
Ulrike Lehr
Energy security is an elusive concept, often not formalized

- **Availability**: geological existence of a fuel
- **Accessibility**: geopolitical and geostrategic elements
- **Affordability**: economic elements
- **Acceptability**: social and environmental elements

(APERC 2007)
Diversity acts as a hedge against different risks

=> Don’t put all the eggs in one basket

Starting point: Simple diversity measure $S_1$

$$S_1 = - \sum_i p_i \ln(p_i)$$

$p_i$ is the share of fuel $i$ in the energy mix.

$S_1$ is increasing in the number of fuels and towards an even distribution
Combined Indicators

Step 2

Include import dependence

Two aspects matter:

1. The share of imported energy \( m_i \) in eq. 2 for each fuel

2. The share \( m_{ij} \) in eq. 3 of each country of origin j within this import share of fuel i

\[
S_2 = \sum_{i=1}^{N} c_{2i} \ln(p_i), \text{ with } c_{2i} = \left( 1 - m_i \left( 1 - \frac{S_{i2}^m}{S_{i2}^{max}} \right) \right)
\]

\[
S_{i2}^m = - \sum_{j=1}^{M} m_{ij} \ln(m_{ij}) \text{ and } S_{i2}^{max} = -M \frac{1}{M} \ln M
\]

Note: \( S1 > S2 \) by definition.
Combined Indicators

Step 3
Include countries’ stability

Weigh with relative risk indicator

\[ S_3 = \sum_{i=1}^{N} c_{3i} p_i \ln(p_i), \text{with } c_{3i} = \left(1 - m_i \left(1 - \frac{S_{i3}^m}{S_{i3}^{max}}\right)\right) \]

\[ S_{i3} = -\sum_{j=1}^{M} A_j \cdot m_{ij} \ln(m_{ij}) \text{ and } S_{i3}^{max} = -M \cdot \frac{1}{M} \ln M \text{ and } A = \left(1 - \frac{\text{risk indicator}}{\max \text{risk indicator}}\right) \]

Possible empirical quantities: Hermes Indicator, Human Development Indicator, Worldwide Governance Indicator

Note: S1 > S2 > S3 by definition.
Combined Indicators

Step 4

Include affordability

Exploration of new energy sources often is more costly than the established technologies -> weigh with normalized additional costs

\[ S_4 = \sum_{i=1}^{N} c_{3i} \left( 1 - \frac{D_i}{TC} \right) p_i \ln(p_i), \text{with } D_i: \text{additional cost of technology } i, TC: \text{total cost} \]

Note: S3 > S4 by definition for all additional cost > 0
Application to historic data: Results

- Energy security increased over the years
  - More sources
  - More countries of origin
- Maximal attainable S1: 2.2 (for 9 energy sources)
- S2, max: (even distribution over all countries of origin)
  - Coal: 3.26
  - Oil: 2.56
  - Gas: 1.39
- S4: inclusion of RES, starts in 2000

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Own calculation.
## Application I: Ex Post Total primary energy supply, PJ

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*Source: BMWi 2009*
Application to historic data: Import shares

Oil: shares remain roughly the same
Gas: shares increase slightly
Hard coal: shares increase steeply, almost triple, due to phase out of hard coal mining
Application to historic data: countries of origin

Oil and gas:
- largest import share from Russia (2007: nearly 32% of all oil imports, 42% of all natural gas imports)

Coal:
- shift from EU to overseas; 1995 almost one third from the EU; 2007 one fifth.
Application to future developments - scenarios

Reference Scenario (in PJ)

- Nuclear
- Non-Renewable Waste Heat, etc.
- Other Renewables
- Biomass and Renewable Waste
- Wind, hydro and Photovoltaics
- Natural Gas
- Mineral Oil
- Lignite
- Hard Coal
Application to future developments - scenarios

Target oriented scenario (in PJ)

- Nuclear
- Non-Renewable Waste Heat, etc.
- Other Renewables
- Biomass and Renewable Waste
- Wind, hydro and Photovoltaics
- Natural Gas
- Mineral Oil
- Lignite
- Hard Coal
Difference between the scenarios: Share of RES

TOS performs better with all indicators.

1. increases the number of baskets,
2. attempts a more even distribution of fuel sources
3. replaces imported fuels by domestic technology

Surprising: S4 cost effect is rather small and turns around by 2030

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Own calculations.
Conclusions

1. The suggested indicator is able to distinguish different future developments
2. Construction of S4 though taking additional costs into account, still emphasizes the diversity aspect strongly.
3. Given the set of indicators, renewable energy, increased efficiency and CHP use support energy security to a large extend.
4. Future works should include “new” import dependence coming with the use of imported materials for instance for the production of PV modules.
Thank you for your attention!

For more:
www.gws-os.com
lehr@gws-os.com

Acknowledgement: This work is part of a study on the costs and benefits of renewable energy on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.
## Application I: Total primary energy supply, PJ

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*Source: BMWi 2009*
Risk Indicators

- China
- Colombia
- Russian Federation
- South Africa
- Venezuela
Application to future developments - scenarios

Reference

• Energy consumption after declines 2010
• 2030: primary energy supply 85%, final energy consumption 90% (of 2004).
• Electricity consumption increases until 2020, then falls back
• Energy intensity decreases by 40%
• Renewable energy contributes 10% to primary energy use.
• 30% (44%) CO$_2$ reduction by 2030 (2050), missing the national targets.

Target oriented scenario

• Faster decrease in energy intensity
• Primary energy consumption decreases until 2020 by 17%.
• Average increase of energy efficiency is 3% (governmental targets)
• Increase of renewable energy after 2010 roughly twice as fast
• 2020: 18% of final energy consumption from RES.
• Aspired 80% reduction of CO$_2$-emissions will be reached just so
• Large amounts of CHP heat