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Additional information on the ESD Policy Brief “Integrative Considerations on Energy Transition”

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Preliminary remarks

- This file consists of additional information regarding the ESD Policy Brief “Integrative Considerations on Energy Transition”.
  The Policy Brief as well as this Annex can be downloaded at https://energy.helmholtz.de/en/translate-to-englisch-forschungshighlights/translate-to-englisch-die-energiewende-integrativ-denken/
- The additional information contains a more detail description
  - of the chosen approach as well as
  - of the results.
- The slides were presented during the “Helmholtz Energy Workshop: Energieszenarios weitergedacht”, carried out at 13.10.2023. For this Policy Brief the slides are updated.

Content (I)

Content (II)

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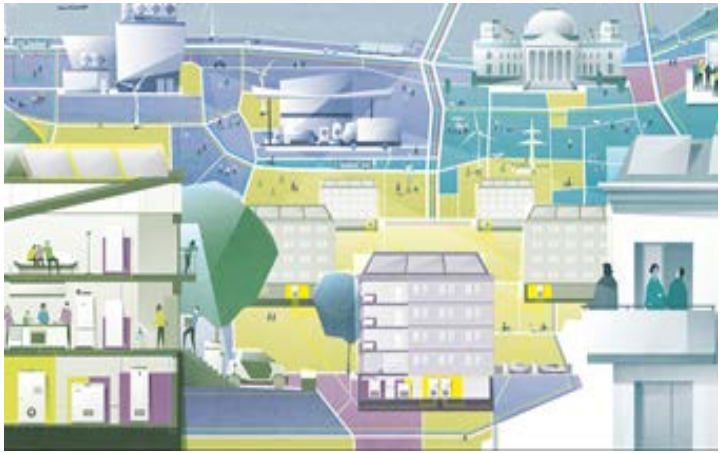
Integrative scenario analysis in the Helmholtz Program Energy System Design: Motivation and approach

Witold-Roger Poganietz, Jürgen Kopfmüller (KIT-ITAS)

Motivation – Integrative scenario analysis

- Energy system
  - is a socio-technical system, and
  - should make an essential contribution to the "Great Transformation" towards sustainability



https://www.kopernikus-projekte.de/vision

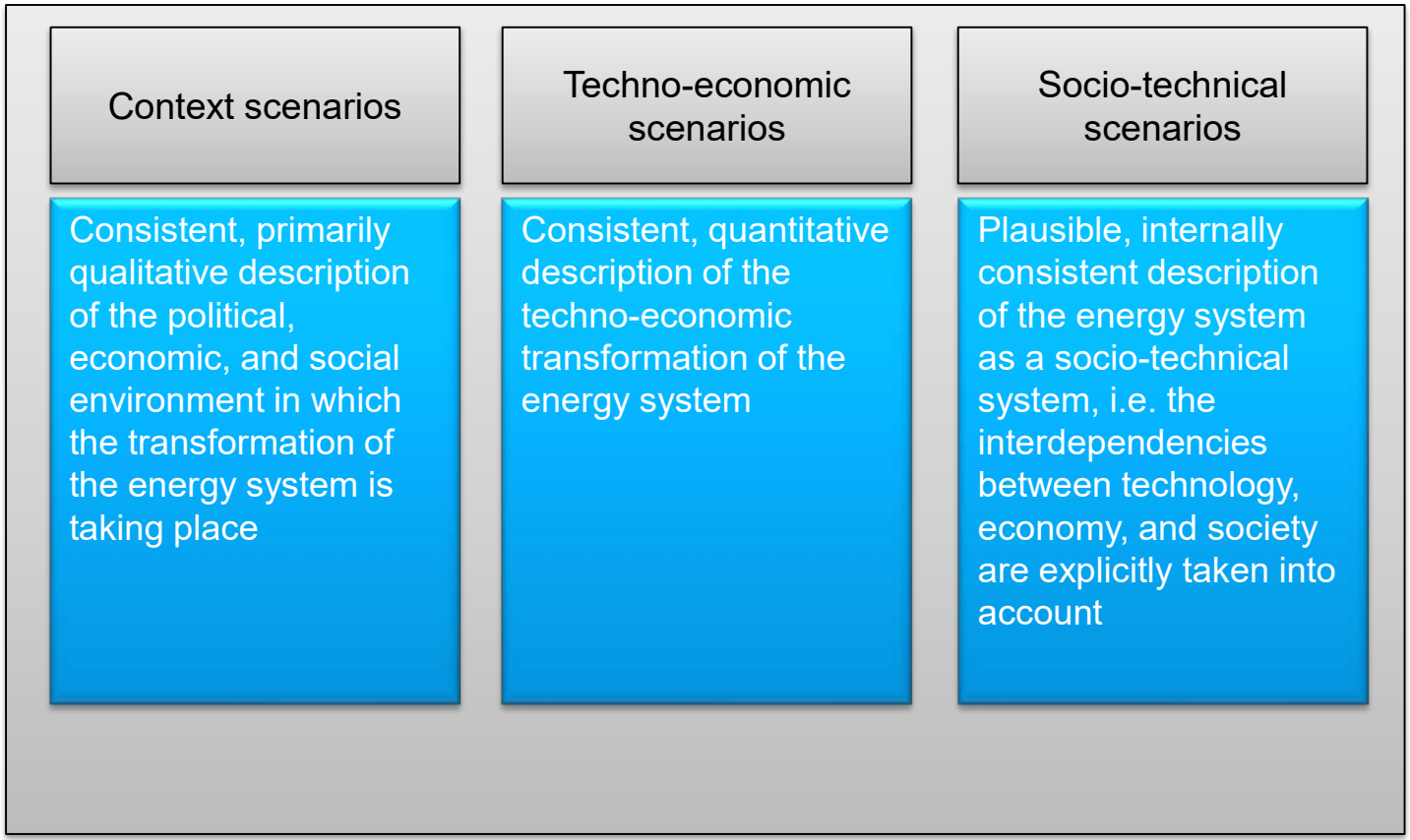
⇨ Necessity of knowledge-based orientation knowledge

⇨ Scenario analysis and evaluation as a core element

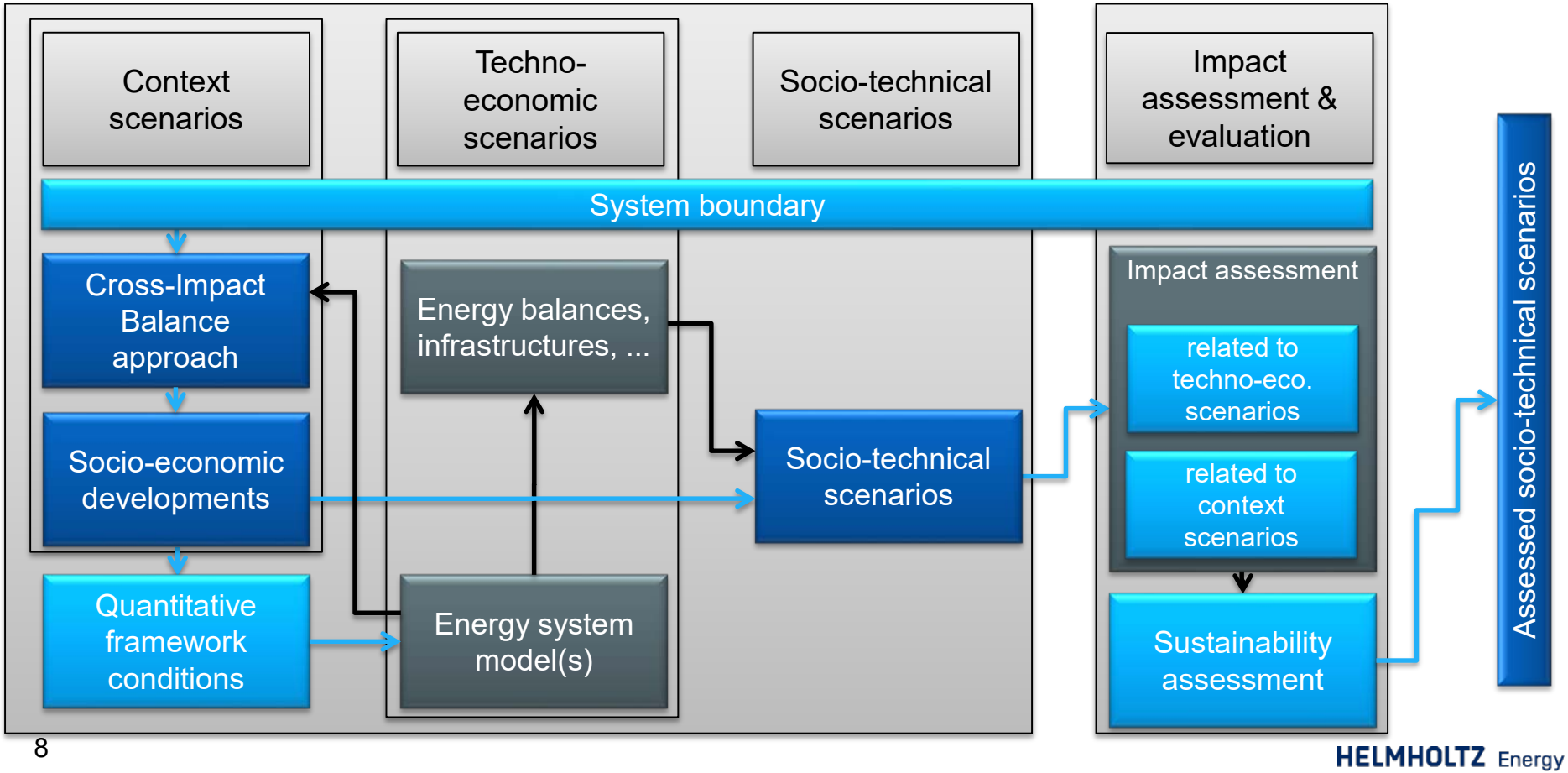
⇨ Addressing technical, economic, social, and environmental aspects:

- For the analysis, the creation of socio-technical scenarios
- For the evaluation, carrying out impact assessments and, building on this, a holistic sustainability analysis

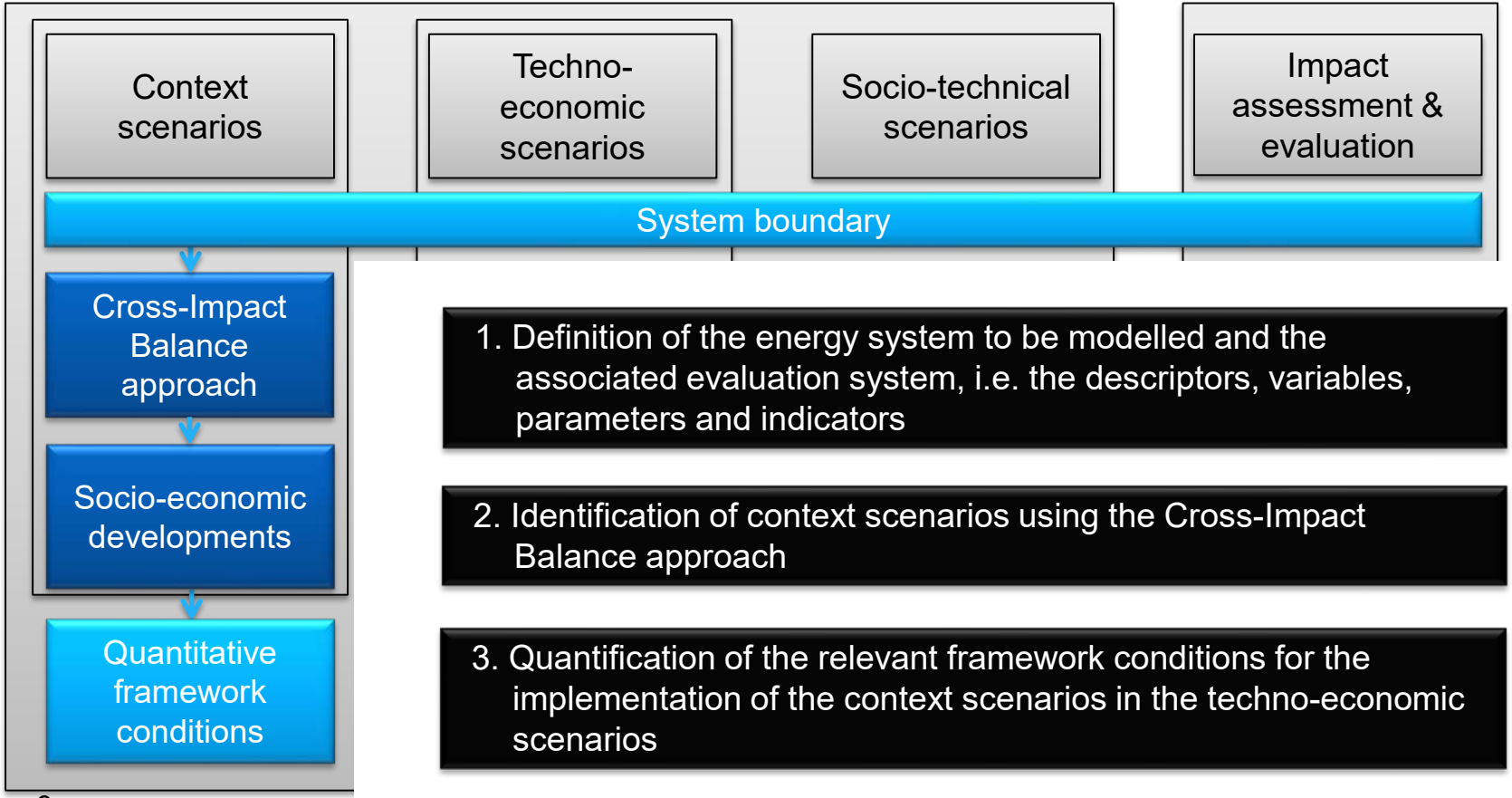
Socio-technical scenario analysis – Key terminology



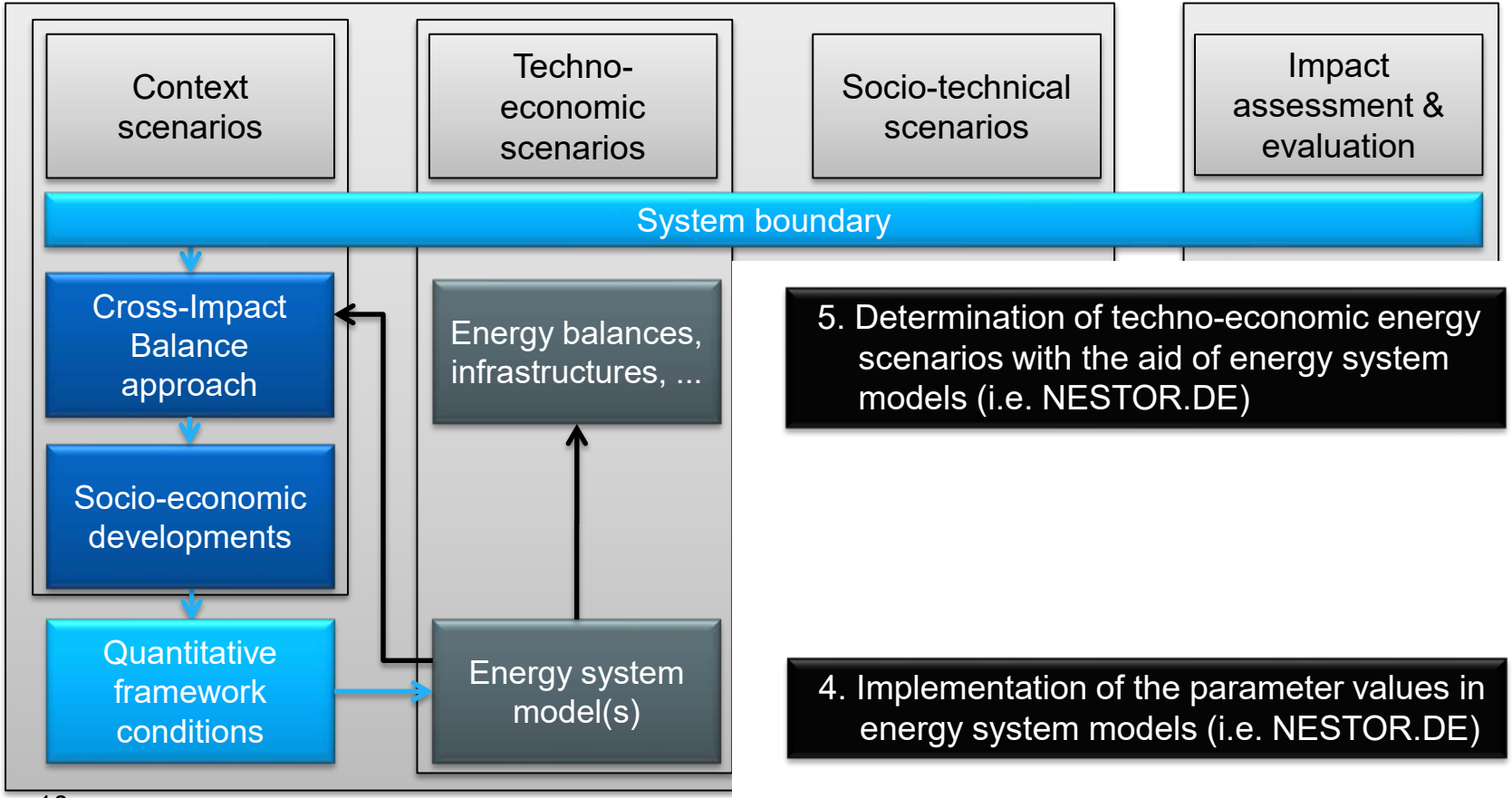
Overview of the approach – Development, analysis, and evaluation of socio-technical scenarios



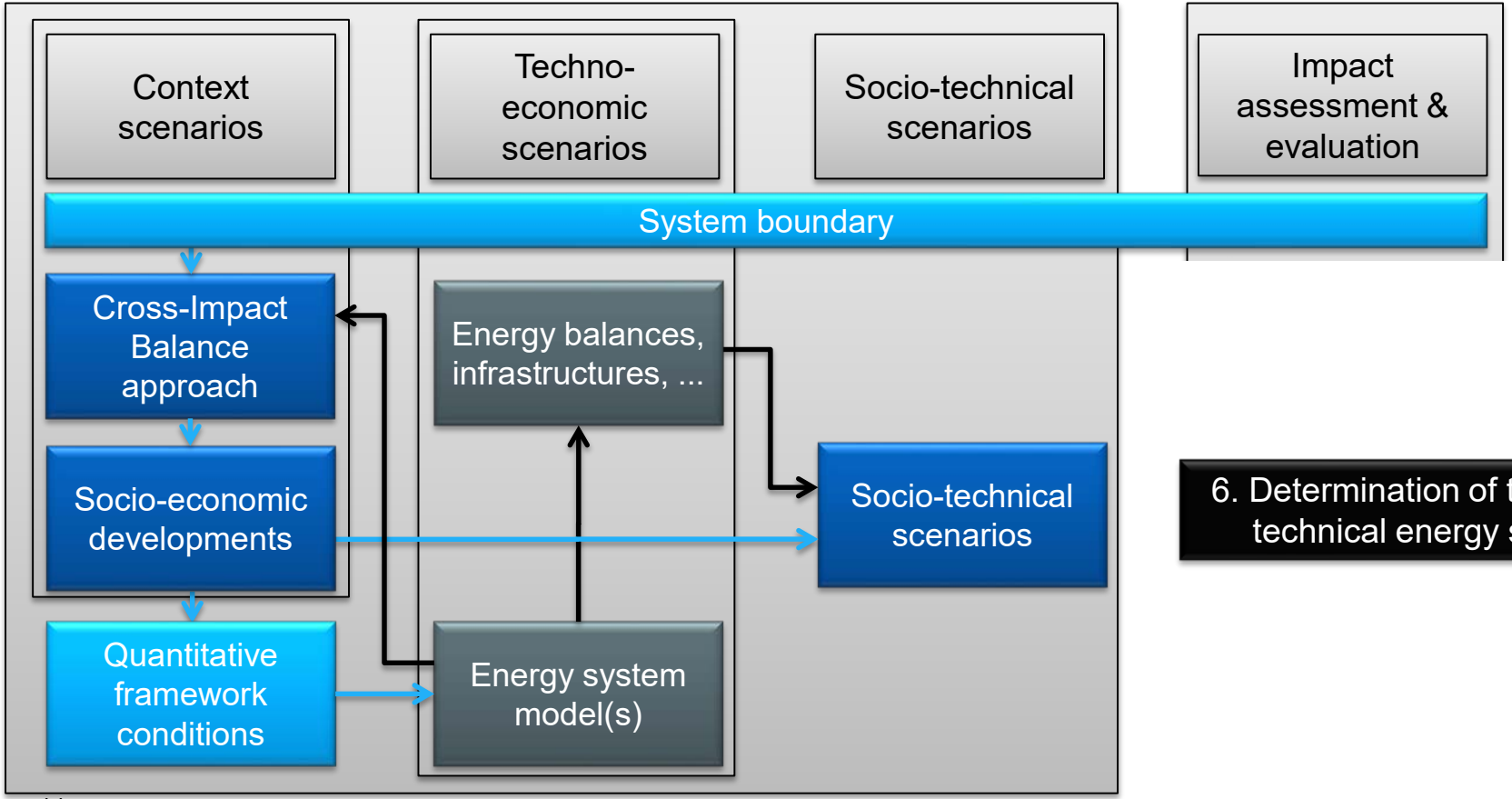
Procedure (I)


Context scenarios
Techno-economic scenarios
Socio-technical scenarios
Impact assessment & evaluation
System boundary
Cross-Impact Balance approach
Socio-economic developments
Quantitative framework conditions
1. Definition of the energy system to be modelled and the associated evaluation system, i.e. the descriptors, variables, parameters and indicators
2. Identification of context scenarios using the Cross-Impact Balance approach
3. Quantification of the relevant framework conditions for the implementation of the context scenarios in the techno-economic scenarios

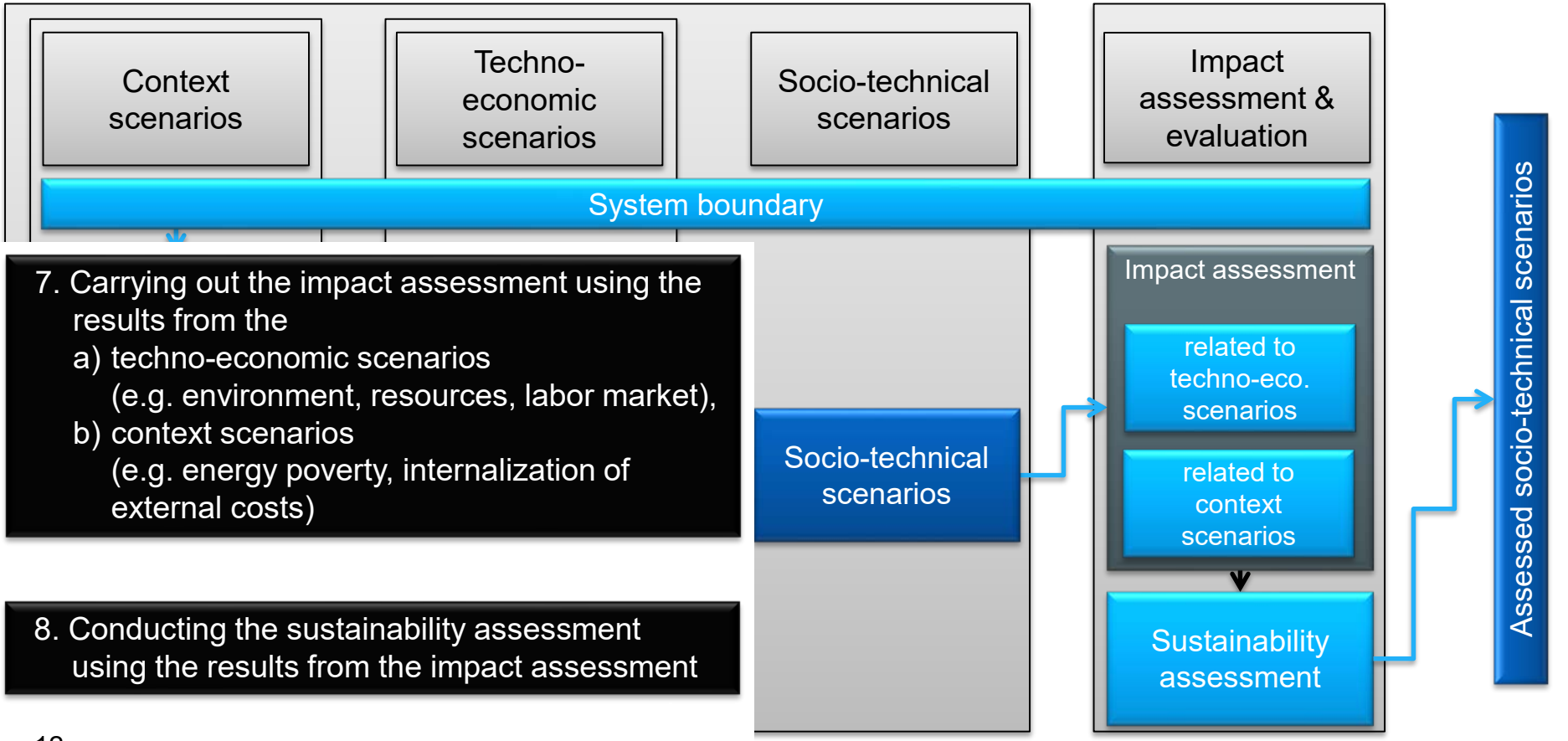
Procedure (II)



Procedure (III)



Procedure (IV)



Expected added value

- Holistic representation and analysis of transforming the energy system
  - National and global socio-economic dynamics (values, policies, education, geopolitical developments, ...) including their uncertainties
  - Interdependent and consistent embedding of the “techno-economic energy system” in the socio-economic framework
- Holistic impact assessment and sustainability assessment
  - Comprehensive impact assessment that considers social as well as techno-economic and environmental impacts
  - Holistic assessment of possible future socio-technical energy systems

⇨ (More) Appropriate breadth of presentation and evaluation of (possible) future transformation processes of the energy system and their effects

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Context scenarios for framing socio-technical scenarios

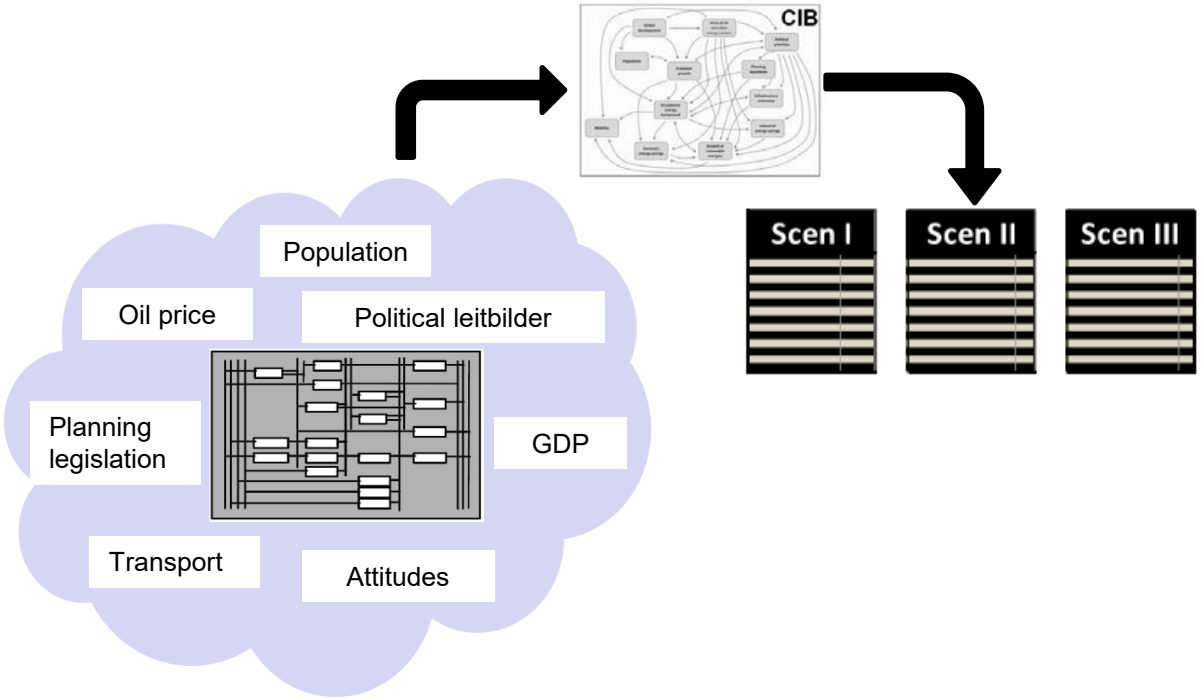
Witold-Roger Poganietz (KIT-ITAS), Stefan Vögele (FZJ-ICE-2)

Objective

- Technological development: not just the result of a “pure” economic optimization
- Developments must be placed in context
- Understanding and modelling transformation processes requires the consideration of factors that are difficult to quantify, including their interaction

➔ Use of Cross-Impact Balance (CIB) analysis

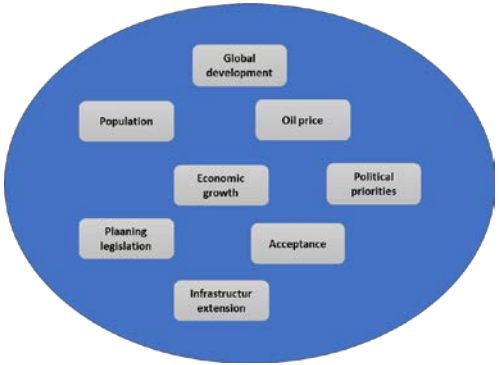
Approach – Cross-Impact Balance analysis (I)



Source: according to Weimer-Jehle (2017)

Approach – Cross-Impact Balance analysis (II)

1. Definition of system boundary and selection of relevant descriptors



2. Determination of possible Variants of the descriptors

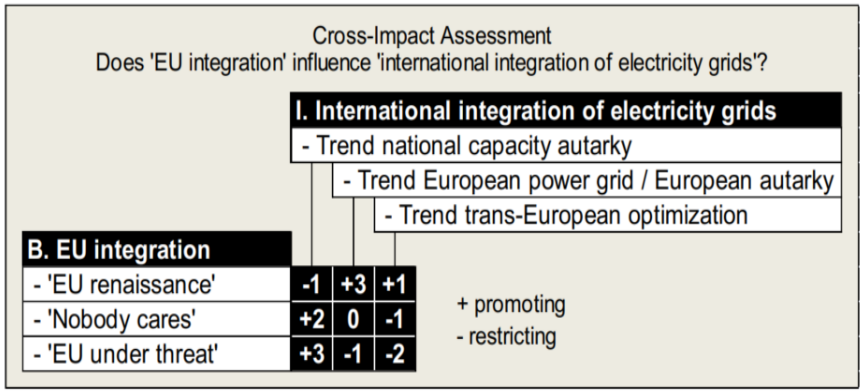
A. Global development	A1 convergence and prosperity	A2 divergence
B. Oil price	B1 moderate growth	B2 rapid growth
C. Population	C1 slowly decreasing	C2 strongly
D. Economic growth	D1 weak	D2 strong
E. Political priority	E1 Energy Change	E2 security
F. Acceptance Energy Change	F1 scepticism	F2 approval
G. Planning legislation	G1 incoherent	G2 promoting speed

Approach – Cross-Impact Balance analysis (III)

3. Concretization of the interrelationship

- Promotion or inhibition of expression of one descriptor by other expression of another descriptor
- Evaluation of the influence from an integer scale (-3, ..., +3)

Example:



Approach – Cross-Impact Balance analysis (IV)

4. Identification of consistent (non-contradictory) scenarios

A set of descriptor variants is consistent if there is no descriptor variant, which is preferred.

	A		B2		C	
	A1	A2	B1	B2	C1	C2
A. Umweltschutz						
A1 schwach			0	0	3	-3
A2 stark			0	0	-3	3
B. Tourismus						
B1 niedrig	0	0			-1	1
B2 hoch	0	0			1	-1
C.Zustand Umwelt						
C1 schlecht	-1	1	3	-3		
C2 gut	0	0	-3	3		
	0	0	-3	3	-3	4

Selected set (A2, B1, C2)
==> There is more evidence for B2 than for B1 (occurrence of variant B2 is more strongly supported than the occurrence of B1)
==> **Set (A2, B1, C2) is inconsistent**

	A		B2		C	
	A1	A2	B1	B2	C1	C2
A. Umweltschutz						
A1 schwach			0	0	3	-3
A2 stark			0	0	-3	3
B. Tourismus						
B1 niedrig	0	0			-1	1
B2 hoch	0	0			1	-1
C.Zustand Umwelt						
C1 schlecht	-1	1	3	-3		
C2 gut	0	0	-3	3		
	0	0	-3	3	-3	4

Selected set (A2, B2, C2):
==> **Set (A2, B2, C2) is consistent**

Selection of relevant descriptors

- Starting point: Descriptors from the Helmholtz project ENERGY-TRANS (2011-2016)
  - Interviewing experts from various fields and with different professional backgrounds
  - 67 expert interviews (Delphi)
- Updating possible descriptor variants to take account of more recent developments (e.g., in the area of demographics, climate policy goals)
- System boundary: Germany in the European context

Source: Pregger et al. (2019). Moving towards socio-technical scenarios of the German energy transition—lessons learned from integrated energy scenario building. Climatic Change (2020) 162:1743–1762. doi.org/10.1007/s10584-019-02598-0

Concretization

Selection of relevant descriptors (I)

International factors

A(I). Global development – general development

A(II). Global development – world market prices for fossil fuels

A(III). Global development – real interest rates

B. EU integration

National factors / General development

C. Population development

Selection of relevant descriptors (II)

National factors / “Economy” sector

D. GDP development

E. Labor market development

F. Development of the service sector compared to industry (Tertiarization)

G. Innovative capacity of the economy

H. Transnational trade flows

I. International interconnectedness of the (electricity) grid system

J. Infrastructural development of the national (electricity) grids

K. Expansion of renewables (electricity)

L. Degree of decentralization of energy supply and storage

M. Market design (electricity)

Selection of relevant descriptors (III)

National factors / “Politics” sector

N. Policy stability related to energy

O. Control instruments in the energy sector

P. Governance of infrastructure expansion

Q. Planning legislation

R. Governmental goals of design

S. Social security regulation

Selection of relevant descriptors (IV)

National factors / “Society” sector

T. Welfare development

U. Acceptance of energy technologies

V. Individual energy demand behavior

W. Educational

National factors / “Culture” sector

X. Social acceptance of the energy transition / NIMBY

Y. Values and principles of market design

Z. Media discourse

Selection of relevant descriptors (V)

11 further “passive” descriptors

Passive descriptors are used to couple context scenarios with techno-economic modelling

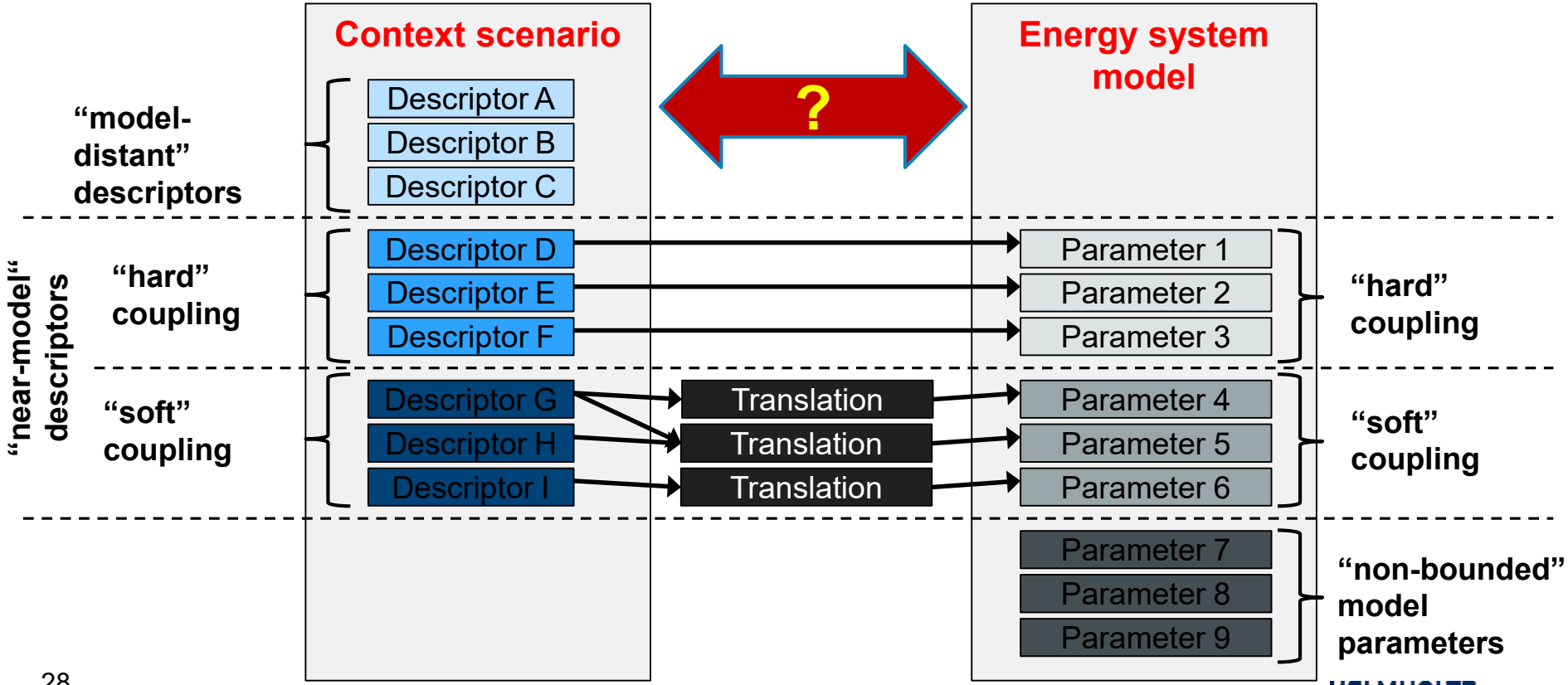
Descriptors

a. Energy demand development – household appliances
b. Efficiency development – electric vehicles
c. Efficiency development – internal combustion engines
d. Renovation rate/ depth
e. Efficiency development – industry
f. Efficiency development – commerce and services
g. District heating
h. Investments in new vehicle concepts and infrastructure
i. Available living space
j. Expansion of renewable heating
k. Rebound effect related to individual energy demand

Coupling of context scenarios with energy system models

Tobias Naegler (DLR-VE), Felix Kullmann (FZJ-ICE-2)

Coupling context scenarios with ESMs: principle



Consideration of model parameters in CIB

1) Identification of exogenous parameters for the energy system model
2) Discursive definition of “model-related” context descriptors:
   Selection criteria are (among others)
   - Descriptor describes central input variable of the model (“hard coupling”)
   - Central input variables of the model can be derived from descriptor(s) (“soft coupling”)

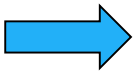
   Boundary conditions to be considered:
   - Limited number of descriptors in total (“close to model” + “far from model”)
   - Sufficient number of well-considered descriptors for the “non-model” context as “glue” for the “story” of the context scenario

   Selection of CIB descriptors taking into account the needs of the model
   → Consistency between context scenario and techno-economic modelling

“Model-related” descriptors (→ Model boundary conditions)

			Descriptor	Unit
International factors		A(I)	Global development – general development	
		A(II)	Global development – world market prices for fossil fuels	$/bbl.
		A(III)	Global development – real interest rates	%
		B	EU integration	
National factors	General	C	Population development	Million
	Economy	D	Economic performance	%/p.a.
		E	Labor market	
		F	Development of the service sector compared to industry	
		G	Innovative capacity of the economy	
		H	Transnational trade flows	
		I	International interconnectedness of the grid system	
		J	Infrastructural development of the national grid	
		K	Expansion of renewables (electricity)	TWh/a
		L	Degree of decentralization of energy supply and storage	
		M	Market design (electricity)	
	Politics	N	Policy stability related to energy	
		O	Policy instruments related to energy	
		P	Governance of infrastructure expansion	
		Q	Planning legislation	
		R	Governmental goals of design	
		S	Social security regulation	
	Society	T	Welfare development	
		U	Acceptance of energy technologies	
		V	Individual energy demand behavior	
		W	Education	
	Culture	X	Social acceptance of the energy transition / NIMBY	
		Y	Values and principles of market design	
		Z	Media discourse	
	Passive descriptors for energy system	a	Energy demand development – household appliances	%/a
		b	Efficiency development – electric vehicles	%/a
		c	Efficiency development – internal combustion engines	%/a
		d(I)	Renovation rate – residential buildings	%/a
		d(II)	Renovation depth – residential buildings	%
		e	Efficiency development – industry	%/a
		f	Efficiency development – commerce and services	%/a
		g	District heating	%/a
		h	Investments in new vehicle concepts and infrastructure	%/a
		i	Available living space	m^2/person
		j	Expansion of renewable heating	TWh/a
		k	Rebound effect related to individual energy demand	

- **“Model-related” descriptors:**
  - Energy prices, interest rates
  - Population, GDP
  - Consumer behavior, value orientation, media discourse
  - “Passive" descriptors (focus on energy requirements):
    - Refurbishment of existing buildings
    - Efficiency development for household appliances, industry, commercial, trade and services, vehicles
- **Derived boundary conditions for modelling**:
  - Living space, energy consumption per living space
  - Production of goods, Gross Value Added (GVA) of individual sectors
  - Freight and passenger transport performance / modal split



- **Energy demand** largely determined by context scenario
- **Technology mix** is **optimized** endogenously

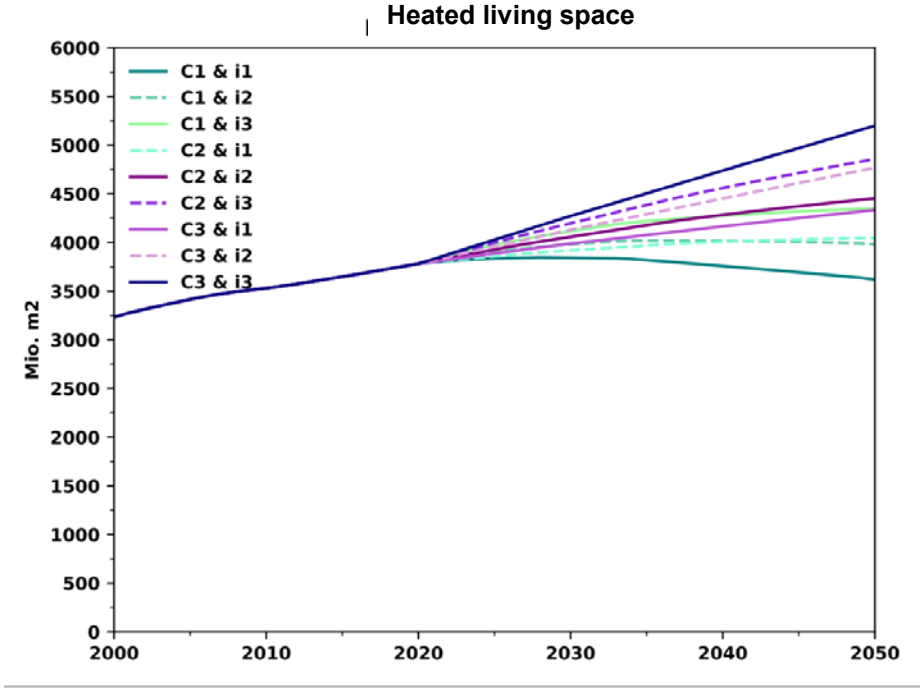
Exogenous model parameters determined by the context

- Population, GDP
- Building:
  - Available living space
  - Space heating requirement per m^2
- Industry:
  - Production volumes of selected goods
  - GVA for selected sectors
- Traffic:
  - Freight and passenger transport performance
  - Modal split
- Cost factors:
  - Energy source prices
  - Interest

- Demand for energy services strongly determined by context scenario
- Technology mix is optimized endogenously
- In the future, specifications from the context scenario regarding technology mix and expansion potential are also being considered

Example: Heated living space

- Relevant context descriptors:
  - C. Population development
  - i. Available living space (per capita; housing trends)
- Sources for temporal development of descriptors:
  - Population: Energy Data of the German Federal Ministry of Economic Affairs and Climate Action (“BMWK energy data”), Federal Statistical Office of Germany (12th and 14th Coordinated Population Projection)
  - Housing trends: linear development today (from BMWK energy data) to target year assumed

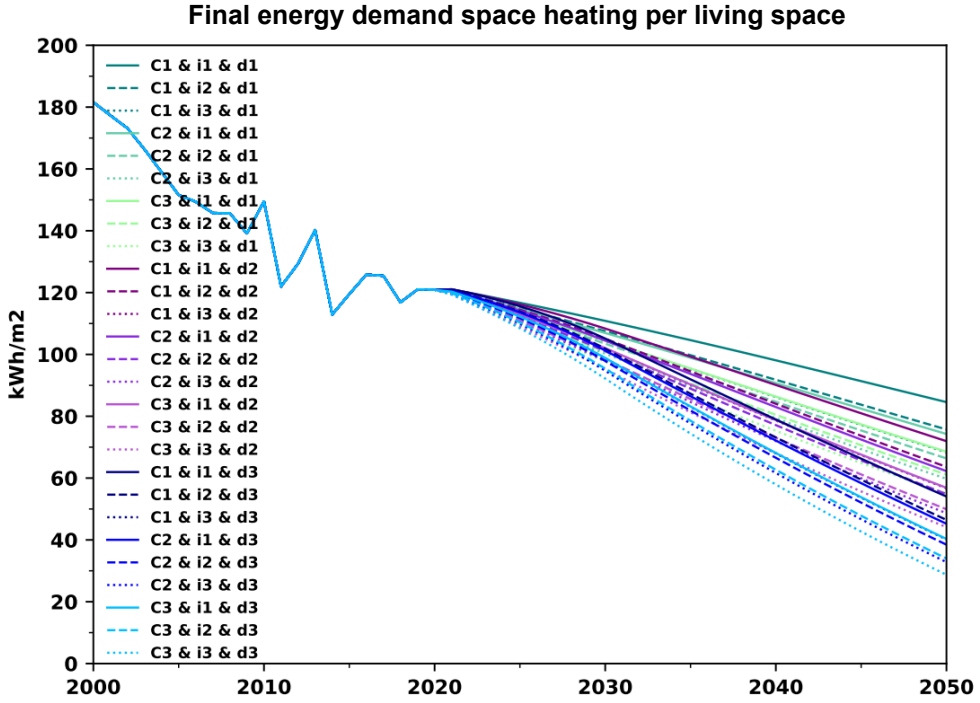


BMWK energy data: Energiedaten – Gesamtausgabe (as of 20.1.2022)
Federal Statistical Office of Germany: 12th coordinated population projection
Federal Statistical Office of Germany: 14th coordinated population projection

Example: Final energy demand space heating per living space

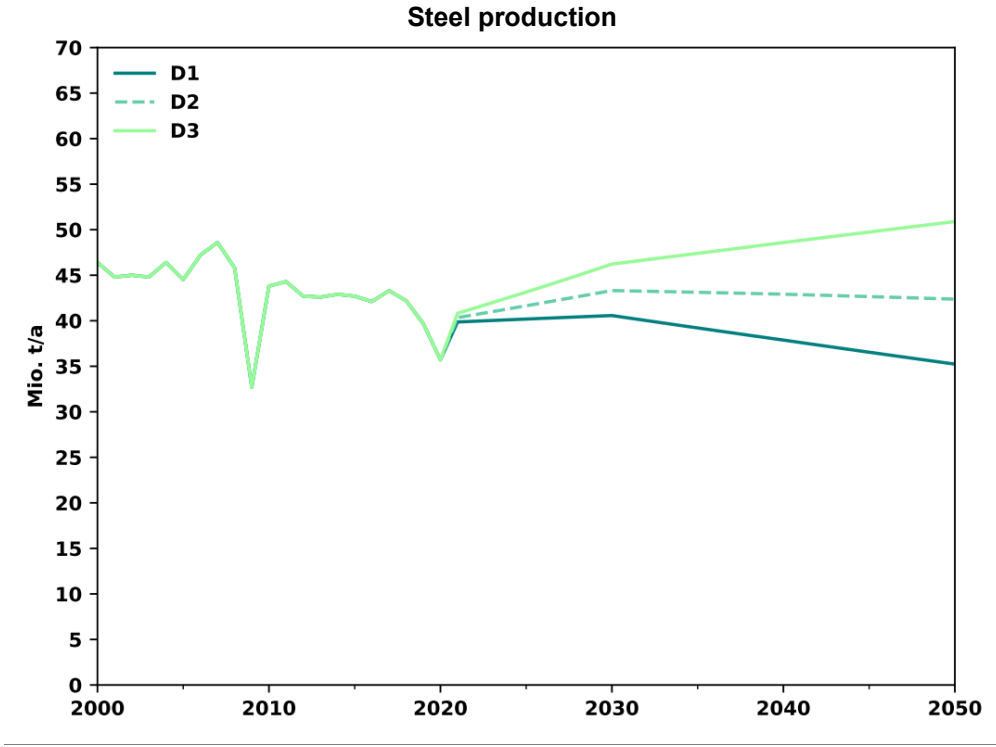
- Relevant context descriptors:
  - C. Population development
  - i. Available living space (per capita; housing trends)
  - d. Refurbishment of existing buildings
- Sources for development over time
  - Living space: see previous slide
  - Renovation of existing buildings: own assumptions

  → Inputs of a simple building model



Example: Steel production

- Relevant context descriptor:
  - D. GDP development
- Development over time until target year
  - GDP: calculation using descriptor assumptions (growth rate per year)
  - Further assumptions:
    - Extrapolation Trend GVA-GDP ratio (from BMWK Energy Data)
    - Shares of individual sectors in GVA (manufacturing industry) from BMWK Long-term scenarios 2021
    - Ratio of steel production to GVA steel sector from BMKW Long-term scenarios 2021

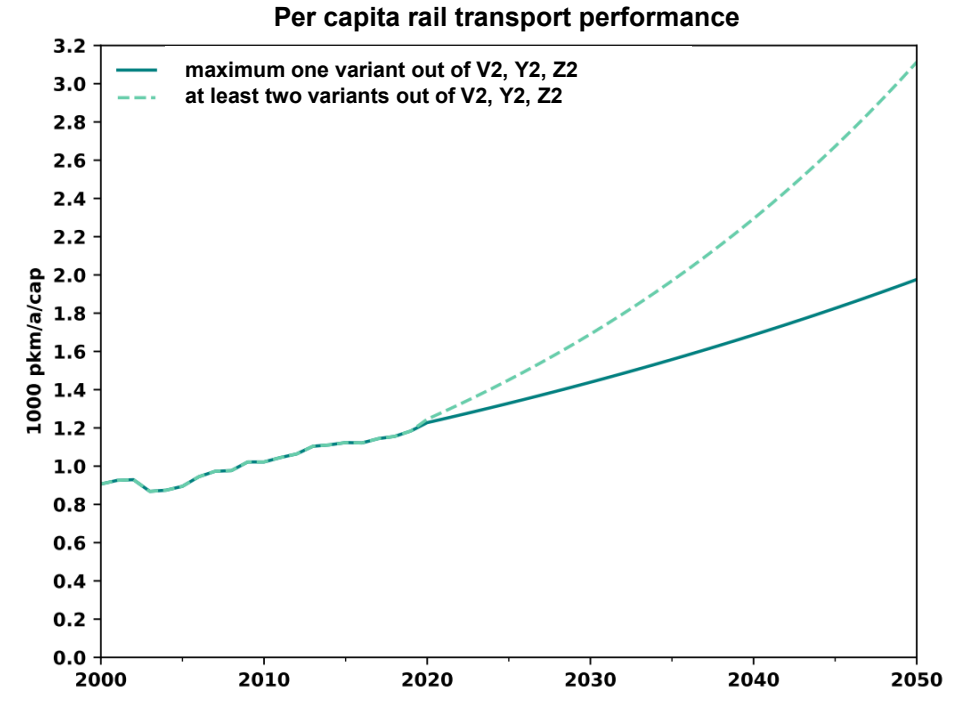


BMWK Energy Data: Energiedaten – Gesamtausgabe (Stand 20.1.2022)
BMWK Long-term scenarios 2021: Langfristszenarien für die Transformation des Energiesystems in Deutschland

Example: Per capita rail transport performance

- Relevant context descriptors:
  - V. Individual energy consumption behavior
  - Y. Value orientation and objectives for economic design
  - Z. Media discourse
- Target values 2050 and timeline:

  Own assumptions based on dena (2021), Agora Energiewende (2021), BMWK long-term scenarios (2021)



Agora Energiewende 2021: Klimaneutrales Deutschland 2045
BMWK long-term scenarios 2021: Langfristszenarien für die Transformation des Energiesystems in Deutschland
dena 2021: dena-Leitstudie Aufbruch Klimaneutralität

Outlook

Other possible constraints of descriptors on model parameters

- Import volumes and / or import costs of hydrogen may depend on:
  - A(I). Global development – general development
  - B. EU integration
  - H. Transnational trade flows
  - ...
- National expansion potential for wind and heat pumps could depend on:
  - U. Technology acceptance towards energy technologies
  - X. Attitude of the population towards the energy transition / NIMBY
  - ...

Often no simple solution as to how model parameters can be derived from the context descriptors → Expert knowledge required!

Conclusions

- Ideally, context descriptors are always selected in coordination with the energy system model to be coupled
- Objective: Context descriptors determine central variables exogenously specified for the model
  → Techno-economic modelling follows the “history” of the context scenario
- Coupling can be “hard” or “soft”
  - “hard”: Descriptor largely corresponds to model input figure
  - “soft”: Model input is calculated from one descriptor or several descriptors (“translation”)
- “Translation” can vary in complexity and may take into account
  - further own sub-models,
  - results of external studies, and
  - expert assessments

Description of the socio-economic contexts

Stefan Vögele (FZJ-ICE-2), Witold-Roger Poganietz (KIT-ITAS)

Preliminary remarks

- Over 1500 consistent combinations of contexts ➔ Selection required
- Objective: To show ranges
- Pre-selection of potentially target-fulfilling scenarios using a simple scenario tool

Preliminary remarks

- Clustering according to scenarios with moderate, low and high economic and population growth
- Next selection step: Select as many different scenarios as possible
- In addition, selection of a scenario with a high degree of sustainability

Context scenario	General description / guiding principle
Mean	Moderate development of the economy and population
NH_max	Focus: High degree of sustainability
LO	Low economic and population growth
HI	Strong economic and population growth

Selected socio-economic contexts

(**Green: direct link to techno-economic model, yellow: change compared to MEAN**)

	MEAN	NH_max	LO	HI
Global development – general development	Fortress world	Fortress world	Fortress world	Market forces
EU integration	EU renaissance	EU renaissance	EU under threat	Nobody cares
Population development	Slight decrease	Moderate increase	Sharp decrease	Moderate increase
Economic performance	Moderate	Strong	Weak	Strong
Innovative capacity of the economy	Unchanged	Improving	Declining	Improving
Transnational trade flows	European orientation – Focus on services	European orientation	Renationalization	European orientation – Focus on services
International interconnectedness of the (electricity) grid system	Trend towards stronger European grid	Trend towards stronger European grid	Trend towards stronger European grid	Trend towards national self-sufficiency
Individual energy demand behavior	Trend towards affinity with technology	Trend towards affinity with technology	Trend towards thriftiness	Trend towards affinity with technology
Values and principles of market design	Trend towards differentiation	Trend towards post-materialism	Trend towards materialism and meritocracy	Trend towards materialism and meritocracy

Socio-economic context “MEAN” (I)

- **Global development – general development:** growing inequalities, increasing demand for resources, armed conflicts are becoming more frequent
- **EU integration:** European integration is progressing
- Relatively low **population decline** (-2.4 million compared to 2022)
- **Economic performance:** Moderate development of GDP (+1.2 % p.a.)
- **Innovative capacity of the economy:** still good, but not outstanding, remains at the current level
- **Transnational trade flows:** Importance of international trade linkages increases, mainly due to expansion of intra-EU trade linkages, but with a focus on services

Socio-economic context “MEAN” (II)

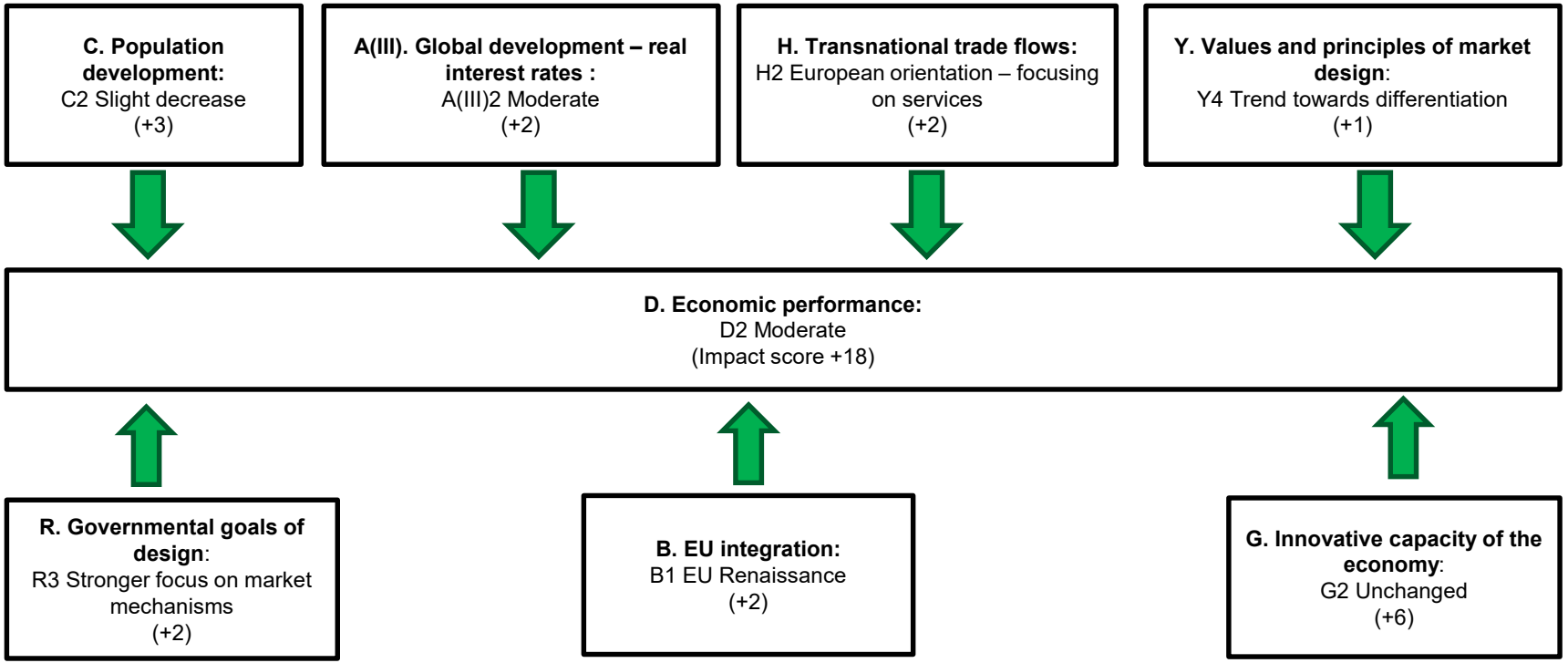
- **International interconnectedness of the (electricity) grid system:** trend towards a stronger European electricity network
- **Individual energy demand behavior:** Trend towards affinity with technology
- **Values and principles of market design:** trend towards differentiation, values such as performance, material growth, experience orientation, general sense of community, etc. are equally represented in society

Socio-economic context “MEAN” (Excerpt)

		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	T	U	V	W	X	Y
		B1	C3	D2	E3	F2	G2	H2	I2	J1	K4	L3	M1	N3	O3	P1	Q4	R3	T3	U3	V3	W2	X1	Y4
A(I). Global development – general development	A(I)3 Fortress World																							
B. EU integration	B1 EU Renaissance																							
C. Population development	C2 Slight increase																							
D. Economic performance	D2 Moderate																							
E. Labor market	E3 Divided labor market																							
F. Tertiarization of the economy	F2 Strong tertiarization																							
G. Innovative capacity of the economy	G2 Unchanged																							
H. Transnational trade flows	H2 European orientation																							
I. Internat. interconnectedness of the grid system	I2 Trend towards European grid																							
J. Infrastructural development of the national grid	J1 Needs-based																							
K. Expansion of renewables (electricity)	K4 Strong																							
L. Centrality/decentrality electricity generation	L3 Trend towards decentr. system architecture																							
M. Market design (electricity)	M1 Security of supply through the market																							
N. Policy stability related to energy	N3 Improving																							
O. Policy instruments related to energy	O3 Preference for technology-specific instruments																							
P. Governance in infrastructure development	P1 Trend towards coordinated expansion																							
Q. Planning legislation	Q4 Compromise																							
R. Governmental goals of design	R3 Stronger focus on market mechanisms																							
T. Welfare development	T3 Increasing inequality																							
U. Acceptance of energy technologies	U3 Slightly increasing																							
V. Individual energy demand behavior	V3 Trend towards affinity with technology																							
W. Education	W2 Focus on STEM																							
X. Social acceptance of the energy transition	X1 Trend to be supportive																							
Y. Values and principles of market design	Y4 Trend towards differentiation																							

Legend: **Green:** supporting influence, **red**: inhibiting influence

Socio-economic context “MEAN” – Example of GDP development



Legend: Green: supporting influence, **red**: inhibiting influence

Socio-economic context “NH_max”

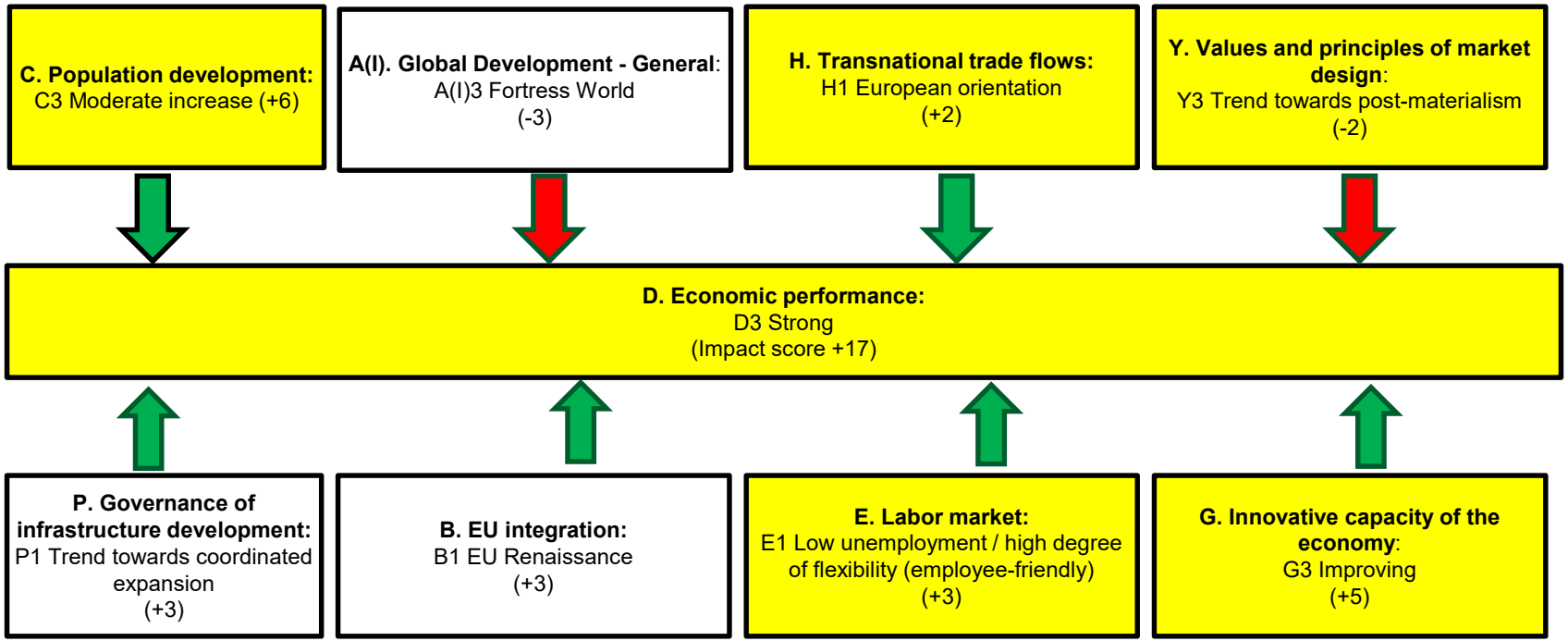
- **Moderate population increase** (+2.0 million compared to 2022)
- **Economic performance:** Strong development of GDP (+1.8% p.a.)
- Germany is continuously **improving the innovative capacity of** its economy and will be a global leader by 2050
- The importance of **international trade links is increasing**, particularly due to the expansion of intra-EU trade links
- **Decoupling** prosperity from material consumption, more careful use of resources
- Greater focus **on citizen participation and transparency**

Socio-economic context “NH_max” (Excerpt)

		C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	T	U	V	W	X	Y
		C4	D3	E1	F2	G3	H2	I2	J1	K4	L3	M1	N3	O3	P1	Q2	R2	T4	U3	V3	W1	X1	Y3
A(I). Global development – general development	A(I)3 Fortress World																						
B. EU integration	B1 EU Renaissance																						
C. Population development	C3 Moderate increase																						
D. Economic performance	D3 Strong																						
E. Labor market	E1 Low unemployment																						
F. Tertiarization of the economy	F2 Strong tertiarization																						
G. Innovative capacity of the economy	G3 Improving																						
H. Transnational trade flows	H2 European orientation																						
I. Internat. interconnectedness of the grid system	I2 Trend towards stronger European grid																						
J. Infrastructural development of the national grid	J1 Needs-based																						
K. Expansion of renewables (electricity)	K4 Strong																						
L. Centrality/decentrality electricity generation	L3 Trend towards a decentr. systems architecture																						
M. Market design (electricity)	M1 Security of supply by government																						
N. Policy stability related to energy	N3 Improving																						
O. Policy instruments related to energy	O3 Preference for technology-unspec. instruments																						
P. Governance in infrastructure development	P1 Trend towards coordinated expansion																						
Q. Planning legislation	Q2 Focus on legitimization and acceptance																						
R. Governmental goals of design	R2 Stronger focus on citizen participation																						
T. Welfare development	T4 Constant inequality																						
U. Acceptance of energy technologies	U3 Slightly increasing																						
V. Individual energy demand behavior	V3 Trend towards affinity with technology																						
W. Education	W1 Focus on STEM																						
X. Social acceptance of the energy transition	X1 Trend to be supportive																						
Y. Values and principles of market design	Y4 Trend towards post-materialism																						

Legend: **Green:** supporting influence, **red**: inhibiting influence

Socio-economic context "NH_max" – Example of GDP development



Legend: Green: supporting influence, **red**: inhibiting influence, yellow boxes: deviation from Scenario MEAN

Socio-economic context “LO”

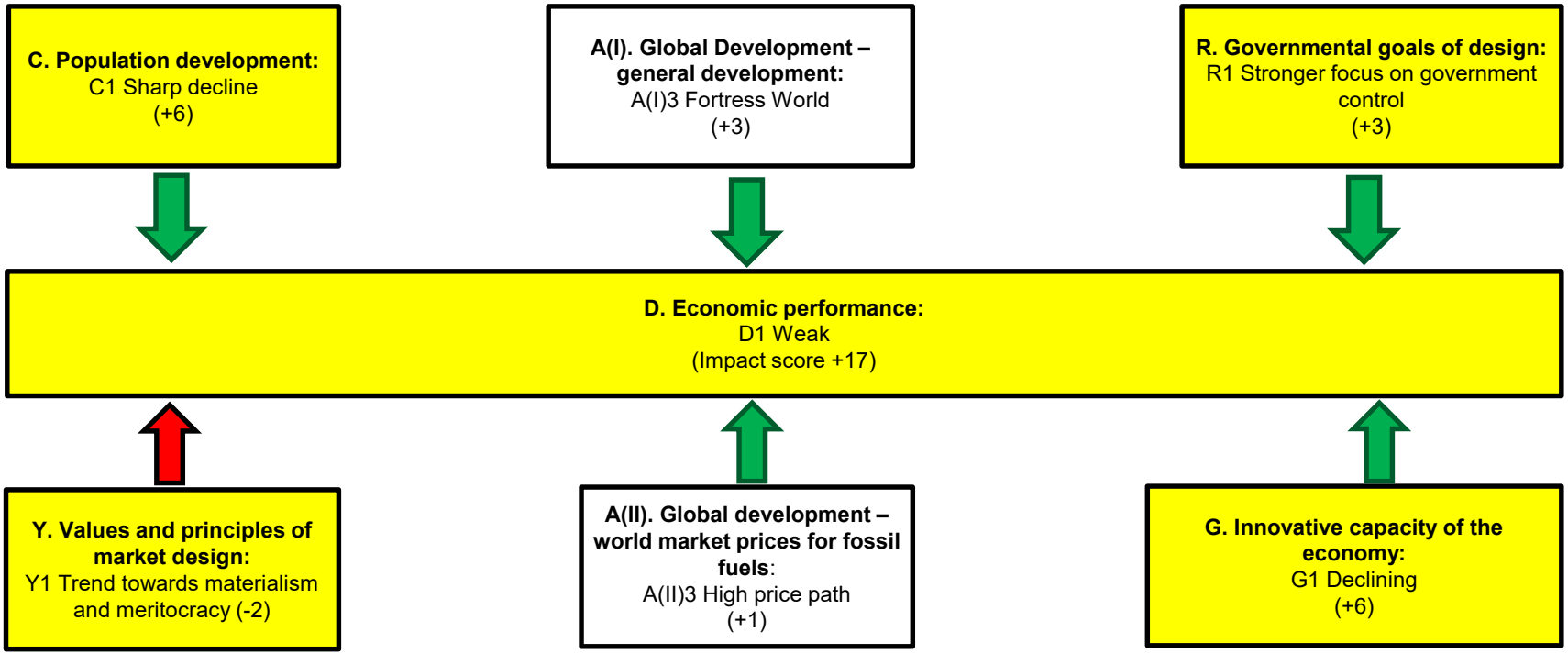
- **National objectives come to the fore**, no uniform energy and climate policy, withdrawal of states from the EU
- **Sharp population decline** (-9.3 million compared to 2022)
- **Economic performance:** Weak increase in GDP (+0.6% p.a.)
- The conditions for **innovative capability** are **deteriorating**. Germany's ability to innovate is falling below that of other economies
- **Reintegration of value chains** in the individual countries
- **Individual energy demand behavior:** Reluctance to buy efficient appliances
- **Material consumption** plays a major role as a target figure

Socio-economic context “LO” (Excerpt)

		C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
		C1	D1	E1	F1	G1	H1	I1	J1	K1	L1	M1	N1	O1	P1	Q1	R1	S1	T1	U1	V1	W1	X1	Y1
A(I). Global development – general development	A(I)1 Fortress World																							
B. EU integration	B1 EU under threat																							
C. Population development	C1 Sharp decrease																							
D. Economic performance	D1 Weak																							
E. Labor market	E1 Divided labor market																							
F. Tertiarization of the economy	F1 Weak tertiarization																							
G. Innovative capacity of the economy	G1 Declining																							
H. Transnational trade flows	H1 Renationalization																							
I. Internat. interconnectedness of the grid system	I1 Trend towards stronger European grid																							
J. Infrastructural development of the national grid	J1 Needs-based																							
K. Expansion of renewables (electricity)	K1 Strong																							
L. Centrality/decentrality electricity generation	L1 Trend towards mixed structure																							
M. Market design (electricity)	M1 Security of supply by government																							
N. Policy stability related to energy	N1 Improving																							
O. Policy instruments related to energy	O1 Preference for technology-specific instruments																							
P. Governance in infrastructure development	P1 Trend towards coordinated expansion																							
Q. Planning legislation	Q1 Compromise																							
R. Governmental goals of design	R1 Stronger focus on government control																							
T. Welfare development	T1 Increasing inequality																							
U. Acceptance of energy technologies	U1 Slightly increasing																							
V. Individual energy demand behavior	V1 Trend towards thriftiness																							
W. Education	W1 Focus on STEM																							
X. Social acceptance of the energy transition	X1 Trend to be supportive																							
Y. Values and principles of market design	Y1 Trend towards materialism …																							

Legend: **Green:** supporting influence, **red**: inhibiting influence

Socio-economic context "LO" – Example of GDP development



Legend: Green: supporting influence, **red**: inhibiting influence, yellow boxes: deviation from Scenario MEAN

Socio-economic context “HI”

- **Trade barriers continue to** be **dismantled**
- **European integration at a standstill**
- **Moderate increase of population** (+2.0 million compared to 2022)
- **Strong economic growth** (+1.8% p.a.)
- Germany **is** continuously **improving the innovative capacity of** its economy and will be a global leader by 2050.
- **International integration of the electricity grids is not being driven forward**, security of supply is ensured through national power self-sufficiency
- **Material consumption** plays a major role as a target figure

Socio-economic context “HI” (Excerpt)

		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	T	U	V	W	Y
		B2	C4	D3	E1	F2	G3	H2	I1	J1	K4	L3	M3	N3	O2	P2	Q2	R2	T4	U3	V3	W1	Y1
A(I). Global development – general development	A(I)1 Market Forces																						
B. EU integration	B2 Nobody Cares																						
C. Population development	C3 Moderate increase																						
D. Economic performance	D3 Strong																						
E. Labor market	E1 Low unemployment																						
F. Tertiarization of the economy	F2 Strong tertiarization																						
G. Innovative capacity of the economy	G3 Improving																						
H. Transnational trade flows	H2 European orientation																						
I. Internat. interconnectedness of the grid system	I1 Trend towards national self-sufficiency																						
J. Infrastructural development of the national grid	J1 Needs-based																						
K. Expansion of renewables (electricity)	K4 Strong																						
L. Centrality/decentrality electricity generation	L3 Trend towards a decentr. system architecture																						
M. Market design (electricity)	M3 Security of supply by government																						
N. Policy stability related to energy	N3 Improving																						
O. Policy instruments related to energy	O2 Preference for technology-specific instruments																						
P. Governance in infrastructure development	P2 Trend towards non-coordinated expansion																						
Q. Planning legislation	Q2 Focus on legitimization and acceptance																						
R. Governmental goals of design	R2 Stronger focus on citizen participation																						
T. Welfare development	T4 Unchanged inequality																						
U. Acceptance of energy technologies	U3 Slightly increasing																						
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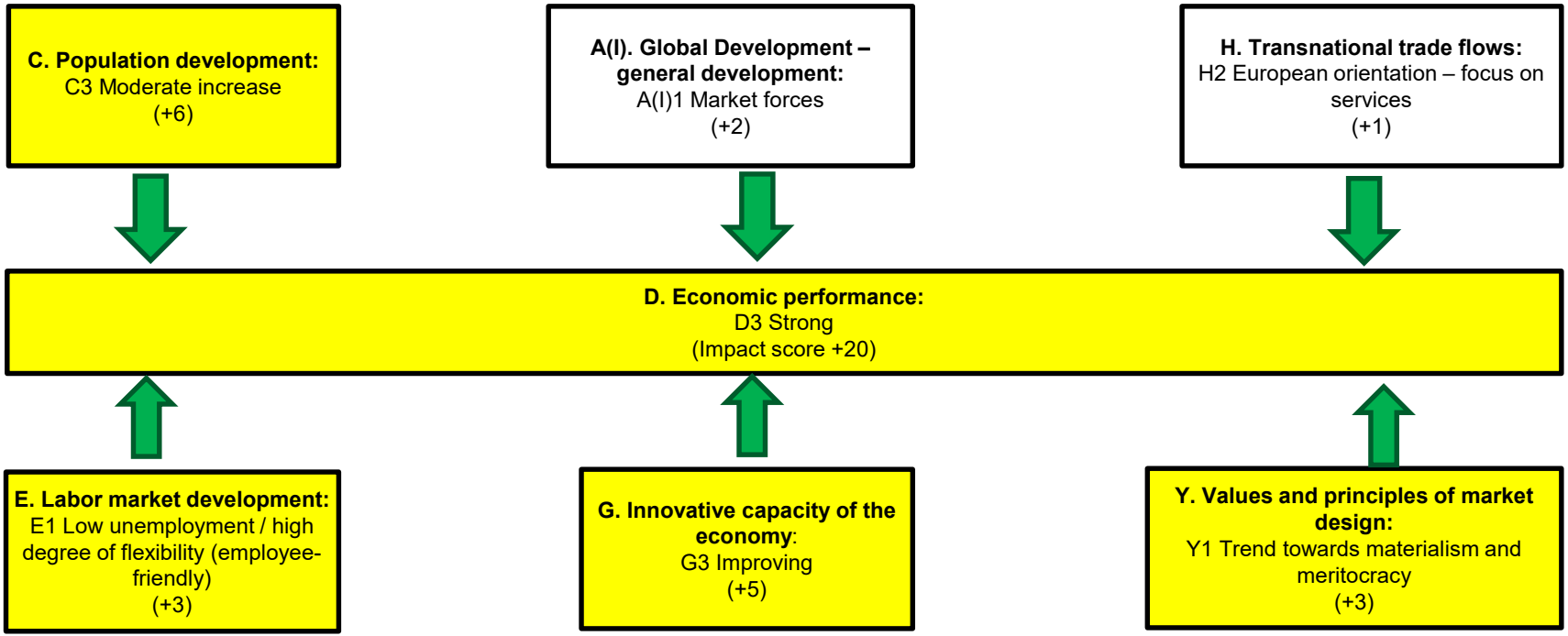
X. Social acceptance of the energy transition	Y1 Trend towards materialism …																						

Legend: **Green:** supporting influence, **red**: inhibiting influence

Socio-economic context “HI” – Example of GDP development



Legend: Green: supporting influence, **red**: inhibiting influence, yellow boxes: deviation from Scenario MEAN

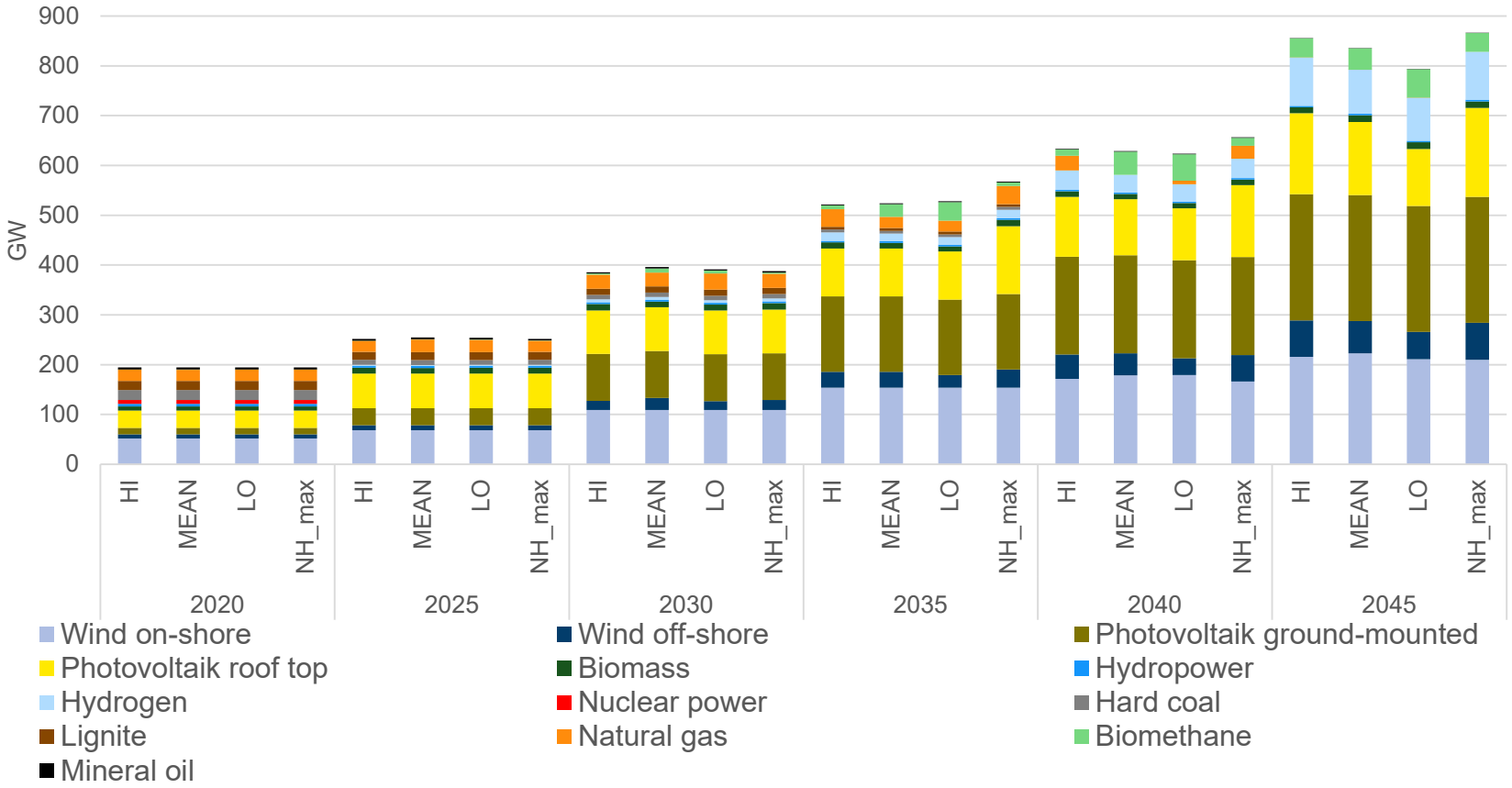
Summary

- Currently focusing on four selected contexts
- Information on “out of the box” context scenarios is generally available
- Descriptor list or list of descriptor variants can always be extended

Results of the energy system modelling

Felix Kullmann (FZJ-ICE-2), Tobias Naegler (DLR-VE)

Electricity generation capacity



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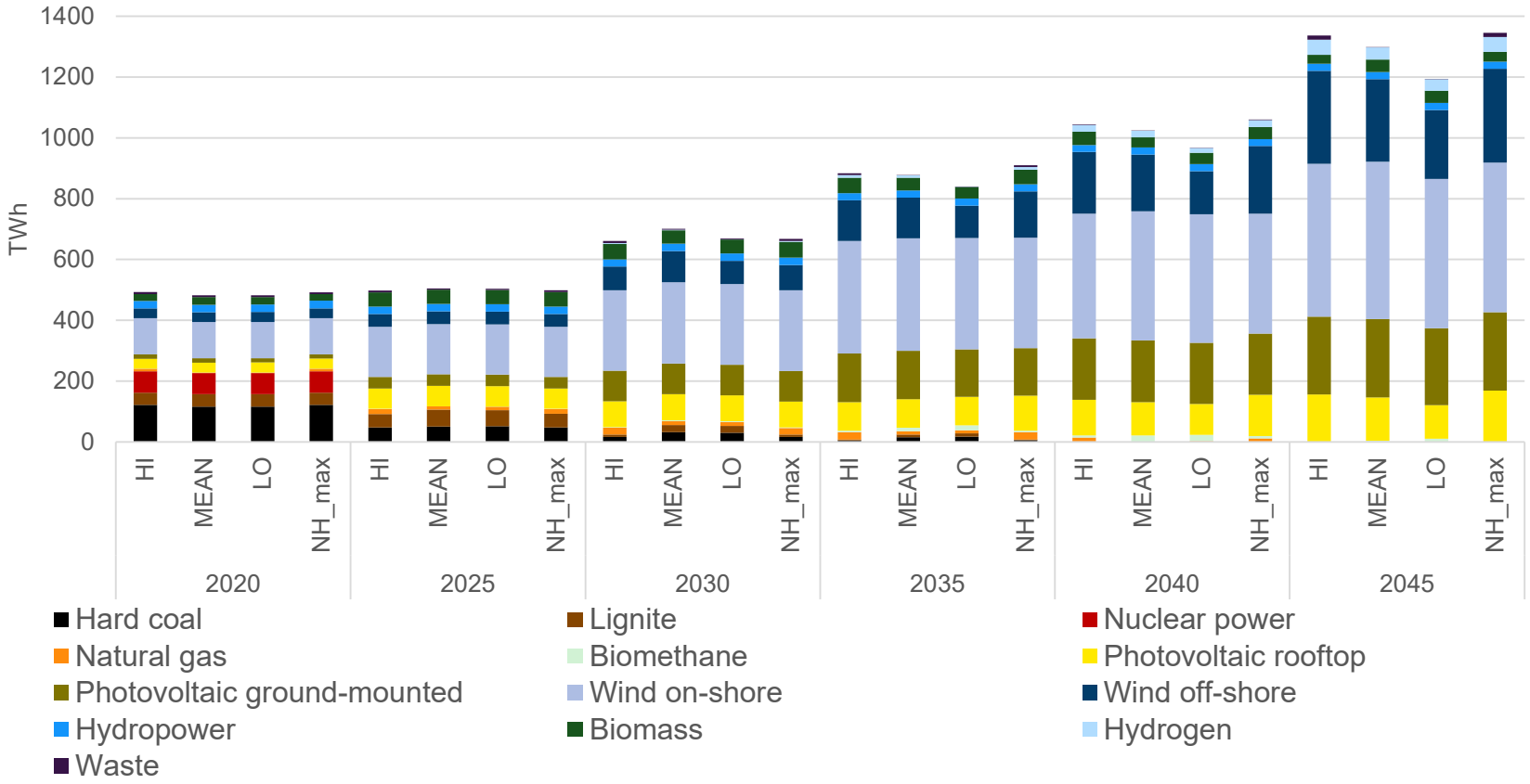
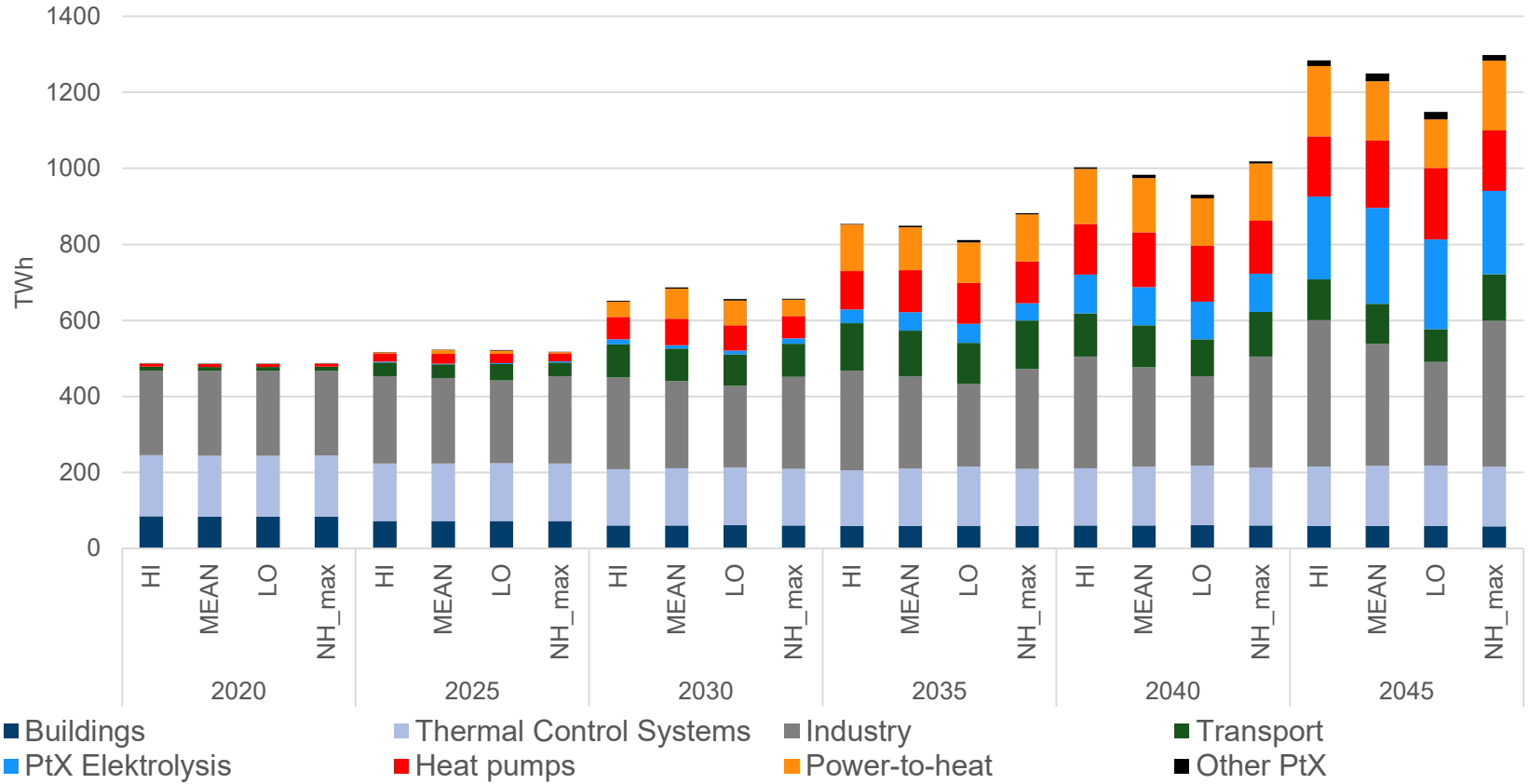
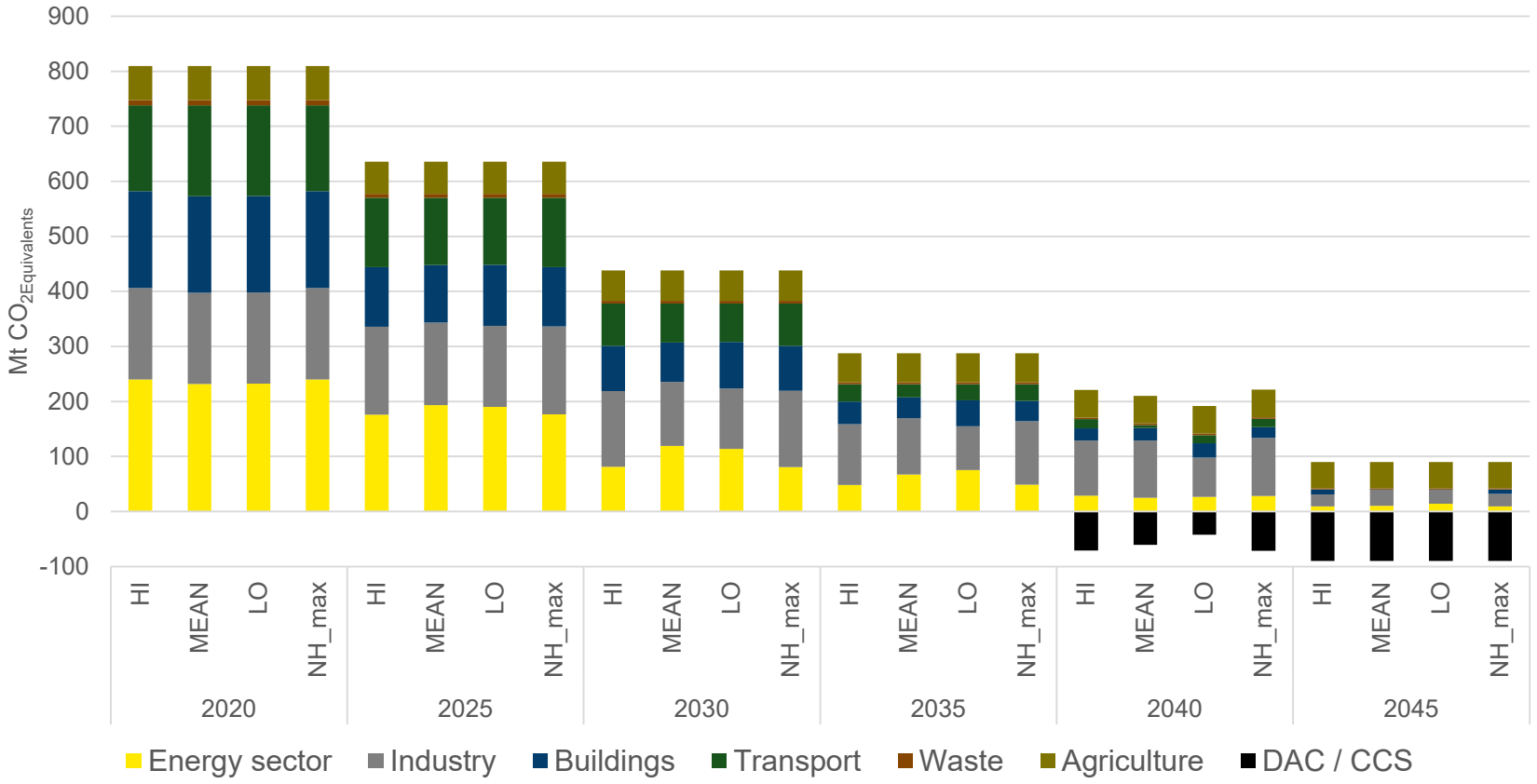
Electricity production



Electricity consumption

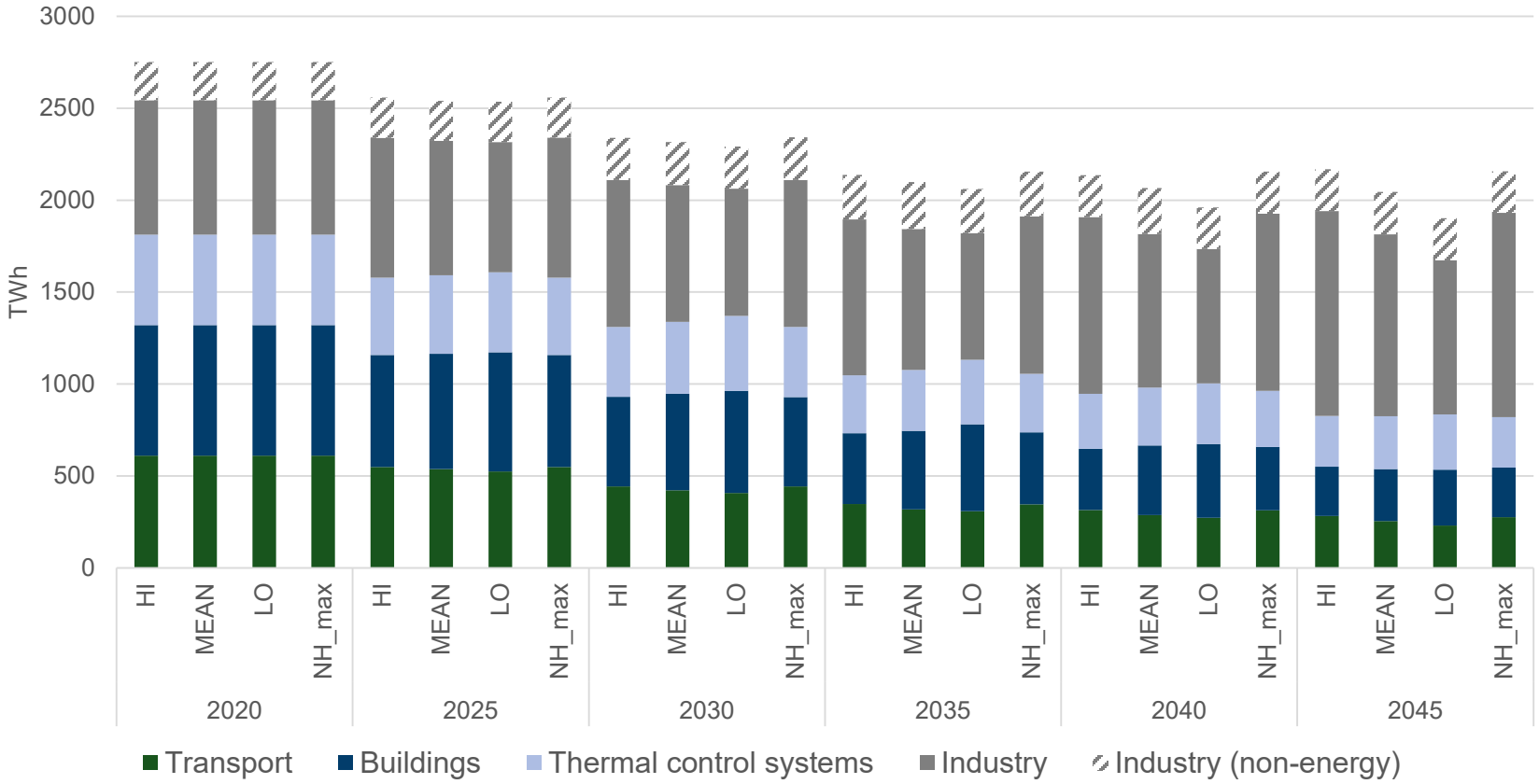


Greenhouse gas emissions



DAC: Direct Air Capture; CCS: Carbon Capture and Storage

Final energy demand



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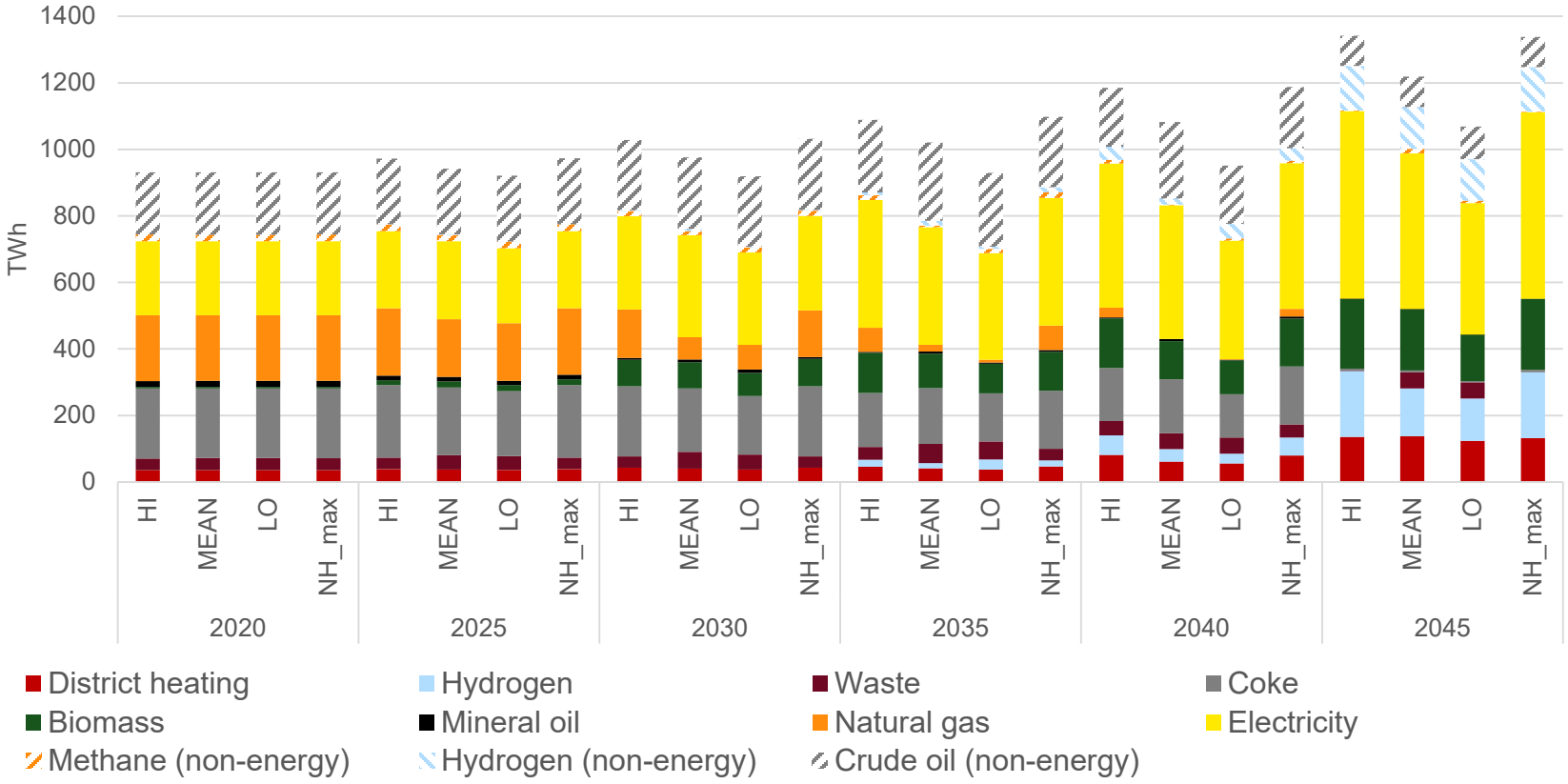
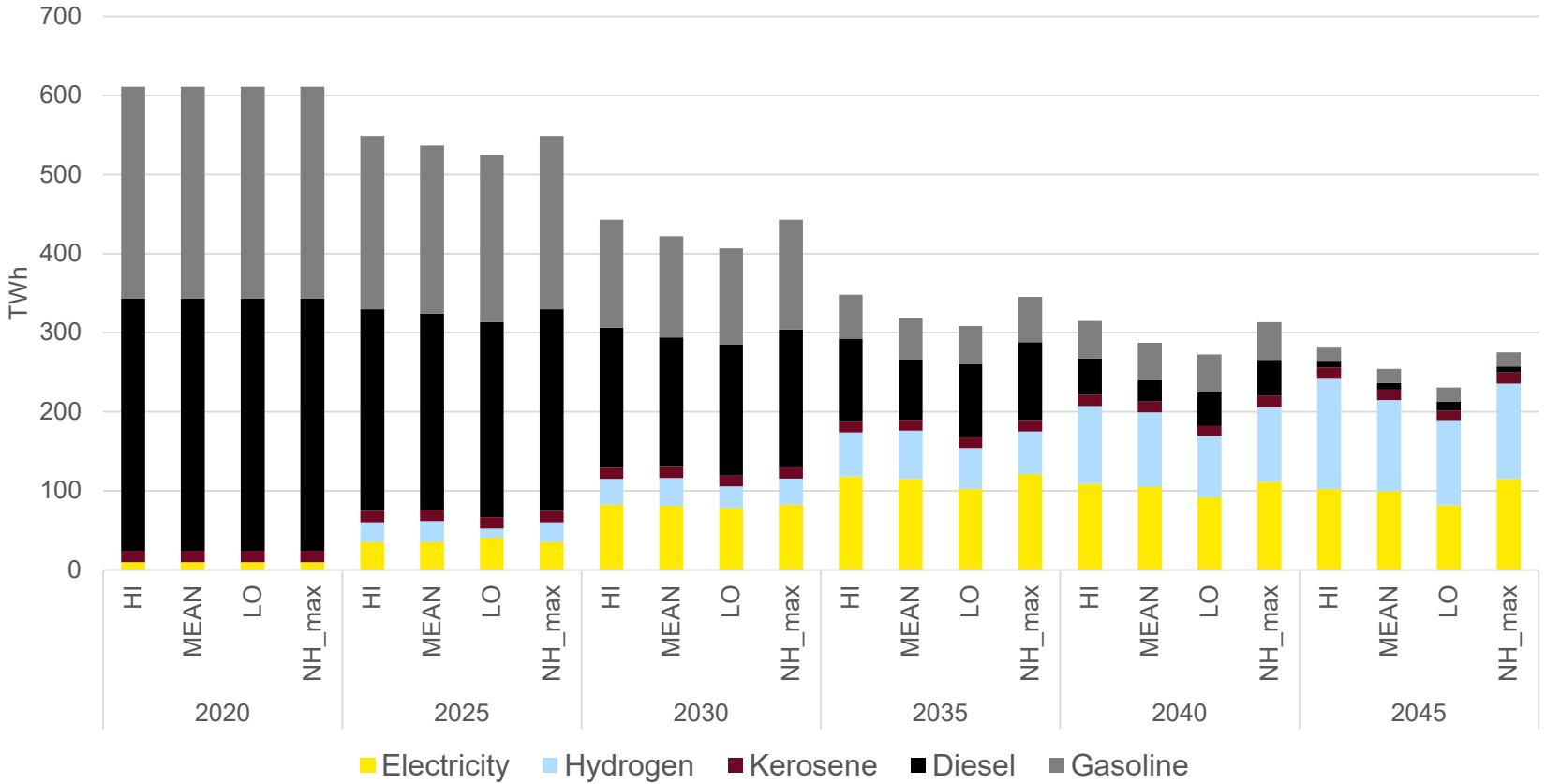
Final energy demand – Industry



Final energy demand – Transport



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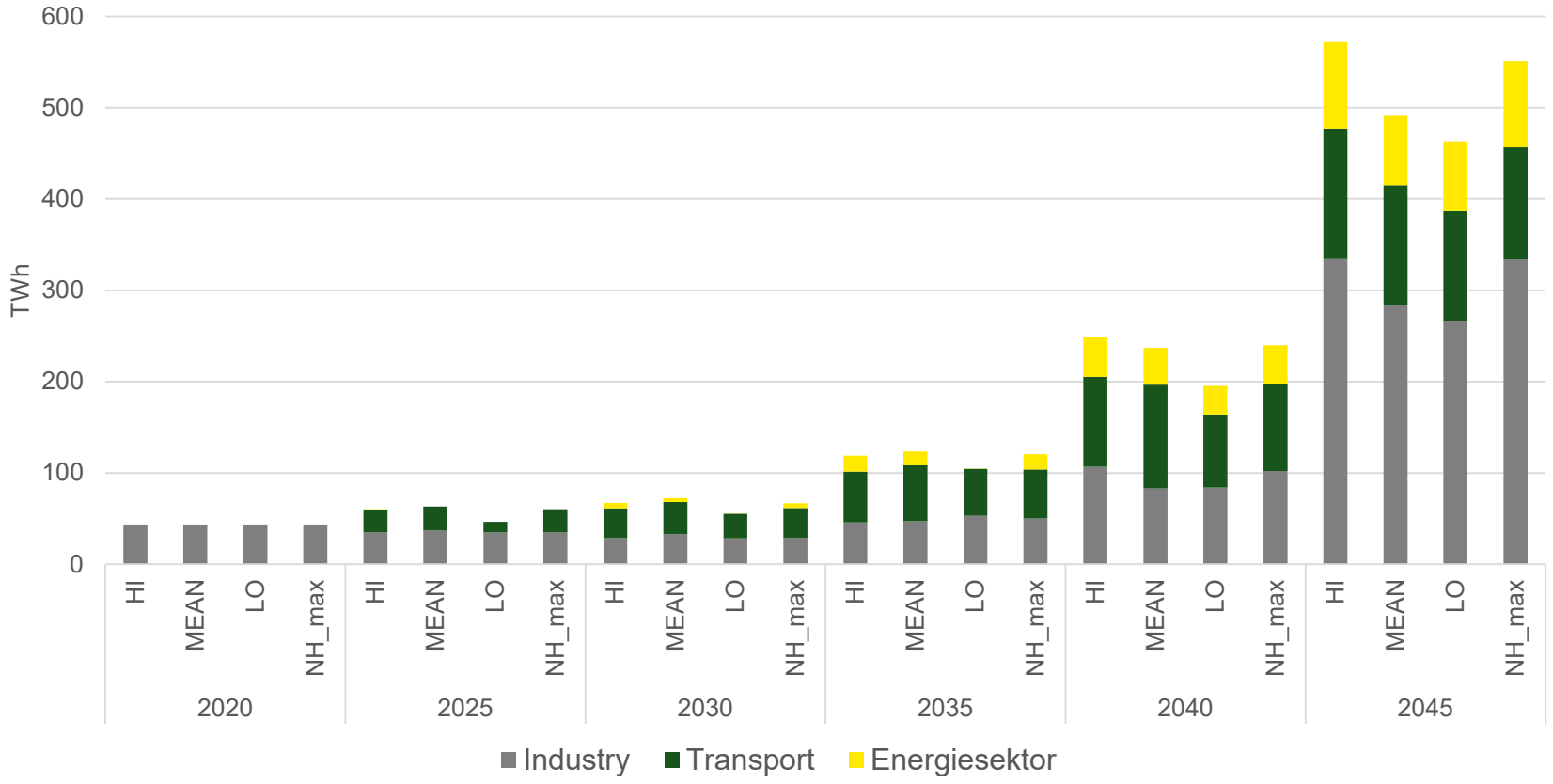
Hydrogen consumption



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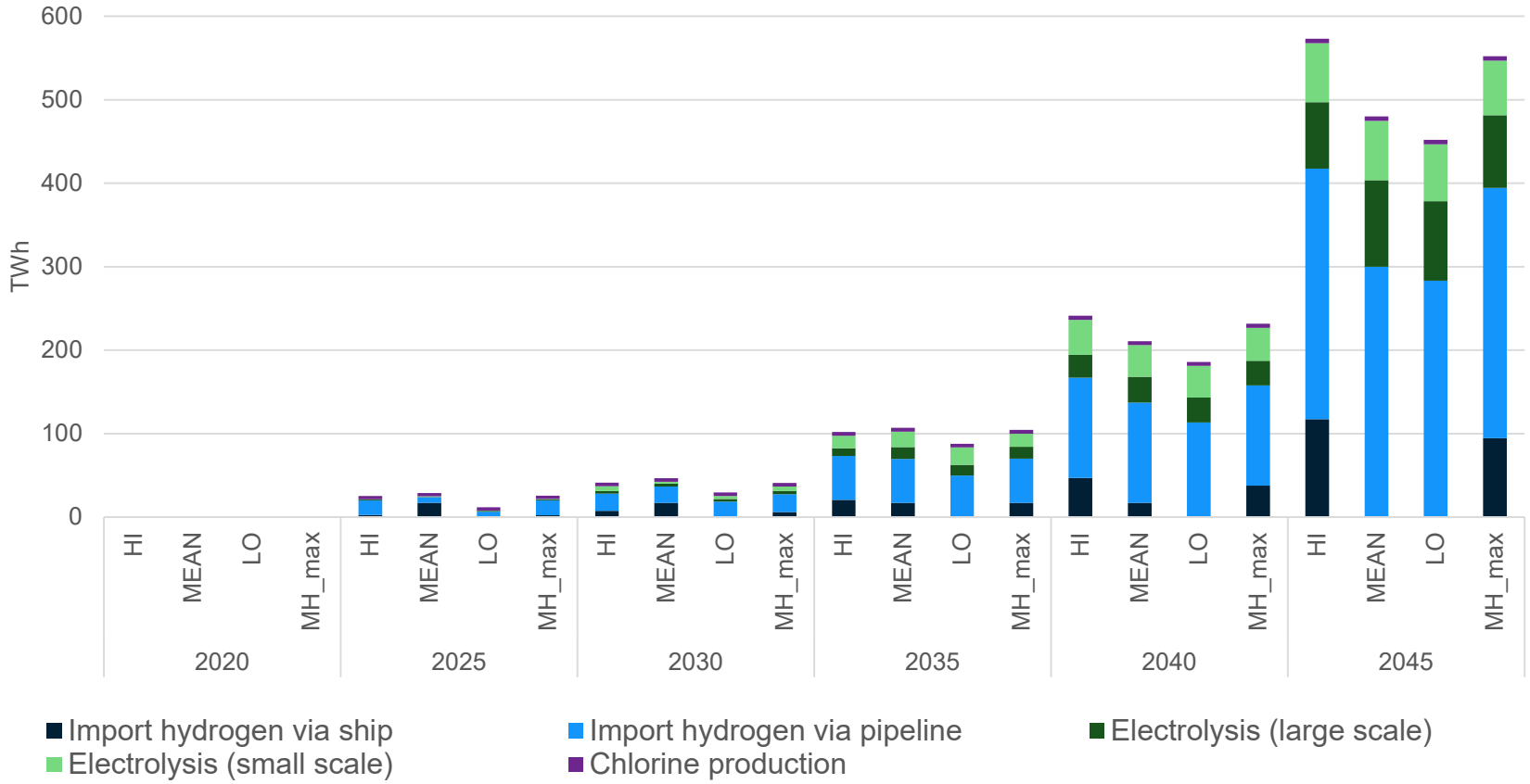
Hydrogen production



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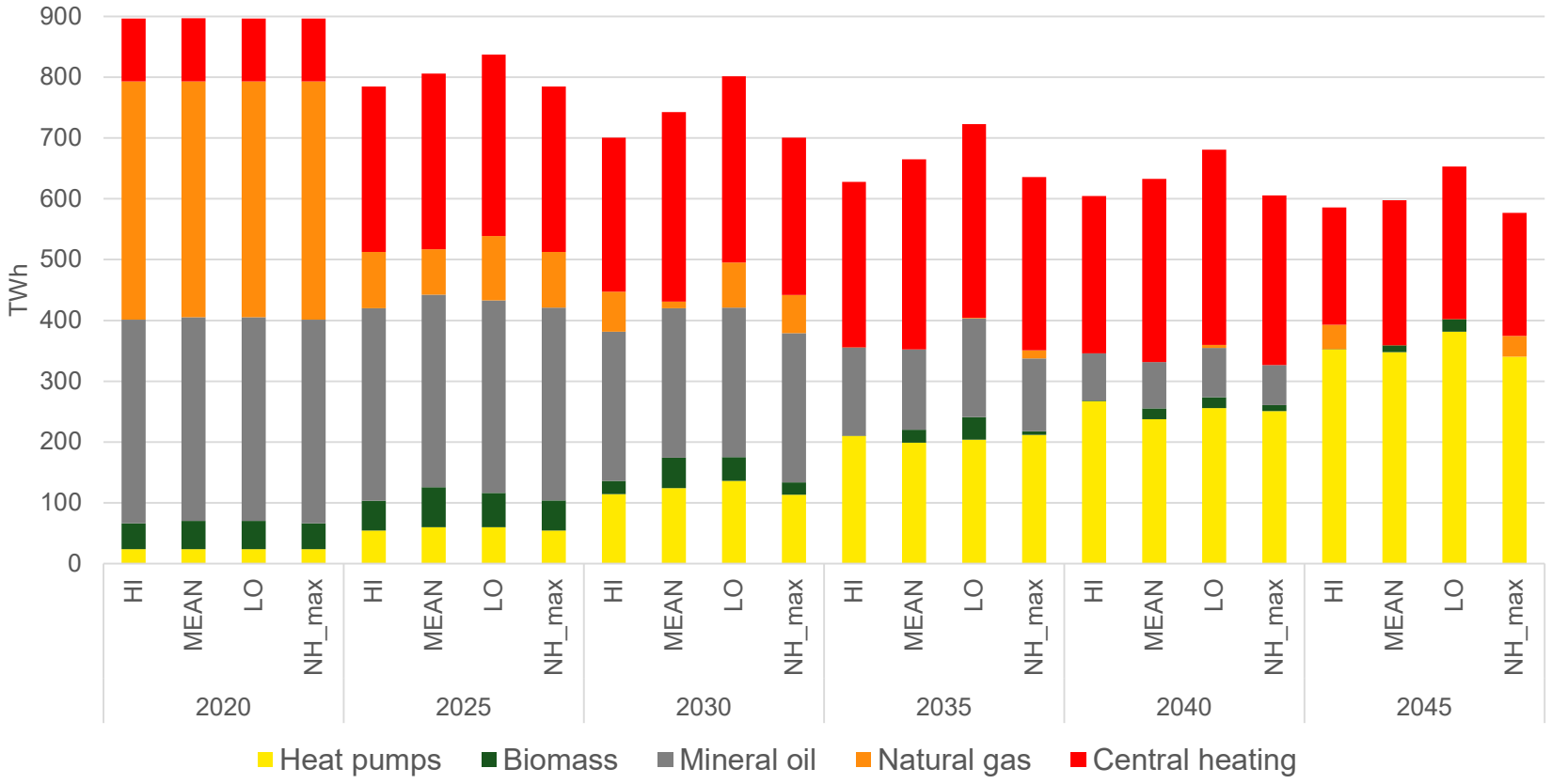
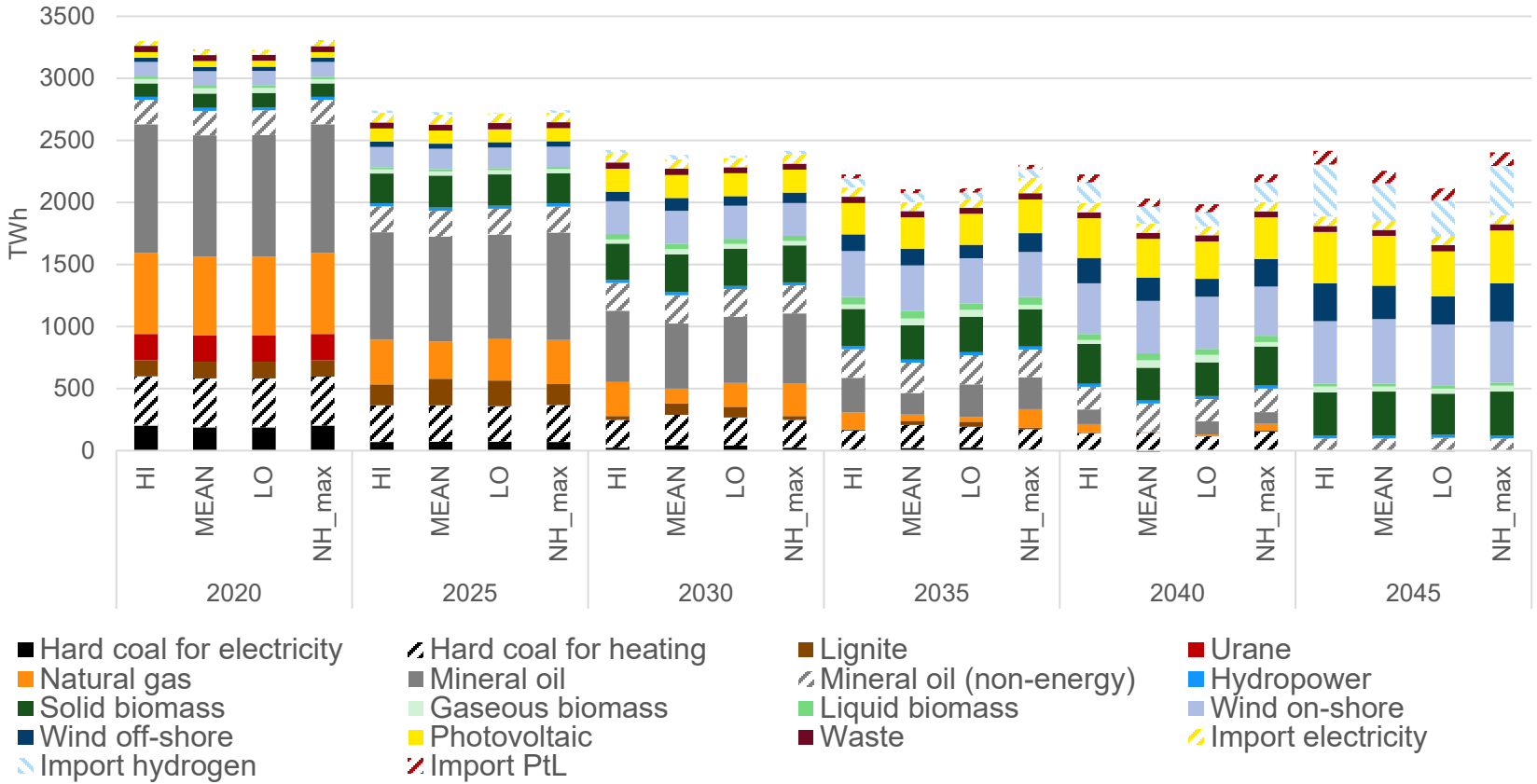
Heat supply in buildings



Primary energy demand



HELMHOLTZ Energy

Impact assessment based on the techno-economic scenarios

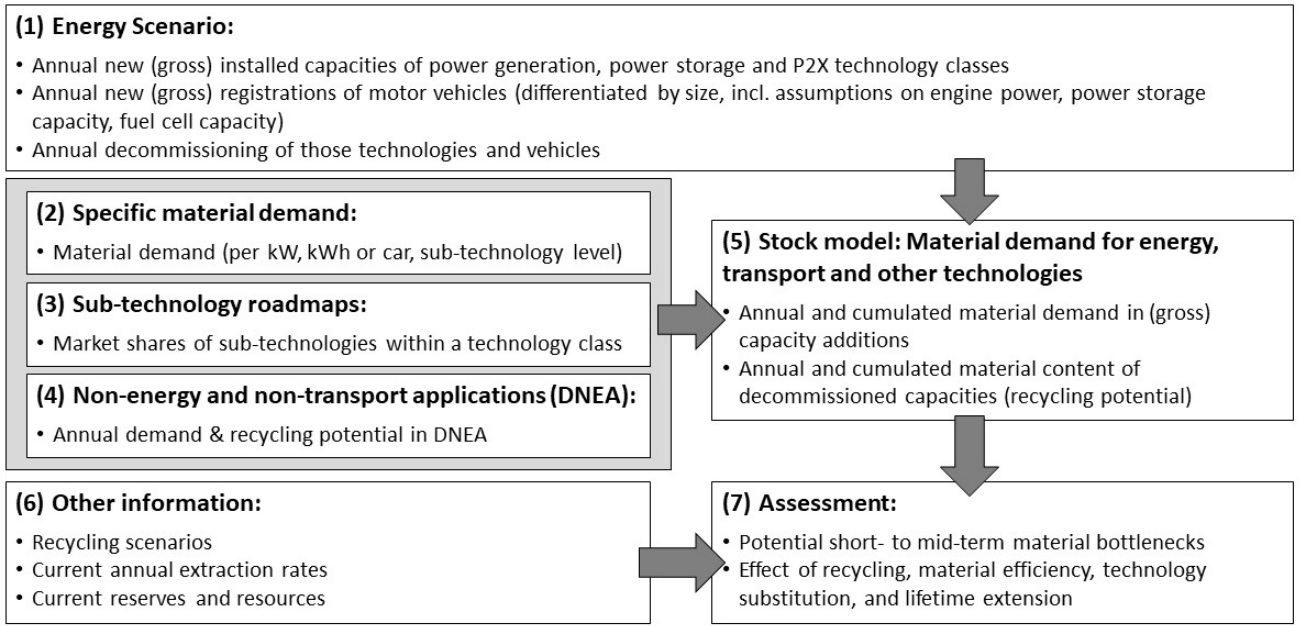
Tobias Naegler (DLR-VE), Stefan Vögele (FZJ-ICE-2)

Impact assessment based on model results

Topics examined:

- **Mineral raw materials**
  - Raw material requirements
  - Risk of market-related short to medium-term shortages of raw materials
  - Geopolitical risks Supply of raw materials
- **Life cycle-based environmental impacts**
  - Climate change
  - Ecosystem quality
  - Human health
  - Resource utilization
- **Employment effects**

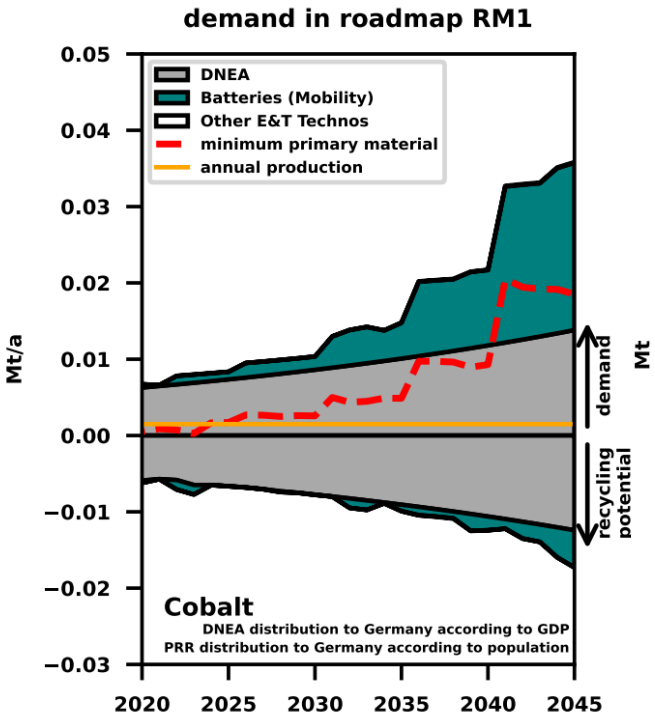
Raw material requirements: basic approach

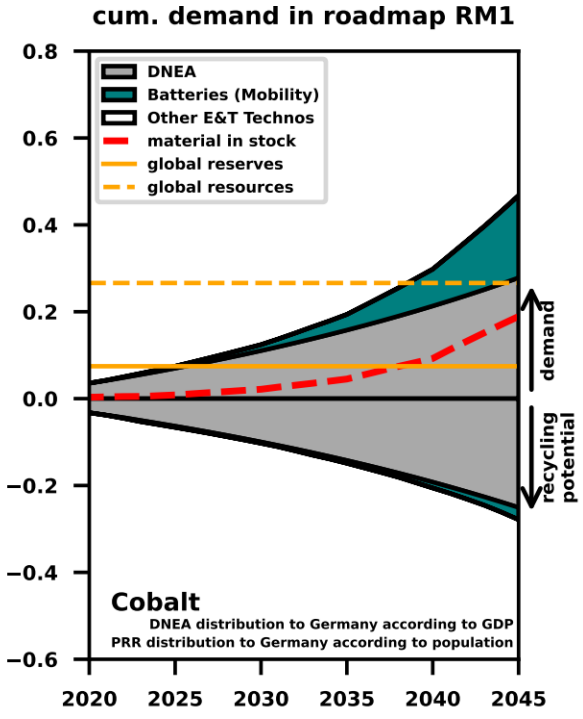


Source: Schlichenmaier and Naegler, May material bottlenecks hamper the global energy transition towards the 1.5°C target? *Energy Reports* 8 (2022), https://doi.org/10.1016/j.egyr.2022.11.025

- Coupling output energy system model with databases:
  - Specific raw material requirements Energy and transportation technologies
  - Future market shares of sub-technologies
- Stock model calculates demand and recycling potential
- Subsequent identification of potential bottlenecks and geopolitical risks

Raw material requirements – Example of cobalt



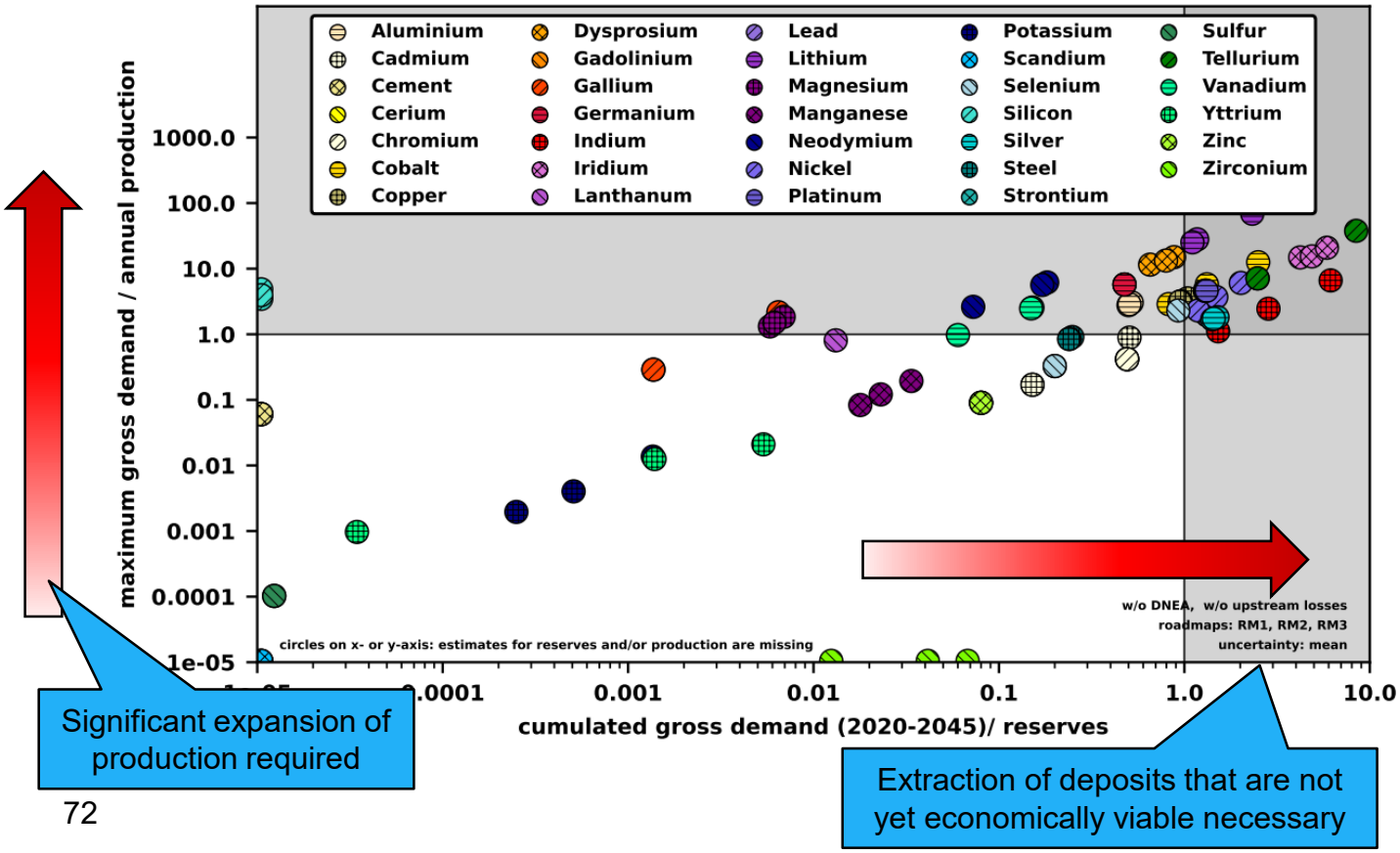


Short and medium-term supply bottlenecks possible if:

- Production must be expanded quickly
- Cumulative demand exceeds reserves in the near future

→ Risk of price increases

Potential bottlenecks due to the sharp rise in demand



Batteries:

- Lithium
- Cobalt
- Nickel

Permanent magnets (wind turbines, electric motors):

- Neodymium
- Dysprosium

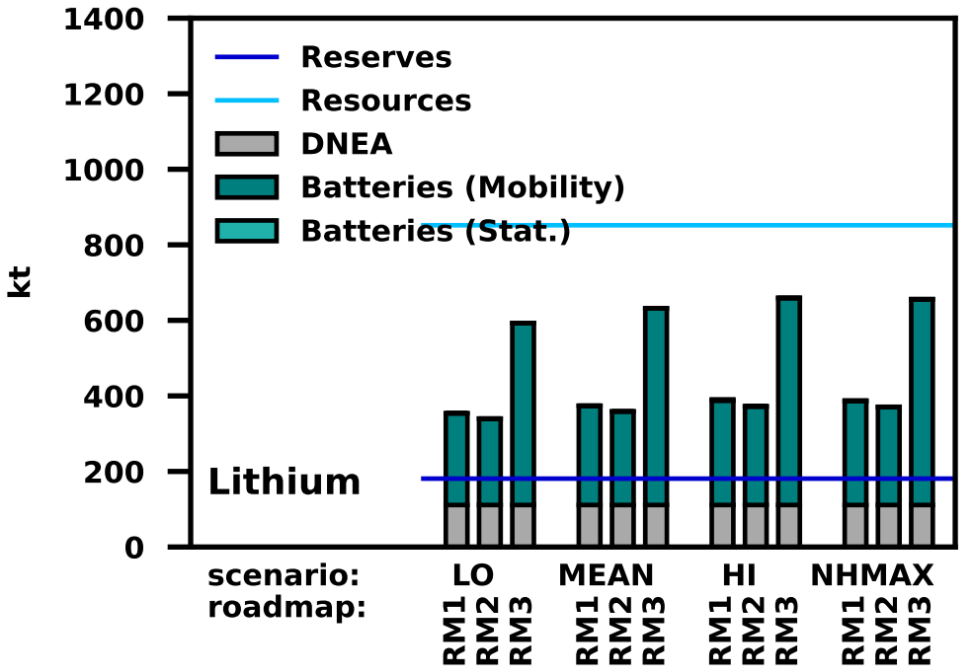
Electrolysers:

- Iridium

PV modules

- Tellurium
- Indium

Raw material requirements – Comparison of scenarios



- Stock of battery electric vehicles (BEV) + plugged-in hybrid electric vehicles (PHEV) in scenario HI greater than in MEAN and LO

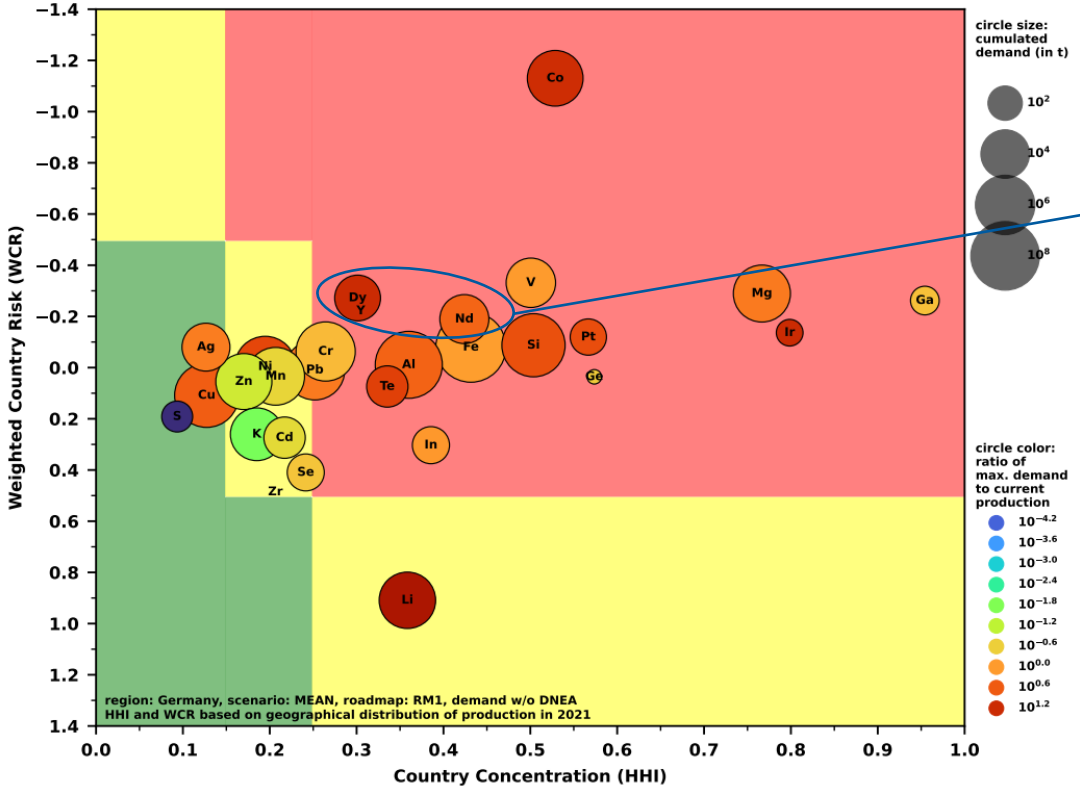
→ reflected in raw material requirements

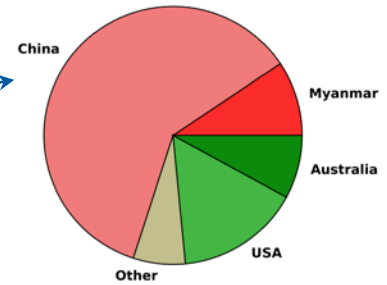
But:

- Assumptions regarding future market shares of battery types influence raw material requirements significantly more than actual scenarios

→ Differences in raw material requirements between “roadmaps” RM1, RM2, RM3 higher than between scenarios

Raw material requirements – Geopolitical risks: Rare Earth Elements





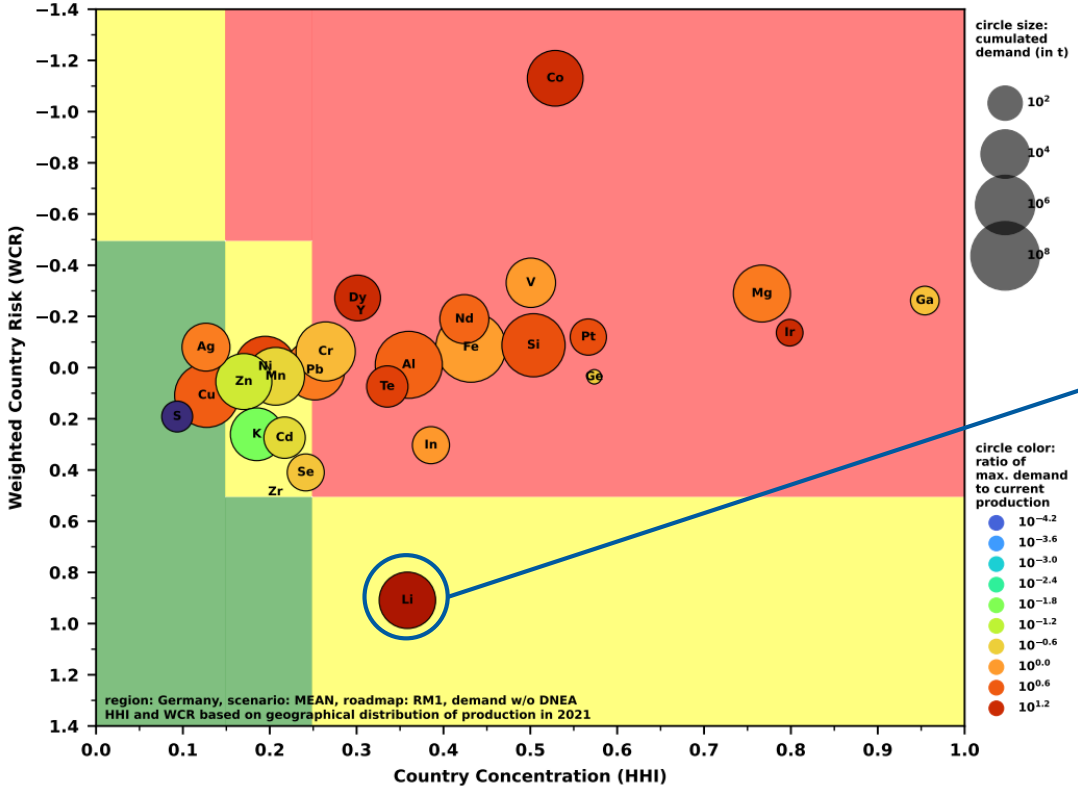
Rare earth elements (REE), e.g. Neodymium & Dysprosium:

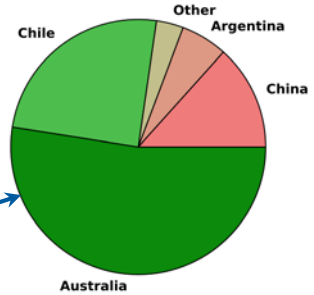
- Permanent magnets in
  - Some wind turbine types
  - Electric motors

Yttrium:

- Some fuel cell and electrolyser types

Raw material requirements – Geopolitical risks: Lithium

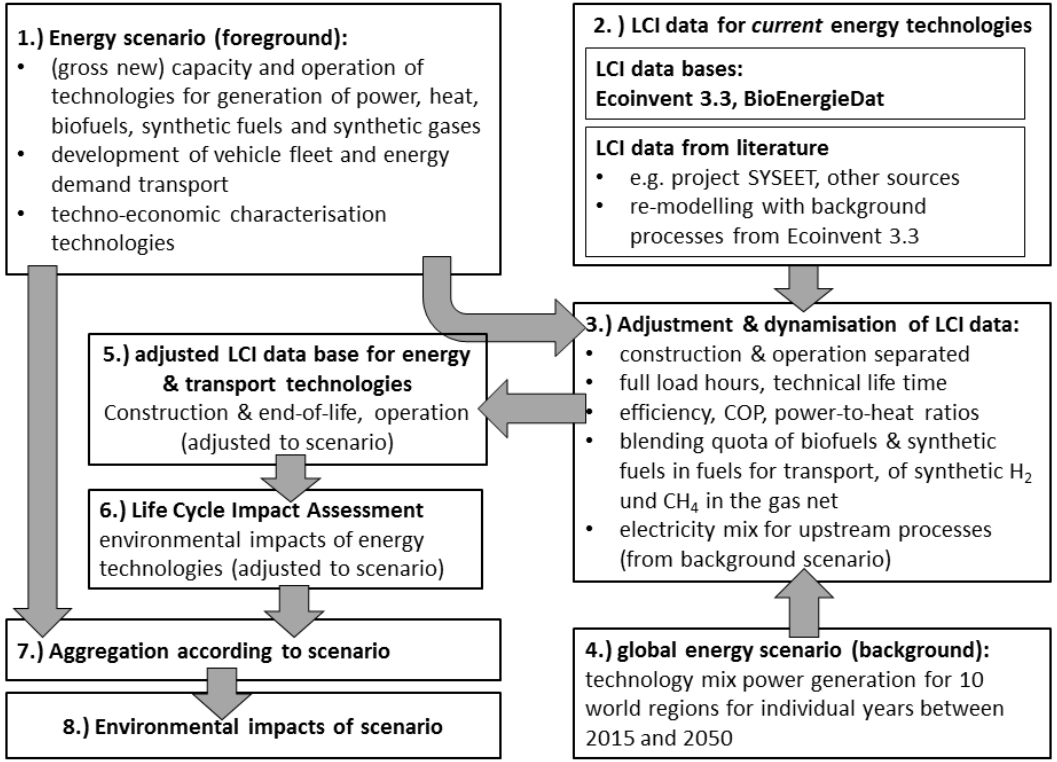




Lithium:

- Many battery types (mobile & stationary application)

Life cycle-based environmental impacts – Approach



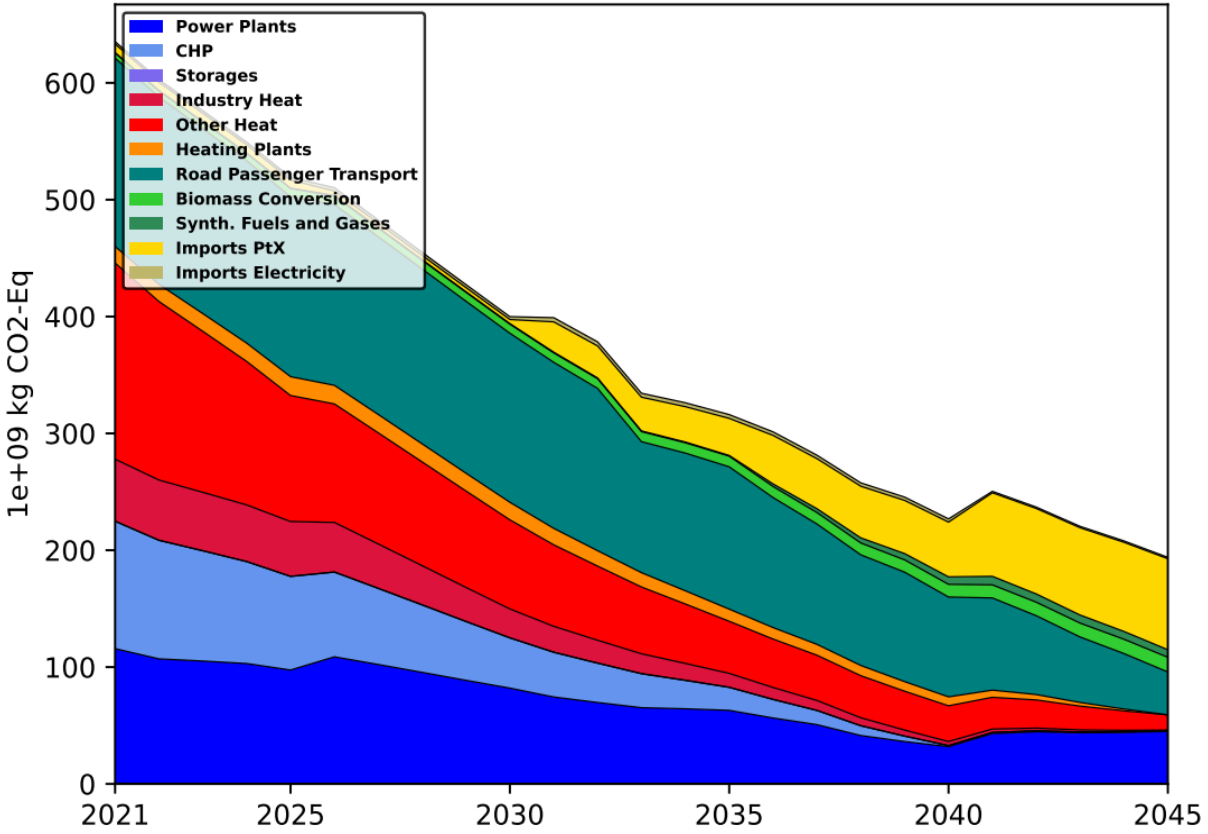
- Linking output ESM with LCA database
- Numerous prospective adjustments and harmonization

→ Life cycle-based environmental impacts of construction and operation for all relevant energy and transportation technologies

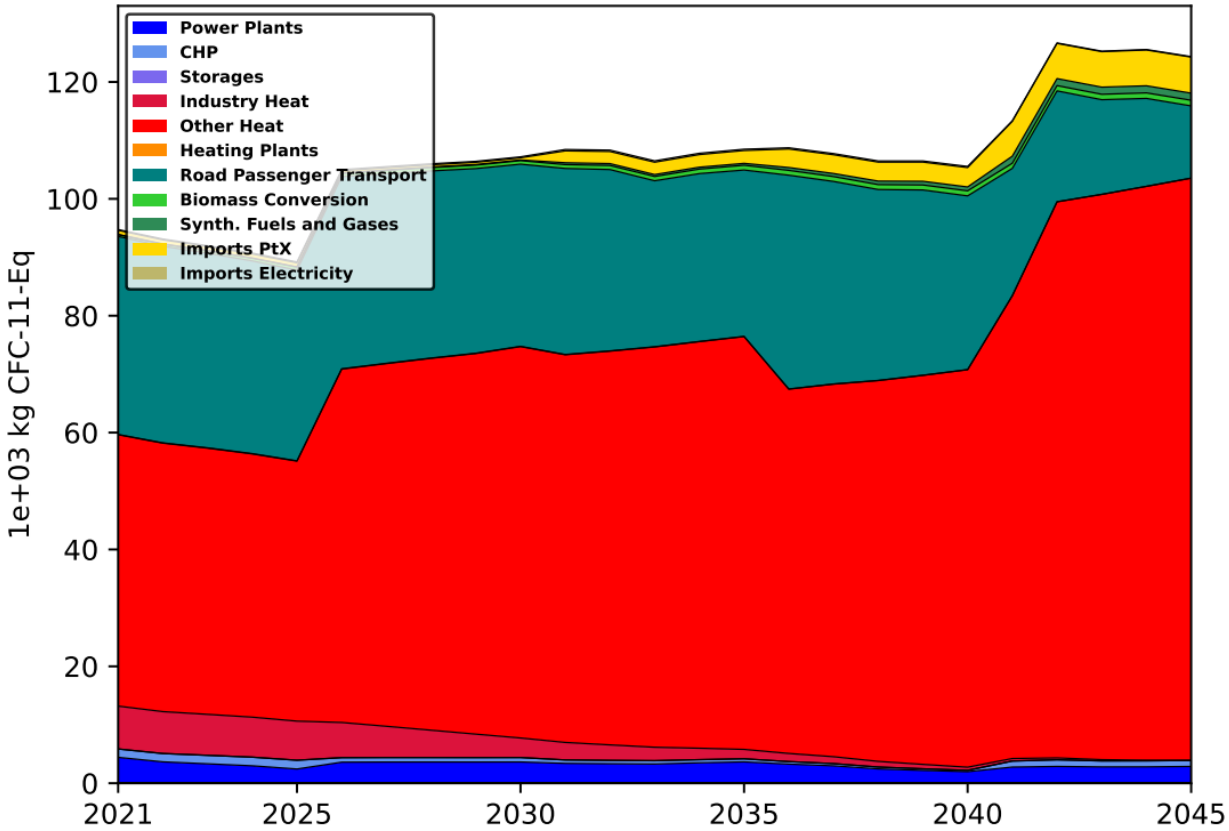
→ Aggregation of environmental impacts of technologies according to each scenario

Source: Naegler et al. Life cycle-based environmental impacts of energy system transformation strategies for Germany. Are climate and environmental protection conflicting goals? *Energy Reports* 8 (2022), https://doi.org/10.1016/j.egyr.2022.03.143

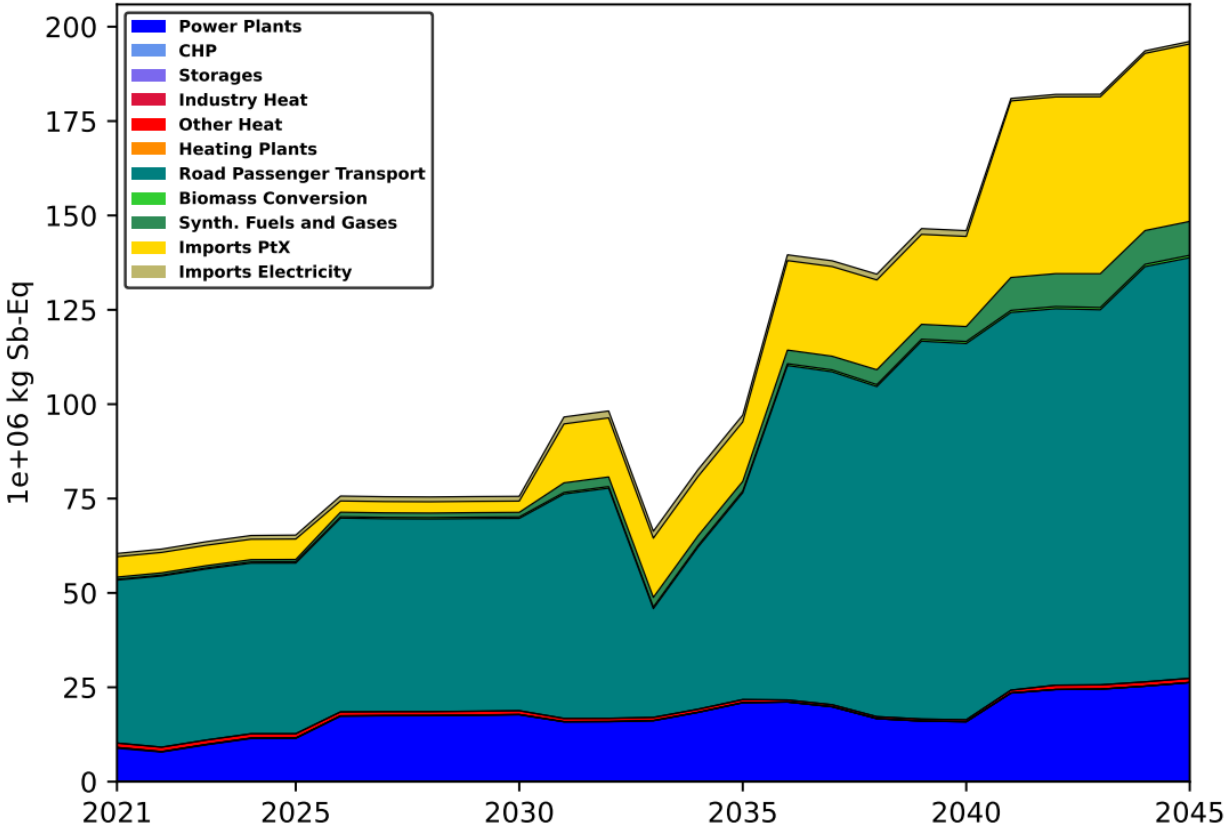
Life cycle-based environmental impacts – Greenhouse gas emissions



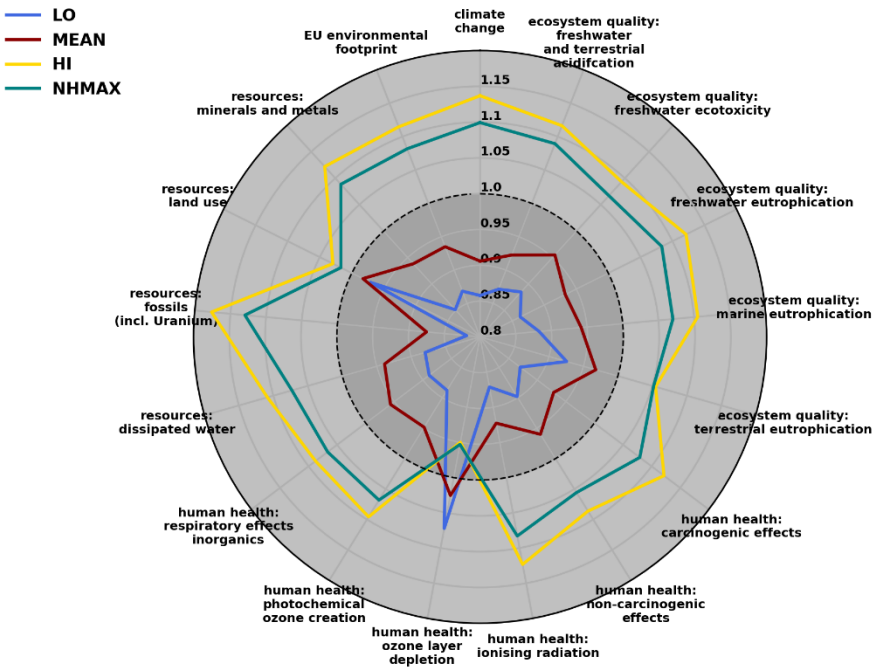
Life cycle-based environmental impacts – Ozone formation



Life cycle-based environmental impacts – Raw material requirements (aggregated)



Life cycle-based environmental impacts – Scenario comparison

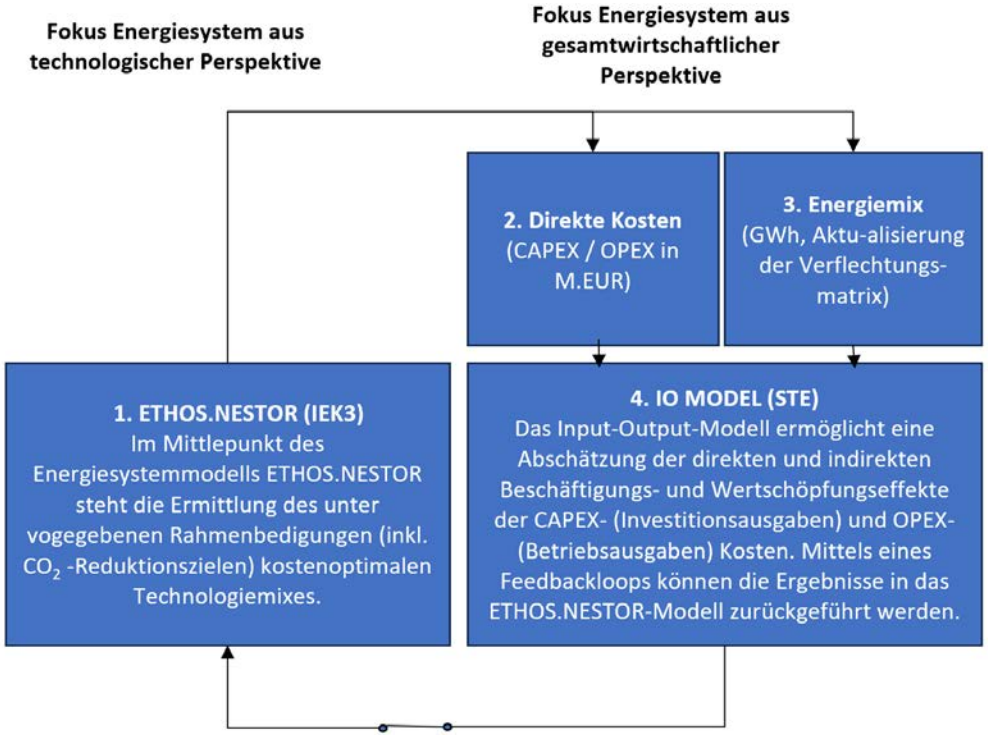


- Depending on the impact category, transformation can reduce or increase environmental impacts
- Life cycle perspective partly takes into account significant environmental impacts in the upstream chain
- Differences in environmental impacts in current scenarios attributable to:
  - Quantitative differences in energy demand & transport services
  - Quantitative differences Development of energy infrastructure and vehicle fleet

Estimation of employment requirement – Method

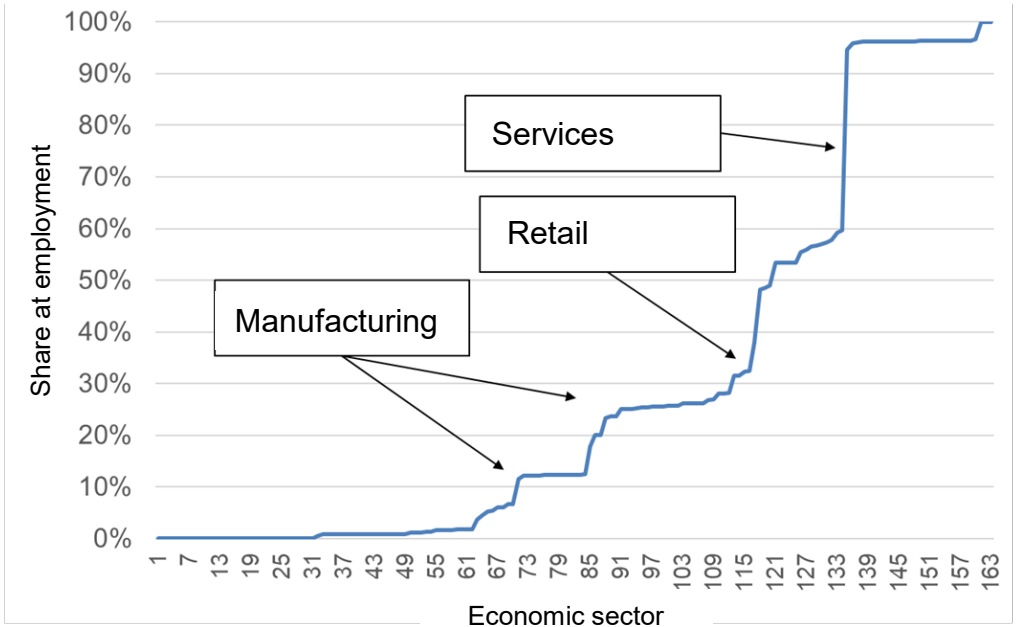
Model IEK3STE

- Coupling of Energy System Model with an Input-Output Model
- **Output:** Development of sectors regarding employment and gross value added



Employment requirement – Results

Impacts of capital expenditures (CAPEX) and operating expenditures (OPEX) effects on employment related to technical development of energy technologies differing between economic sectors (Scenario MEAN)



Only some economic sectors are directly affected by CAPEX and OPEX expenditures (31 of 163).

In particular manufacturing of goods, like metal production, machine construction, and vehicle construction, will experience a strong demand for labor.

Indirectly, all economic sectors will profit from an increased labor demand, in particular retail and services.

Impact assessment based on the context scenarios

Jürgen Kopfmüller, Witold-Roger Poganietz, Volker Stelzer (all KIT-ITAS)

Procedure

List of active descriptors

A(I)	Global development – general development
A(II)	Global development – world market prices for fossil fuels
A(III)	Global development – real interest rates
B	EU integration
C	Population development
D	Economic performance
E	Labor market
F	Development of the service sector compared to industry
G	Innovative capacity of the economy
H	Transnational trade flows
I	International interconnectedness of the grid system
J	Infrastructural development of the national grid
K	Expansion of renewables (electricity)
L	Degree of decentralization of energy supply and storage
M	Market design (electricity)
N	Policy stability related to energy
O	Policy instruments related to energy
P	Governance of infrastructure expansion
Q	Planning legislation
R	Governmental goals of design
S	Social security regulation
T	Welfare development
U	Acceptance of energy technologies
V	Individual energy demand behavior
W	Education
X	Social acceptance of the energy transition / NIMBY
Y	Values and principles of market design
Z	Media discourse

Estimating the effects of descriptors on sustainability indicators

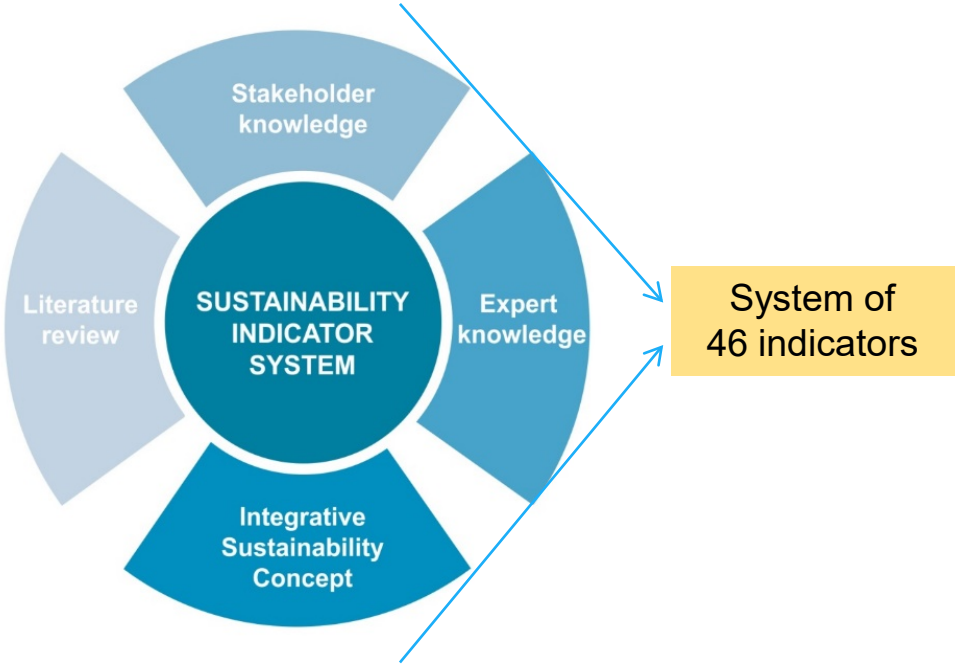
→ Use of expert knowledge

→ Evidence and plausibility considerations

→ Literature

Sustainability indicators: Starting point

Indicator system from the Helmholtz Alliance project "Energy-Trans"



Amongst others

Proportion of disposable income spent on energy in households with disposable income < EUR 1,300
Public spending on energy research
Number of employees in the RE sector
Number of start-ups in the RE and efficiency sector
"Gender pay gap" in the highest salary groups in the energy sector
Acceptance of renewable energy systems in the neighbourhood
Acceptance of grid expansion for 100 % RE supply
Degree of internalization of energy-related external costs
Share of private households that produce renewable energy
Number of energy cooperatives in the RE sector
Market share of the four largest electricity providers in Germany

In red: selected indicators to illustrate the procedure

Source:
Rösch, C.; Bräutigam, K.-R.; Kopfmüller, J.; Stelzer, V.; Fricke, A.
Sustainability assessment of the German energy transition. 2018.
Energy, Sustainability and Society, 8 (1), Art. no. 12. DOI:10.1186/s13705-018-0153-4

Impact assessment Step 1

Descriptors with direct influence ...

A(I)	Global development – general development
A(II)	Global development – world market prices for fossil fuels
A(III)	Global development – real interest rates
B	EU integration
C	Population development
D	Economic performance
E	**Labor market**
F	**Development of the service sector compared to industry**
G	Innovative capacity of the economy
H	Transnational trade flows
I	International interconnectedness of the grid system
J	Infrastructural development of the national grid
K	Expansion of renewables (electricity)
L	Degree of decentralization of energy supply and storage
M	Market design (electricity)
N	Policy stability related to energy
O	Policy instruments related to energy
P	Governance of infrastructure expansion
Q	Planning legislation
R	Governmental goals of design
S	**Social security regulation**
T	**Welfare development**
U	Acceptance of energy technologies
V	Individual energy demand behavior
W	Education
X	Social acceptance of the energy transition / NIMBY
Y	**Values and principles of market design**
Z	Media discourse

... on the indicator

Share of expenditure on energy
of disposable income in households
with disposable income < 1,300 Euros

Impact assessment Step 1

Descriptors with direct influence ...

A(I)	Global development – general development
A(II)	Global development – world market prices for fossil fuels
A(III)	Global development – real interest rates
B	EU integration
C	Population development
D	Economic performance
E	Labor market
F	Development of the service sector compared to industry
G	Innovative capacity of the economy
H	Transnational trade flows
I	International interconnectedness of the grid system
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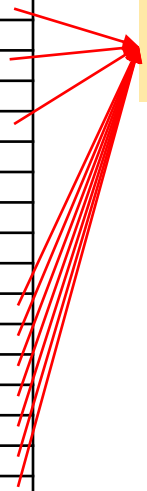
Y	**Values and principles of market design**
Z	**Media discourse**



... on the indicator

Share of private households that produce renewable energy

Impact assessment Step 1

Descriptors with direct influence ...

A(I)	**Global development – general development**
A(II)	Global development – world market prices for fossil fuels
A(III)	Global development – real interest rates
B	**EU integration**
C	Population development
D	**Economic performance**
E	Labor market
F	Development of the service sector compared to industry
G	**Innovative capacity of the economy**
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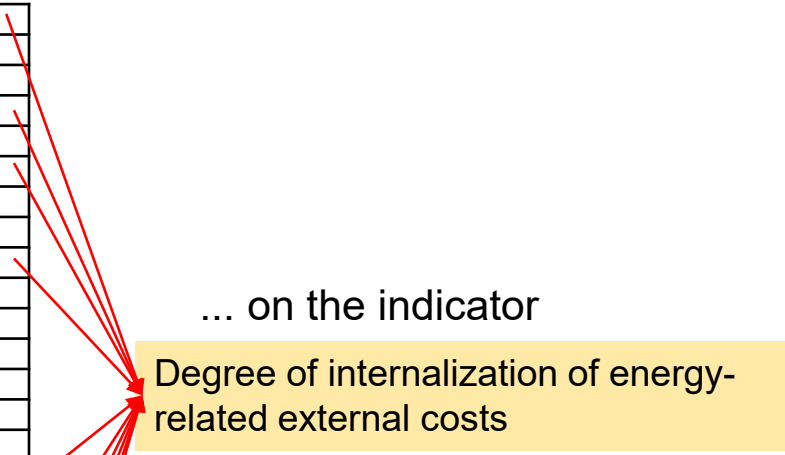


Impact assessment Step 2

Proportion of disposable income spent on energy in households with disposable income < EUR 1,300

Descriptor	Scenario LO Descriptor characteristics	Scenario HI Descriptor characteristics	Scenario MEAN Descriptor characteristics	Scenario NH_max Descriptor characteristics
E. Labor market	Divided labor market	Low unemployment / high flexibility	Divided labor market	Low unemployment / high flexibility
Impact assessment	- 3	+ 3	- 3	+ 3
F. Tertiarization of the economy	Weak	Strong	Strong	Strong
Impact assessment	- 1	- 3	- 3	- 3
S. Social security regulation	Emphasizing liberal elements	Emphasizing conservative-corporatist elements	Emphasizing liberal elements	Emphasizing conservative-corporatist elements
Impact assessment	- 2	0	- 2	0
T. Welfare development	Increasing inequality / low income increase	Unchanged inequality / strong income increase	Increasing inequality / strong income increase	Unchanged inequality / strong income increase
Impact assessment	0	+ 3	+ 3	+ 3
Y. Values and principles of market design	Trend towards materialism and performance	Trend towards materialism and performance	Trend towards differentiation	Trend towards post-materialism
Impact assessment	- 2	- 2	0	+ 2
Total impact assessment (Equal weighting of the descriptors)	**- 2**	**0**	**- 1**	**+ 1**

Scale: + 5 to - 5

Impact assessment Step 2

Share of private households that produce renewable energy (I)

Descriptor	Scenario LO Descriptor characteristics	Scenario HI Descriptor characteristics	Scenario MEAN Descriptor characteristics	Scenario NH_max Descriptor characteristics
J. Infrastructural development of the national grid	Needs-based	Needs-based	Needs-based	Needs-based
Impact assessment	+ 3	+ 3	+ 3	+ 3
L. Degree of decentralization of energy supply and storage	Trend towards mixed structure	Trend towards decentralized system architecture	Trend towards mixed structure	Trend towards decentralized system architecture
Impact assessment	+ 2	+ 4	+ 2	+ 4
N. Policy stability related to energy	Improving	Improving	Improving	Improving
Impact assessment	+ 3	+ 3	+ 3	+ 3
T. Welfare development	Increasing inequality / low income increase	Unchanged inequality / strong income increase	Increasing inequality / strong income increase	Unchanged inequality / strong income increase
Impact assessment	0	+ 3	+ 3	+ 3
U. Acceptance of energy technologies	Slightly increasing	Slightly increasing	Slightly increasing	Slightly increasing
Impact assessment	+ 1	+ 1	+ 1	+ 1

Scale: + 5 to - 5

Impact assessment Step 2

Share of private households that produce renewable energy (II)

Descriptor	Scenario LO Descriptor characteristics	Scenario HI Descriptor characteristics	Scenario MEAN Descriptor characteristics	Scenario NH_max Descriptor characteristics
V. Individual energy demand behavior	Trend towards thriftiness	Trend towards affinity with technology	Trend towards affinity with technology	Trend towards affinity with technology
Impact assessment	+ 1	+ 3	+ 3	+ 3
W. Education	Focus on STEM / strong access restriction	Focus on STEM / low access restrictions	Focus on STEM / strong access restriction	Focus on STEM / low access restrictions
Impact assessment	+ 1	+ 3	+ 1	+ 3
X. Social acceptance of the energy transition / NIMBY	Trend towards positive attitude	Trend towards positive attitude	Trend towards a positive attitude	Trend towards a positive attitude
Impact assessment	+ 3	+ 3	+ 3	+ 3
Y. Values and principles of market design	Trend towards materialism and meritocracy	Trend towards materialism and meritocracy	Trend towards differentiation	Trend towards post-materialism
Impact assessment	+ 2	+ 2	+ 1	- 2
Z. Media discourse	Great diversity of opinion/ strong tabloidization	Great diversity of opinion/ low tabloidization	Great diversity of opinion/ low tabloidization	Great diversity of opinion/ low tabloidization
Impact assessment	+ 2	+ 3	+ 3	+ 3
Total impact assessment (Equal weighting of the descriptors)	**+ 2**	**+ 3**	**+ 2**	**+ 3**

Scale: + 5 to - 5

Impact assessment Step 2

Internalization of external costs (I)

Descriptor	Scenario LO Descriptor characteristics	Scenario HI Descriptor characteristics	Scenario MEAN Descriptor characteristics	Scenario NH_max Descriptor characteristics
A(I). Global development – general development	Fortress world	Market forces	Fortress world	Fortress world
Impact assessment	- 3	+ 3	- 3	- 3
B. EU integration	EU under threat	Nobody cares	EU renaissance	EU renaissance
Impact assessment	- 3	- 2	+ 3	+ 3
D. Economic performance	Weak	Strong	Moderate	Strong
Impact assessment	- 2	+ 3	+ 1	+ 3
G. Innovative capacity of the economy	Decreasing	Improving	Unchanged	Improving
Impact assessment	- 3	+ 3	0	+ 3
O. Policy instruments related to energy	Preference for technology-specific economic instruments	Preference for technology-specific economic instruments	Preference for technology-unspecific economic instruments	Preference for technology-unspecific economic instruments
Impact assessment	+ 1	+ 1	+ 3	+ 3
R. Governmental goals of design	Stronger focus on state control	Stronger focus on citizen participation and transparency	Stronger focus on market mechanisms	Stronger focus on citizen participation and transparency
Impact assessment	+ 3	+ 1	+ 2	+ 1

Scale: + 5 to - 5

Impact assessment Step 2

Internalization of external costs (II)

Descriptor	Scenario LO Descriptor characteristics	Scenario HI Descriptor characteristics	Scenario MEAN Descriptor characteristics	Scenario NH_max Descriptor characteristics
T. Welfare development	Increasing inequality / low income increase	Unchanged inequality / strong income increase	Increasing inequality / strong income increase	Unchanged inequality / strong income increase
Impact assessment	- 3	+ 3	+ 2	+ 3
V. Individual energy demand behavior	Trend towards thriftiness	Trend towards technology affinity	Trend towards technology affinity	Trend towards technology affinity
Impact assessment	+ 3	+ 2	+ 2	+ 2
X. Social acceptance of the energy transition / NIMBY	Trend to be supportive	Trend to be supportive	Trend to be supportive	Trend to be supportive
Impact assessment	+ 3	+ 3	+ 3	+ 3
Y. Values and principles of market design	Trend towards materialism and meritocracy	Trend towards materialism and meritocracy	Trend towards differentiation	Trend towards post-materialism
Impact assessment	- 3	- 3	+ 2	+ 4
Z. Media discourse	High diversity of opinion / strong tabloidization	High diversity of opinion / low tabloidization	High diversity of opinion / low tabloidization	High diversity of opinion / low tabloidization
Impact assessment	+ 1	+ 2	+ 2	+ 2
Total impact assessment (Equal weighting of the descriptors)	**- 0,5**	**+ 1,5**	**+ 1,5**	**+ 2**

Scale: + 5 to - 5

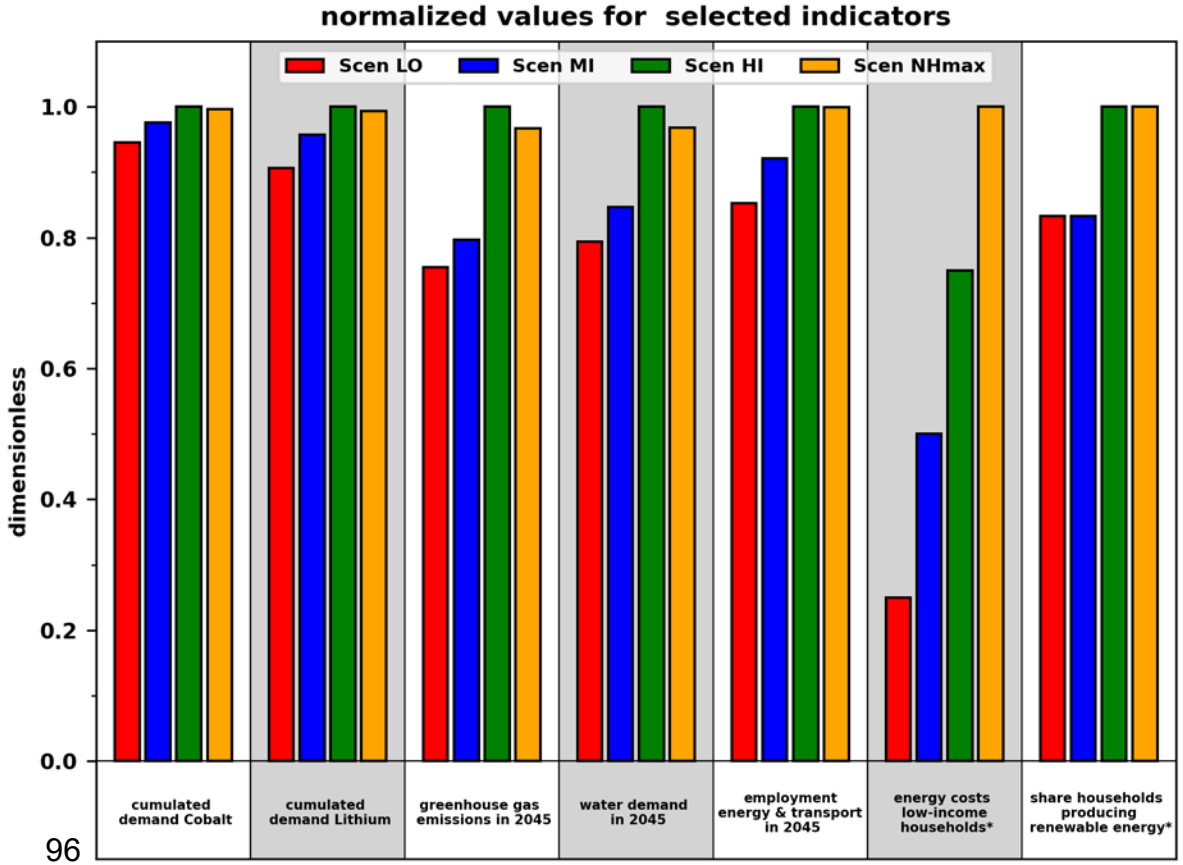
From Impact Assessment to Sustainability Assessment

- Two different sources, creation processes and forms of information
  → Necessary: uniform evaluation (standards)
- Prerequisite for evaluation: referencing of impact assessment results possible approaches:
  - Improvement / deterioration over time
  - Definition of target values
  - Comparative evaluation (→ criteria necessary for “better / worse than”)

  → necessary: Target capability, directional certainty of indicators
- Possibilities for an overall view of impact assessment results
  - for a scenario or in a scenario comparison
  - for identifying strengths / weaknesses pattern or / and aggregated overall result

Summary and outlook

Scenario comparison for selected indicators



Normalization of indicator values: For each indicator, the absolute indicator values of all scenarios are divided by the highest indicator value of all scenarios.

* The standard results for the two non-model based indicators “energy costs of low-income households” and “share of households producing renewable energy” can take on (unitless) values between -3 and +3, which *qualitatively* describe the differences between the scenarios. The indicator values were first rescaled to a scale of 0 to 1 and then normalized as described above.

Innovative elements / added value of the integrative approach

- Holistic representation and analysis of the energy system and its transformation
  - Mapping of social and socio-economic factors / dynamics (values, policy baselines, education, geopolitics, ...) as a framework
  - consistent embedding of the "techno-economic energy system" in this framework
- More holistic impact assessment and sustainability evaluation of possible future socio-technical energy systems
  - appropriate criteria
  - More differentiated picture of strengths / weaknesses
  - Illumination of sustainability "side effects" (e.g. of climate neutrality)

➡ Improved orientation for transformation processes of the energy system (need for action, priorities, ...)

Outlook

- Updating the descriptor set and the NH indicator set
- Deriving further influences from the descriptors on techno-economic analyses
- Making previously non-modellable indicators (more) modellable
- Impact assessment – evaluation
  - Impact assessments for further indicators based on the context scenarios
  - Definition of target values (→ distance-to-target approach)
    for both types of indicators
  - Use of the Multi-Criteria Decision Analysis (MCDA) methodology:
    Comparison of different scenarios or possible measures in response to specific performance weaknesses in the scenarios
  - Weighting of descriptors / evaluation indicators
    according to relevance aspects (criteria required!), social preferences, ...
    (by experts, stakeholders, ...)