TECHNISCHE UNIVERSITÄT WIEN

International Institute for Applied Systems Analysis

IIASA


# FLEXIBILITY AND RESILIENCE via SYSTEM INTEGRATION

Klimatag - 03.04.2024, TU Wien

HTTPS://COLAB.TUWIEN.AC.AT/DISPLAY/CD/1.5.+VORLAGEN

# Background

**Title:** Integrative energy infrastructure planning tools for cross-sectoral resilience and flexibilisation concepts.
**Sponsor/Call:** Forschungsförderungsgesellschaft / ENERGIEFORSCHUNG 2022 - SCHWERPUNKT 3 & 4
**Type/Runtime:** Sondierungsprojekt / 12.2023 – 11.2024 (12 months) /
**Acronym:** FFG BioFlex Project

| Consortium | Affiliation |
|---|---|
| Fabian Schipfer, Michael Harasek | TU Wien Institut für Verfahrenstechnik, Umwelttechnik und technische Biowissenschaften (ICEBE), Fachbereich Thermische Verfahrenstechnik und Simulation > Lead |
| Johannes Schmidt, Sebastian Wehrle | Universität für Bodenkultur (Boku), Institut für Nachhaltige Wirtschaftsentwicklung |
| Florian Kraxner, Shubham Tiwari | International Institute for Applied System Analysis (IIASA), Agriculture, Forestry, and Ecosystem Services Group |

**Input:** IEA Bioenergy <> ETSAP (International Energy Agency - Energy Technology Systems Analysis Program)
*Schipfer, F., E. Mäki, U. Schmieder, N. Lange, T. Schildhauer, C. Hennig, und D. Thrän. „Status of and Expectations for Flexible Bioenergy to Support Resource Efficiency and to Accelerate the Energy Transition“. Renewable and Sustainable Energy Reviews 158 (1. April 2022): 112094. https://doi.org/10.1016/j.rser.2022.112094.*

**Context:**

Austrian energy system → climate neutrality in 16 (!) years
Energy system models → Engineering for economic and ecological sustainability
BUT are the resulting pathways also engineered for **reliability and flexibility**?

TECHNISCHE UNIVERSITÄT WIEN



# Methodology – Part 1

**Risk management – Guidelines ISO31000:2018**

- Terms and definitions
  Risk, consequences, likelihood …
- Iterative process →

Critical reflection of scenario modelling, risk assessment techniques (ISO31010), resilience engineering, and dynamic adaptive planning

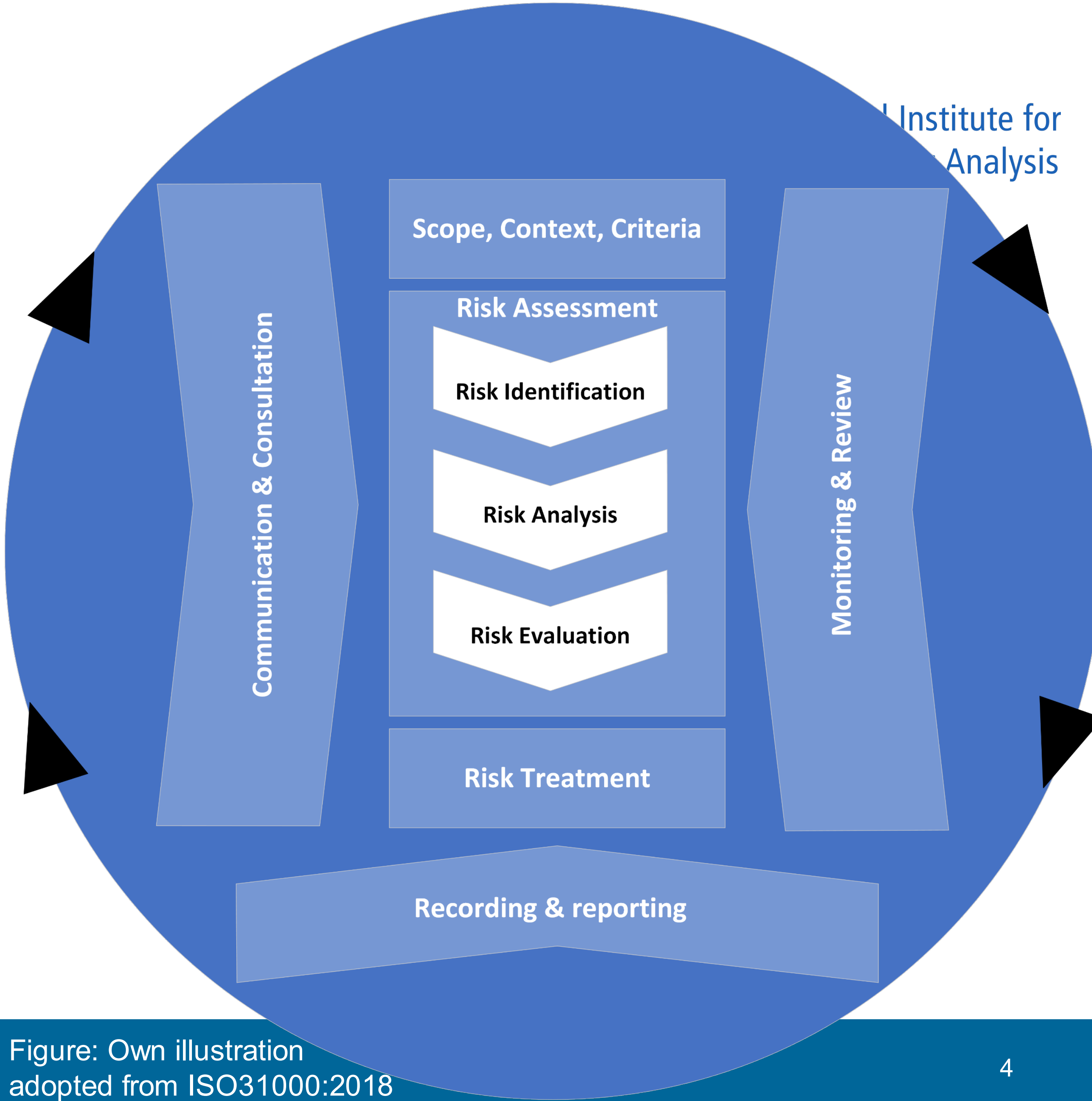



Figure: Own illustration
adopted from ISO31000:2018

TECHNISCHE UNIVERSITÄT WIEN

# Part 1

International Institute for Applied Systems Analysis

## Scope, context, criteria

**“Physical energy”**

- Power and heat from photovoltaic, wind, water, and geothermal, ambient heat
- Main infrastructure = power grids, partly heat networks
- Energy-water nexus
- “plug-in” technologies

**“Chemical energy”**

- Power, heat, fuels from fossil fuels, biomass, hydrogen, waste
- All infrastructures are relevant
- Food-Materials-Energy-Water nexus
- Metabolism character with inputs & outputs

TECHNISCHE UNIVERSITÄT WIEN

# Part 1

International Institute for Applied Systems Analysis

## Scope, context, criteria

**"Physical energy"**

- Power and heat from photovoltaic, wind, water, and geothermal, ambient heat
- Main infrastructure = power grids, partly heat networks
- Energy-water nexus
- "plug-in" technologies

**"Chemical energy"**

- Power, heat, fuels from fossil fuels, biomass, hydrogen, waste
- All infrastructures are relevant
- Food-Materials-Energy-Water nexus
- Metabolism character with inputs & outputs

**Multi-sector coupling**

- = system integration
- Network of networks: power, heat, gas, oil, rail, road, water, hydrogen, CO2, …
- Conversion technologies as "connectors"

**System integration is an opportunity AND a threat (!!)**

# Risk identification

**Earth system uncertainties categories:**

Atmosphere | Biosphere | Hydro/Cryosphere | Geosphere

**Human system uncertainties categories:**

Technosphere | Sociosphere | Cybersphere | Econosphere

# Risk identification

**Earth system uncertainties categories:**

Atmosphere | Biosphere | Hydro/ Cryosphere | Geosphere

**Human system uncertainties categories:**

Technosphere | Sociosphere | Cybersphere | Econosphere

**Uncertainty types:**

- Variabilities
- Extremes
- Trends
- Cascades

# Methodology – Part 2

Review and best practices of energy system models
despite large variations in relevant search terminologies

**Information and documentation —Thesauri (for information retrieval) and interoperability with other vocabularies (ISO25964-1:2011)**

No distinct discipline / scientific field is occupied with whole-energy system modeling
→ no joint controlled vocabulary is used for describing models, e.g., in

- Energy market design
- Power system modeling and dispatch models
- Transmission expansion and district heating network planning
- Bioenergy supply chain / value chain / value chain network design
- Circular Economy and Bioeconomy modelling
- Sector coupling and multi-sector coupling ….

# Part 2



## Risk identification & evaluation

Definition by Risk Management – Guidelines ISO31000:2018
**Risk = effect of uncertainty on objective**
can be positive, negative, or both, and can address, create, or result in opportunities and threats

**Objectivity requirement in risk assessment**

# Risk identification & evaluation

Definition by Risk Management – Guidelines ISO31000:2018

**Risk = effect of uncertainty on objective**

can be positive, negative, or both, and can address, create, or result in opportunities and threats ✓

| **Relevant definitions and implementations meeting this “objectivity requirement”** | **Yes / No** |
|---|---|
| Definition by Knight, F.H. (1921) | ✓ |
| Implementation in most of the 31 risk assessment techniques of ISO31010 | ✗ |
| Theoretical implementation in the 9 decision-making under uncertainty techniques (Marchau et al. 2019) | ✓ |
| Implementation in 9 resilience engineering techniques discussed in Patriarca et al. (2021) | ✗ |
| IPCCs continuously calibrated “uncertainty and confidence language” (Shukla et a., 2019) | ✗ |
| Traditional deterministic scenario modeling and current advancements in modelling “flexibility” | ✗ ? |

TECHNISCHE UNIVERSITÄT WIEN

# Part 2

International Institute for Applied Systems Analysis

# Risk treatment

**Systems engineering and systems design for**

Preferred term: **EFFICIENCY** → **The current focus of modeling disciplines**

Related terms: *sustainability, affordability, accessibility, acceptability, accuracy, precision, profitability, effectivity, rapidity, stiffness, resource conserving, …. sufficiency (!), appropriateness, adequacy*

Preferred term: **RELIABILITY** → **The current focus of risk assessment**

Related terms: *security, resilience, safety, robustness, rigidity, adaptability, redundancy, rebound*

Preferred term: **FLEXIBILITY** + → **Opportunity for a novel modeling paradigm**

Related terms: *plasticity, buoyancy, elasticity, agility, versatility, ductility, transformability, malleable to adaptation, interconnectivity, options, substitutability, responsiveness, resourcefulness*

# Preliminary conclusions – modeling requirements

**“all models are wrong” but which are useful to assess …?**

- How to measure the opportunities (balancing) and threats (unbalancing) of system flexibilisation and system complexification via multi-sector coupling and system integration?
- The role of chemical energy, including bioenergy, hydrogen, and e-fuels, beyond 2040?
- What storage and infrastructure requirements are we facing in the next decades?
  Which (parts of) infrastructure to keep from phased-out traditional chemical energy (i.e. fossil fuels)?
- Effectiveness of existing controls regarding risk treatment? Tipping points (beneficial and harmful)?

# Relevant publications

**Schipfer, F.**, Mäki, E., Schmieder, U., Lange, N., Schildhauer, T., Hennig, C., Thrän, D., 2022. Status of and expectations for flexible bioenergy to support resource efficiency and to accelerate the energy transition. Renewable and Sustainable Energy Reviews 158, 112094. https://doi.org/10.1016/j.rser.2022.112094

**Höltinger, S.**, Mikovits, C., Schmidt, J., Baumgartner, J., Arheimer, B., Lindström, G., Wetterlund, E., 2019. The impact of climatic extreme events on the feasibility of fully renewable power systems: A case study for Sweden. Energy 178, 695–713. https://doi.org/10.1016/j.energy.2019.04.128

**Knight, F.H**. Risk, Uncertainty and Profit. New York, NY: Sentry Press., 1921.

**Marchau, V**incent A. W. J., Warren E. Walker, Pieter J. T. M. Bloemen, und Steven W. Popper, Hrsg. Decision Making under Deep Uncertainty: From Theory to Practice. Cham: Springer International Publishing, 2019. https://doi.org/10.1007/978-3-030-05252-2.

**Patriarca, R**iccardo, Alessandro De Paolis, Francesco Costantino, und Giulio Di Gravio. „Simulation Model for Simple yet Robust Resilience Assessment Metrics for Engineered Systems“. Reliability Engineering & System Safety 209 (1. Mai 2021): 107467. https://doi.org/10.1016/j.ress.2021.107467.

**Shukla, P.R**., J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, und et al. „IPCC, 2019: Annex I: Glossary [van Diemen, R. (ed.)]. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems“, 2019. https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/11_Annex-I-Glossary.pdf.

TECHNISCHE
UNIVERSITÄT
WIEN

**All publications:**
https://perma.cc/M7DY-NWA8

**Peer-reviewed publications:**
https://orcid.org/0000-0001-6732-6919

# Thank you for your attention

**Submit your manuscript here:**
**https://energsustainsoc.biomedcentral.com/circularbioeconomy**


**fabian.schipfer@tuwien.ac.at**

Technische Universität Wien
Institute of Chemical, Environmental and Bioscience Engineering
Research Unit - Thermal Process Engineering and Simulation

Getreidemarkt 9/166
A-1060 Vienna
https://www.tuwien.at/en/tch/icebe/e166-02
**www.schipfer.eu**


SCIENTISTS FOR FUTURE ÖSTERREICH

TECHNISCHE UNIVERSITÄT WIEN

International Institute for Applied Systems Analysis

IIASA


# BACK-UP SLIDES

Klimatag – 03.04.2024, TU Wien

TECHNISCHE UNIVERSITÄT WIEN

## Part 2

International Institute for Applied Systems Analysis

# Risk identification & evaluation

Definition by Risk Management – Guidelines ISO31000:2018
**Risk = effect of uncertainty on objective**

**Objectives:** Satisfying societal needs via a physical provisioning system
100% renewable power by 2030, Climate neutrality by 2040, Efficiency, Security
→ see e.g., Austrian national energy and climate plans (NECPs/NEKPs)

**Effects & consequences:**

regarding nodes (also referred to as vertices, technologies, sources, users):
power, heat, fuel, metabolic waste treatment, food, and material (by-)production

regarding edges (also referred to as links, infrastructure, grids):
networks for power, heat, gas, oil, rail, road, water, hydrogen, CO2, …

TECHNISCHE UNIVERSITÄT WIEN

# Summary 2/2

International Institute for Applied Systems Analysis

**Project goals:**

Risk management for the multi-faceted Austrian energy system

1. Review the capabilities of existing models
2. Test capabilities of selected
   power system (by Boku) and a
   bioenergy supply chain model (by IIASA)
3. Formulate a research and modeling agenda

**Potential implications:**

More robust and coherent science-policy recommendations

a) Strategies for the amplification of synergies and the mitigation of trade-offs inherent to system integration (also referred to as multi-sector coupling)
b) Moving multi-perspectivity into the spotlight, fostering responsible interdisciplinarity

# Results – risk treatment (Step 3/3)

Broadening the definition of "flexibility":

**Ability to <u>shift resources</u>**

- **through time,** ← short-, medium-, long-term storage
- **through space,** ← via networks & trade
- **between sectors &** ← via multi-sector coupling
- **between options** ← via portfolios



"Flexibilisiation" = increasing the ability …

# Results – risk treatment (Step 3/3)

Broadening the definition of “flexibility”:

**Ability to <u>shift resources</u>**

- **through time,** ← short-, medium-, long-term storage
- **through space,** ← via networks & trade
- **between sectors &** ← via multi-sector coupling
- **between options** ← via portfolios

**... to balance scarcities with surpluses**

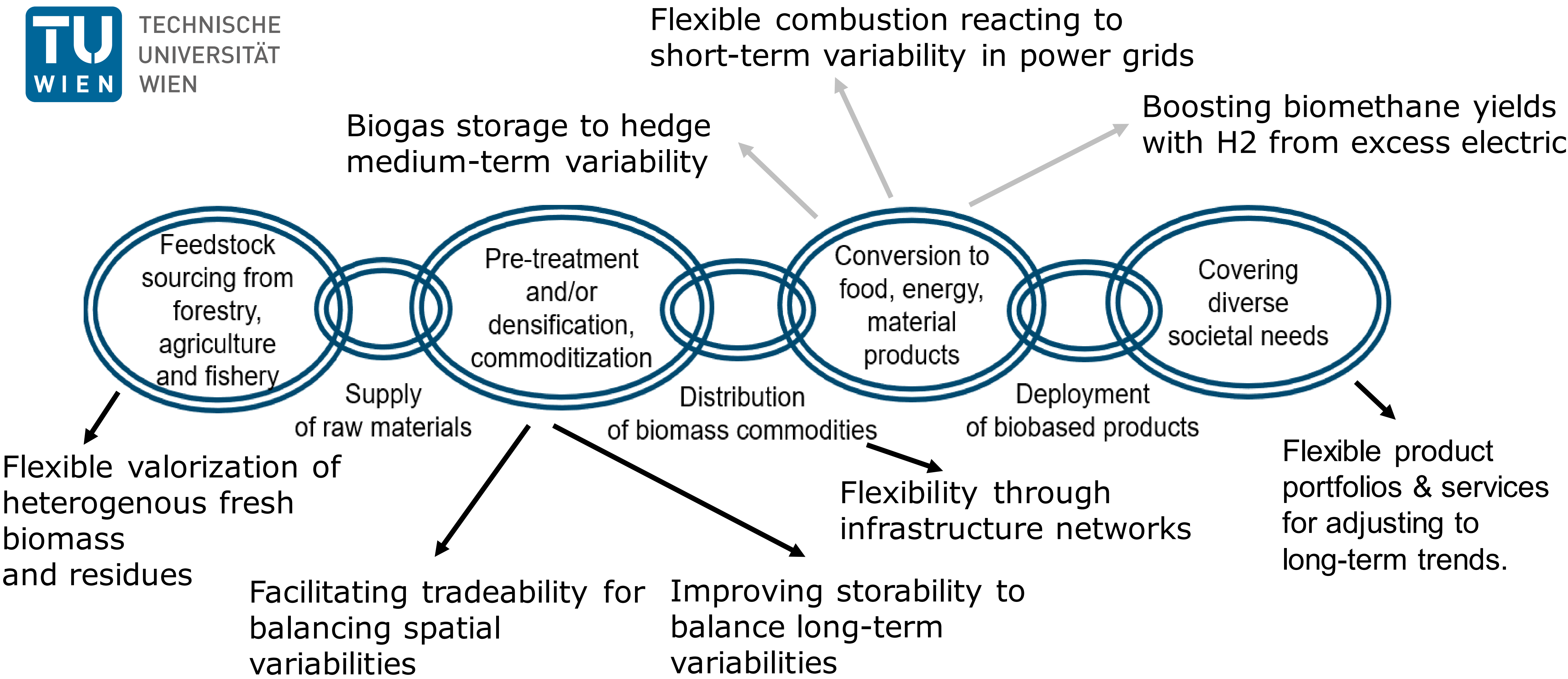
<u>Mitigating shortages</u>
system reliability/resilience

<u>Balancing</u>
via connectors

<u>Valorizing surpluses</u>
(broader) systems’ efficiency



“Flexibilisiation” = increasing the ability ...




Schipfer, F., Mäki, E., Schmieder, U., Lange, N., Schildhauer, T., Hennig, C., Thrän, D., 2022. Status of and expectations for flexible bioenergy to support resource efficiency and to accelerate the energy transition. Renewable and Sustainable Energy Reviews 158, 112094. https://doi.org/10.1016/j.rser.2022.112094 **IEA Bioenergy TCP Task44 "Flexibility & System Integration" Results of 1st Triennium**

# Flexibility assessment:

**System reliability/resilience**

**Resource efficiency**

- Overall costs, revenue, share of wasted energy, wasted biomass, emissions ...
- Optimisation problem
- Competitive market equilibrium for optimal resource allocation
- BUT varying results depending on considered system boundaries

# Flexibility assessment:

**System reliability/resilience**

"It´s basically probability"
Sugababes, Overloaded, 2000

**Resource efficiency**

- Overall costs, revenue, share of wasted energy, wasted biomass, emissions …
- Optimisation problem
- Competitive market equilibrium for optimal resource allocation
- BUT varying results depending on considered system boundaries

# Measuring reliability ….

**A vast body of literature:**

for concepts of reliability, resilience, stability, security, safety, continuity, health, persistence, robustness ….

in multiple established and upcoming disciplines and research areas including

- Process safety domains > Safe & Sustainable by Design
- Resilience Engineering
- Graph and network theory > applications in Ecosystem Modelling
- Disaster Risk Management
- Decision-making Under Deep Uncertainty
- U.S. MultiSector Dynamics Modelling Community of Practice (CoP)
- …

# Flexibility assessment:

To assess the contributions of ...

- Combined Bioenergy heat & power
- Storage of renewable gases
- Storage and trade of wood pellets
- H2 production & trade
- Coupling power grids & mobility
- Biorefineries for materials & energy
- ....
- ....
- Diversification of feedstock portfolio
- Diversification of power generation- / product portfolio

Evaluate the ability to shift resources through time, through space, between sectors & between markets.

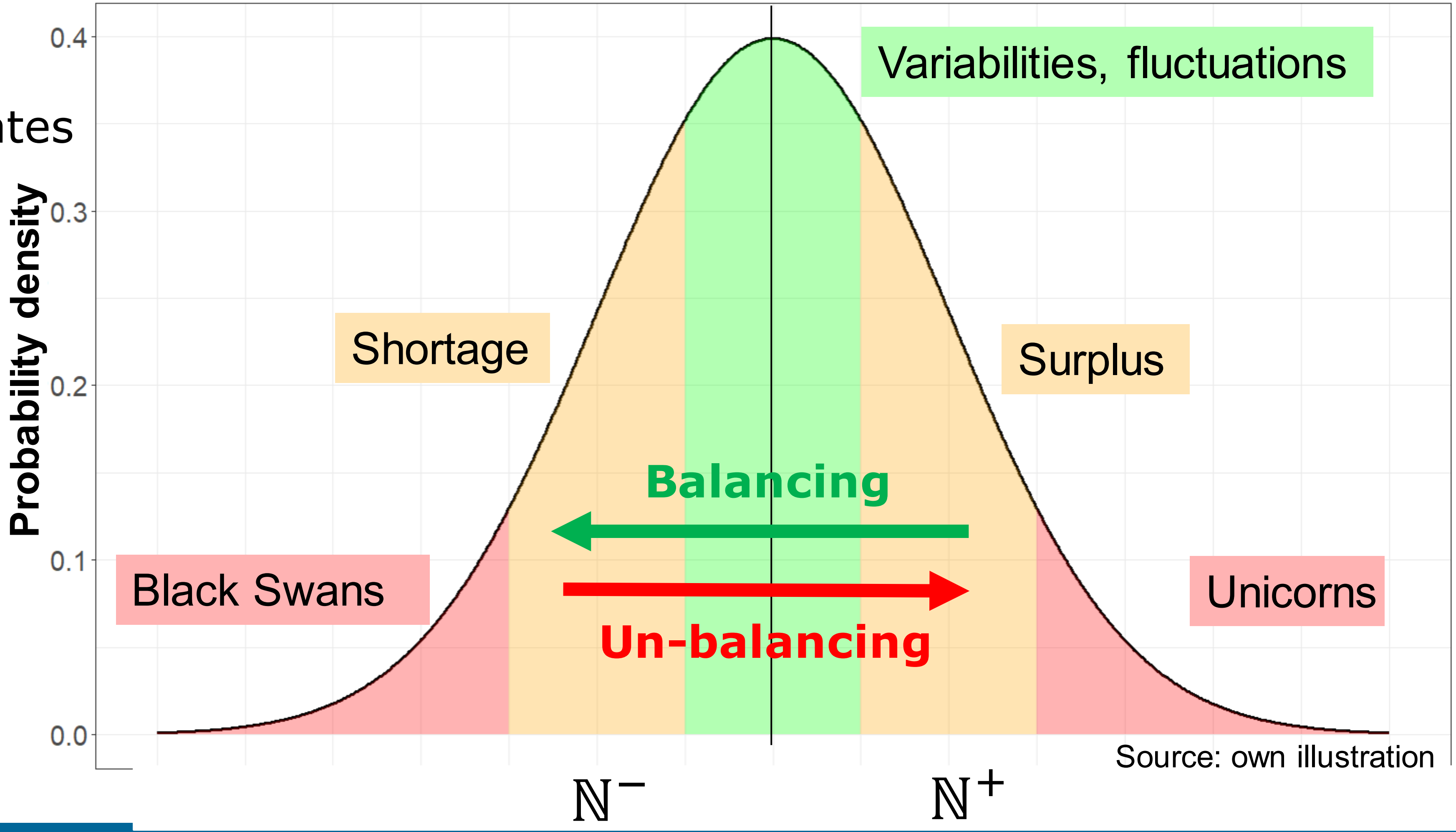
TECHNISCHE UNIVERSITÄT WIEN

# Opportunities ← and dangers → of increasing flexibility

Flexibility e.g., through multi-sector coupling creates **systemic risks**

Modelling to anticipate Opportunities & dangers, synergies & trade-offs, of multi-sector coupling!

**Illustrative example of (un)balancing scarcities & surpluses**



Source: own illustration

# Interdisciplinary jargon awareness

- We must “abolish the idea of the possibility of a metalanguage” , “no discourse is truly objective” (see Timothy Morton in Hyperobjects)
- Each discipline, subdiscipline, focus, case-study uses own jargon = key-words & syntax
- Scientific practice is to filter what´s relevant based on language ← fundamental barrier for interdisciplinarity
- “Cognitive biases” are intrinsically human, influencing our every day judgements & decisions (see Daniel Kahneman, more practically also Bell Hooks ...)

**A possible way forward:**

1. Linguistic flexibility → know your biases, and the biases of others – be open to varying wordings
2. Attach glossaries & definitions that meet the requirements for transmitting your own message
   How much variation in terms of synonyms can your message handle?
3. Build inter-disciplinary Rosetta stones based on thesauri to facilitate literature research, translation of concepts between disciplines, dissemination to other fields, expertise matching on common problems