

MADM Methods for Sustainability Assessment of Energy Scenarios

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INATECH Method Development

- Selection of MADM Methods
- Application of more than one MCDA Methods [Løken 2007]
 - The decision makers can compare and discuss inconsistencies
 - Gives the decision makers a broader decision basis
 - Gives more reliable process and enhanced confidence in decision making
- Selected MADM Methods: AHP, TOPSIS, PROMETHEE
 - Literature review
 - Different characteristics





- Triple bottom line of sustainability [Elkington 1999]
- Seven preliminary scenario attributes for method assessment:

Economic	Ecologic	Social
Employment (install. + O&M of technology)	Climate change	Human health*
Production cost	Space requirement	
Security of supply	Resource requirement	

*Could also be grouped as ecological indicator

 Number of criteria planned for the integrated sustainability assessment: 13 to 15





Approximation of Scenario Attribute Values

- Example for climate change score (preliminary values)
 - Moderately ambitious scenario 1

Technology	Electricity Production (TWh/a)	Emission (g CO ₂ eq/kWh)	Climate Change (Mt CO ₂ eq)
Wind onshore	132	5	0.66
Wind offshore	128	5	0.66
PV	63.8	17	1.08
Geothermal	19.2	81	1.55
Heat Pump	(14.4)	29	0.42
Natural Gas CC	14.1	339	4.78
Natural Gas CHP	51.5	339	17.44
Total			26.59

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Approximation of Scenario Attribute Values

Attribute scores for four scenarios (preliminary values)

		Production cost (Mio. Euro)	Employ- ment (1000 Pers.)	Security of supply (-)	Climate change (Mt CO ₂ eq.)	Resource use (t of antimony eq.)	Land use (Mt organic subst. soil)	Human health (Mio. CTUh)	
	Moderately ambitious scenario 1	40 807	4186	1535	26.59	934	155.56	346.22	
	Moderately ambitious scenario 2	46 106	4137	1618	16.15	1084	174.14	327.12	
	Highly ambitious scenario 1	364 914	6487	2264	19.58	1561	240.83	425.91	
	Highly ambitious scenario 2	74 081	7376	2834	12.78	1784	285.24	460.99	
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NATECH Pairwise Comparison in AHP

- Pairwise comparison of two criteria values
- Relative score can be between 1 and 9; example:

Value of a_{ij}	Interpretation	
1	<i>i</i> and <i>j</i> are equal	
3	<i>i</i> is slightly better than <i>j</i>	
5	<i>i</i> is better than <i>j</i>	
7	<i>i</i> is strongly better than <i>j</i>	
9	<i>i</i> is absolutely better than <i>j</i>	





INATECH AHP-Qualitative Scoring

(Subjective) pairwise comparison

	Climate change (Mt CO ₂ eq.)		Moderately ambitious scenario 1	Moderately ambitious scenario 2	Highly ambitious scenario 1	Highly ambitious scenario 2
Moderately ambitious scenario 1	26.59	Moderately ambitious scenario 1	1	1/7	1/6	1/9
Moderately ambitious scenario 2	16.15	Moderately ambitious scenario 2	7	1	3	1/4
Highly ambitious scenario 1	19.58	Highly ambitious scenario 1	6	1/3	1	1/5
Highly ambitious scenario 2	12.78	Highly ambitious scenario 2	9	4	5	1

Challenges: expert knowledge, consistency in large matrix

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INATECH AHP-Quantitative Scoring

Directly calculated pairwise comparison

	Climate change (Mt CO ₂ eq.)		Moderately ambitious scenario 1	Moderately ambitious scenario 2	Highly ambitious scenario 1	Highly ambitious scenario 2
Moderately ambitious scenario 1	26.59	Moderately ambitious scenario 1	1	16.15/ 26.59	19.58/ 26.59	12.78/ 26.59
Moderately ambitious scenario 2	16.15	Moderately ambitious scenario 2	26.59/ 16.15	1	19.58/ 16.15	12.78/ 16.15
Highly ambitious scenario 1	19.58	Highly ambitious scenario 1	26.59/ 19.58	16.15/ 19.58	1	12.78/ 19.58
Highly ambitious scenario 2	12.78	Highly ambitious scenario 2	26.59/ 12.78	16.15/ 12.78	19.58/ 12.78	1

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INATECH AHP/ 0-1 Normalization

Linear interpolation between values

	Climate change (Mt CO ₂ eq.)	Score
Moderately ambitious scenario 1	26.59	0
Moderately ambitious scenario 2	16.15	(16.15-26.59)/ (12.78-26.59)
Highly ambitious scenario 1	19.58	(19.58-26.59)/ (12.78-26.59)
Highly ambitious scenario 2	12.78	1

	Score
Worst Value = 26.59	0
Best Value = 12.78	1







- Ranking for 0-1 normalization, equal weighting:
 - 1. ModScen2
 - 2. HighScen2
 - 3. ModScen1
 - 4. HighScen1









- In this method two artificial alternatives are hypothesized:
 - Ideal alternative: the one which has the best level for all attributes considered
 - Negative ideal alternative: the one which has the worst attribute values
- TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative





INATECH TOPSIS Result

- Ranking for equal weighting:
 - 1. ModScen2
 - 2. HighScen2
 - 3. ModScen1
 - 4. HighScen1





- Outranking method
- Based on preference function approach
- PROMETHEE II (complete ranking): based on net flow







INATECH PROMETHEE Result

- Open Software GoDeSS
- Preference function:
 - Linear v-shape
 - p value: 10% from minimal value [Wulf 2019]
- Ranking for equal weighting:
 - 1. ModScen2
 - 2. ModScen1
 - 3. HighScen2
 - 4. HighScen1



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INATECH Conclusion

- All three methods give similar results for the best and worst alternative
- There are some uncertainties in the procedure for several methods
- Application of several methods is useful to enhance confidence of the result
- Subjective scoring (AHP) is not suitable for our assessment

Disclaimer: Score data was created on very rough preliminary data, for the purpose of a methodological check only.

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 "Any weighting scheme is not mainly natural science based but inherently involves value choices…" [Sala et al. 2018]





INATECH Open Questions

- Which method is to be used for AHP scoring? Different for each criteria?
- Which preference function and p- or q-value are to be used for PROMETHEE? Different for each criteria?
- Are the selected MADM methods (AHP, TOPSIS, PROMETHEE) suitable for sustainability assessment of energy systems?
- Extra Questions:
 - Are essential sustainability indicators missing?
 - Which weighting method is to be used? (Number of decision makers? Aggregation method?)

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INATECH Criteria for MADM Method Selection

- Compensatory properties
- Understandability: simpler is better
- Workload
- Result sequence: if possible cardinal
- Sustainability approach
- Number of indicators





INATECH AHP-Priority Vector

Climate change (Million ton CO₂ eq)

	Qualitative Scoring	Quantitative Scoring	0-1 Normaliz ation
Moderately ambitious scenario 1	0.040	0.164	0
Moderately ambitious scenario 2	0.244	0.271	0.334
Highly ambitious scenario 1	0.140	0.223	0.224
Highly ambitious scenario 2	0.577	0.342	0.442



Priority Vector

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