Comparison of model based energy scenarios for Germany and methodical outlook

Semi-annual ETSAP meeting

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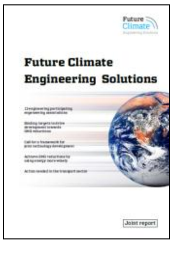
Part 1: Comparison of energy scenarios for Germany

Energy scenarios for Germany – IEK STE

- In 2009 the IEK-STE performed scenario calculations up to 2050 for Germany.
- Base of the calculation was a common project between STE and the Association of German Engineers (VDI) – the STE/VDI project.
- This cooperation was established as part of an international project - 'Future Climate – Engineering Solutions' - of engineering associations from different countries chaired by the Danish Society of Engineers to present a global engineering prelude to the COP15 meeting in Copenhagen in 2009.



- The results were handed over to national political representatives during a conference in Copenhagen ahead of the COP15 meeting.
- The STE-scenarios were compared with 23 studies including a total of about 65 scenarios.

Energy scenarios for Germany – IER, EWI

- To support a new energy concept for the period up to 2050, the German government commissioned scientific institutes to calculate energy scenarios for the period up to 2030 respectively up to 2050. The institutes were IER, RWI, ZEW (called “IER”) respectively EWI, GWS, Prognos (called “EWI").
- The models used by IER were mainly TIMES PanEU (bottom up energy system model), E2M2 (electricity model) and NEWAGE (energy economy model).
- EWI mainly used PANTA RHEI (energy economy model) and DIME (electricity model).

➡ Comparison of the STE scenarios based on the STE/VDI project including engineering viewpoints and using cost optimization with the scenarios made for the German government (IER and EWI).


Die Entwicklung der Energiemärkte bis 2030

Energieprognose 2009

Hauptbericht

IER rwi ZEW


ewi gws prognos

Studie

Energieszenarien für ein Energiekonzept der Bundesregierung

Basic assumptions in reference scenarios

	Unit	2008	2030	2050
Population	Million			
IER			79.7	n.a.
EWI		82.1	79.1	73.8
STE			81	77
GDP	Billion $€_{2000}$			
IER			2784	n.a.
EWI		2235	2632	3158
STE			3034	4007
Oil Price	$\$_{2008}$/bbl			
IER			76.7	n.a.
EWI		92	110	130
STE			86	130

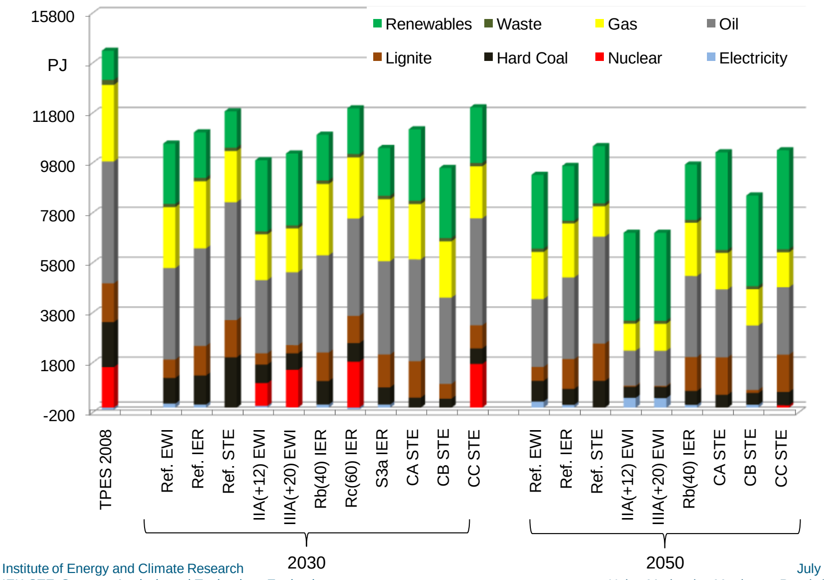
Analyzed and compared scenarios I

Scenario	CO_2 restriction in 2050 (ref 1990)	Nuclear power	CCS (Carbon Capture and Storage)	Important exogenous guidelines
EWI-Ref.	None	Nuclear phase out by 2022	Optional available from 2025	Further progress in actual policy measurements and ambitious future trends including strong grid extension, integration of European markets and innovative market design Energy efficiency: 1.7-1.9%/y Share of Renewables in gross final energy demand 2020: ≥16%
IER-Ref.	n.a.	Nuclear phase out by 2022	Optional available from 2020	Business as usual with the projection of actual policy measurements
STE-Ref.	None	Nuclear phase out by 2022	Optional available from 2020	Business as usual with the projection of actual policy measurements
EWI-IIA	-85%	Extension of operation for 12 years	Optional available from 2025	GHG: -40% until 2020 Energy efficiency: 2.3 to 2.5 %/y Share of Renewables in gross final energy demand 2020: ≥18% Share of Renewables in total primary energy supply 2050: ≥50%
EWI-IIIA	-85%	Extension of operation for 20 years	Optional available from 2025	

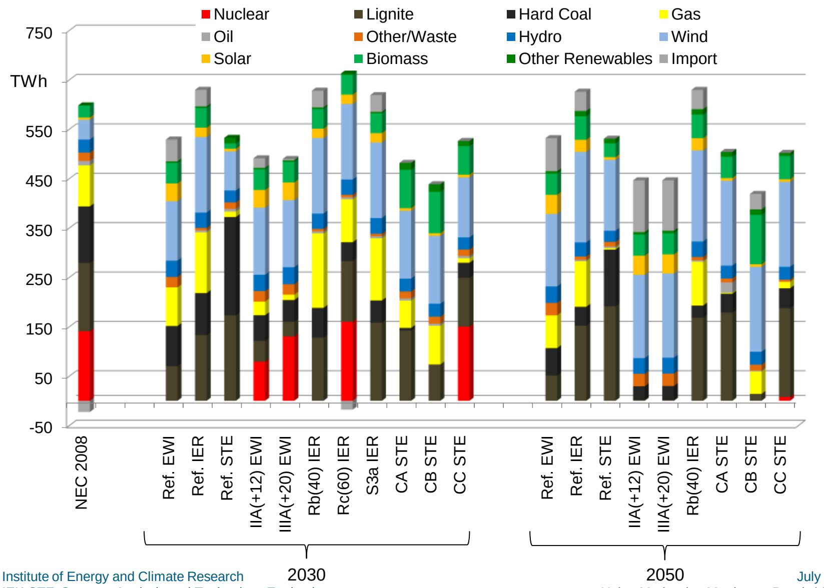
Analyzed and compared scenarios II

Scenario	CO_2 restriction in 2050 (ref 1990)	Nuclear power	CCS (Carbon Capture and Storage)	Important exogenous guidelines
IER-Ra(40)	n.a.	Extension of operation to 40 years	Optional available from 2020	Business as usual with the projection of actual policy measurements
IER-Rb(60)	n.a.	Extension of operation to 60 years	Optional available from 2020	
IER-S3a	-71%	Nuclear phase out by 2022	Optional available from 2020	International climate protection agreement comes into force
STE-CA	-77%	Nuclear phase out by 2022	Optional available from 2020	Optional import of solar electricity from North Africa
STE-CB	-77%	Nuclear phase out by 2022	Not available	Optional import of solar electricity from North Africa. Strong energy saving, lower limit for renewables. 120 g/km CO_2 for new cars, similar for trucks. Lower limit for electric+hybrid-plugin vehicles
STE-CC	-77%	Extension of operation to 60 years	Optional available from 2020	Optional import of solar electricity from North Africa

Total primary energy supply



Net electricity consumption



Part 2: Computation of sustainable transition paths

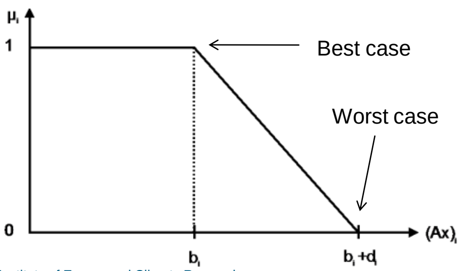
Motivation

- Optimizing the energy system is characterized by the clash of partly contradictory economic, environmental and social interests.
- A general approach to this problem is the idea of "sustainable development" where "sustainable" means: "**Meeting the needs of the present generation without compromising the ability of future generations to meet their own needs**" [Coley, 2008].
- How to meet greenhouse gas (GHG) emission targets at minimal system cost alone is not adequate to measure an energy system's state of development and to monitor its progress or lack of progress towards sustainability. For this purpose indicator sets have been developed like EISD which we use here [IAEA et al., 2005].
- In STE we are developing a new application in energy systems analysis which differs from other analyses computed by means of this or similar models twofold:
  - First, the desired evolution and the final state of the energy system is not determined by a greenhouse gas mitigation path but by the targets of various energy indicators for sustainable development (EISD) [IAEA et al., 2005].
  - Second, the optimization driver is not the minimization of system cost but the maximization of overall fulfillment of the sustainability targets.

Comparison of crisp and fuzzy LP I

➡ The optimization approach is fuzzy linear programming based on our modified technology orientated bottom-up model IKARUS-LP.

Conventional (crisp) LP	Fuzzy LP
MIN $z = \mathbf{Cx}$ s.t. $\mathbf{Ax} \leq \mathbf{b}$ $\mathbf{x} \geq \mathbf{0}$	$\mathbf{Cx} \tilde{\lesssim} \tilde{z}$ $\tilde{\mathbf{A}}\mathbf{x} \tilde{\lesssim} \tilde{\mathbf{b}}$ (including some crisp $\leq$) $\mathbf{x} \geq \mathbf{0}$



The fuzzy problem is transformed into a crisp model by using the membership functions $\mu_i(x)$ for the fuzzy constraints. The main idea is to maximize “total fulfillment”, i.e. maximizing a minimum operator for the set of membership functions $\mu_i(x)$.

Comparison of crisp and fuzzy LP II

- In the case of fuzzy right-hand sides only, the equivalent crisp Linear Program can be written as

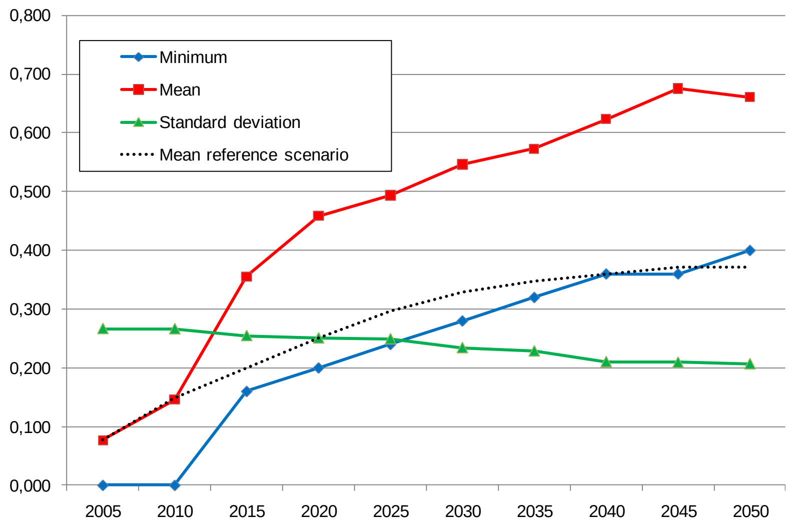
$$\mathrm{MAX}\lambda, \lambda := \min \lambda_i$$
$$\mathrm{s.t.}\, \lambda \leq \mu_i$$
$$\mu_i = \frac{1}{d_i}\left(b_i + d_i - (\mathbf{Ax})_i\right)$$

- In the case of a fuzzification of coefficients as well as right hand side, the mathematics is more complicated (leads to a mixed integer problem) and will not be shown here.

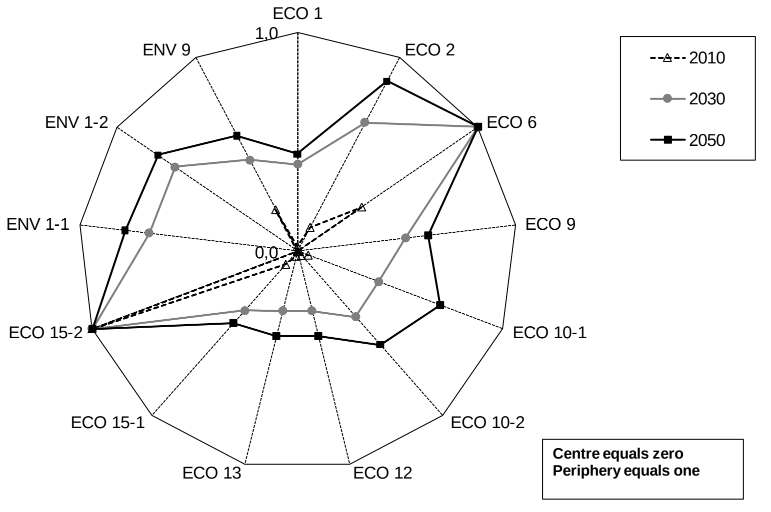
Energy indicators for sustainable development (EISD)

indicator	fuzzy constraint	target		unit
		ideal	not acceptable	
ECO 1	$\frac{TPES}{population} \lesssim \tilde{b}$	x ≤ 69	x ≥ 173	$\frac{GJ}{cap}$
ECO 2	$\frac{TPES}{GDP} \lesssim \tilde{b}$	x ≤ 1.74	x ≥ 6.7	$\frac{MJ}{€}$
ECO 6	$\frac{EE\ industry}{value\ added\ industry} \lesssim \tilde{b}$	x ≤ 3.7	x ≥ 5.7	$\frac{MJ}{€}$
ECO 9	$\frac{EE\ residential}{population} \lesssim \tilde{b}$	x ≤ 9.2	x ≥ 34.5	$\frac{GJ}{cap}$
ECO 10-1	$\frac{EE\ pax\ vehicles}{person\text{-}km\ pax\ vehicles} \lesssim \tilde{b}$	x ≤ 3.35	x ≥ 5.17	$\frac{liter\ petrol}{pax \cdot 100km}$
ECO 10-2	$\frac{EE\ freight\ vehicles}{tonne\text{-}km\ freigth\ vehicles} \lesssim \tilde{b}$	x ≤ 2.62	x ≥ 4.88	$\frac{liter\ diesel}{tonne \cdot 100km}$
ECO 12	PES non-carbon $\gtrsim \tilde{a} \cdot$ TPES	x = 1	x ≥ 0.14	1
ECO 13	PES renewables $\gtrsim \tilde{a} \cdot$ TPES	x = 1	x ≥ 0.03	1
ECO 15-1	PES imported $\lesssim \tilde{a} \cdot$ TPES	x ≤ 0.33	x ≥ 0.75	1
ECO 15-2	PES renewable imp. $\lesssim \tilde{a} \cdot$ TPES	x ≤ 0.2	x ≥ 0.33	1
ENV 1-1	$CO_2 \lesssim \tilde{a} \cdot$ TPES	x ≤ 126	x ≥ 798	Mt
ENV 1-2	$\frac{CO_2\ emissions}{population} \lesssim \tilde{b}$	x ≤ 1.6	x ≥ 9.7	$\frac{t}{cap}$
ENV 9	nuclear electricity $\lesssim \tilde{b}$	x = 0	x ≥ 151	TWh

Evolution of the fulfillment of the EISD – Statistics of all indicators



Evolution of the fulfillment of each EISD



Methodical outlook

Outlook and next steps

- **Now:**

  Transferring the IKARUS structure and data to TIMES using ANSWER-TIMES and Excel.

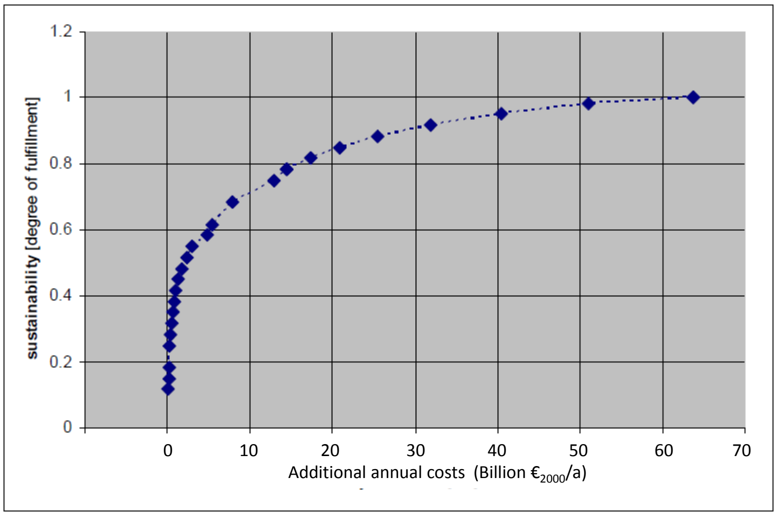
- **Future:**

  Including
  - **Fuzzy optimization**
  - **Multi objective optimization**
  - **Integration of macroeconomics**
  - **Computation of sustainable transition paths with TIMES**

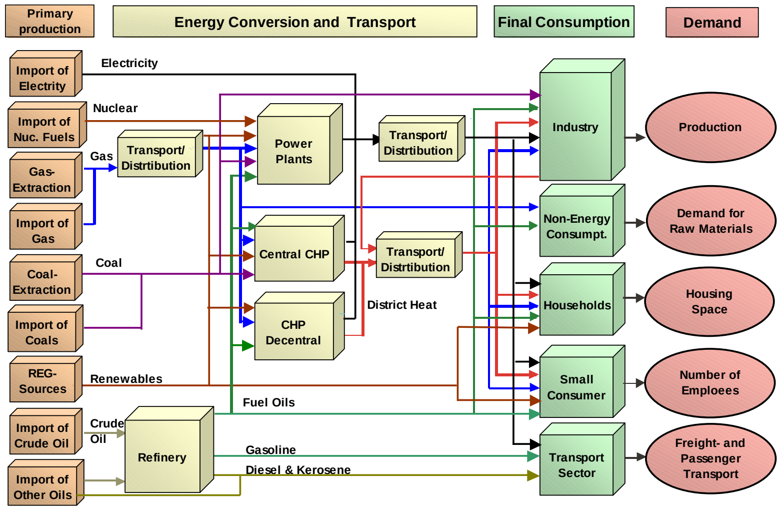
Thank you for your attention

Backup

Real multi criteria optimization: Sustainability and system costs



IKARUS-LP energy system model for Germany



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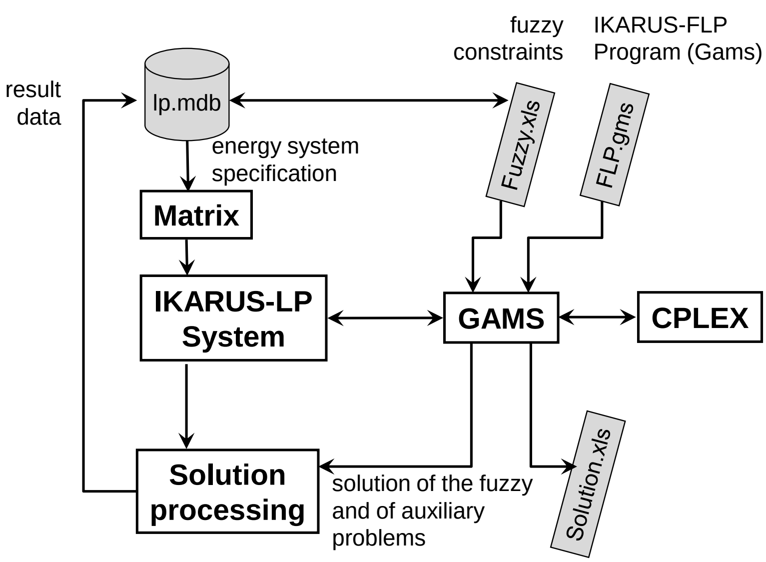
Layout of IKARUS-FLP program



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