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Integration of Energy System Modelling and Multi-criteria Analysis

31st May 2016, Frontiers in Energy Research, Energy Science Center, ETH Zurich

Outline

- Introduction
- Methodology
- Multi-criteria analysis of global energy system scenarios
  - Economic indicators
  - LCA-based indicators
  - Other societal indicators
  - Security of supply indicators
- External cost assessment of global energy system scenarios
- Multi-criteria optimisation in the global energy system model
- Outlook

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Introduction

Island[4]

Japan[5]

Europe[2]

China[1]

Africa[3]

[1]www.chinadialogue.net, [2]www.utilities-me.com, [3]www.lightingafrica.org, [4]www.whoi.edu, [5]www.energyandcapital.com

Introduction

Motivation

- Today's global energy system is characterized by the **dominant use of fossil resources**. Thus, there are growing concerns about **climate change.**
- **But there are also but also other environmental, economic, and social aspects related to the energy system** such as air pollution, energy access, and energy supply security.
- For the transformation to more sustainable energy systems we must consider all these aspects along with their spatial and temporal dimensions.

Goals of my PhD thesis

- Multi-dimensional analysis of energy systems
- Identification of sustainability trade-offs from the transformation of energy systems
- Support decision-making

➢Integration of energy system modelling and multi-criteria analysis

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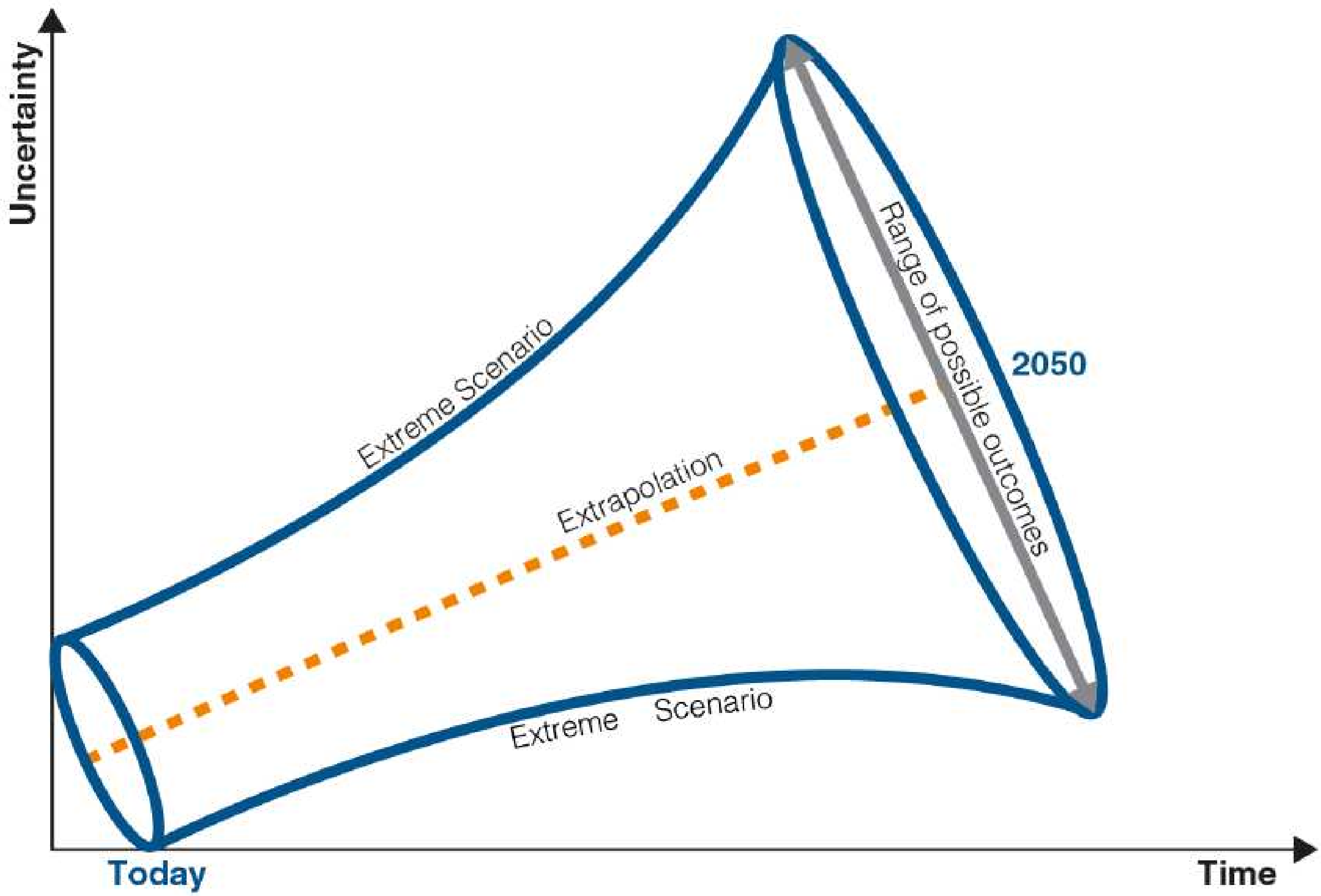
Methodology

- Energy system modelling
- Multi-criteria analysis

Methodology

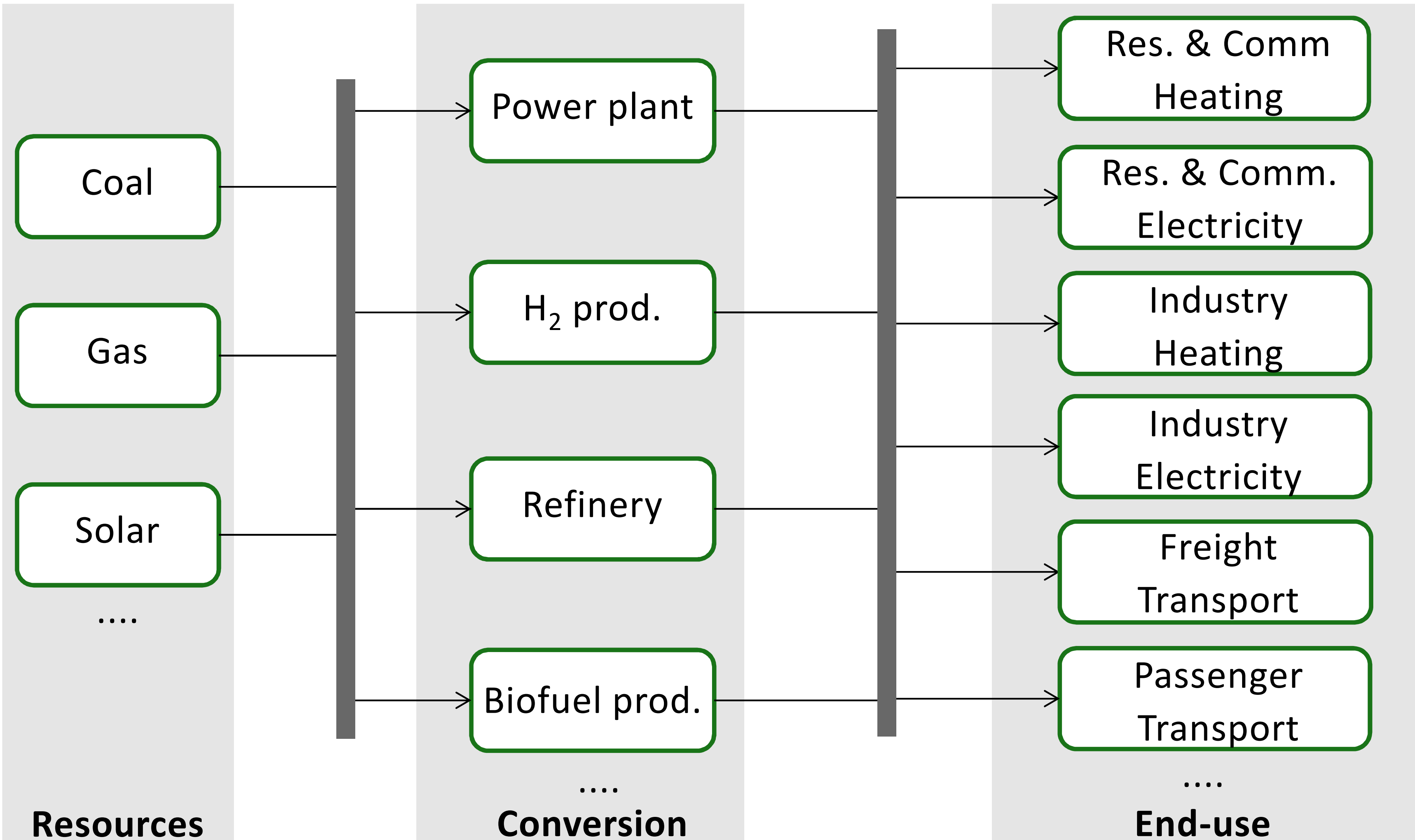
Energy-economic system modelling



WEC/PSI (2013)

Methodology

Energy-economic system modelling @PSI



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Methodology

- Energy system modelling
- Multi-criteria analysis

Methodology

Multi-criteria analysis of energy technologies

Environment

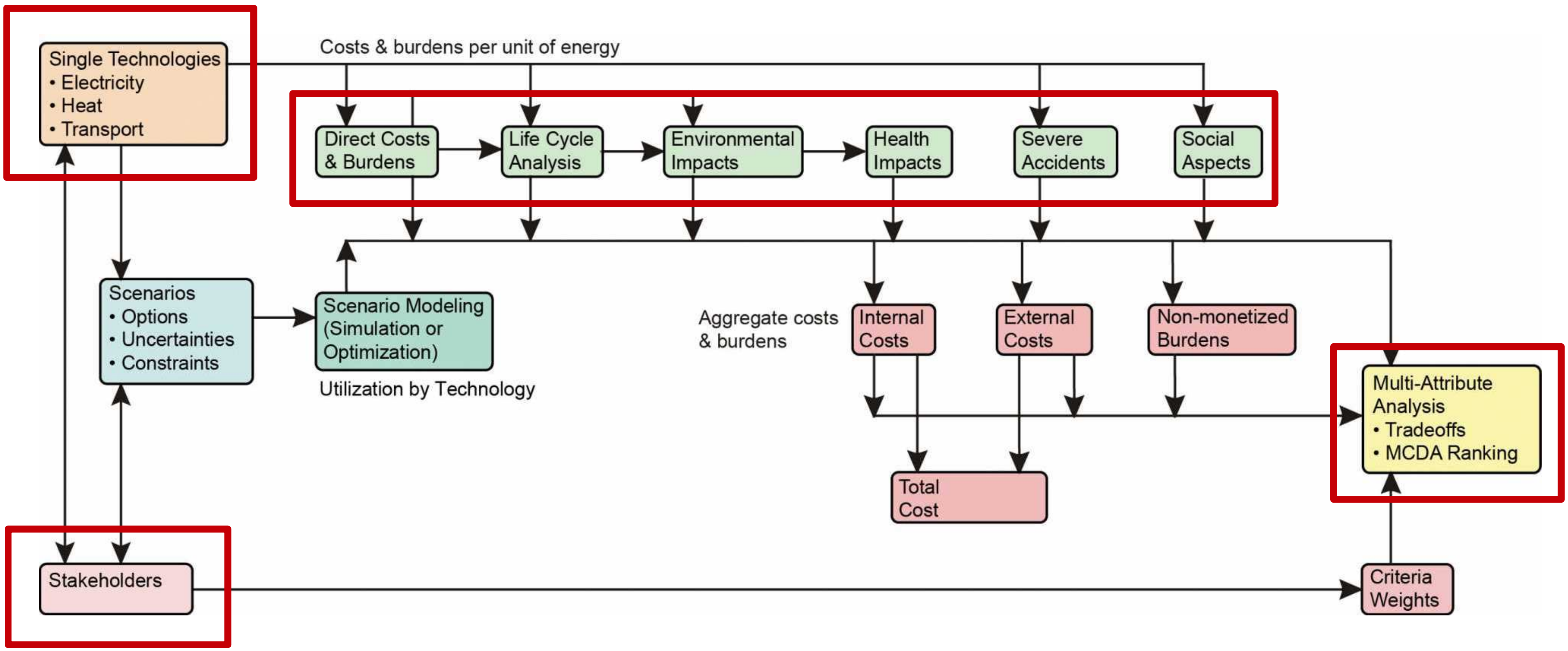
Economy

Society

Security of Supply

Methodology

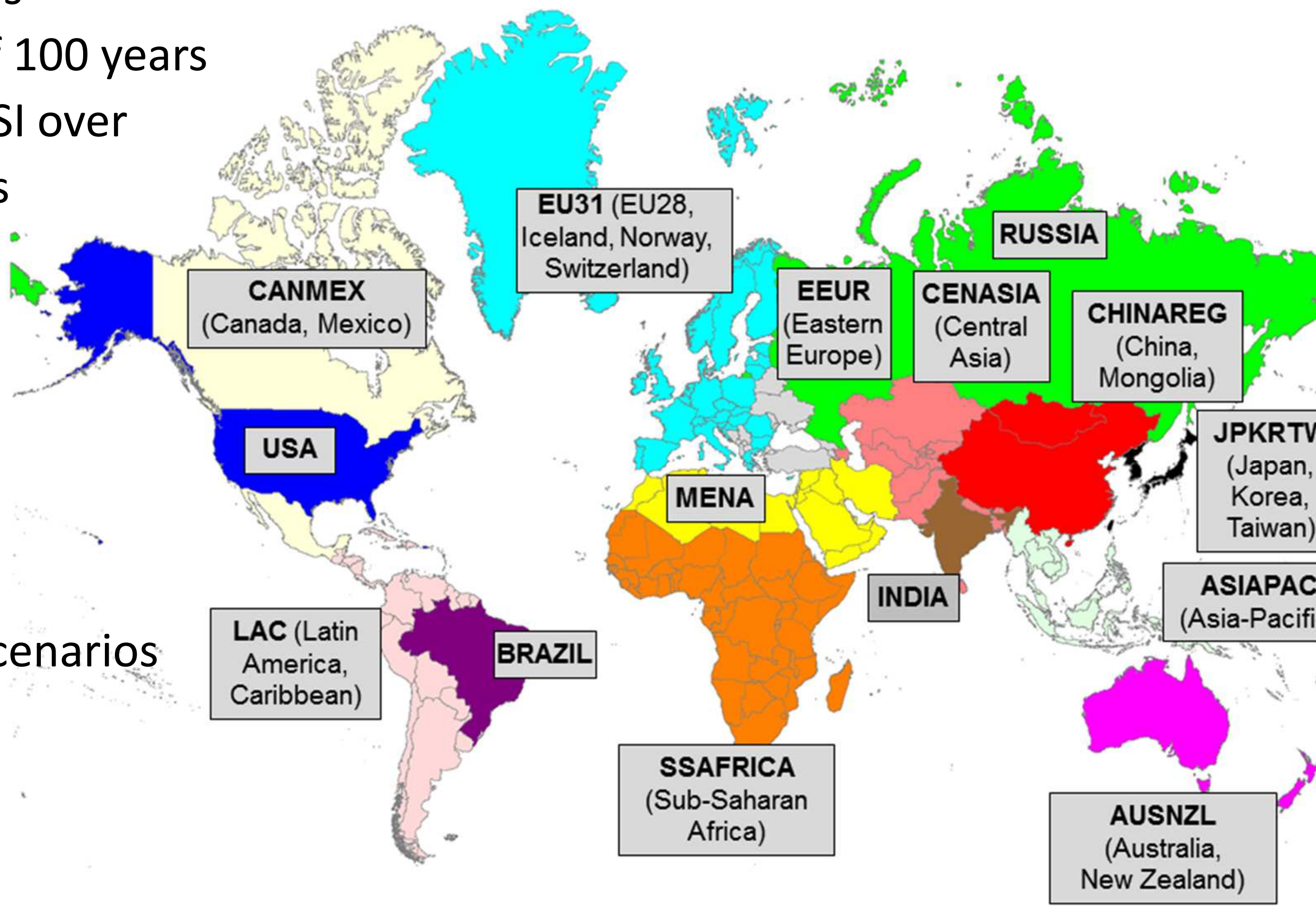
Multi-criteria analysis of energy technologies @PSI



www.psi.ch/ta

Global Multi-regional MARKAL (GMM) model

- Energy system model (partial equilibrium)
- 15 world regions
- Time horizon of 100 years
- Developed at PSI over the last 15 years



WEC/PSI (2013)

- WEC/PSI World Energy Scenarios
  - JAZZ
  - SYMPHONY

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World Energy Council (WEC)

- Formed in 1923
- UN-accredited global energy body
- More than 3000 member organisations located in over 90 countries
- representing the entire energy spectrum from governments, private and state corporations, academia, NGOs and energy-related stakeholders.

- Network of leaders and practitioners **promoting an affordable, stable and environmentally sensitive energy system** for the greatest benefit of all.
- Informs global, regional and national energy strategies by hosting high-level events, **publishing authoritative studies**, and working through its extensive member network to facilitate the world's energy policy dialogue.

- Regular reports:
  - World Energy Resources
  - World Energy Trilemma
  - World Energy Issues Monitor
  - **World Energy Scenarios**

WORLD ENERGY COUNCIL

All information from www.worldenergy.org

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WEC/PSI World Energy Scenarios (2013)

	Scenario JAZZ	Scenario SYMPHONY
Goals	• Affordable access to energy through free markets • High income • Mainly adaptation to environmental damages	• Secure access to energy • Targeted regulation through states and international organizations • Mainly avoidance of environmental damages
Economic Growth (Gross Domestic Product, GDP)	GDP growth has priority (3.5% annual average to 2050)	Less GDP growth (3.1% annual average to 2050)
Population	Increase (8.7 billion in 2050)	Strong increase (9.3 billion in 2050)
Climate Policy	CO_2 markets develop slowly (CO_2 price in 2050: 23–45 \$/tCO_2)	Rapid state control (CO_2 price in 2050: 70–80 \$/tCO_2)
Energy Efficiency / Intensity	Efficiency increases based on economic criteria	State promotion of measures for efficiency and energy savings
Unconventional Resources (Shale oil/gas, oil sands)	Expanded opening of markets. High incentives for use due to high energy demand.	Regulation (regarding water use, market access). Fewer incentives due to lower demand.
Renewable Energy	Limited promotion. "The market" selects the technologies.	Selective state promotion
Non-renewable Energy	Limited support: • CCS market driven, pilot plants by 2030 • Nuclear plants under construction partially not in operation	State support: • CCS available from 2020 • Nuclear energy

https://www.psi.ch/eem/wec-comparison

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Integration of economic indicators

Environment

- Greenhouse gas emissions
- Resources (metal, fossil)
- Ecosystem damages

Economy

- Energy system cost
- Energy cost
- Pollution tax

Society

- Human health impacts
- Chemical waste
- Expected mortality in accidents
- Maximum consequences of accidents (conflict potential)

Security of Supply

- Diversity of energy supply
- Import dependency
- Energy intensity, TFC/TPES
- Reserves-to-production ratio
- Refining capacity
- Renewable / Oil share in TPES

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Integration of LCA-based indicators

Life-cycle assessment (LCA)

- Evaluation of environmental impacts associated with all the stages of a product's life from cradle to grave, i.e., raw material extraction, materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.
- Life-cycle inventory datasets in background database ecoinvent

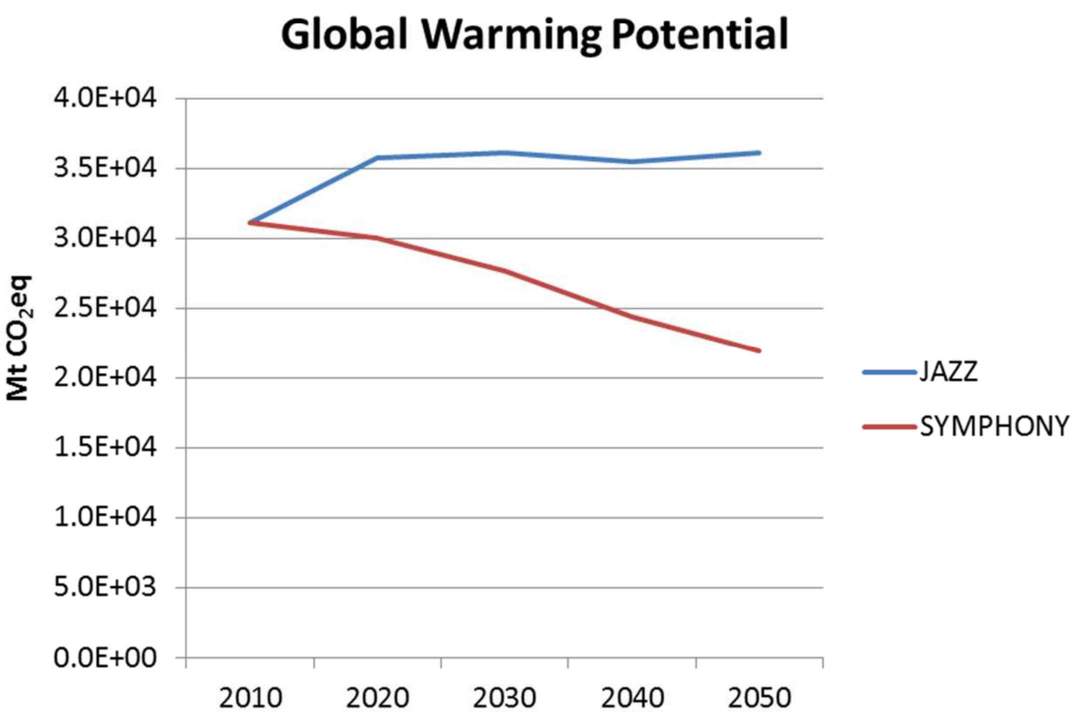
Research questions

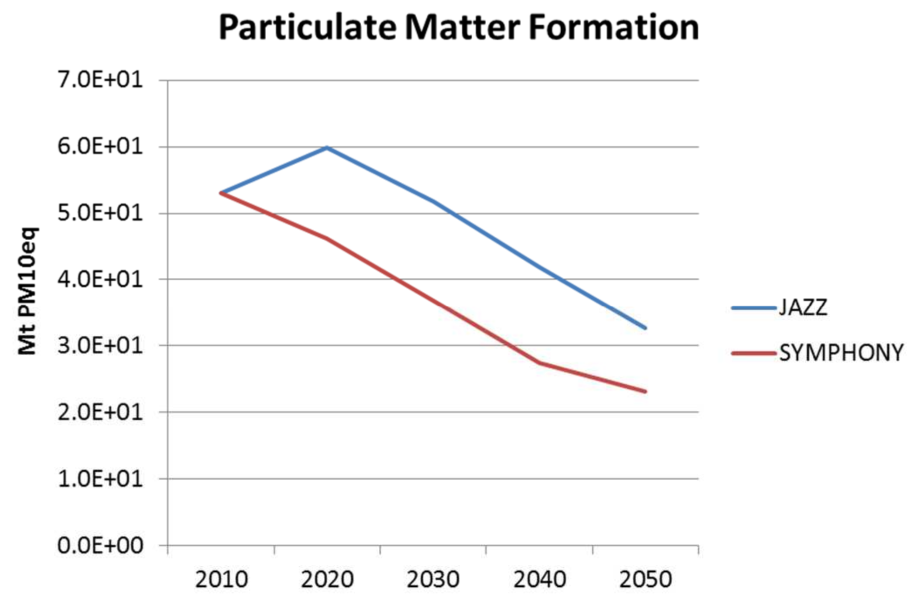
- How can LCA-based indicators be integrated in existing energy system models without double-counting of impacts?
- What are the environmental impacts of the global energy system from a life-cycle perspective?

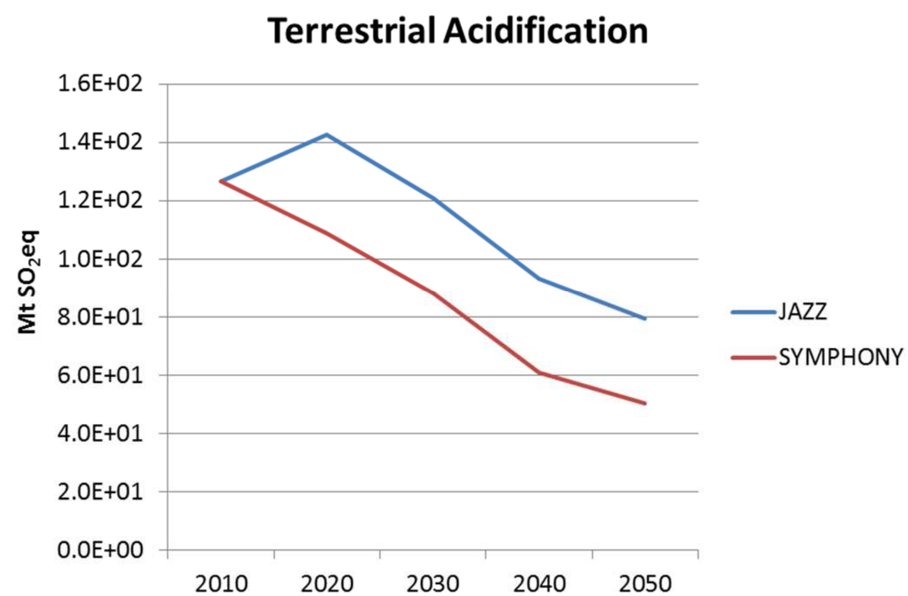
Collaborators

- Chris Mutel
- Martin Densing, Evangelos Panos

Preliminary Results







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Integration of other societal indicators

Risk assessment

- Energy-related Severe Accident Database (ENSAD)
- Accidents can occur at all stages of an energy chain, i.e. extraction, transport, and plant.
- In ENSAD, data on all energy-related accidents is collected and classified into energy chains and activities within those chains.

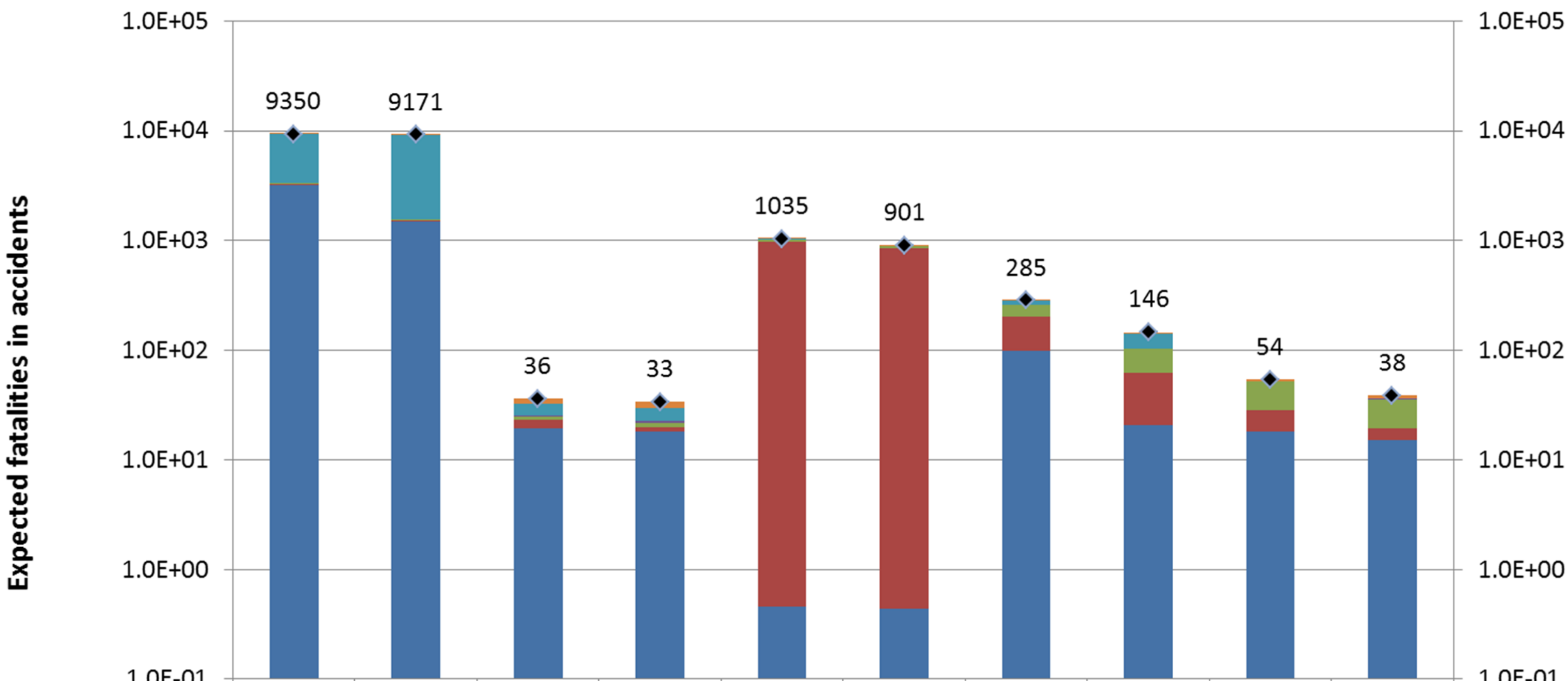
Research questions

- How can accident risk assessment indicator be integrated in existing energy system models?
- What are the expected consequences from accidents in the global energy system based on historic evidence?

Collaborators

- Peter Burgherr
- Martin Densing, Evangelos Panos

Preliminary Results



	JAZZ - 2050 - CHINAREG - P	SYMPH - 2050 - CHINAREG - P	JAZZ - 2050 - EU31 - P	SYMPH - 2050 - EU31 - P	JAZZ - 2050 - MENA - P	SYMPH - 2050 - MENA - P	JAZZ - 2050 - RUSSIA - P	SYMPH - 2050 - RUSSIA - P	JAZZ - 2050 - USA - P	SYMPH - 2050 - USA - P
Other renewables	4	4	4	4	4	5	4	4	2	2
Hydro	6031	7611	7	7	6	5	23	38	0	0
Nuclear	0	1	1	1	0	0	0	0	0	1
Gas	33	18	1	2	54	39	56	43	24	16
Oil	91	51	4	2	970	852	103	41	10	4
Coal	3191	1486	19	18	0	0	99	21	18	15
◆ Total	9350	9171	36	33	1035	901	285	146	54	38

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Integration of security of supply indicators

Security of supply

- "uninterrupted availability of energy sources at an affordable price" (IEA, 2015)
  - **Long-term** energy security: timely investments in the supply of energy
  - **Short-term** energy security: ability of the energy system to react to sudden changes within the supply-demand balance

Research questions

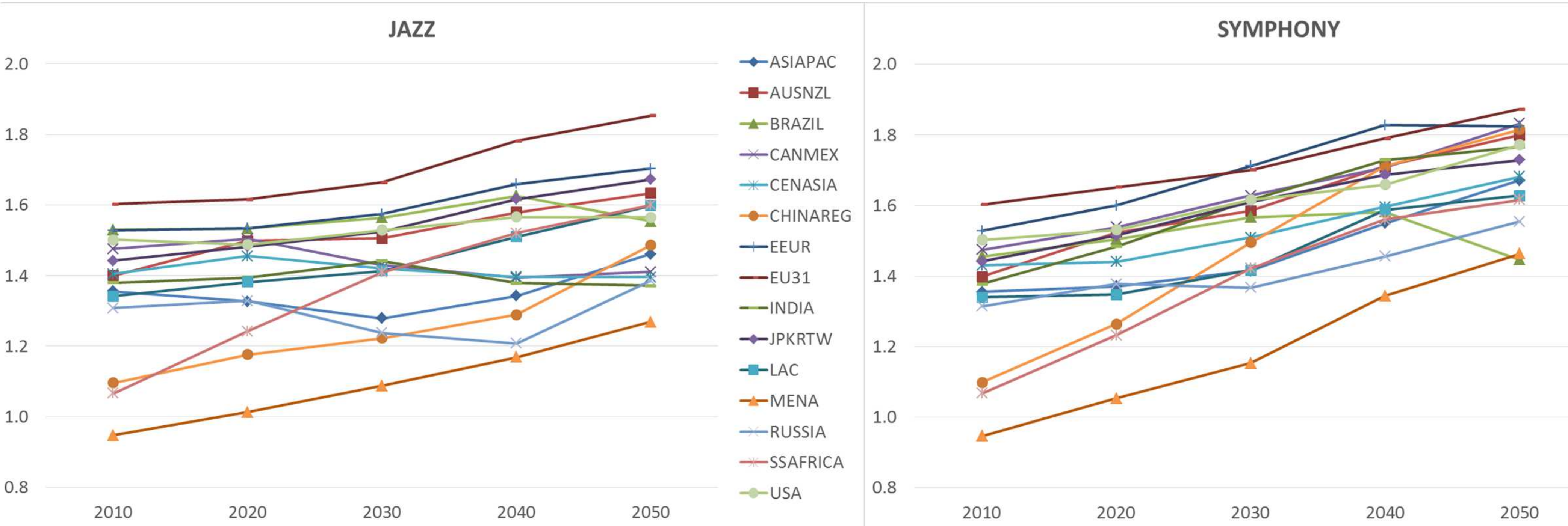
- What are important security of supply indicators?
- How does the security of supply of the global energy system evolve?

Collaborators

- Moritz Köhme
- Martin Densing, Evangelos Panos

Preliminary Results

Shannon-Wiener Index for Total Primary Energy Supply (TPES)



M. Köhme (2016)

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External cost assessment

Externalities

- Costs or benefits imposed upon a third party when goods and services are produced and consumed.
  - **External costs**: Third party has a drawback.
  - **External benefits**: Third party has an advantage.

Research questions

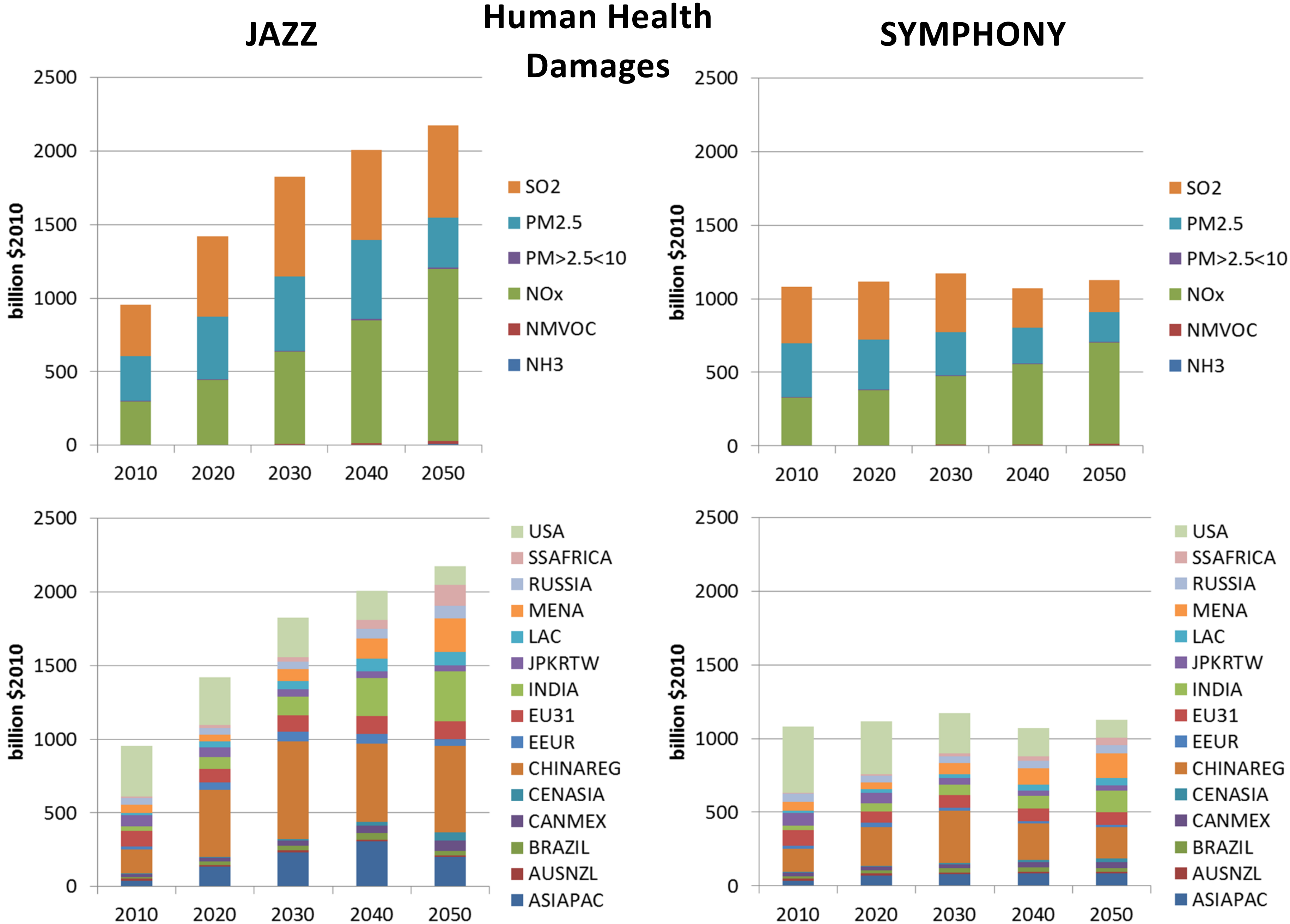
- What are the external costs of the global energy system?
- How do the external costs compare with the GDP in the respective period?

Collaborators

- Michael Hegglin
- Chris Mutel
- Evangelos Panos
- Martin Densing

Preliminary Results

Human Health Damages



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Multi-criteria optimization

Research questions

- How do energy systems look which are optimized for other indicators than cost or weighted combinations of indicators?
- How much does achieving other sustainability goals cost?

Collaborators

- Martin Densing
- Nagore Sabio
- Evangelos Panos

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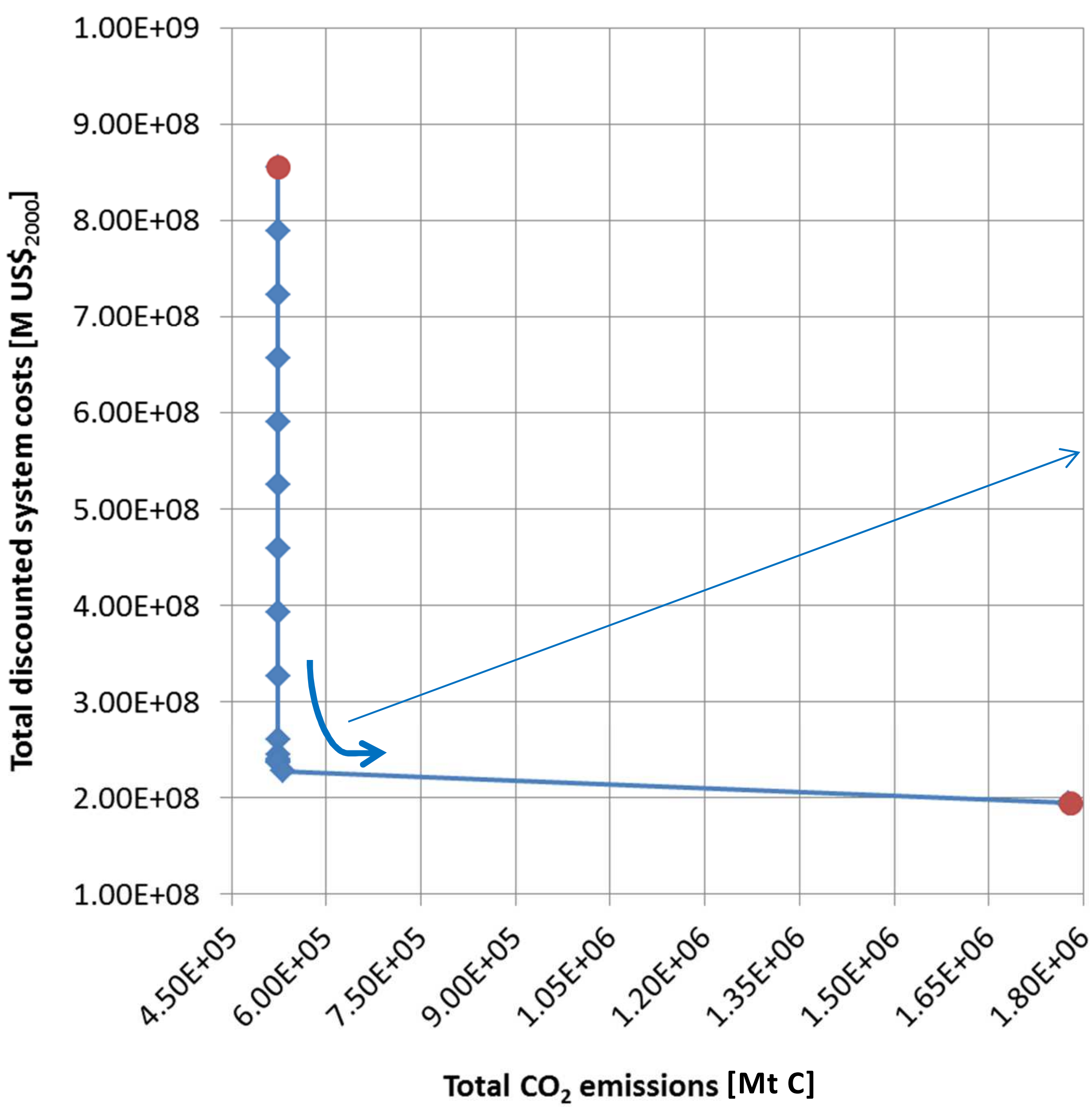
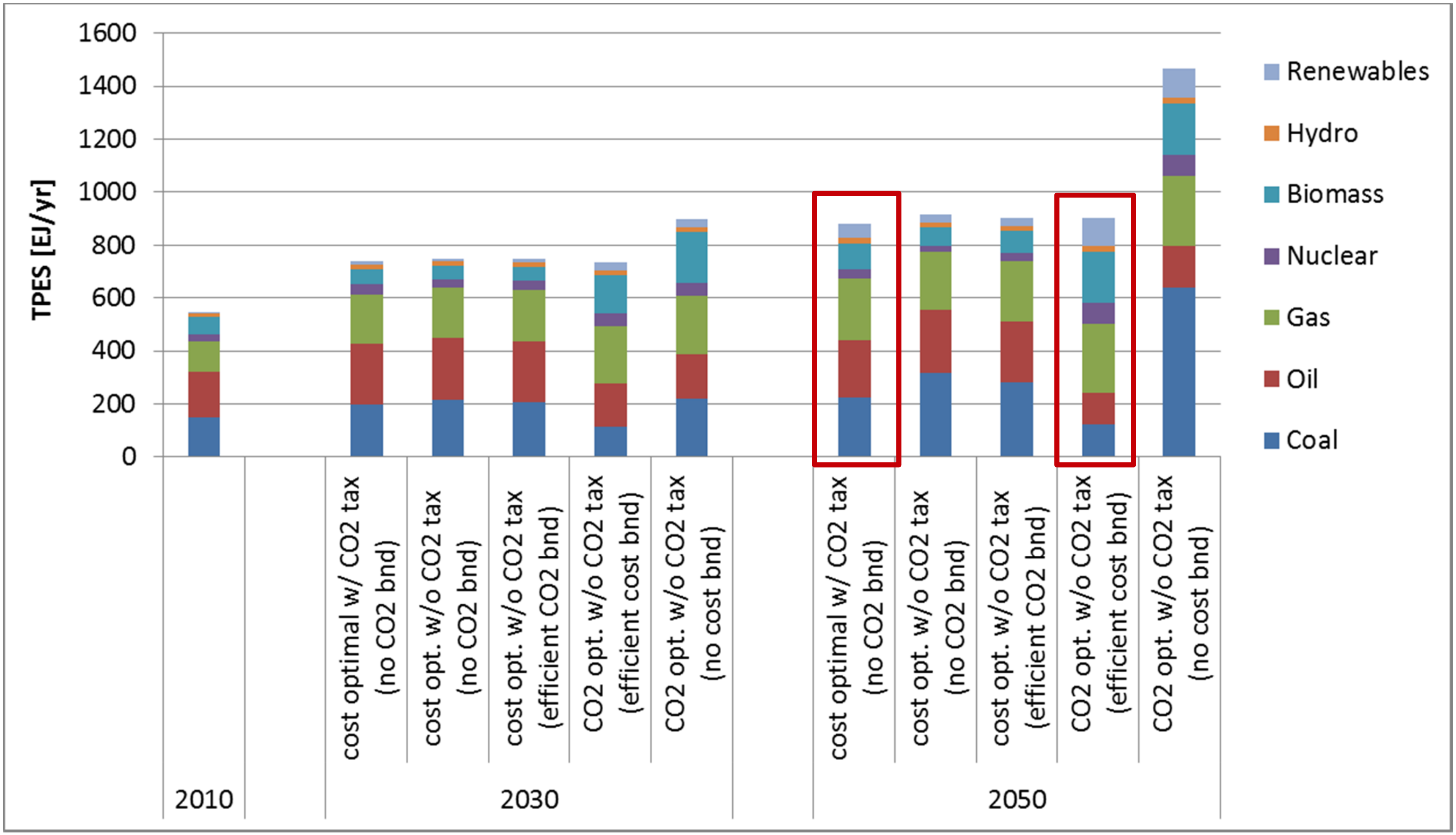
Preliminary Results: Epsilon constraint approach



	COST	CO2	COMMENT
JAZZ_20	8.55E+08	5.24E+05	min CO2 @8.55E8 cost bnd
JAZZ_21	7.89E+08	5.24E+05	
JAZZ_22	7.23E+08	5.24E+05	
JAZZ_23	6.57E+08	5.24E+05	
JAZZ_24	5.91E+08	5.24E+05	
JAZZ_25	5.25E+08	5.24E+05	
JAZZ_26	4.59E+08	5.24E+05	
JAZZ_27	3.93E+08	5.24E+05	
JAZZ_28	3.27E+08	5.24E+05	
JAZZ_29	2.61E+08	5.24E+05	
JAZZ_32	2.44E+08	5.24E+05	
JAZZ_34	2.40E+08	5.24E+05	
JAZZ_35	2.38E+08	5.24E+05	
JAZZ_36	2.37E+08	5.24E+05	efficient solution
JAZZ_33	2.36E+08	5.25E+05	
JAZZ_31	2.28E+08	5.32E+05	
JAZZ_30	1.95E+08	1.78E+06	min CO2 @1.95E8 cost bnd
JAZZ_14	*1.95E+08*	*1.78E+06*	*min cost @no CO2 bnd*
JAZZ_15	*8.55E+08*	*5.24E+05*	*min CO2 @no cost bnd*

Preliminary Results: Epsilon constraint approach



I would like to thank:

- Martin Densing
- Evangelos Panos
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- Nicolas Weidmann
- Christian Bauer
- Peter Burgherr
  (all from PSI)

- Michael Hegglin
- Moritz Köhme
  (both from ETHZ)

- Nagore Sabio
- Neil Strachan
  (both from UCL)