Theory
- Utility functions or value functions (nytjaföll) have to be defined for each environmental factor (similar to the Battelle system)
  - The “Utility” (notagildi) of an environmental factor is measured on a scale 0-10 (grading), where 10 is the “best” value (full utility), 0 is the “worst” value, e.g. total loss of certain environmental quality (zero utility)
- When the utility functions have been determined, it is possible to combine the impacts through weighting (the weights or importance factors $k_i$). In this manner an Environmental Quality Index, EQI („umhverfisvísitala“), is obtained:

$$EQI = U(x) = \sum_{i=1}^{n} k_i U_i(x_i)$$
Both the weights $w_i$ and the utility function values (scores) can be assessed, using the Analytic Hierarchy Process (AHP).

The Analytic Hierarchy Process was proposed by Thomas Saaty (a mathematician/economist in Chicago) in 1983, in order to evaluate different investment alternatives.

It is based on simple comparison matrices, where each environmental factor is compared for all alternatives on a qualitative basis. The weights are obtained in the same manner.

A more precise description can be found in several Operation Analysis textbooks. See also Karahnjukar-AHP.pdf on the course website.
The elements $a_{ij}$ of the comparison matrix have to satisfy the following conditions: $a_{ij}=1/a_{ji}$, $a_{ii}=1$, $a_{ij} \cdot a_{jk}=a_{ik}$. Consistency! $CR<0.1$ for $n>3$ and $<0.08$ for $n \leq 3$ (see Karahnjukar-AHP.pdf)

Comparison of environmental factors, weighting: $EF_i$

$$\begin{array}{cccccccc}
EF_1 & EF_2 & EF_3 & EF_4 & EF_5 & EF_6 & EF_7 \\
EF_1 & 1 & & & & & \\
EF_2 & 1 & 1 & & & & \\
EF_3 & & 1 & & & & \\
EF_4 & & & 1 & 1/4 & & \\
EF_5 & & & 4 & 1 & & \\
EF_6 & & & & 1 & & \\
EF_7 & & & & & 1 &
\end{array}$$

$EF_5$ is 4 times more important than $EF_4$.
Step 1. For each column in the matrix, do the following: Find the sum of each column. Divide each entry in column $i$ by the sum of entries in that column. Repeat for all columns.

The raw data matrix $A$

<table>
<thead>
<tr>
<th></th>
<th>$a_{11}$</th>
<th>$a_{41}$</th>
<th>$a_{22}$</th>
<th>$a_{42}$</th>
<th>$a_{33}$</th>
<th>$a_{43}$</th>
<th>$a_{44}$</th>
<th>$a_{45}$</th>
<th>$a_{55}$</th>
<th>$a_{46}$</th>
<th>$a_{66}$</th>
<th>$a_{47}$</th>
<th>$a_{77}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum a_{4i}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Normalising matrix $A$

<table>
<thead>
<tr>
<th></th>
<th>$a_{11}/\sum a_{1i}$</th>
<th>$a_{41}/\sum a_{4i}$</th>
<th>$a_{22}/\sum a_{2i}$</th>
<th>$a_{42}/\sum a_{4i}$</th>
<th>$a_{33}/\sum a_{3i}$</th>
<th>$a_{43}/\sum a_{4i}$</th>
<th>$a_{44}/\sum a_{4i}$</th>
<th>$a_{45}/\sum a_{4i}$</th>
<th>$a_{55}/\sum a_{5i}$</th>
<th>$a_{46}/\sum a_{4i}$</th>
<th>$a_{66}/\sum a_{6i}$</th>
<th>$a_{47}/\sum a_{4i}$</th>
<th>$a_{77}/\sum a_{7i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum a_{4i}$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Finding the proper weights/importance factor $k_i$

**Step 2.** To find the approximate weight (importance) $w_i$ for environmental factor $EF_i$, calculate the average value of the entries in row $j$ in $A_{\text{norm}}$, for instance the 5th row:

$$w_5 = \frac{a_{51}^* + a_{52}^* + a_{53}^* + a_{54}^* + a_{55}^* + a_{56}^* + a_{57}^*}{7}$$

$w_5$ is the **best estimate** of the proper weight, satisfying the conditions: $a_{ij}=1/a_{ji}$, $a_{ii}=1$, $a_{ij} \cdot a_{jk}=a_{ik}$
A Case history

**Evaluation of three industrial development alternatives for the East Coast of Iceland**

- Industrial and regional development of the underpopulated East Coast of Iceland
  - a political and sociological dilemma

- Three possible Industrial Development Solutions
  - 340 thousand tons aluminium smelter plus massive 685 MW hydropower development (Kárahnjúkavirkjun)
  - 6 million tons oil refinery without hydropower development
  - General government/private sector aided development with a development fund

- Survey of general environmental consequences of all three alternatives

- Environmental Comparison of the three alternatives
  - Multi-attribute-utility-theory
  - Analytic Hierarchy Process Methodologies (AHP)
  - Environmental Quality Index (EQI)
Development of the underpopulated East Coast Region of Iceland

A political and social dilemma

Total population of Iceland: 330 thousand population units
Reykjavík (capital region): 200 thousand population units
East Coast population: 11 thousand population units
Reyðarfjörður population: 1500 population units

Iceland: 1 unit=1.0; China: 1 unit=4000
The Eyjabakkar Delta

A part of the 15000 km² uninhabitated virgin highlands north of Vatnajökull glacier. Largest untouched wilderness in Western Europe. A sanctuary for some 10 thousand moulting pink-footed geese.

This area would have been flooded, if plans for construction of a 43 km² water reservoir for the 210 MW Fjötsdalur powerplant had been realised.
Aluminium Smelter with hydropower development-ALT 1

Environmental Consequences

- Extensive land use with massive disruption of virgin mountain highlands. Irreversible environmental consequences.
- Negative social impact; environmental friendly image (-); ecotourism (-)
- Negative economic impact for traditional industries in the area but positive impact for the area as a whole (??). In particular the place where the smelter is located.
- Positive social and economic impact (+). Many jobs created with fiscal improvement for both local governments and persons.
- 30% increase of Icelandic CO₂ emissions. Covered by the “Icelandic Clause” decided at COP 7 in Marrakesh 2001.
- Industrial pollution of hitherto pristine environment.
Environmental Consequences

- Oil spill accidents entail considerable environmental risk
- Negative social impact; environmental friendly image; ecotourism
- Negative economic impact for traditional industries in the area but positive impact for the region as a whole. In particular the place where the refinery is located.
- Positive social and economic impact (+). Many jobs (high level) created with fiscal improvement for both local governments and persons.
- 30% increase of Icelandic CO$_2$ emissions, which violates the Kyoto (Kjó-tó) protocol agreement (no-use of green energy, and not covered by the “Icelandic Clause”)
- Limited industrial pollution
- Limited land use (about 50 ha coastal site)
General government/private sector aided development-ALT 3

Environmental Consequences

- Positive social impacts. Some possible job creation in new industries (exotic products based on area’s natural resources)
- Conservation of the environmental friendly image of the region
- Ecotourism and safari/hunting expeditions; mountain lodges
- Traditional industries in the area can be expected to continue suffering hard times
- Difficult but perhaps not impossible to establish information technology firms, hitech and skills based companies
- Economic impacts weaker than for the industrial development solutions, but more equally distributed throughout the region
- Airborne and industrial pollution continues at current low levels
Environmental Comparison of the Three Development Alternatives

*Environmental Factors Considered as Multi-Attribute-Utilities*

- Land Use (industrial and hydropower sites, reservoirs and overhead lines): (LU)
- Economic Impacts: (EI)
- Social Impacts: (SI)
- Consequences for the natural environment: (CNE)
- Industrial Pollution: (IP)
- Greenhouse Gas Emissions: (GGE)
- Environmental Risks: (ER)
The AHP Comparison Matrix

Comparison of effects on scale 1-9; $a_{ij}=1/a_{ji}$, $a_{ii}=1$, $a_{ij} \cdot a_{jk}=a_{ik}$

<table>
<thead>
<tr>
<th></th>
<th>LU</th>
<th>EI</th>
<th>SI</th>
<th>CNE</th>
<th>IP</th>
<th>CGE</th>
<th>ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU</td>
<td>1,000</td>
<td>0,500</td>
<td>0,333</td>
<td>2,000</td>
<td>3,000</td>
<td>3,000</td>
<td>1,333</td>
</tr>
<tr>
<td>EI</td>
<td>2,000</td>
<td>1,000</td>
<td>0,750</td>
<td>2,000</td>
<td>3,000</td>
<td>1,000</td>
<td>0,500</td>
</tr>
<tr>
<td>SI</td>
<td>3,000</td>
<td>1,333</td>
<td>1,000</td>
<td>3,000</td>
<td>4,000</td>
<td>2,000</td>
<td>1,000</td>
</tr>
<tr>
<td>CNE</td>
<td>0,500</td>
<td>0,500</td>
<td>0,333</td>
<td>1,000</td>
<td>2,000</td>
<td>0,750</td>
<td>0,500</td>
</tr>
<tr>
<td>IP</td>
<td>0,333</td>
<td>0,333</td>
<td>0,250</td>
<td>0,500</td>
<td>1,000</td>
<td>0,333</td>
<td>0,200</td>
</tr>
<tr>
<td>CGE</td>
<td>0,333</td>
<td>1,000</td>
<td>0,500</td>
<td>1,333</td>
<td>3,000</td>
<td>1,000</td>
<td>0,500</td>
</tr>
<tr>
<td>ER</td>
<td>0,750</td>
<td>2,000</td>
<td>1,000</td>
<td>2,000</td>
<td>5,000</td>
<td>2,000</td>
<td>1,000</td>
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<tr>
<td>SUM</td>
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<td>6,667</td>
<td>4,167</td>
<td>11,833</td>
<td>21,000</td>
<td>10,083</td>
<td>5,033</td>
</tr>
</tbody>
</table>
The AHP weights

<table>
<thead>
<tr>
<th></th>
<th>LU</th>
<th>EI</th>
<th>SI</th>
<th>CNE</th>
<th>IP</th>
<th>CGE</th>
<th>ER</th>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU</td>
<td>0.126</td>
<td>0.075</td>
<td>0.080</td>
<td>0.169</td>
<td>0.143</td>
<td>0.298</td>
<td>0.265</td>
<td>0.1651</td>
</tr>
<tr>
<td>EI</td>
<td>0.253</td>
<td>0.150</td>
<td>0.180</td>
<td>0.169</td>
<td>0.143</td>
<td>0.099</td>
<td>0.099</td>
<td>0.1561</td>
</tr>
<tr>
<td>SI</td>
<td>0.379</td>
<td>0.200</td>
<td>0.240</td>
<td>0.254</td>
<td>0.190</td>
<td>0.198</td>
<td>0.199</td>
<td>0.2371</td>
</tr>
<tr>
<td>CNE</td>
<td>0.063</td>
<td>0.075</td>
<td>0.080</td>
<td>0.085</td>
<td>0.095</td>
<td>0.074</td>
<td>0.099</td>
<td>0.0817</td>
</tr>
<tr>
<td>IP</td>
<td>0.042</td>
<td>0.050</td>
<td>0.060</td>
<td>0.042</td>
<td>0.048</td>
<td>0.033</td>
<td>0.040</td>
<td>0.0450</td>
</tr>
<tr>
<td>CGE</td>
<td>0.042</td>
<td>0.150</td>
<td>0.120</td>
<td>0.113</td>
<td>0.143</td>
<td>0.099</td>
<td>0.099</td>
<td>0.1095</td>
</tr>
<tr>
<td>ER</td>
<td>0.095</td>
<td>0.300</td>
<td>0.240</td>
<td>0.169</td>
<td>0.238</td>
<td>0.198</td>
<td>0.199</td>
<td>0.2056</td>
</tr>
<tr>
<td>SUM</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
The AHP Scores

**SCORES are on a scale 0 (worst) to 10 (best)**

<table>
<thead>
<tr>
<th>LAND USE (LU)</th>
<th>ALTERNATIVE 1</th>
<th>ALTERNATIVE 2</th>
<th>ALTERNATIVE 3</th>
<th>ALTERNATIVE 1</th>
<th>ALTERNATIVE 2</th>
<th>ALTERNATIVE 3</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATIVE 1 (AI)</td>
<td>1,000</td>
<td>0,143</td>
<td>0,111</td>
<td>0,059</td>
<td>0,020</td>
<td>0,087</td>
<td>0,550 (worst)</td>
</tr>
<tr>
<td>ALTERNATIVE 2 (Oil)</td>
<td>7,000</td>
<td>1,000</td>
<td>0,167</td>
<td>0,412</td>
<td>0,140</td>
<td>0,130</td>
<td>2,274</td>
</tr>
<tr>
<td>ALTERNATIVE 3 (GD)</td>
<td>9,000</td>
<td>6,000</td>
<td>1,000</td>
<td>0,529</td>
<td>0,840</td>
<td>0,783</td>
<td>7,170 (best)</td>
</tr>
<tr>
<td>SUM</td>
<td>17,000</td>
<td>7,143</td>
<td>1,278</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ECONOMIC IMPACTS (EI)</th>
<th>ALTERNATIVE 1</th>
<th>ALTERNATIVE 2</th>
<th>ALTERNATIVE 3</th>
<th>ALTERNATIVE 1</th>
<th>ALTERNATIVE 2</th>
<th>ALTERNATIVE 3</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATIVE 1</td>
<td>1,000</td>
<td>1,200</td>
<td>4,000</td>
<td>0,480</td>
<td>0,474</td>
<td>0,500</td>
<td>4,850 (best)</td>
</tr>
<tr>
<td>ALTERNATIVE 2</td>
<td>0,833</td>
<td>1,000</td>
<td>3,000</td>
<td>0,400</td>
<td>0,395</td>
<td>0,375</td>
<td>3,900</td>
</tr>
<tr>
<td>ALTERNATIVE 3</td>
<td>0,250</td>
<td>0,333</td>
<td>1,000</td>
<td>0,120</td>
<td>0,132</td>
<td>0,125</td>
<td>1,260 (worst)</td>
</tr>
<tr>
<td>SUM</td>
<td>2,083</td>
<td>2,533</td>
<td>8,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LU: 2\textsuperscript{nd} last row: ALTERNATIVE 3 (Gen. Developm.) is nine times better than ALTERNATIVE 1 regarding land use
EI: 2\textsuperscript{nd} last row: ALTERNATIVE 3 (Gen. Developm.) has only 1/4 as much economic benefit as ALTERNATIVE 1
### Environmental Quality Index for the three development alternatives

**EQI calculated using the AHP methodology**

<table>
<thead>
<tr>
<th>Environmental Factor</th>
<th>LU</th>
<th>EI</th>
<th>SI</th>
<th>CNE</th>
<th>IP</th>
<th>GGE</th>
<th>ER</th>
<th>EQI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance weights $w_i$</td>
<td>0.1651</td>
<td>0.1561</td>
<td>0.2371</td>
<td>0.0817</td>
<td>0.0450</td>
<td>0.1095</td>
<td>0.2056</td>
<td></td>
</tr>
<tr>
<td>ALT 1: Aluminium Smelter with hydropower development</td>
<td>0.553</td>
<td>4.485</td>
<td>1.638</td>
<td>0.576</td>
<td>0.808</td>
<td>0.963</td>
<td>3.056</td>
<td>2.00</td>
</tr>
<tr>
<td>ALT 2: Oil Refinery without hydropower development</td>
<td>2.274</td>
<td>3.899</td>
<td>2.973</td>
<td>2.150</td>
<td>1.150</td>
<td>0.963</td>
<td>0.797</td>
<td>2.19</td>
</tr>
<tr>
<td>ALT 3: Government/private sector development with a 0.3 billion USD Development Fund</td>
<td>7.173</td>
<td>1.255</td>
<td>5.390</td>
<td>7.274</td>
<td>7.740</td>
<td>8.670</td>
<td>7.836</td>
<td>6.16</td>
</tr>
</tbody>
</table>
Conclusions

- The Analytic Hierarchy Process offers a good methodology for environmental comparison of alternatives
- As expected the “green” alternative has the highest $EQI (6,16)$
- The two industrial alternatives receive a very low score or $EQI \approx 2$
- Faced with a choice between the two industrial alternatives, the oil refinery seems only slightly favourable in terms of the $EQI (2,19 \text{ vs } 2,00)$
- The oil refinery has the advantage that the interior highlands are left untouched for future generations to enjoy
- The Government of Iceland should perhaps have studied the “green” alternative, before deciding to go for the smelter and the huge Karahnjukar power plant. The profitability of the plant has been severely criticized for being unacceptable (energy price too low), and this seems to be justified by recent disclosure of records by the owner, National Power Corporation (Landsvirkjun)
Multi-Attribute-Utility Theories
General comments

Margfeldisáhrifa-nytjafræði; almennt um aðferðina

- Positive Points (kostir)
  - Well suited for engineers and natural scientists
  - Easy to apply probabilistic methodologies, e.g.
    \[ P[U(X) \leq u] = F_U(u) \]
  - Possible to introduce “fancy” mathematical tools, e.g.
    dynamic programming ("aðgerðargreining") or non-linear
    optimization ("ólínuleg beztun")
  - EXPERT CHOICE, an available commercial software

- Negative Points (Gallar)
  - The public looses insight into what is going on. Also likely
    that a large part of the Assessment Team will not be happy
    or satisfied with such methods
Why did we (the Icelandic Government) choose the aluminium smelter

Although CO$_2$ emission would exceed 500.000 tons per annum, and thus technically speaking be in violation of the Kyoto (kjó-tó) Protocol, Iceland was allowed 10% increase of its emissions during the first period 1990-2012 (total CO$_2$ emission 1990 about 2.7 million tons), i.e. 270.000 tons. The 500.000 tons p.a. will grossly exceed this limit.
The progress made in Iceland before 1990 to reduce the use of fossil fuels and carbon dioxide emission from local sources should be acknowledged by the international community. It should therefore be recognized that latitude for further reduction of emissions from moveable sources in the country is very limited. Moreover, the government considers any emission reduction, which prevents the use of its “green” and environmental friendly energy resources, adverse to the aims of the Kyoto Protocol. In this context it should be borne in mind that industrial development (meaning aluminium smelters) in Iceland will generate much less CO$_2$ emissions than elsewhere, where fossil fuel will be the energy source” (very curious statement!)
### Unharnessed Hydropower in the World


#### Economically feasible unharnessed hydropower in some European countries:

<table>
<thead>
<tr>
<th>Country</th>
<th>TWh/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>852</td>
</tr>
<tr>
<td>Norway</td>
<td>187</td>
</tr>
<tr>
<td>Sweden</td>
<td>85</td>
</tr>
<tr>
<td>France</td>
<td>70</td>
</tr>
<tr>
<td>Italy</td>
<td>65</td>
</tr>
<tr>
<td>Iceland</td>
<td>40</td>
</tr>
</tbody>
</table>

#### Economically feasible unharnessed hydropower in the different continents:

<table>
<thead>
<tr>
<th>Continent</th>
<th>TWh/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>2714</td>
</tr>
<tr>
<td>Africa</td>
<td>1852</td>
</tr>
<tr>
<td>North America</td>
<td>3012</td>
</tr>
<tr>
<td>South America</td>
<td>3036</td>
</tr>
<tr>
<td>Asia</td>
<td>5523</td>
</tr>
<tr>
<td>Middle East</td>
<td>168</td>
</tr>
<tr>
<td>Oceania</td>
<td>189</td>
</tr>
</tbody>
</table>

However, it was at that time claimed by the authorities that only in Iceland can aluminium smelters be built using “green” energy!!!!!
The Marrakesh Meeting or COP 7 in 2001

Ministerial meeting of the FCCC countries in November 2001

- More than 80 ministers for the environment, top government officials, and NGO’s attended

- The main result can be seen on the website of the FCCC Secretariate in Bonn: http://unfccc.int. Environmentalists agreed that the “Earth”, i.e. our climate, was the looser. In order to reach an agreement, most countries were accorded any provisions or conditions they had laid down, and all objections considered.

- The so-called Icelandic exemption clause was approved, subject to certain conditions.
The Icelandic Clause

Importance of “green” energy utilization acknowledged

- Covers new energy intensive industrial facilities in one location or enlargement of existing facilities after 1990
- If such industrial facility (new or enlargement) increases the total annual emissions (reference year 1990) more than 5% within the first Protocol phase 2001-2007, it may be exempted

- Conditions
  - The total emissions of a country is less than 0.05% of that of all industrial nations 1990
  - Only renewable energy shall be used (hydropower, geothermal), which leads to less global emissions per production unit
  - Best possible pollution control and best available technology to prevent greenhouse gas emission shall be used

- Such emission, due to large industrial facilities in one country, ≤ 1,6 Mtons CO₂/year
See you next Thursday. Last lecture: The Reykjavik domestic airport. **Relocation or let it stay!** Invite friends who are interested in the relocation of Reykjavik Airport
Profitability of the 685 MW Kárahnjúkavirkjun

- An avid spokesman for hydropower development confesses that the building of a large hydropower plant on these premises is more like a social project, that is, it does not necessarily have economic benefit rather social benefit only.

- Initial cost 1.2 billion dollars (685 MW), 2003 prices
  - Annual costs
    - Amortization (30 year loan at 6.5%): 78 million USD
    - Operation cost (1% of stofnkorstnaði): 12 million USD
    - Total: 90 million USD
  - Annual max. income (Landsvirkjun refuses to divulge the unit price of electricity (possibly as low as 18 Mils/kWh)). Annual production capacity 4450 Gwst. Annual sale (4200 Gwst. \(\text{á} 2.0 \text{cent/kWst}\)) could amount to 84 million USD, i.e. negative profitability.

- The aluminium smelter has never paid any taxes in Iceland!