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Tom Kober :: Laboratory for Energy System Analysis :: Energy Economics Group

Energy Modelling Perspectives to support the Transition of the Energy Sector

BusinessNZ Energy Council, Wellington, 8 May 2019

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PSI research site

← Basel Germany ↑ Aarau/Bern ↓ Zurich →

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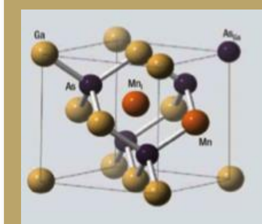
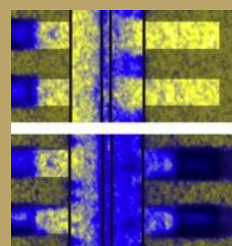
PSI's Mission

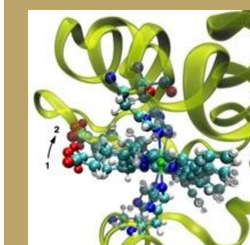
Matter and materials



Energy and environment



Human health



Development
Construction
Operation

Large research facilities

Swiss and foreign users from academia and industry

more that 2400 external users/year (39 beamports)

Knowledge & expertise

Education

Technology transfer

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Expertise of the Laboratory for Energy systems Analysis as part of PSI's Energy divisions

Technology Assessment

Life Cycle

Health Impact

Internal / External Costs

Comparative Risk

Energy Systems / Scenario Modeling

Systemic technology interdependencies

Policy measures and market conditions

Uncertainty and behavioural aspects

Energy Technology

Decision Support and Interaction / Elicitation with Stakeholders

Probabilistic Safety Assessment

Human Reliability Analysis

Critical Infrastructure and Resilience

Energy Systems Analysis framework

Energy systems analysis with various spatial foci from local to global

city

Swiss national

European regional

Global an various regions thereof

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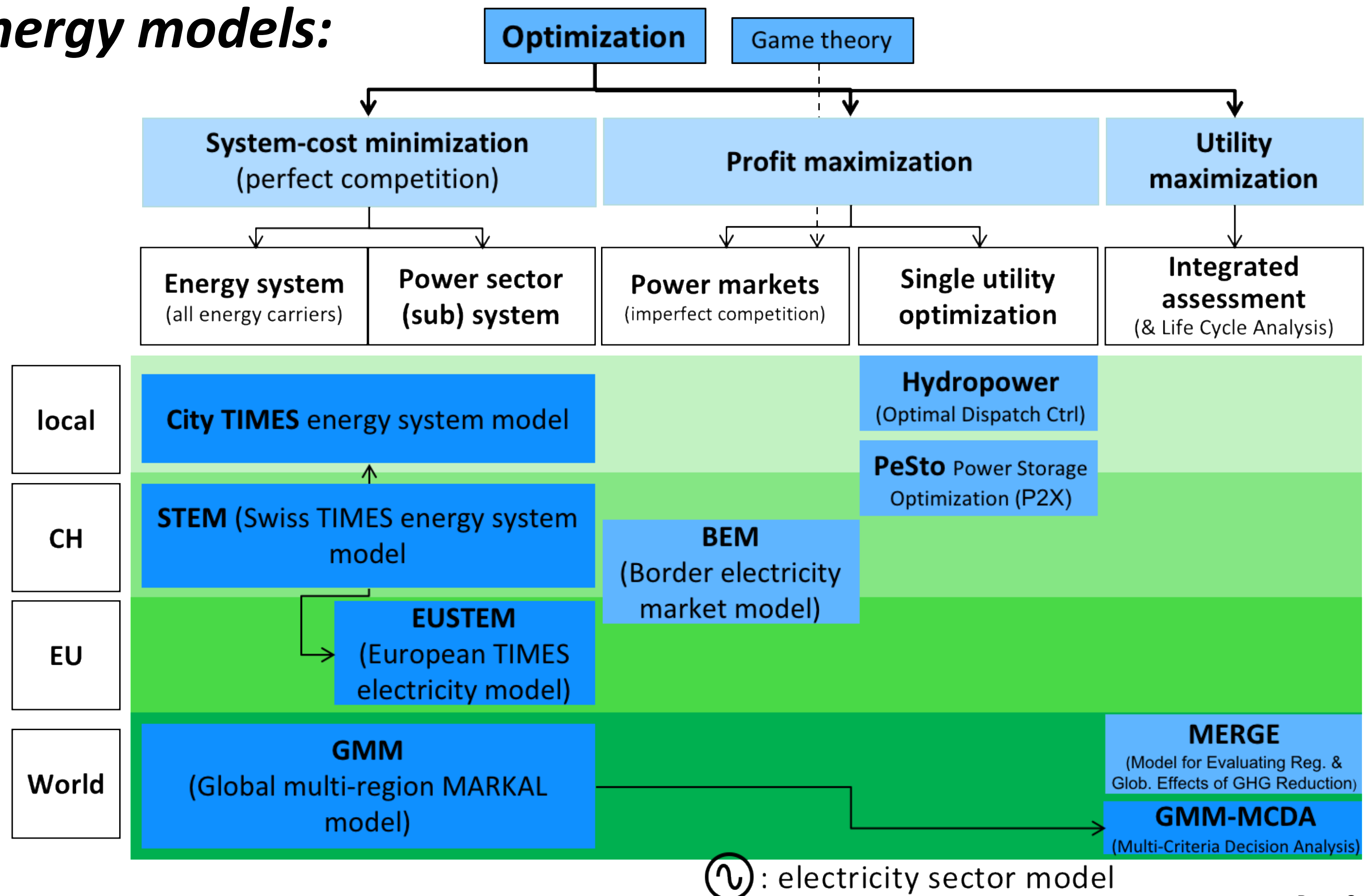
Energy Economics Group – Goals & Objectives

- Improved ***understanding of energy transition pathways*** and ***policy strategies*** for realising sustainable ***energy systems*** at the ***Swiss, European and global levels.***
- *Our **energy models:***



Research project portfolio

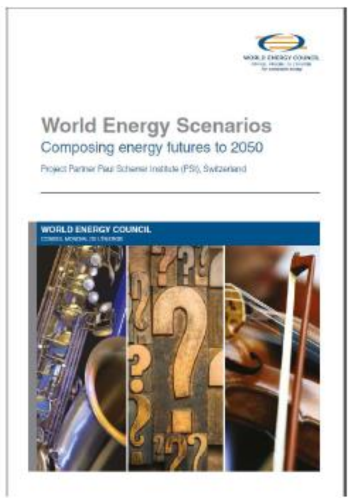
- **Swiss projects**
  – Scenario modelling scoping on the Swiss Energy Strategy 2050
  – Energy transformation in the mobility sector
  – Storage (hydropower, batteries and power-to-gas, as well as heat)
  – Energy in industry
  – Digitalisation and energy in the buildings sector
  – CO_2 capture, usage and storage (CCUS)
  – Electricity market design

- **International projects**
  – Support to the European Commission on future R&I for decarbonization
  – Use of High performance computing for energy modelling
  – TIMES model development in the framework of IEA-ETSAP
  – Engagement in the Integrated Assessment Modelling Consortium (IAMC)
  – World Energy Scenarios 2019 (2013 / 2016) and deep-dive studies

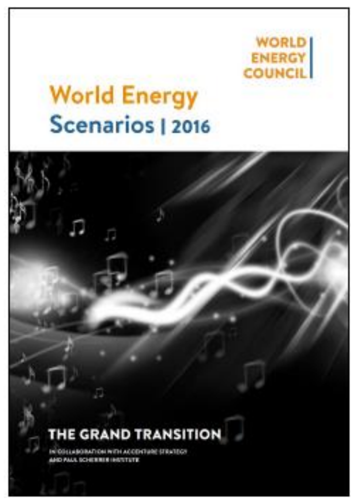
World Energy Council & Paul Scherrer Institute

- WEC scenario quantification is done by PSI, using the GMM energy system model
  – The quantification is an exploration of possible developments, not a forecast
- Key scenario drivers are expressed in coherent storylines and given as input to GMM
- Currently, update of the scenarios in progress & to be launched at the World Energy Congress in Abu Dhabi in Sep. 2019

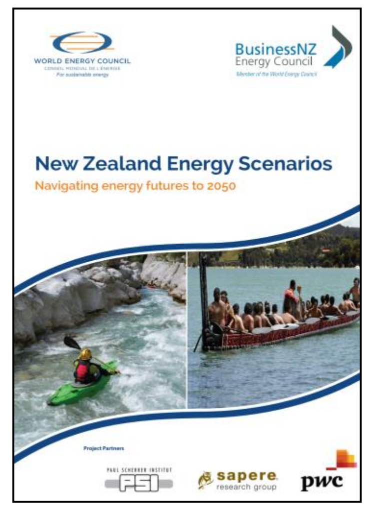
Global transport scenarios (2011)



World energy scenarios (2013)



World energy scenarios (2016)



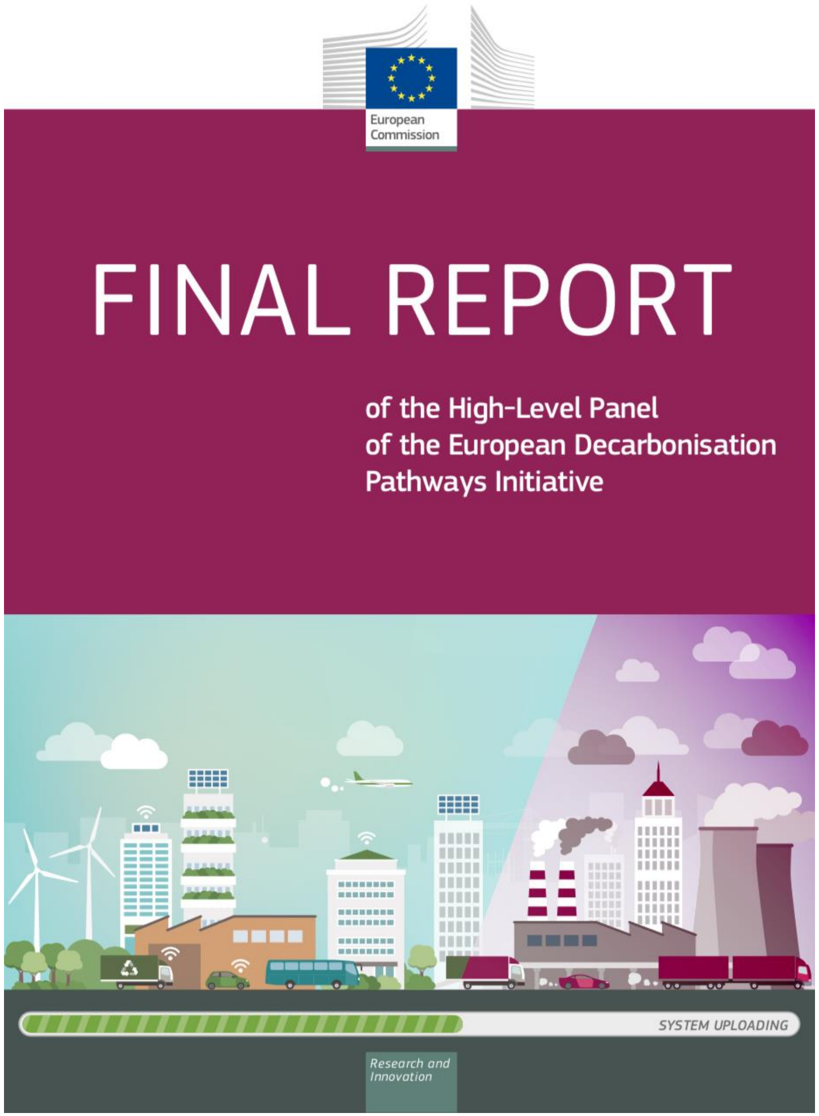
New Zealand (2015)

Latin America & the Caribbean (2017)

Support to decision making

EU-H2020 project **D**ialogu**E** on **E**uropean **D**ecarbonisation **S**trategies (DEEDS)

- Support to the High Level Panel (HLP) of the European Decarbonisation Pathways Initiative
- Informing EC on **research and innovation priorities** (relevance for EU-FP9)
- Insights regarding future research and innovation needed for deep decarbonisation in Europe
- Focus of PSI-LEA on the themes **energy supply and mobility**



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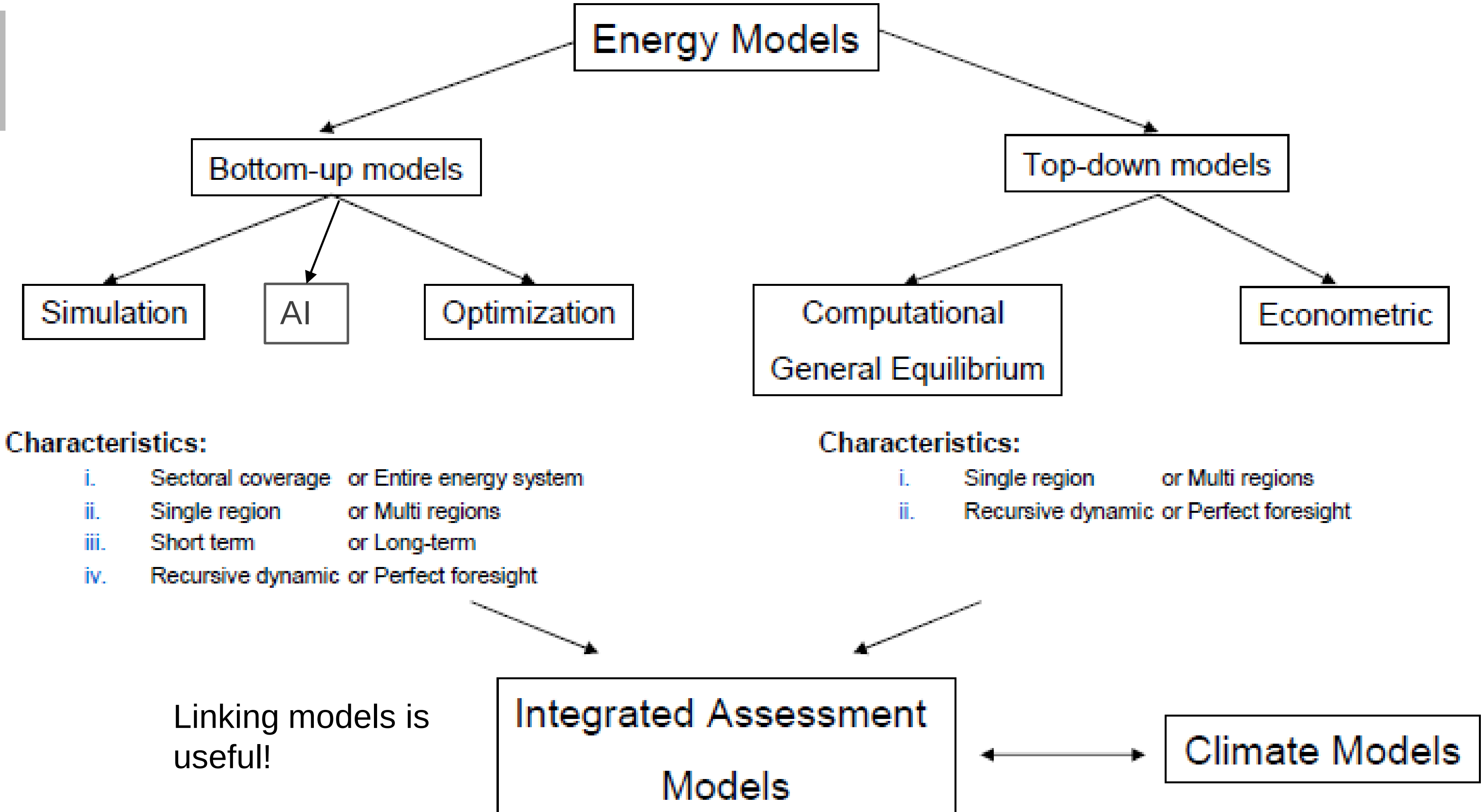
High-level recommendations on Research and Innovation related to Decarbonisation

- **Sustained R&I** activities on decarbonisation **across all sectors**
- Mission-oriented programmes on **system-level transdisciplinary innovation**
- **Partnerships with industry** to address the most difficult aspects of decarbonisation
- **Transition Super-Labs** as very-large-territory initiatives of real-life management of the energy transition

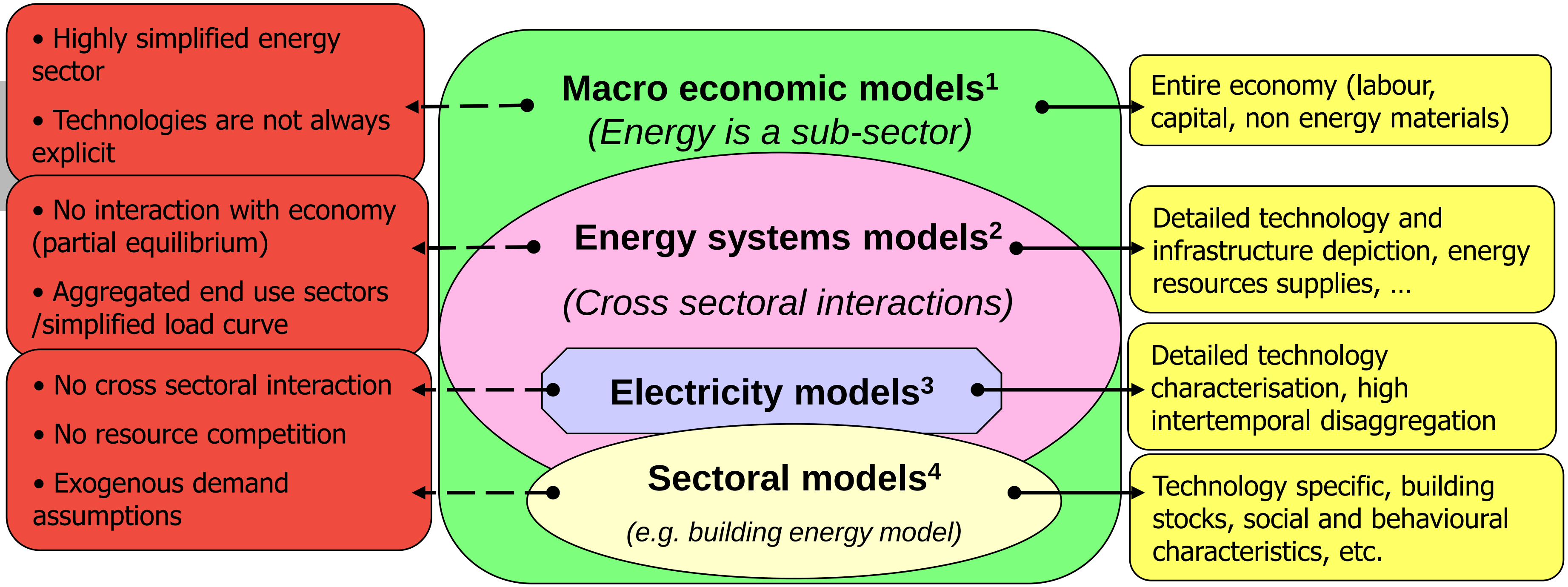
Decarbonisation and the corresponding transformation process is a **systemic and societal challenge**. To support decision making, **new analytical tools** are to be developed for an improved understanding of the interdependencies and impacts of zero-carbon solutions.

Classification of energy models



Based on: Remme and Blesl 2008

Overview of energy-economic models



Given the models' objectives and scope, there are **always trade-offs** between energy-systems approaches, sectoral models and macro-economic models. No **one size fits all →** advance existing **&** apply multiple models

1 CGE , CITE, Geneswis, GEMINI-E3, GEM-E3, MultiSWISSEnergy, MERGE, Global Trade Analysis Project (GTAP), SwissOLG, SwissGem
2 MARKAL, ETEM, TIMES
3 MARKAL electricity model, Electricity trade model, System dynamics mode, Prognos, DIME
4 Building energy model, SMEDE
Source: Kannan, R. and H. Turton (2013). A long-term electricity dispatch model with the TIMES framework, Environment Modeling and Assessment, 18 (3): 325-343, DOI: 10.1007/s10666-012-9346-y

Advancing Energy Modelling to tackle new energy challenges

High resolution analytics

- Temporally & spatially
- Technologically detailed: low/zero-carbon solutions enabled by digitalization (new technologies, new markets)
- Consumer groups

Linking and integrating energy models and other sectoral models/approaches

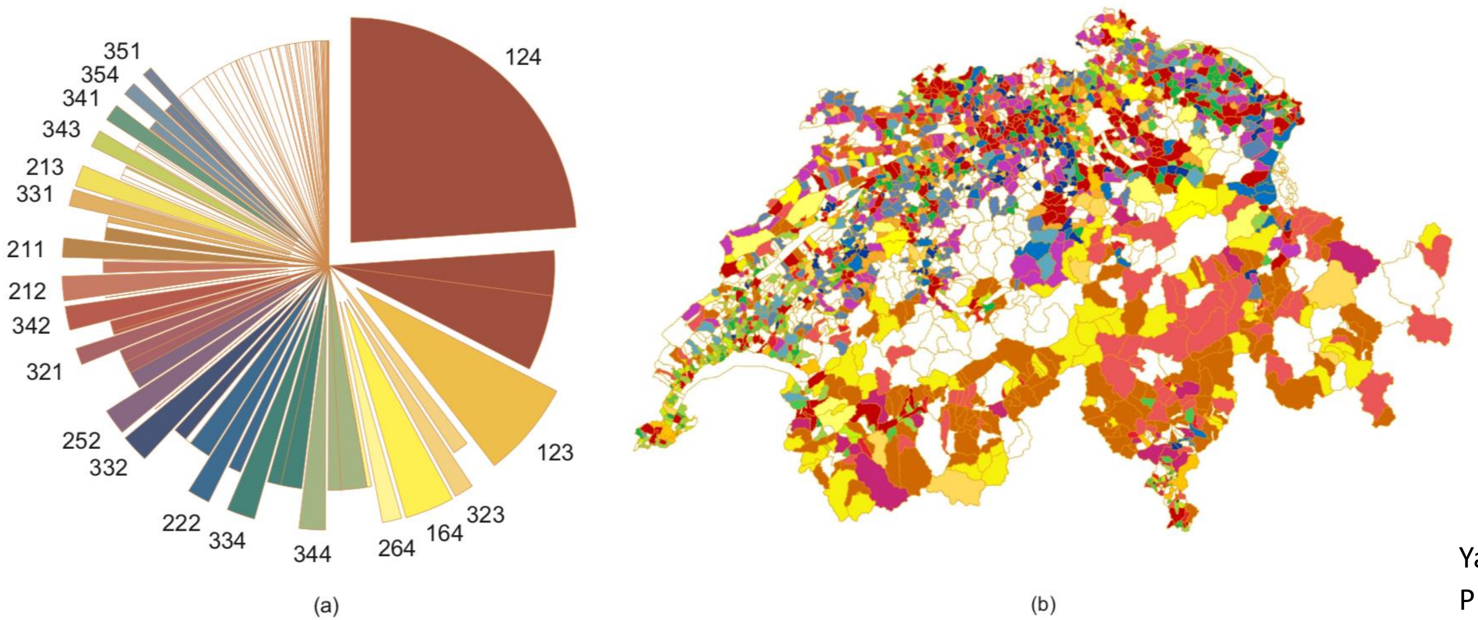
- Macro-economic
- Engineering
- Water
- Biodiversity
- Land- and agricultural models
- People-centered approaches incl. behavioural aspects

Advanced uncertainty analyses

- Parametric and stochastic programming
- Machine learning

Modelling framework with **increased spatial details**

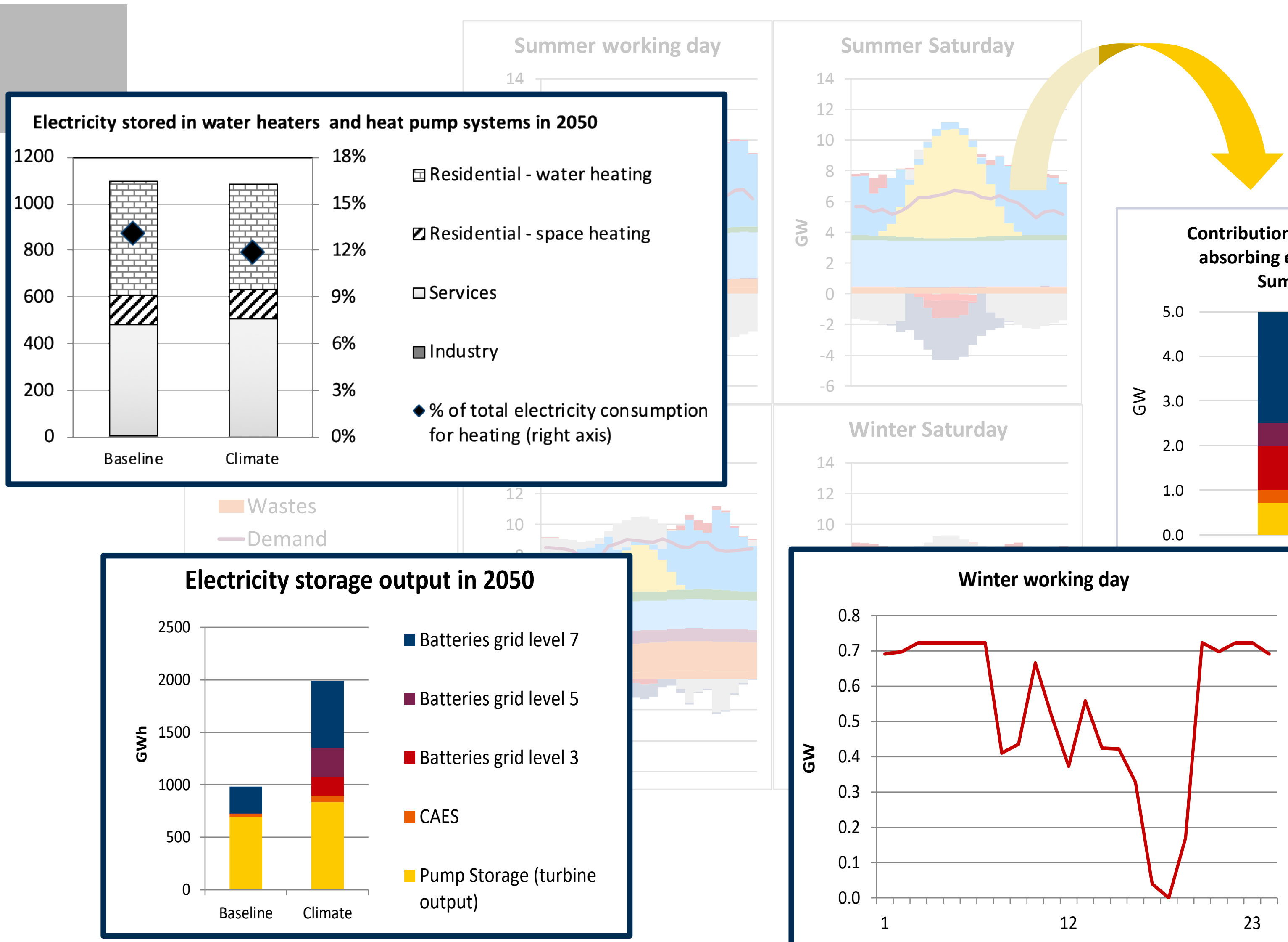
- Application of GIS-referenced systems and clustering methods
- Representation of spatial characteristics, i.e. related to land and resource availability and consumption & infrastructure patterns
- Energy in cities !
  – Over 50% of the world population lives in cities
  – 70% of the global energy-related CO_2 is emitted in cities
  – In 2050, ca. 70% of the global population is expected to life in cities

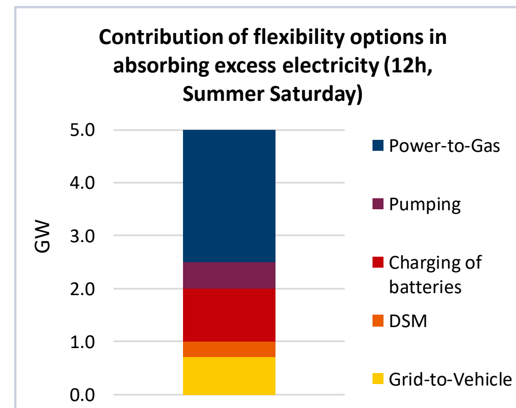


Yazdanie et al. 2018
Project: IDEAS4Cities

Fig. 11. Archetype selection for modeling. Relative national energy demand share in the base year (excluding Zurich and Basel) (a) and color-coordinated geographic representation (b). Key archetypes selected for modeling labeled and extruded in (a); model archetype results approximate non-extruded archetype slices of the same color. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Analysing system flexibilities through **advanced technology modelling**





High resolution models need high computational performance and specific speed-up methods

“Conceptual” speed-up methods, e.g.:
- Spatial and temporal (dis)aggregation
- Rolling investment horizon
- Benders decomposition

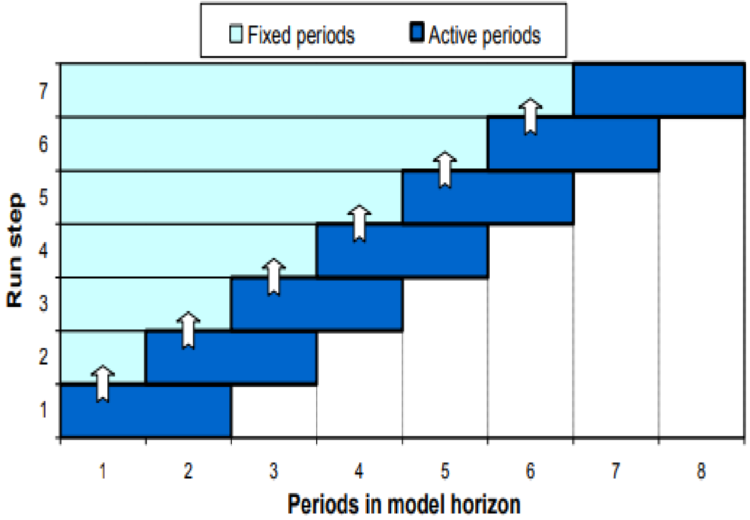


Figure 2: Implementation of the rolling investment horizon (source [1])

High Performance Computing
- interior-point parallel solution algorithms
- Challenge: finding the right annotation of the model matrix

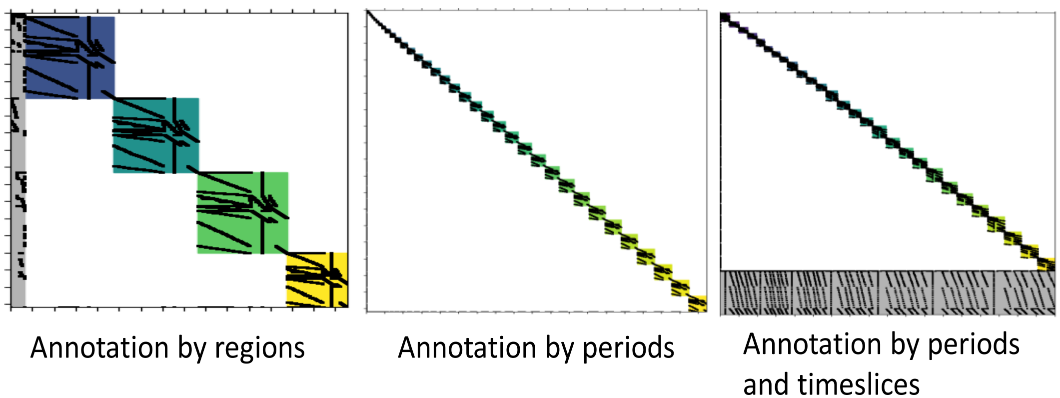


Figure 3: Different annotation strategies of EUSTEM, and the derived blocks of variables and equations. Grey columns correspond to linking variables, grey rows to linking constraints

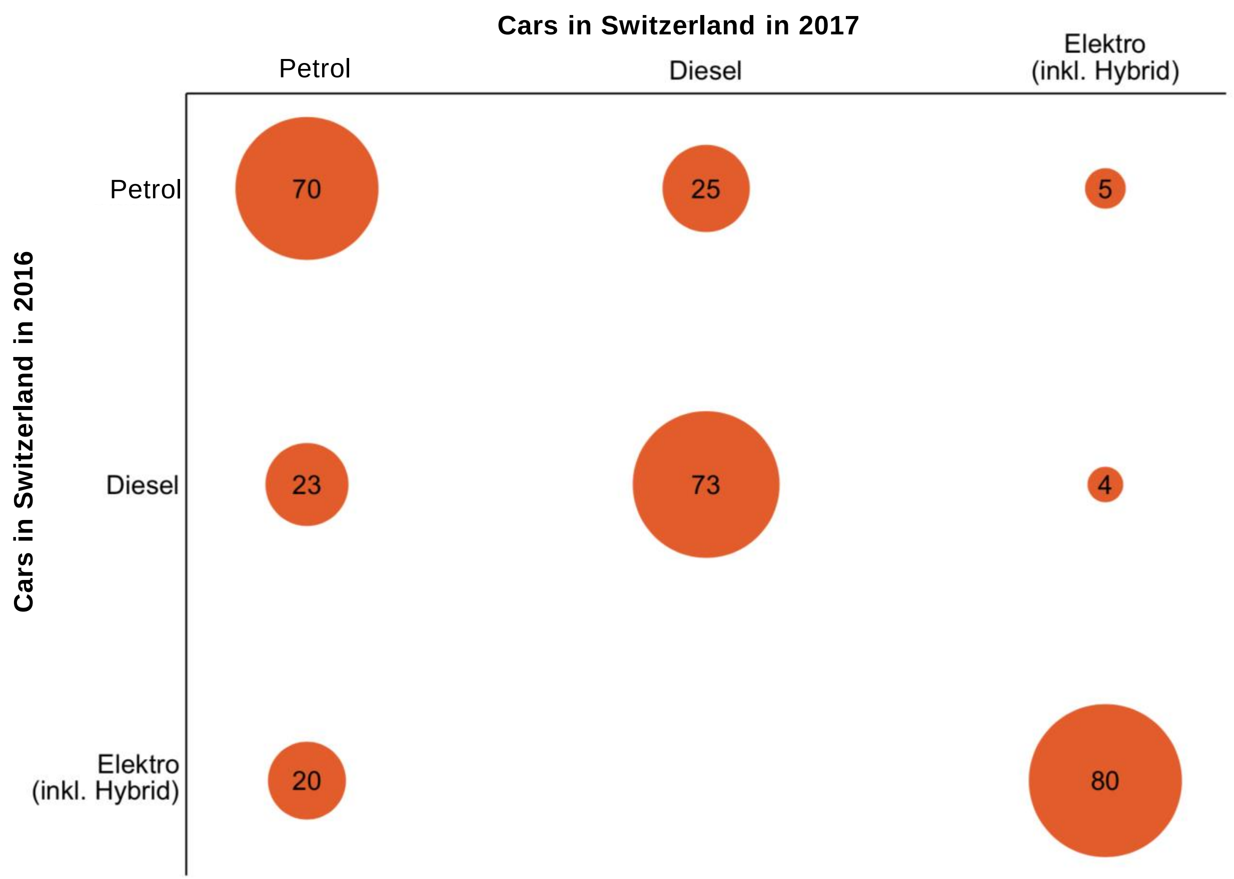
Source: Panos, E. 2019,
Project: BEAMME

Incorporation of behavioural aspects in terms of technology choice and energy consumption

Advanced energy modelling using:

- Detailed consumer segmentation (preferences based on consumer surveys)
- Linkage of energy model with agent-based model

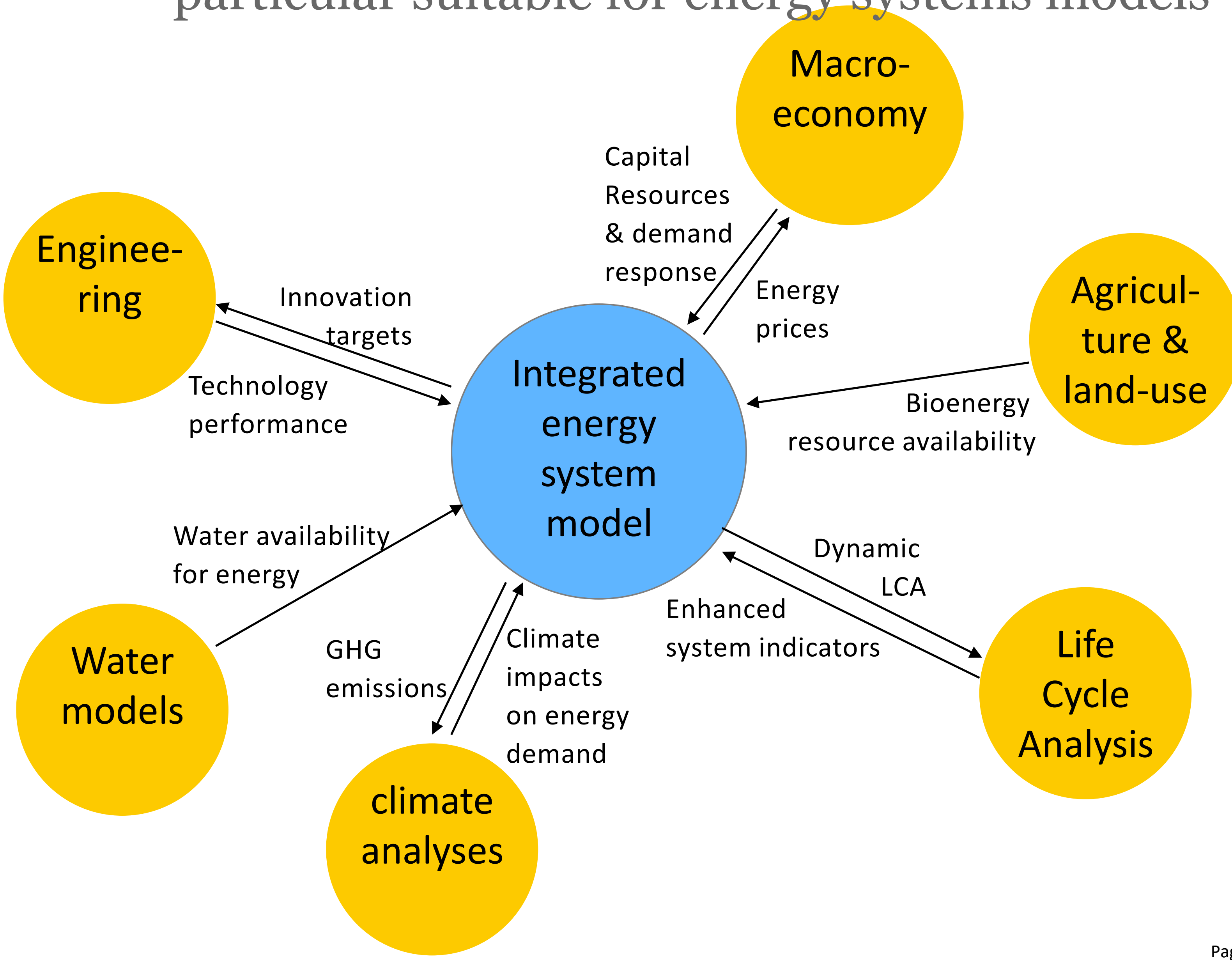
Routine and positive experience determine car technology choice



Source: Burger et al. 2018

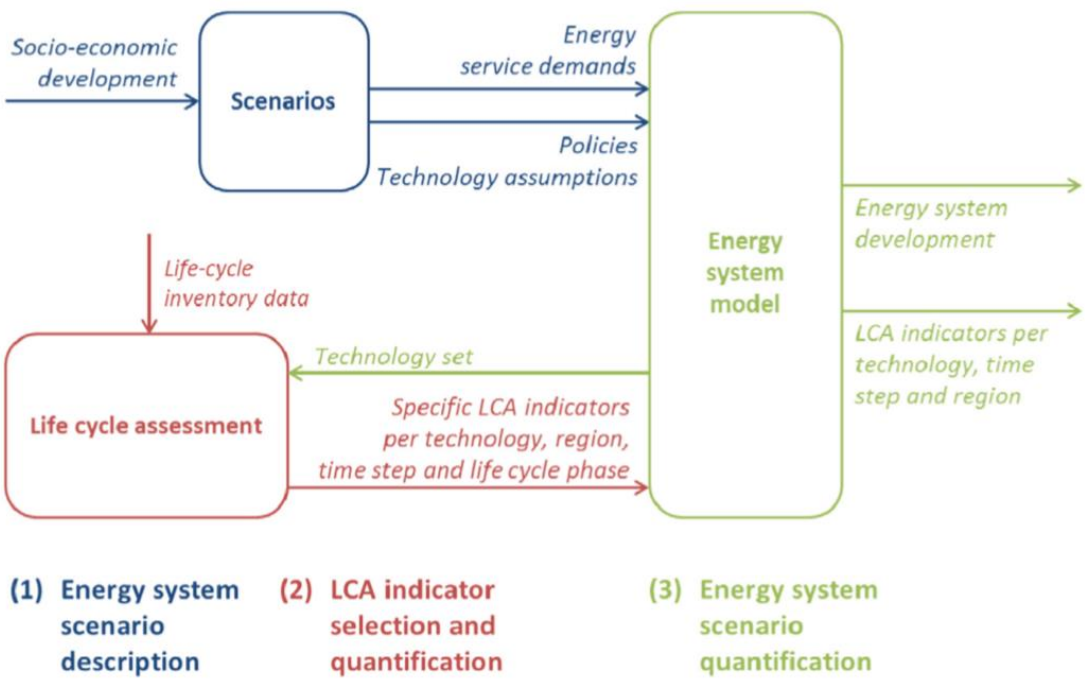
Project: SCCER Joint Activity CREST-Mobility

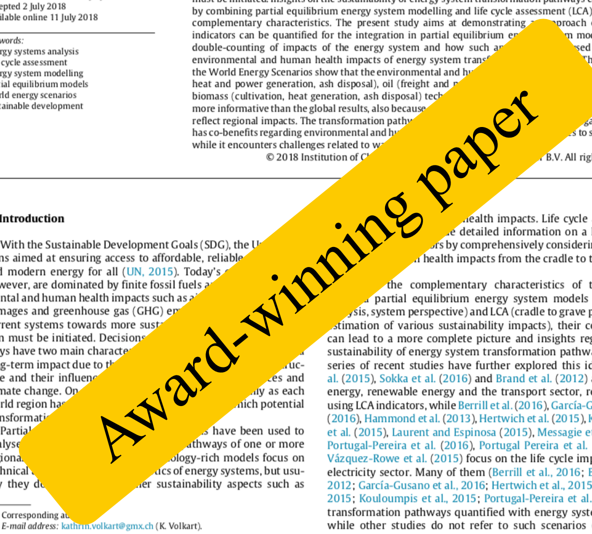
Connecting energy modelling with other domains particular suitable for energy systems models



Advanced methodology to combine life cycle analysis (LCA) and energy modelling

- Integration of LCA indicators into a global energy systems model
- Analysis of co-benefits of climate change mitigation in view of other SDGs
  - ➢ *Reduction of deaths and illnesses due to pollution*
  - ➢ *Reduction of the release of hazardous chemicals to water and protection of water-related ecosystems*
  - ➢ *Preservation of terrestrial ecosystems*





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Research article

Integrating life cycle assessment and energy system modelling: Methodology and application to the world energy scenarios

Kathrin Volkart *, Christopher L. Mutel, Evangelos Panos

Laboratory for Energy Systems Analysis, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

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Sustainable development

ABSTRACT

Today's energy systems are dominated by finite fossil fuels and related environmental and human health impacts. To strive for the Sustainable Development Goal (SDG) related to energy, their transformation must be initiated. Insights on the sustainability of energy system transformation pathways can be gained by combining partial equilibrium energy system modelling and life cycle assessment (LCA) due to their complementary characteristics. The present study aims at demonstrating a…proach on how LCA indicators can be quantified for the integration in partial equilibrium en… …m models without double-counting of impacts of the energy system and how such a… …sed to estimate environmental and human health impacts of energy system trans… …The results for the World Energy Scenarios show that the environmental and hu… …oal (mining, heat and power generation, ash disposal), oil (freight and … …tors) and biomass (cultivation, heat generation, ash disposal) tech… …nd to be more informative than the global results, also because … …indicators reflect regional impacts. The transformation pathw… …gation policies has co-benefits regarding environmental and hu… …s to several SDGs, while it encounters challenges related to wa…

1. Introduction

With the Sustainable Development Goals (SDG), the U… tions aimed at ensuring access to affordable, reliable… and modern energy for all (UN, 2015). Today's … however, are dominated by finite fossil fuels a… mental and human health impacts such as a… damages and greenhouse gas (GHG) em… current systems towards more sust… tion must be initiated. Decisions… ways have two main characte… long-term impact due to th… …truc- ture and their influen… …ces and climate change. On… …ly as each world region ha… …hich potential transformati…

Partial… …s have been used to analyse… …athways of one or more regiona… …ology-rich models focus on technical … …tics of energy systems, but usu- ally they d… …er sustainability aspects such as

…health impacts. Life cycle assessment …e detailed information on a large set of …rs by comprehensively considering environ- …health impacts from the cradle to the grave of

… the complementary characteristics of technology- … partial equilibrium energy system models (long-term …ysis, system perspective) and LCA (cradle to grave perspective, …stimation of various sustainability impacts), their combination can lead to a more complete picture and insights regarding the sustainability of energy system transformation pathways. Thus, a series of recent studies have further explored this idea: Igos et al. (2015), Sokka et al. (2016) and Brand et al. (2012) analyse the energy, renewable energy and the transport sector, respectively, using LCA indicators, while Berrill et al. (2016), García-Gusano et al. (2016), Hammond et al. (2013), Hertwich et al. (2015), Kouloumpis et al. (2015), Laurent and Espinosa (2015), Messagie et al. (2014), Portugal-Pereira et al. (2016), Portugal Pereira et al. (2014) and Vázquez-Rowe et al. (2015) focus on the life cycle impacts of the electricity sector. Many of them (Berrill et al., 2016; Brand et al., 2012; García-Gusano et al., 2016; Hertwich et al., 2015; Igos et al., 2015; Kouloumpis et al., 2015; Portugal-Pereira et al., 2016) use transformation pathways quantified with energy system models, while other studies do not refer to such scenarios (Hammond

* Corresponding au…
E-mail address: kathrin.volkart@gmx.ch (K. Volkart).

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Volkart et al. 2018

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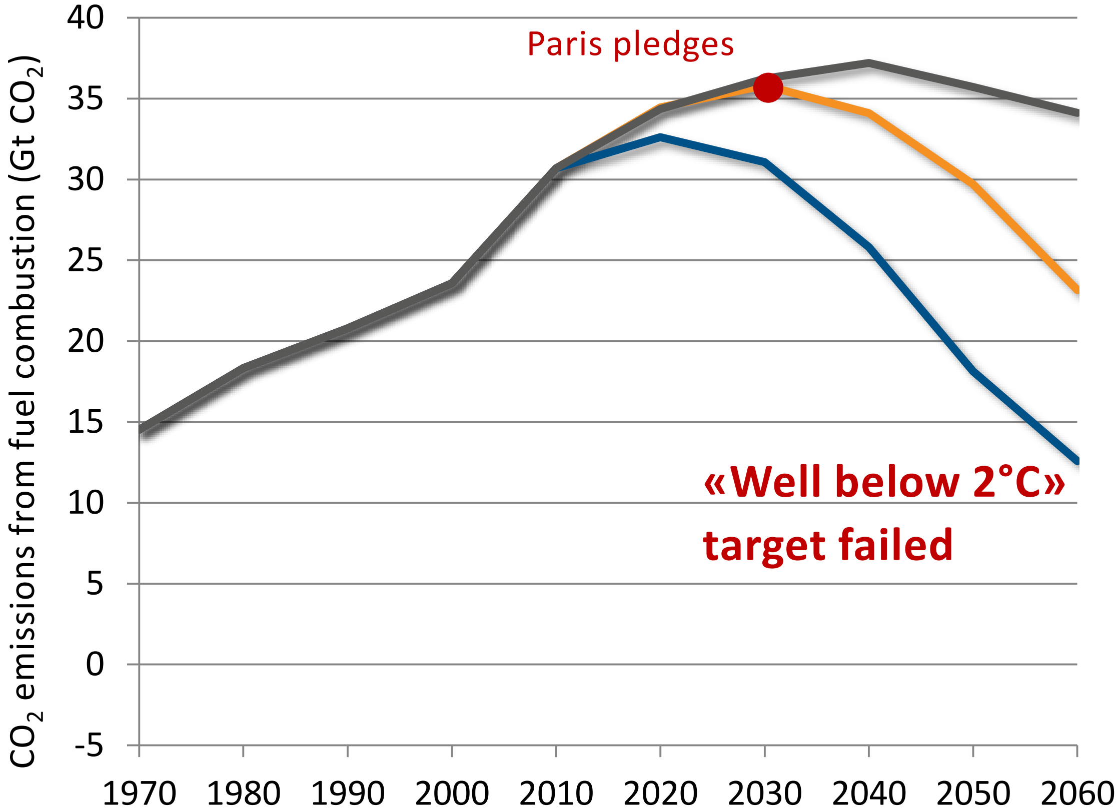
Global CO_2 emissions (energy related)



Hard Rock: +5%*
∫ (2010-2060)=1800 GtCO_2
≈ +3.5 - 4°C temperature increase

Modern Jazz: -28%*
∫ (2010-2060)=1600 GtCO_2
≈ on track for +3°C

Unfinished Symphony: -61%*
∫ (2010-2060)=1200 GtCO_2
≈ slightly above +2°C

*in 2060 compared to 2014

Modern Jazz (market oriented)
- Market chooses technologies
- Technology innovation
- Energy access for all

Hard Rock (fragmented policies)
- Low global cooperation
- Focus on energy security
- Best fit local solutions

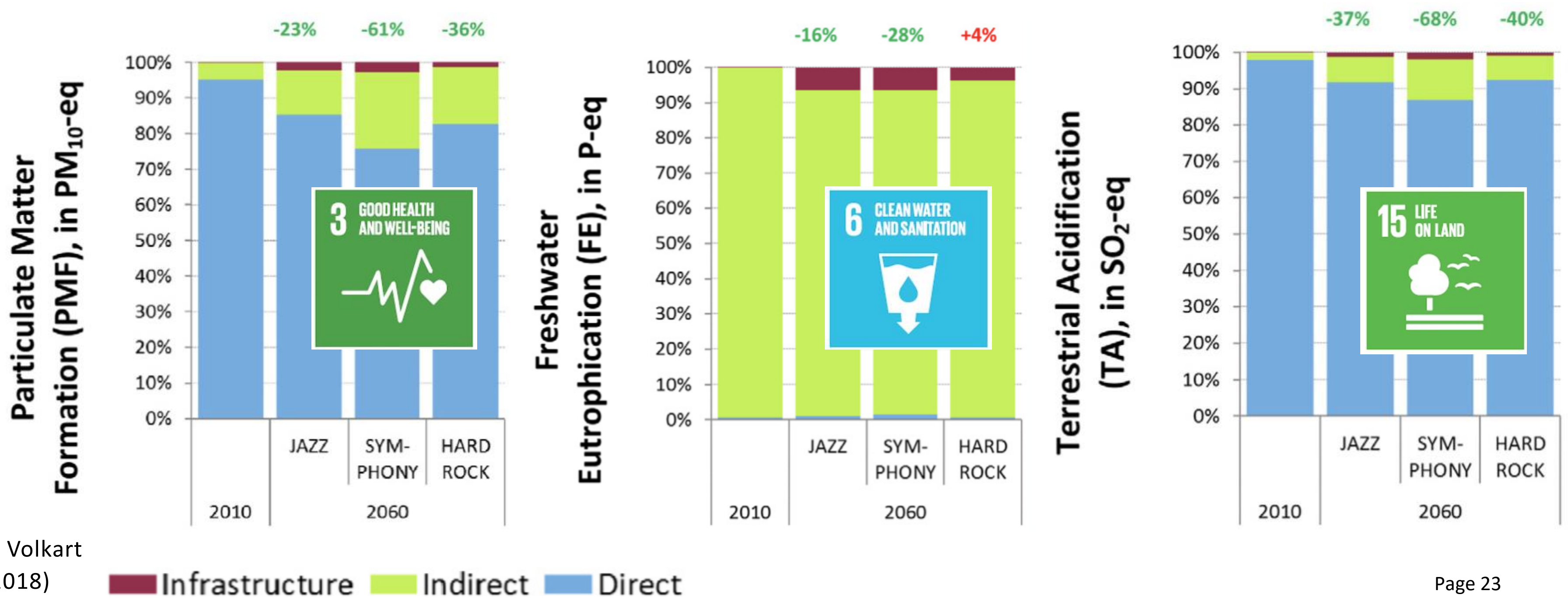
Unfinished Symphony (regulation oriented)
- Strong policies focusing on sustainability
- Harmonised climate action
- Targeted support for technologies

Source: World Energy Council (2016)

Co-benefits of climate change mitigation in view of other SDGs

- Reduction of deaths and illnesses due to pollution
- Reduction of the release of hazardous chemicals to water and protection of water-related ecosystems
- Preservation of terrestrial ecosystems

Results for China (region):



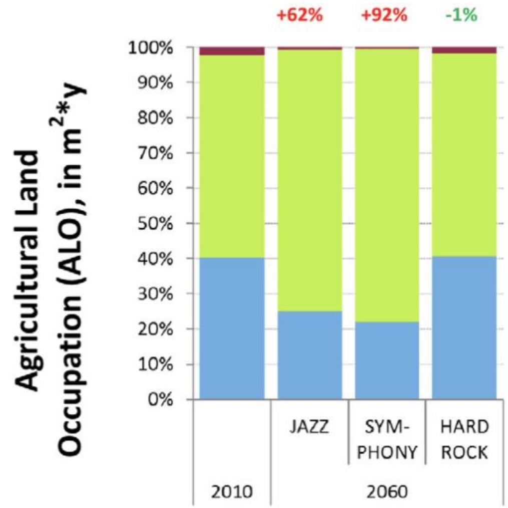
Source: Volkart et al. (2018)

Flipsides related to deployment of climate-friendly technology

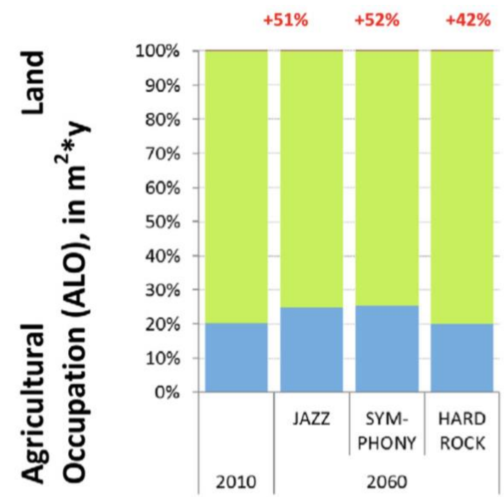
- More land occupation for bioenergy

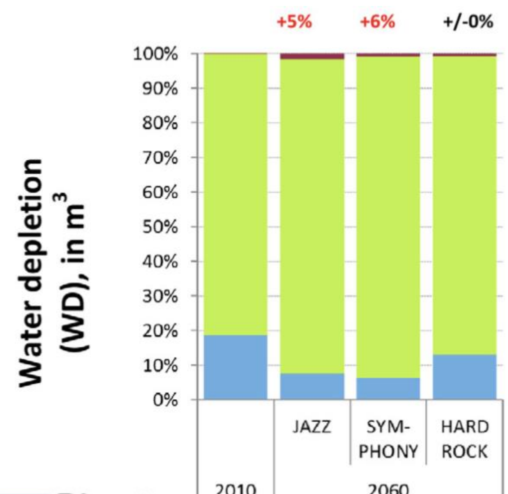
- Increased depletion of water resources

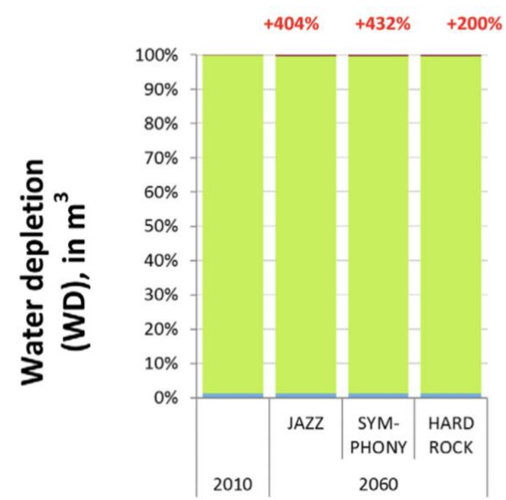
China (region)



Sub-Sahara Africa





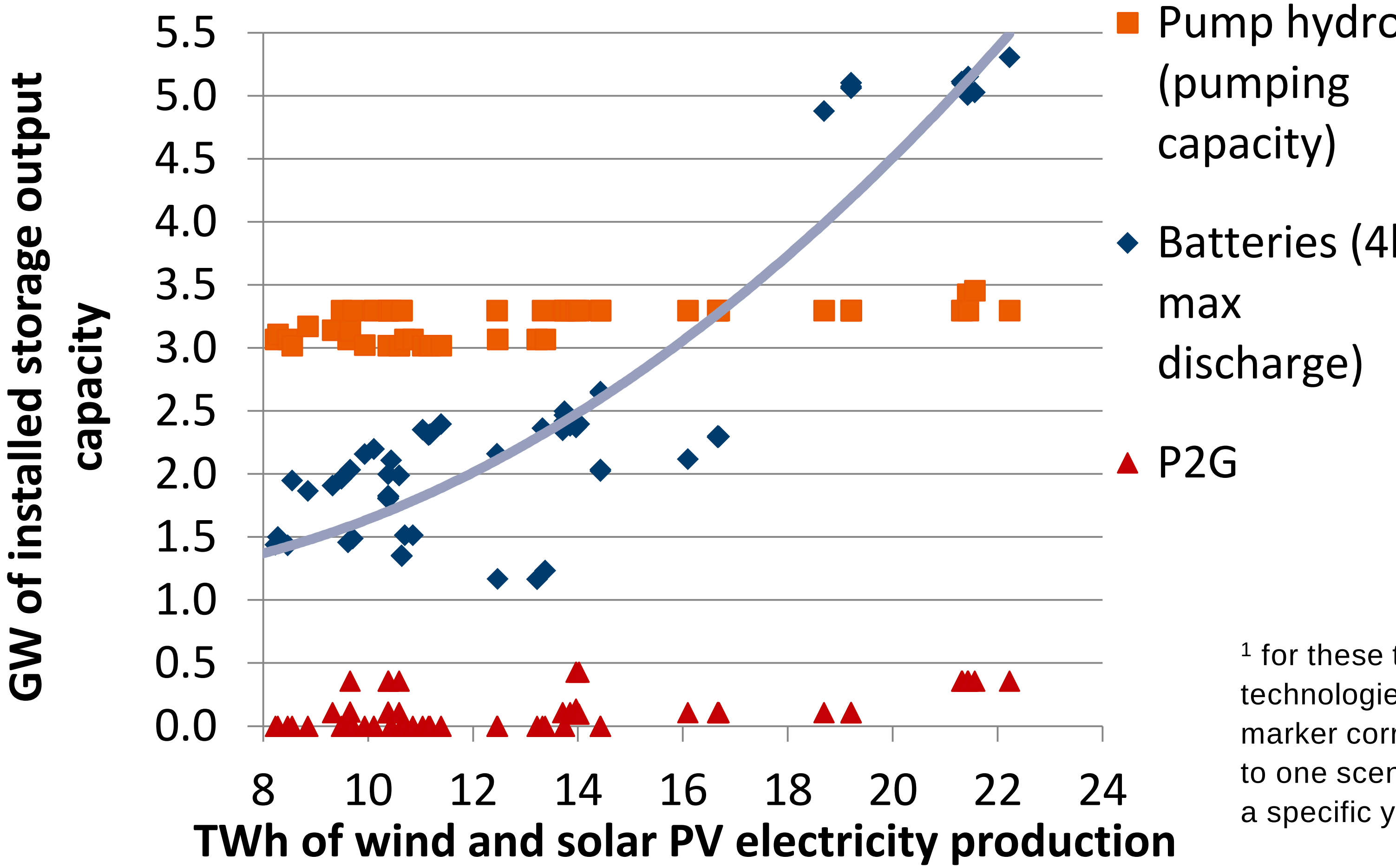


Infrastructure Indirect Direct

Source: Volkart et al. (2018)

Uncertainty analysis using parametric variation: here focus storage technology

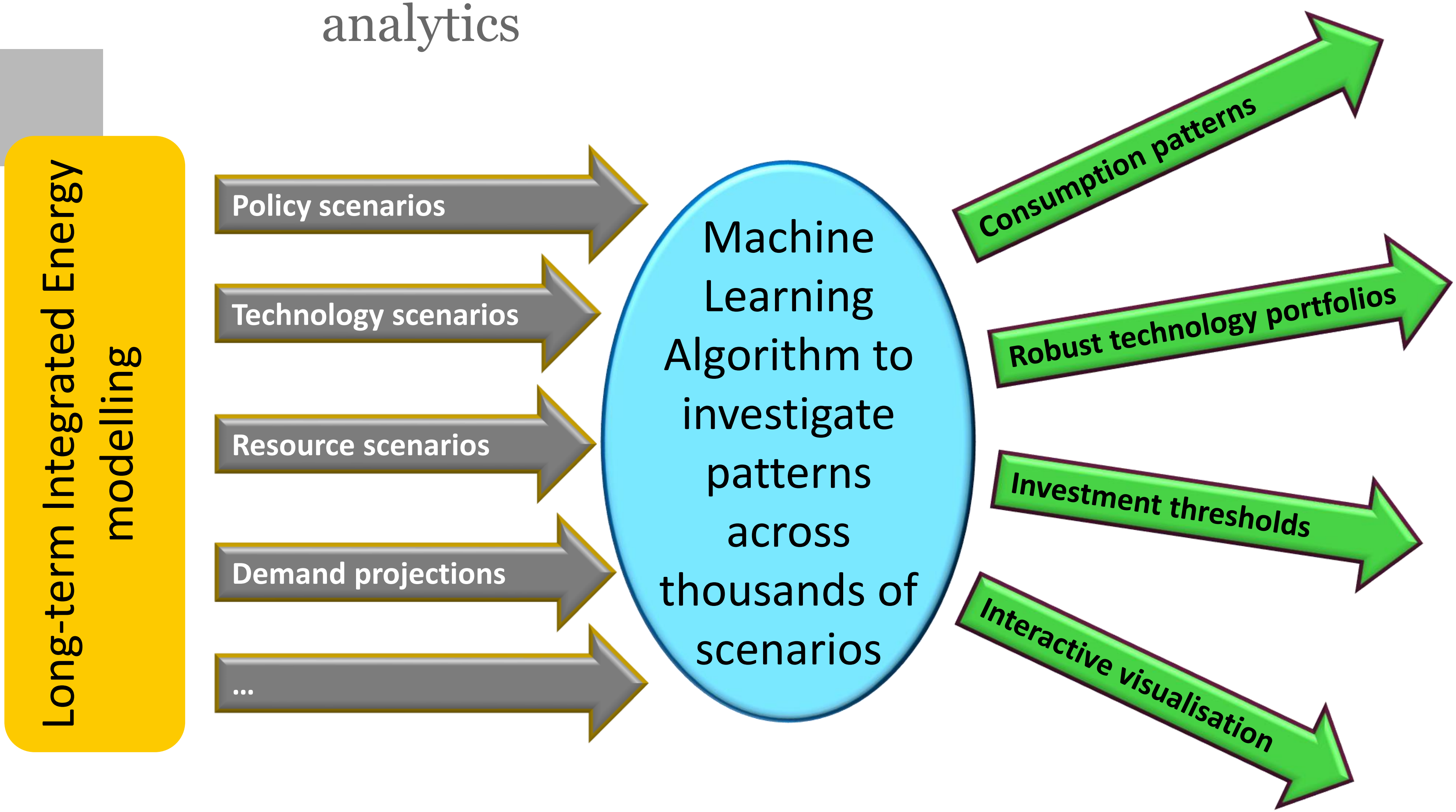
Storage requirements vs solar/wind deployment, across all ISCHESS national energy scenarios assessed[1]



[1] for these three technologies, each marker corresponds to one scenario and a specific year

Source: Fuchs et al. 2017

Advanced uncertainty analysis: combining energy modelling and machine learning analytics



Conclusions

- Need for increased system integration to achieve deep decarbonisation of the energy system

- Innovative analytical tools for decision support
  - High resolution
  - Integrated modelling frameworks & model linkage
  - Multi-dimensional uncertainty analysis using a combination of well-established modelling tools & novel data analytics
  - High-Performance Computing emerging for very complex models

- Increasing role of energy modelling in a world of growing complexity and interconnectivity

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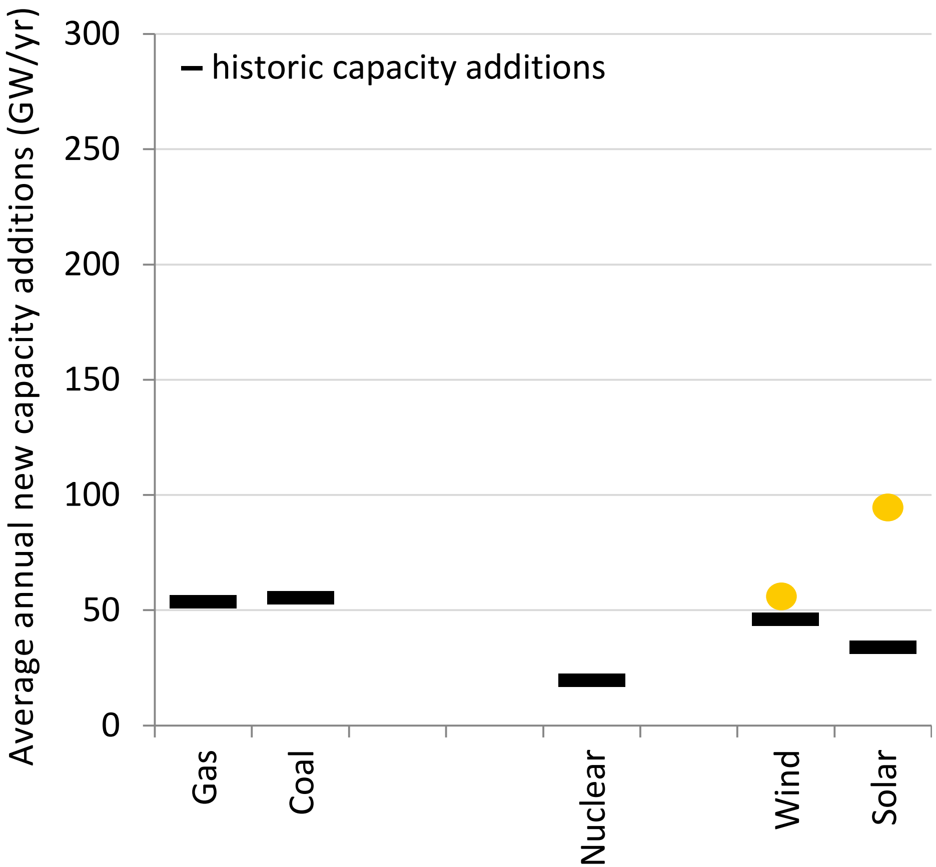
Thank you for your attention!

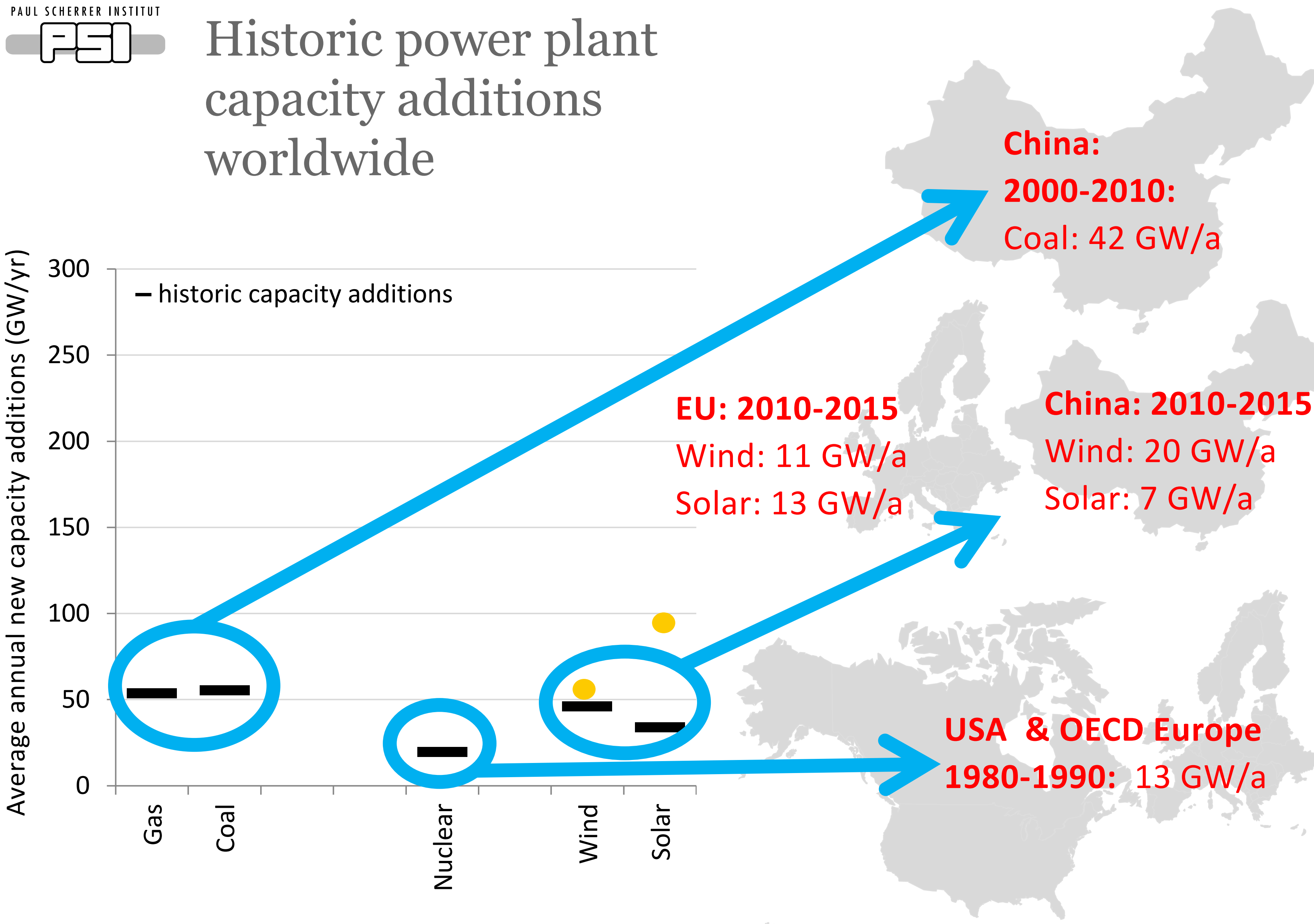
Contact:
tom.kober@psi.ch

Historic power plant capacity additions worldwide



N.B.: Historical data correspond to 2000-2010 for coal and gas, to 1980-1990 for nuclear energy, and to 2010-2015 for wind and solar. The data is assembled from: EPIA (2014, 2016), GWEC (2016), IEA-PVPS (2016), IEA-CCS (2012) and Platt’s (2013).

Historic power plant capacity additions worldwide



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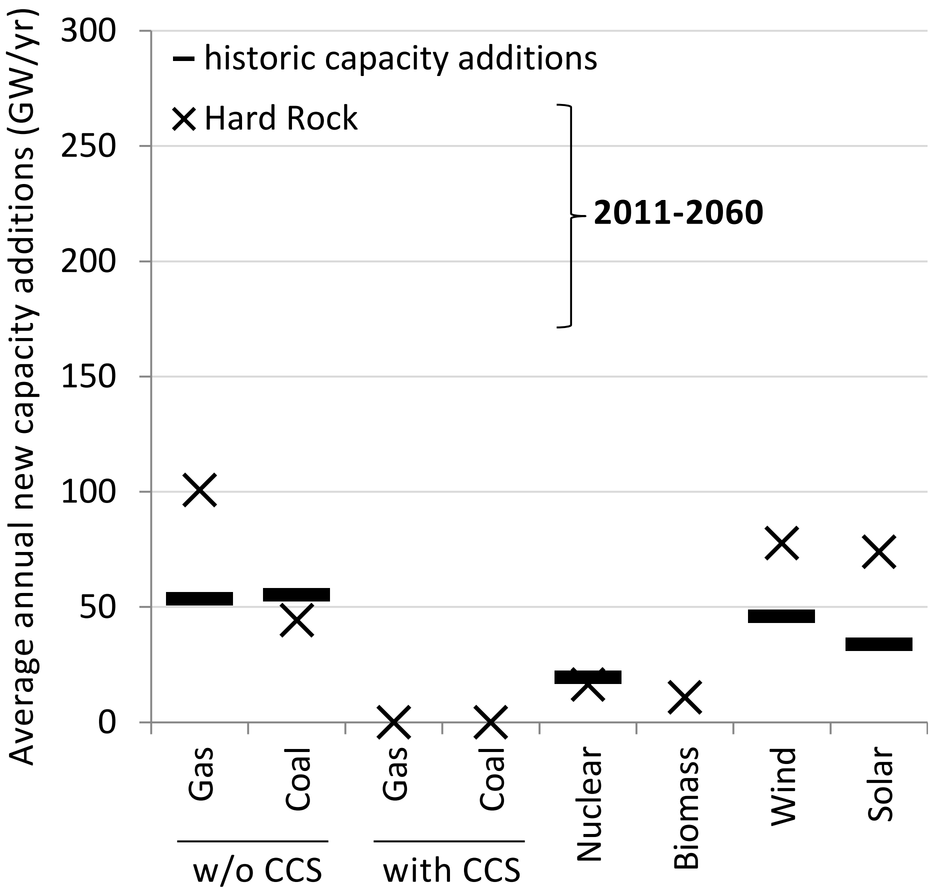
New power plant capacity additions



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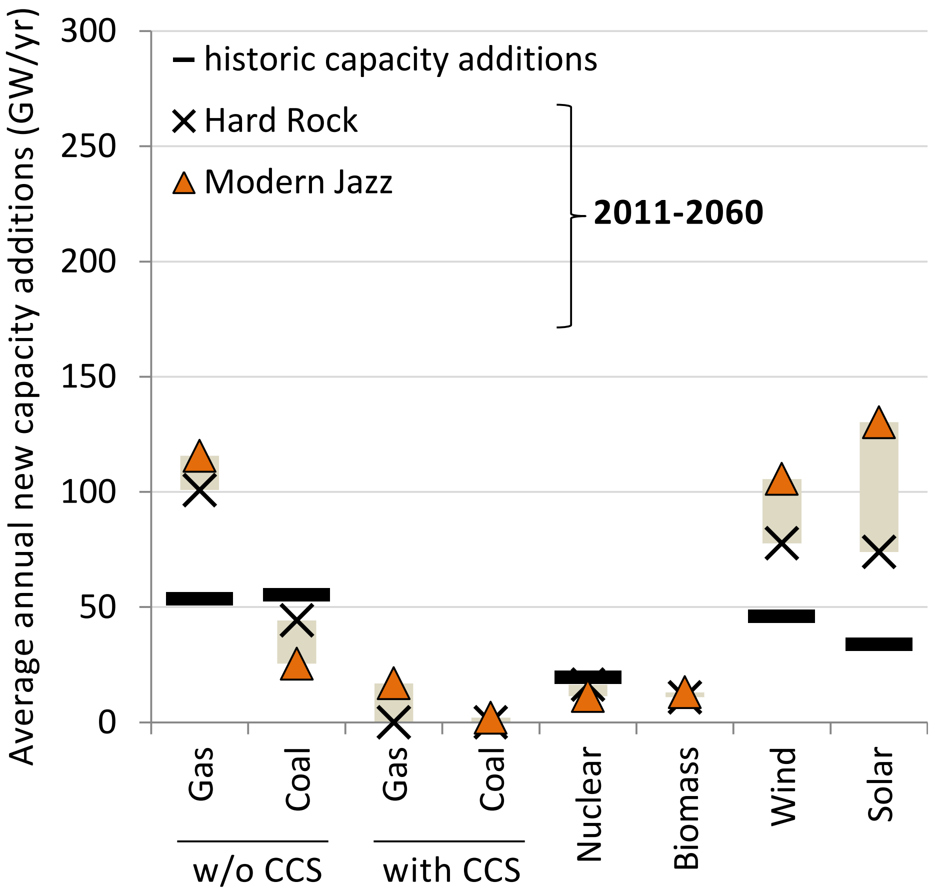
New power plant capacity additions



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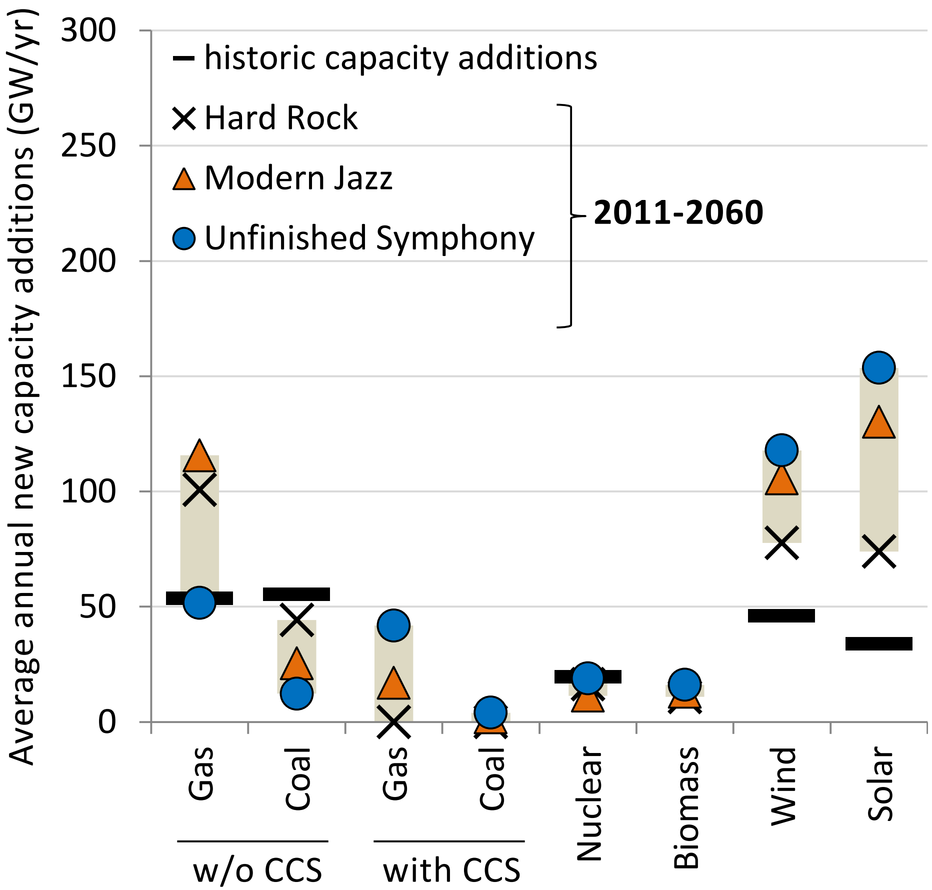
New power plant capacity additions



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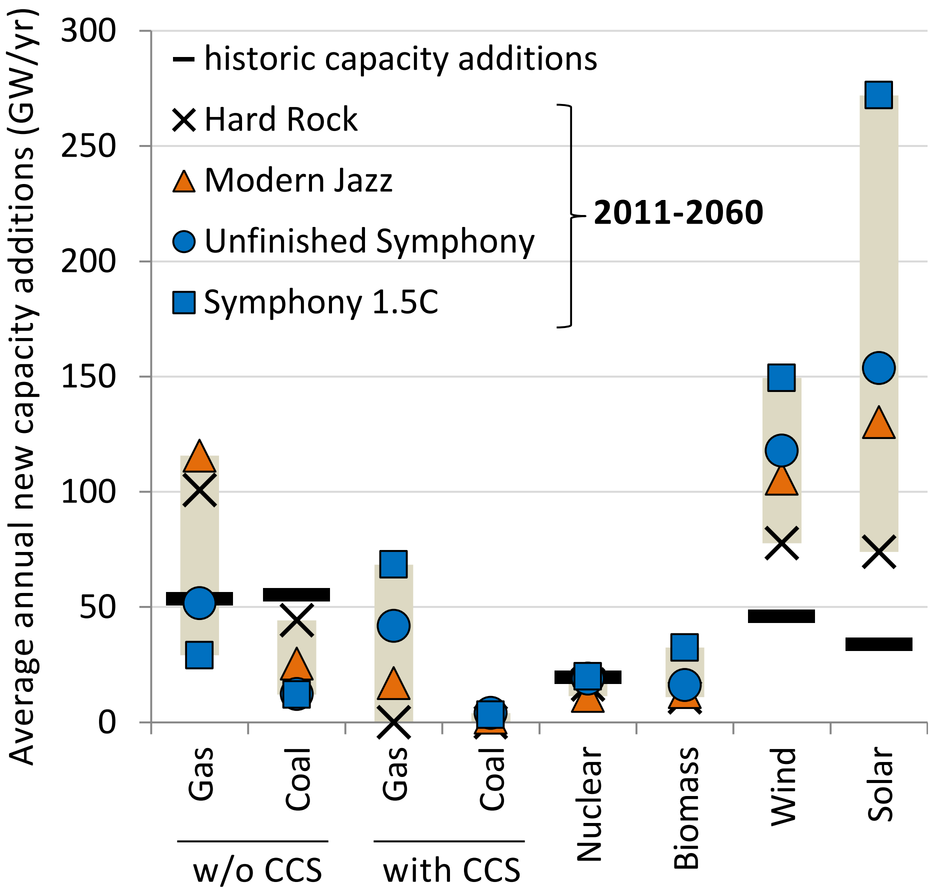

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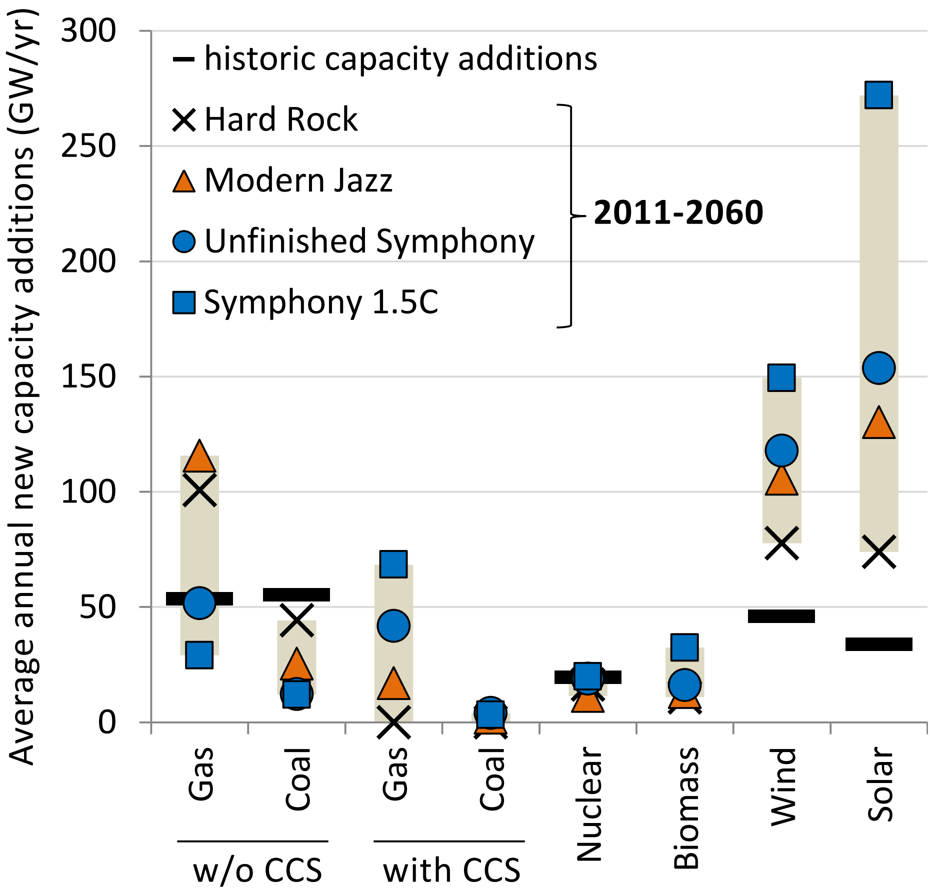
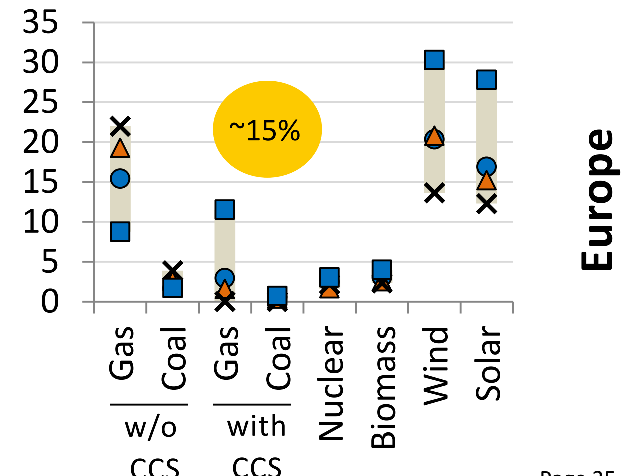
New power plant capacity additions

total share of global annual new capacity additions





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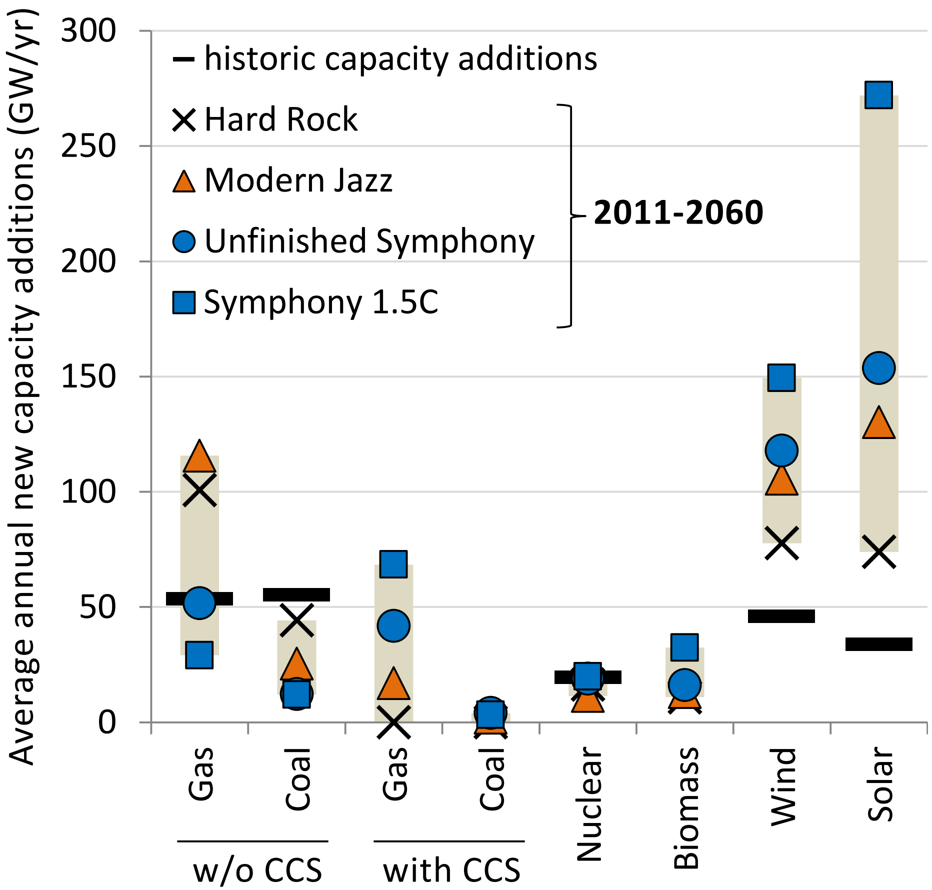
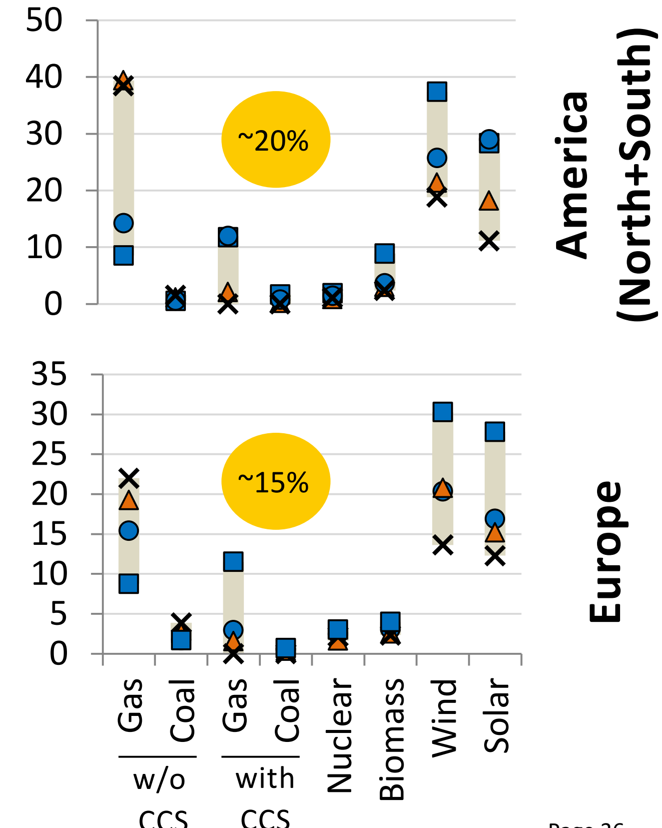
New power plant capacity additions

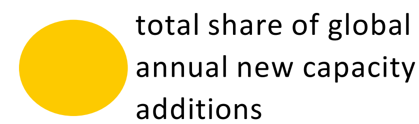
total share of global annual new capacity additions

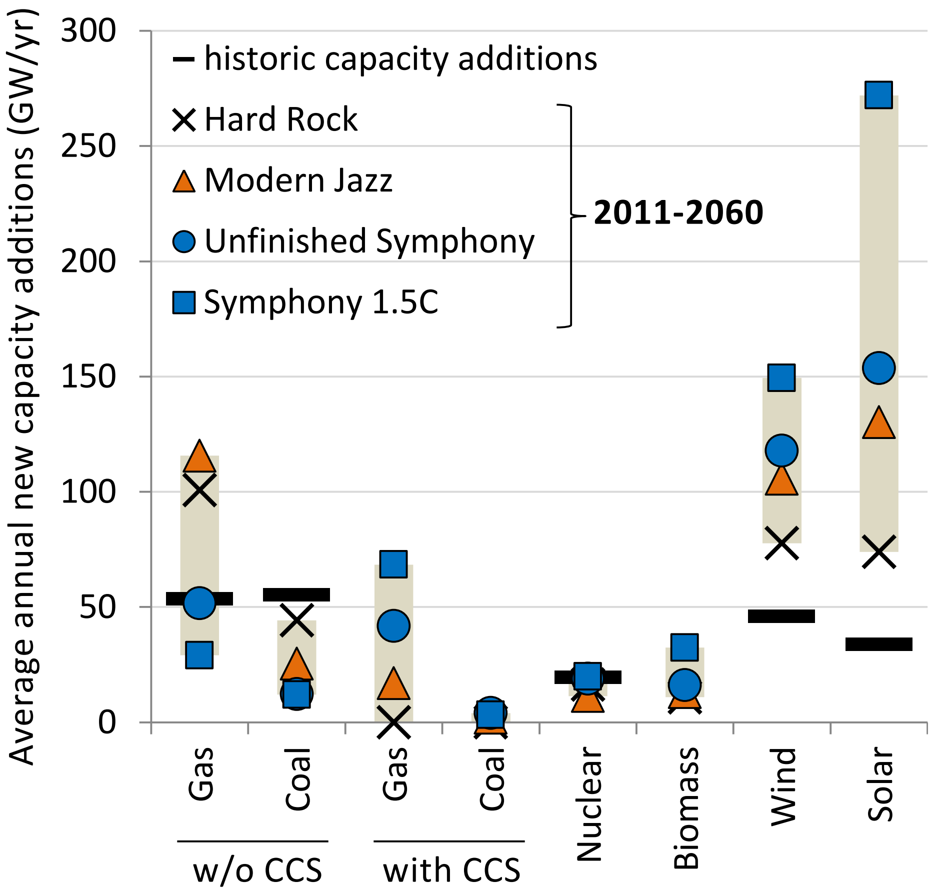


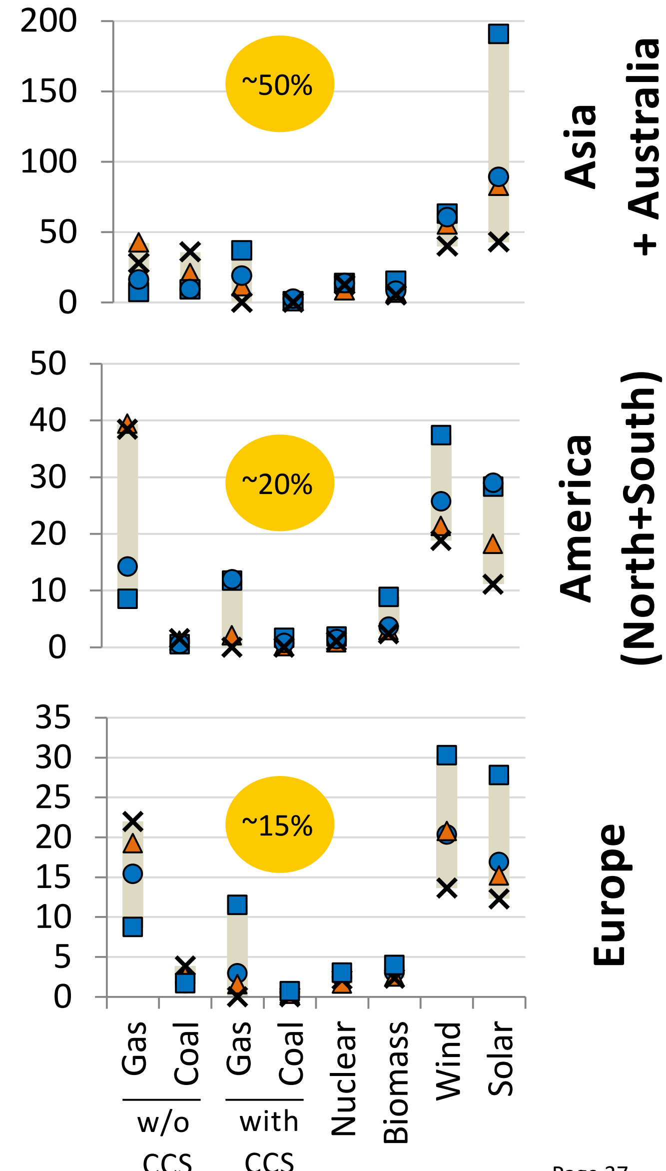


N.B.: Historical data correspond to 2000-2010 for coal and gas, to 1980-1990 for nuclear energy, and to 2010-2015 for wind and solar. The data is assembled from: EPIA (2014, 2016), GWEC (2016), IEA-PVPS (2016), IEA-CCS (2012) and Platt's (2013).

New power plant capacity additions



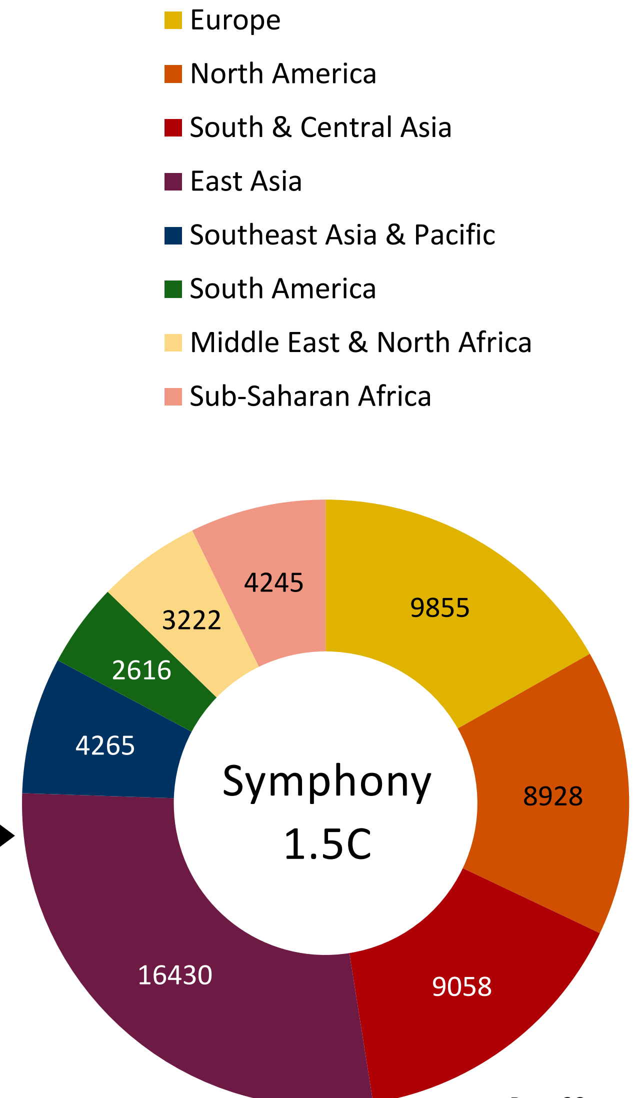




N.B.: Historical data correspond to 2000-2010 for coal and gas, to 1980-1990 for nuclear energy, and to 2010-2015 for wind and solar. The data is assembled from: EPIA (2014, 2016), GWEC (2016), IEA-PVPS (2016), IEA-CCS (2012) and Platt's (2013).

Global cumulative investments in power generation (2011-2060, billion USD_{2010} undiscounted)

	Hard Rock	Modern Jazz	Unfinished Symphony	Symphony 1.5
Coal	4200	2500	1600	1600
Oil	400	300	300	260
Gas	7600	9800	8100	8900
Nuclear	3200	2300	3500	3800
Hydro	2700	2800	3400	4800
Biomass	2300	2500	3300	6100
Wind	8800	12200	12900	15800
Solar	6600	7700	10200	15800
Others	60	900	1300	1540
Total	**36400**	**41000**	**44600**	**58600**



In *Symphony 1.5* 360 GW of coal without CCS utilised at 20% and lower in 2040

→ **Stranded assets!**

Types of energy models

	Model classification	Key words	Examples
Top-down	*Input-Output*	Structural description of economy, short-term	DESTATIS
	Econometric	Empirical evidence from long time series, macro-economic feedback, long-term, rely on data	E3ME
	Computable General Equilibrium (CGE)	Assume perfect markets, include macro-economic feedback effects, less technologic detail, long-term	GEM-E3, PACE, Newage
	System Dynamics	Behaviour of interacting social systems, long-term, difficult to validate and calibrate	ASTRA, POLES
Bottom-up	*Partial Equilibrium*	Similar to CGE with more technologic details, sector or sub-sector focus, long-term	WEM, POLES, PRIMES
	Optimisation	Technology detailled, lack macro-economic feedback effects, require cost information, long-term	MARKAL, TIMES, MESSAGE
	Simulation	Replicate consecutive rules to describe inter-relation of elements of the energy system in a simplified way	LEAP
	Multi-Agent	Strategic behaviour, asymmetric information, com-plex, empirical data, focus on operational aspects	Power ACE

Source: Herbst et al. 2012