Integrating Global Energy-economic System Modelling and Life-cycle Assessment

Kathrin Volkart

Energy Economics group, Laboratory for Energy Systems Analysis, Paul Scherrer Institut, Switzerland

Motivation

Today's energy system

The world faces various challenges related to the (global) energy system, e.g.

- climate change
- resource depletion
- energy access
- human health damages

Addressing one of the challenges mentioned above may influence (the solution of) other challenges.

→ This leads to complex decisions for energy policy-makers.

→ Therefore, integrated and consistent assessment methodologies are required for decision support and for the transition to sustainable energy systems.
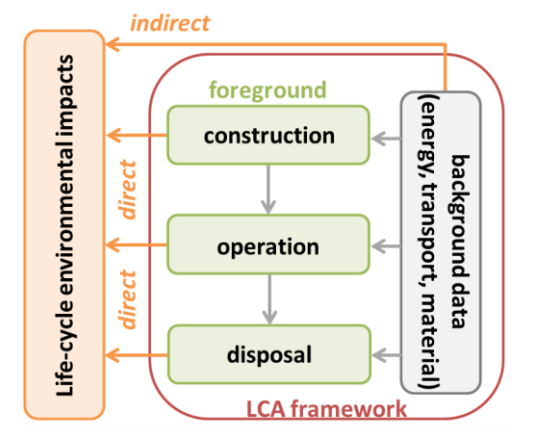
Concept and Methodology

Life-cycle assessment (LCA)

LCA is used for environmental assessment of energy technologies. The *ecoinvent* database provides detailed background data.

Characteristics:
- detailed environmental indicators
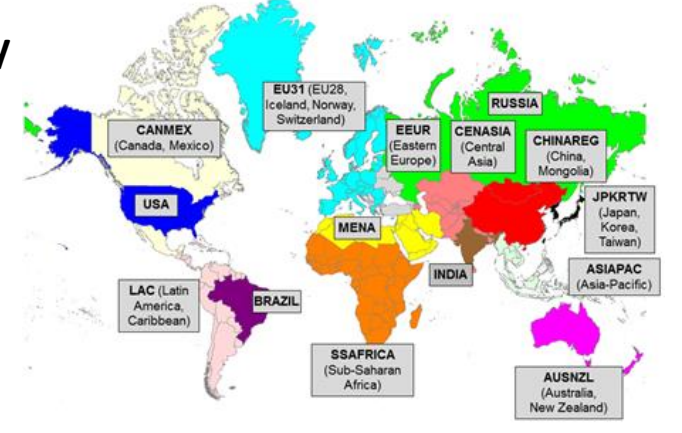- detailed human health indicators

Energy system modelling

The 15-region Global Multi-regional MARKAL (GMM) energy system model is used to develop, quantify and analyze scenarios of the global energy system.
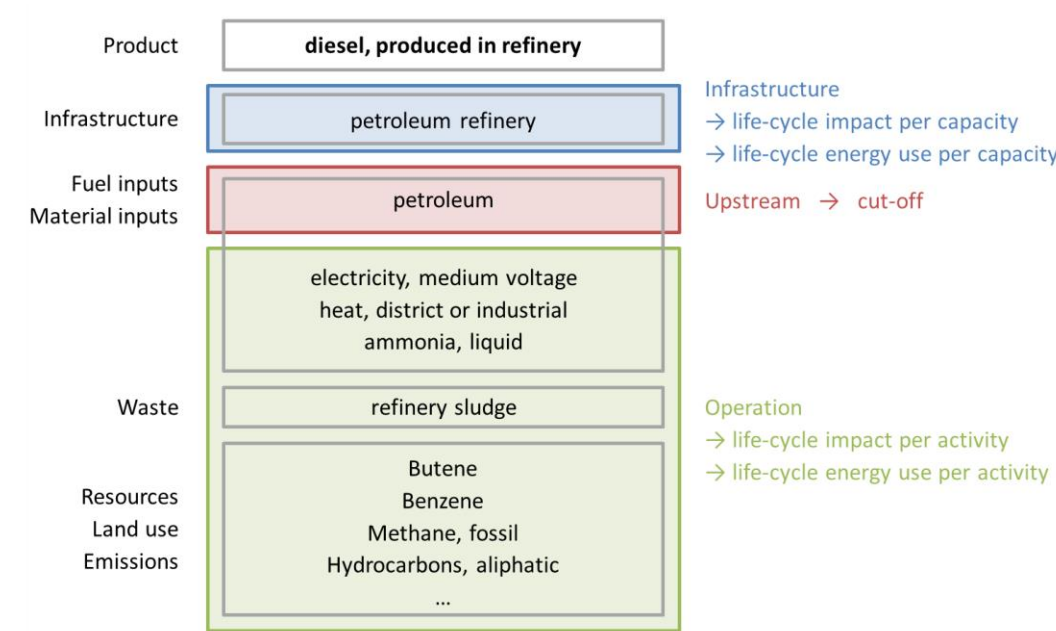
Characteristics:
- system perspective
- temporal development
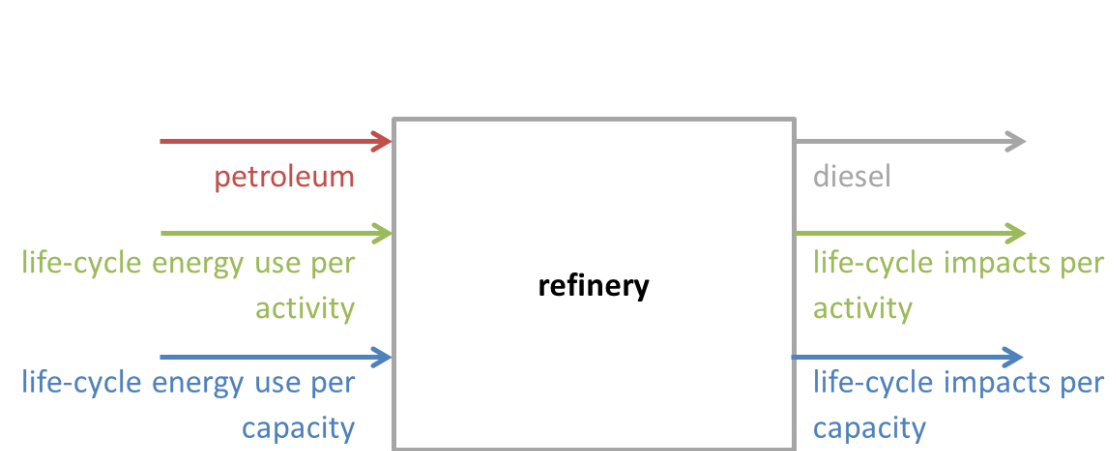- techno-economic indicators

Integration

Methodological approach

(1) Disaggregation of the relevant *ecoinvent* datasets into upstream, infrastructure and operation phase

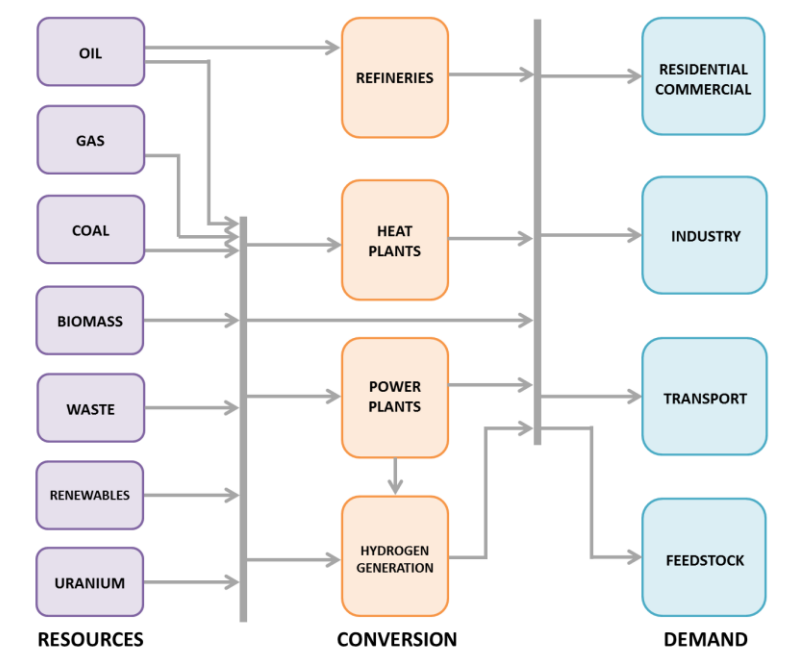|	
Product	diesel, produced in refinery
Infrastructure	petroleum refinery
Fuel inputs	petroleum
Material inputs	electricity, medium voltage; heat, district or industrial; ammonia, liquid
Waste	refinery sludge
Resources / Land use / Emissions	Butene; Benzene; Methane, fossil; Hydrocarbons, aliphatic …

Infrastructure → life-cycle impact per capacity → life-cycle energy use per capacity

Upstream → cut-off

Operation → life-cycle impact per activity → life-cycle energy use per activity

(2) Calculation of the LCA results per activity and capacity for each process of the GMM model

petroleum → refinery → diesel

life-cycle energy use per activity → life-cycle impacts per activity

life-cycle energy use per capacity → life-cycle impacts per capacity

LCA software: Brightway2

(3) Integration of the LCA results in the GMM model

RESOURCES: OIL, GAS, COAL, BIOMASS, WASTE, RENEWABLES, URANIUM

CONVERSION: REFINERIES, HEAT PLANTS, POWER PLANTS, HYDROGEN GENERATION

DEMAND: RESIDENTIAL/COMMERCIAL, INDUSTRY, TRANSPORT, FEEDSTOCK

Results for World Energy Council (WEC/PSI) scenarios

Assessment of global environmental impacts 2010 to 2030
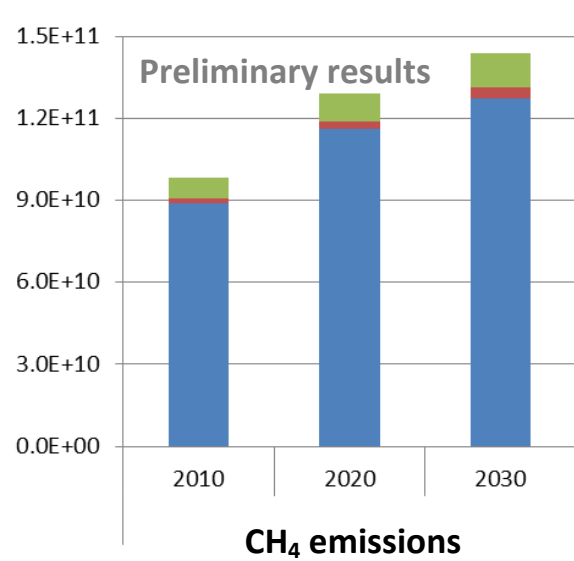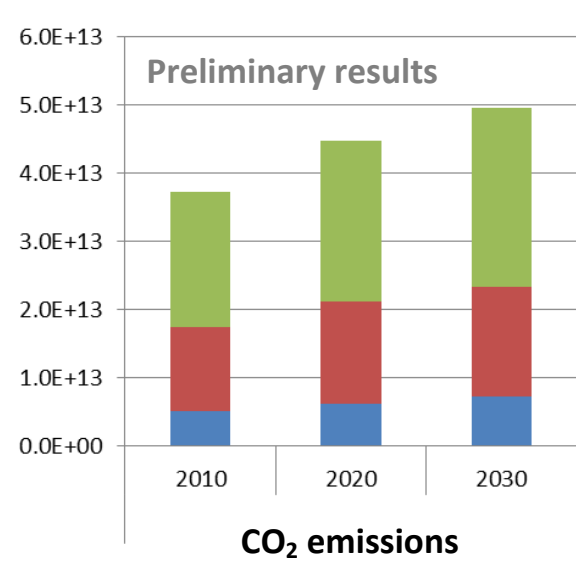
JAZZ scenario
- Affordable access to energy through free markets
- GDP growth has priority
- Population increase to 8.7 billion in 2050
- CO_2 price in 2050: 23–45 \$/tCO_2
- Mainly adaptation to environmental damages
- CCS is market driven; pilot plants by 2030
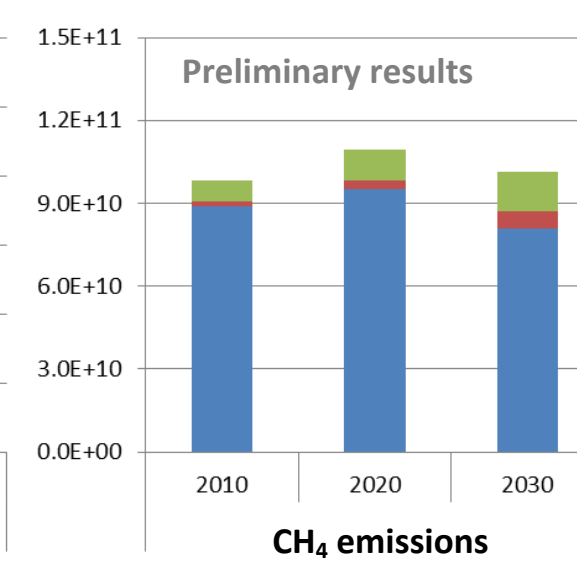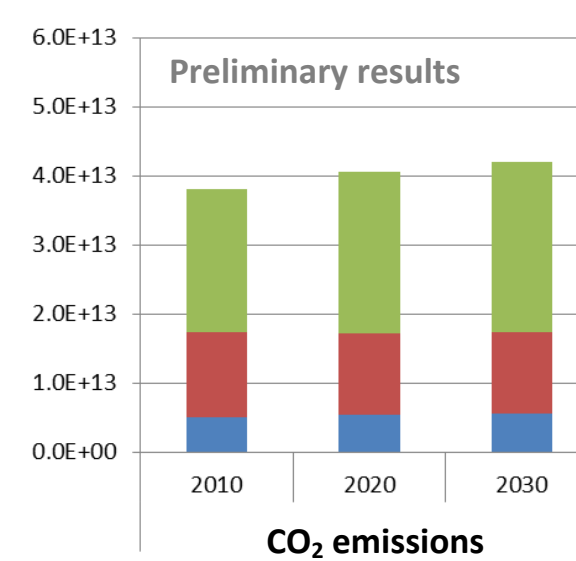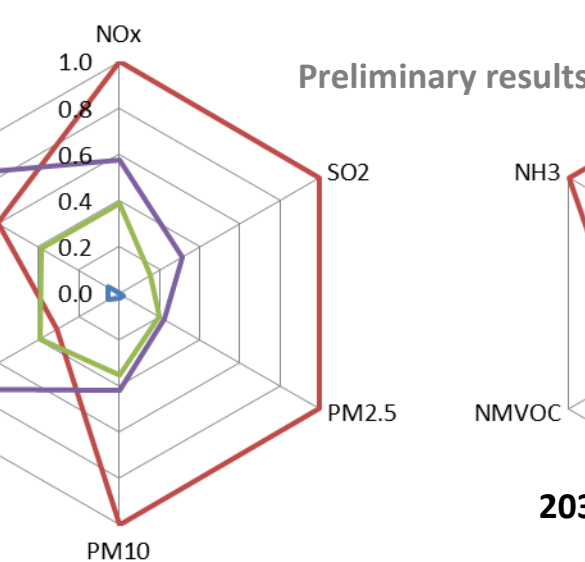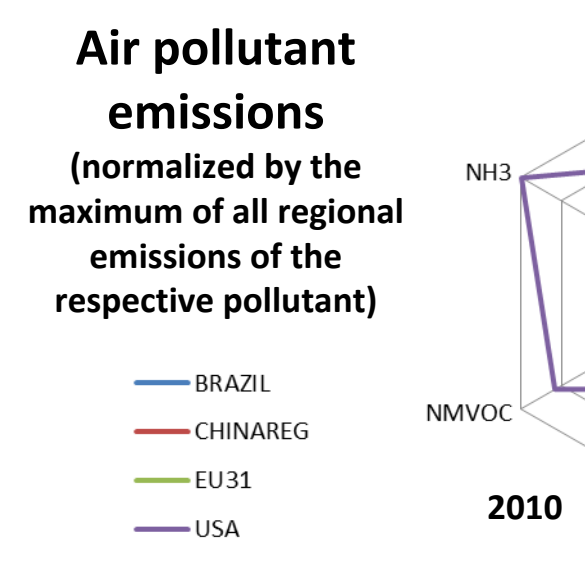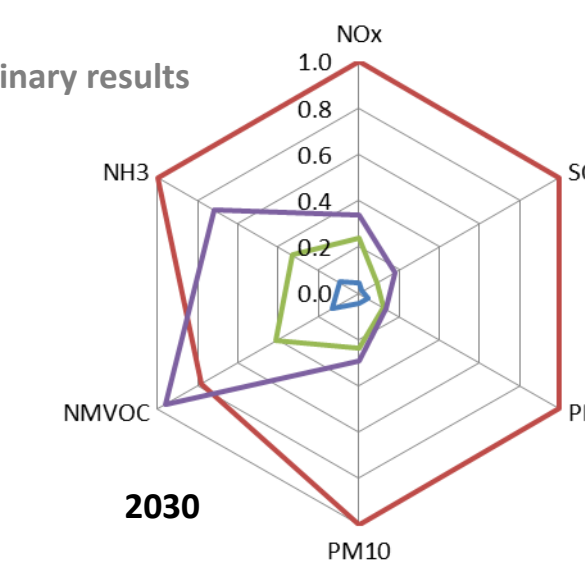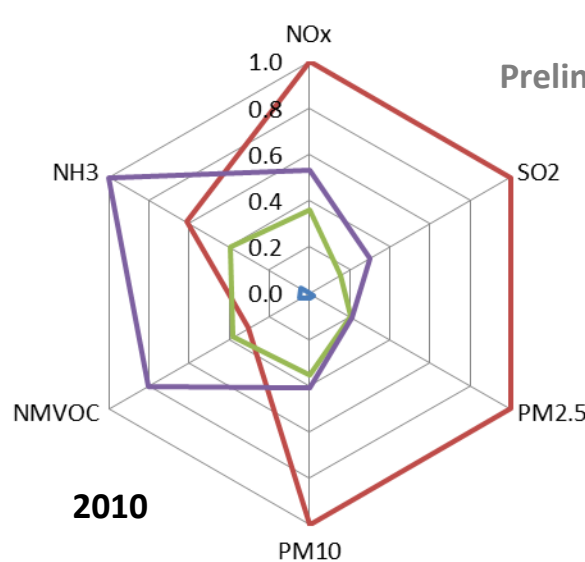- Nuclear plants under construction partially not in operation

SYMPHONY scenario
- Secure access to energy through regulation
- Less GDP growth compared to JAZZ
- Strong population increase to 9.3 billion in 2050
- CO_2 price in 2050: 70–80 \$/tCO_2
- Mainly mitigation of environmental damages
- CCS available from 2020
- State support for nuclear energy

Greenhouse gas emissions (in kg)

Preliminary results

legend:
- demand (residential/commercial, industry, transport)
- conversion (biofuel, hydrogen, electricity, heat)
- upstream (fuel chains)

CO_2 emissions — CH_4 emissions (JAZZ)

CO_2 emissions — CH_4 emissions (SYMPHONY)

Air pollutant emissions (normalized by the maximum of all regional emissions of the respective pollutant)

legend:
- BRAZIL
- CHINAREG
- EU31
- USA

Radar axes: NOx, SO2, PM2.5, PM10, NMVOC, NH3

2010 / 2030 (JAZZ) — 2010 / 2030 (SYMPHONY)
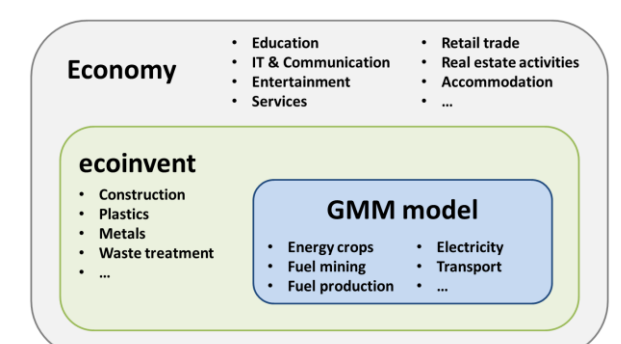
Challenges

Methodological difficulties

- Finding equivalent processes in the two models, i.e. allocation of one *ecoinvent* to each GMM process
- Harmonizing of *ecoinvent* and GMM modelling data by adjusting information on:
  - energy carrier flows
  - units
  - efficiencies
- Regionalization, i.e. choice of the *ecoinvent* region(s) used to model the corresponding region in the GMM model
- Modelling of future technologies that are not represented in the *ecoinvent* database
- Modelling of the energy own-use of the energy sector

Conclusions

Preliminary findings

Methodology
- The methodological approach was successfully implemented, i.e. the GMM energy system model was extended by environmental data on LCA basis.
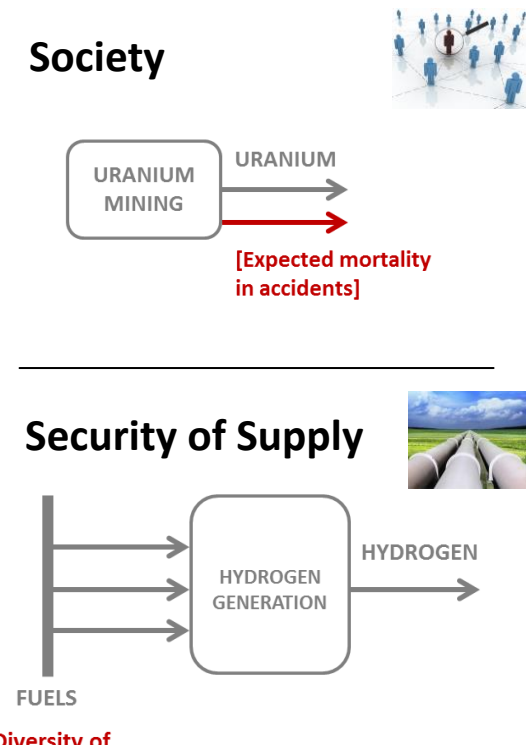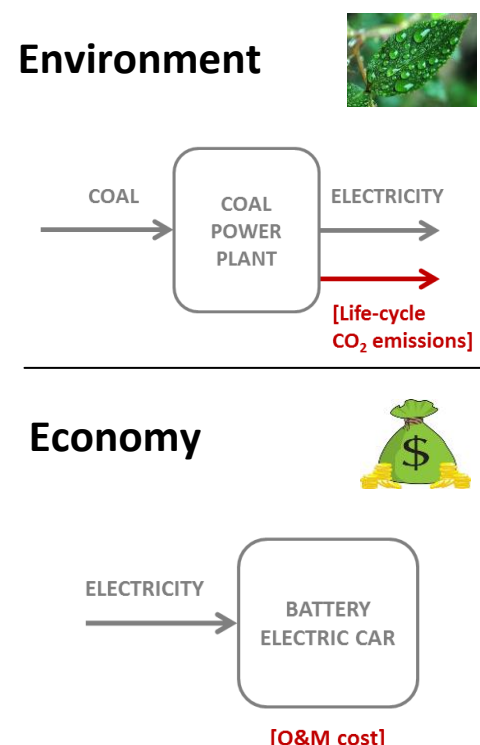
Economy — ecoinvent — GMM model

- The modelling challenges were overcome within the limits of the two models.

Results
- Regionally and temporally differentiated LCA results were generated for a variety of key air pollutants and greenhouse gases.
- The global emissions calculated based on the modelling framework were validated with real global emission data from 2010.

Goals of the PhD thesis

Integrating the GMM model and Multi-criteria Decision Analysis (MCDA)

Environment
COAL → COAL POWER PLANT → ELECTRICITY
[Life-cycle CO_2 emissions]

Society
URANIUM MINING → URANIUM
[Expected mortality in accidents]

Economy
ELECTRICITY → BATTERY ELECTRIC CAR
[O&M cost]

Security of Supply
FUELS → HYDROGEN GENERATION → HYDROGEN
[Diversity of fuel supply]

The further assessments based on the existing framework include:
- External cost calculations
- Optimization of other indicators than costs / Near cost-optimal solutions

Extensions to existing framework encompass:
- Integration of further sustainability indicators
- Multi-criteria assessment
  min (cost) → min (w_1 * $INDICATOR_1$ + w_2 * $INDICATOR_2$ + …)

Expected overall insights are:
- Trade-offs between different sustainability aspects of energy systems
- Policy recommendations based on multi-criteria assessment of energy systems

Acknowledgements