Smart infrastructure investment for the transition to a low-carbon electricity system

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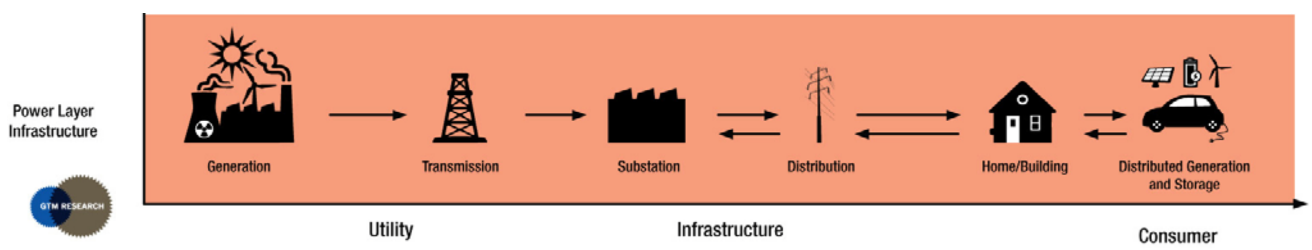
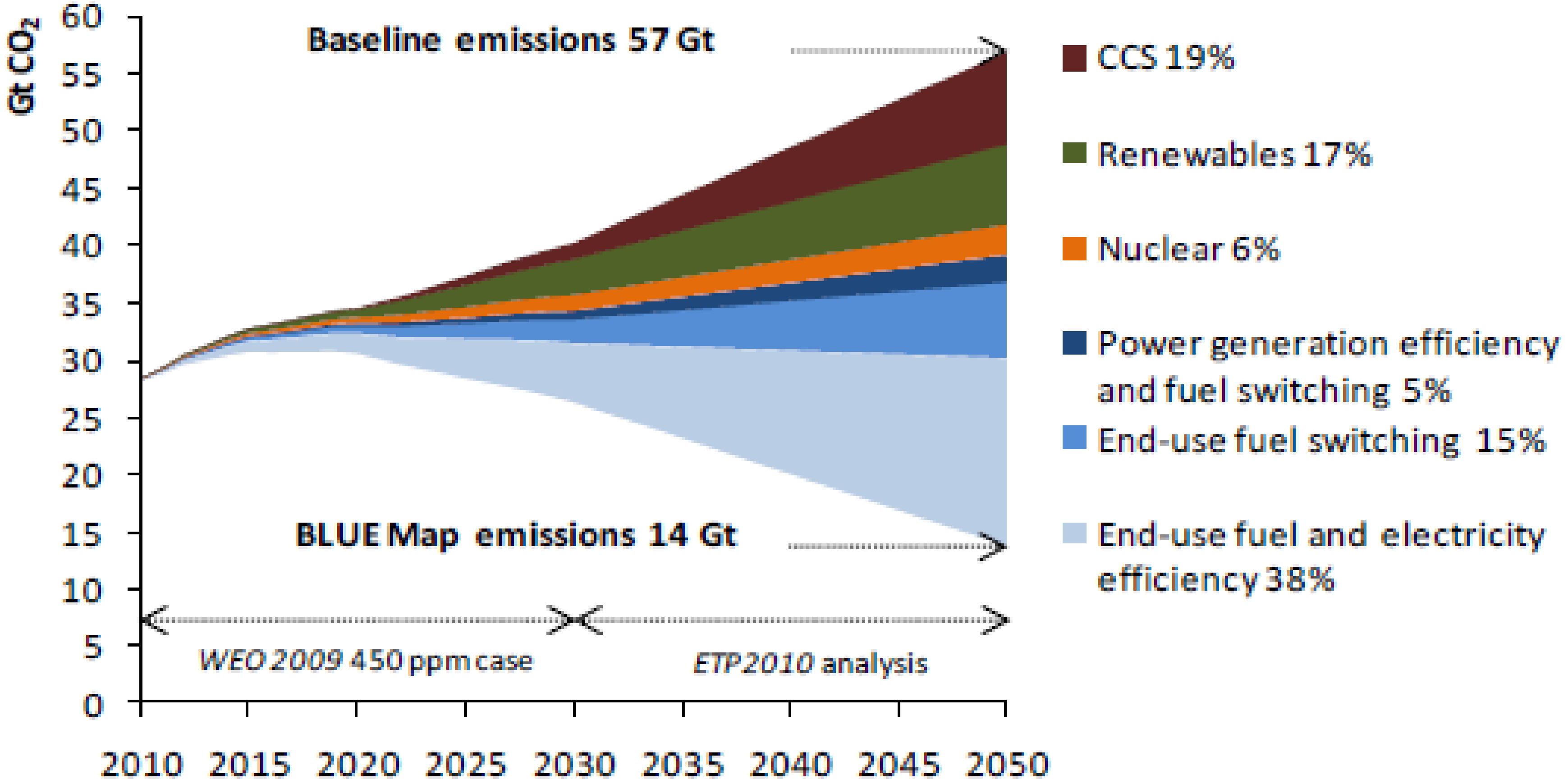
A Smart Grid? Yes, please! How can I get one?



Overview

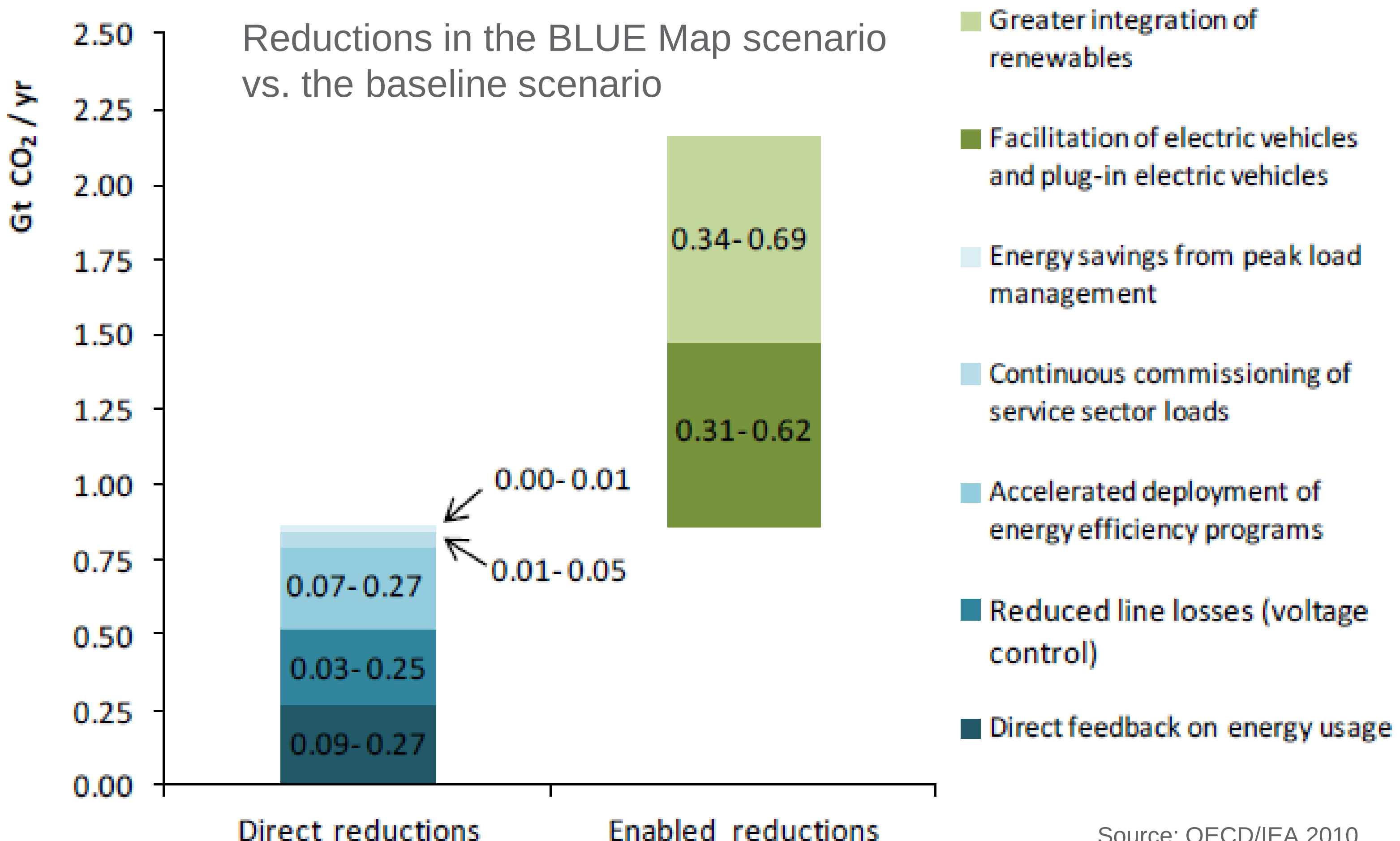
- Background and motivation
  - The need for an energy transition
  - The need for an intelligent electricity infrastructure
- Approaching a system transition
  - Pre-analytical vision
  - Governing and managing the transition
- The modelling approach
  - Distributed investment in infrastructure technologies
  - Social Simulation in support of scenario analysis
- Conclusions and outlook

IEA: Tech-scenarios for reducing global CO_2 emissions



Source: OECD/IEA 2010

Smart Grid related CO_2 emission reduction by 2050



Source: OECD/IEA 2010

The transition to a low-carbon energy system

- Climate change issues raise dramatically the pressure on our current fossil-based energy system
- In some countries, substantial shares of conventional energy production have to be replaced in a short period of time (e.g. „Energiewende“)
- A future low-carbon electricity system will rely on a wide range of technologies: spatially distributed, intermittent generating capacity, distributed storage and flexible consumption
- The electricity system will have to change from a strictly hierarchical, demand driven system to a more complex system with partially self-organized substructures and active involvement of the prosumers
- Deployment is deeply affected by human, societal, institutional and economic factors, creating substantial uncertainty. Failure is an option.

The need for an intelligent electricity infrastructure

- We need Smart Grid technologies for
  - Enabling renewable production on a massive scale
  - Providing services for the user to become a prosumer
  - Enabling efficient electricity markets in a liberalized sector
- While keeping the level of power grid investments reasonable, by
  - Balancing loads / coping with volatility on all scales
- Substantial investment into technology is required
  - By distributed heterogeneous stakeholders
  - Investment decisions are not independent
- A change in actor configurations is required, often in conflict with political and economic power of incumbent stakeholders
- "Smart Grids need even smarter governance" (Gogel 2009)

(Some) economics of electrical infrastructure

- Infrastructures are complex systems with very specific technical, economic and political characteristics (Finger et al., 2005)
  - Based on physical networks
  - High proportion of fixed cost, natural monopoly, high risk of investment (Youngson 1967, Lakshmanan 1989)
  - Serve major societal objectives or needs
  - Market failures – externalities, public good characteristics, increasing returns, network effects
- Common goods: rivalry due to non-excludability but limited capacity
  - "Between" private goods (market domain) and public goods (state domain)
  - Quest for polycentric governance of complex economic systems (Ostrom 2010)

Pre-analytical vision of the transition

- We face a lock-in to the fossil fuel-based economy deeply rooted in societal structures and activities
- This lock-in cannot be solved by
  - Simple state intervention like public procurement, due to the complexity and size of the problem
  - Purely market-oriented measures (correcting prices) may be insufficient to alter current paths of technological development and user practices
- Given technical feasibility, a profound system change requires changes at different levels: human behaviour, societal norms and values, institutional arrangements and economic framework conditions

Towards managing the system transition

- Core issue: What policies and governance frameworks are necessary for the transition to a smart electricity system?
- A generic model of policy relevance for managing transitions is still lacking
  - Available frameworks for analysis, such as multi-level (niche-regime-landscape, Geels 2005) or multi-phase (Rotmans 2005) perspectives are purely conceptual in nature
  - Transition is often assumed as being too complex to be framed into a formal model
- Promising approach: distinguish layers to structure the complexity (Bompard 2012), model them close to empirical reality
  - Physical, Cyber
  - Social, Market, Policy

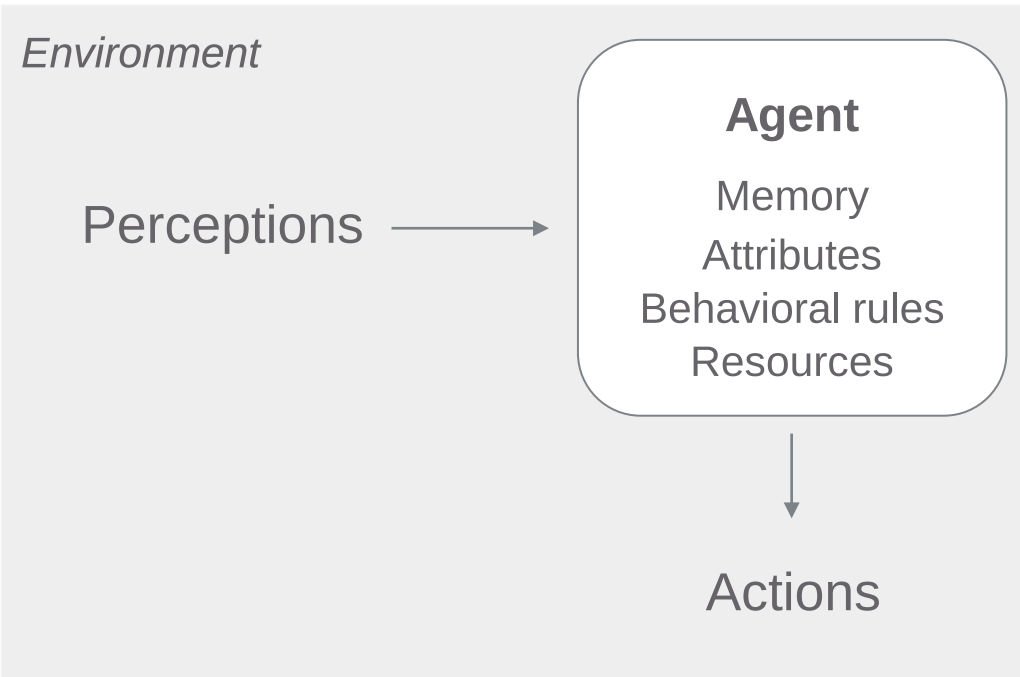
Simulation of investment decisions – a contribution to scenario analysis in AIT-F&PD

- Why experimenting with models?
  (Binder and Steiner 2009, Gebetsroither 2012)
  - No real object to observe
  - Long time horizon
  - Real experiments (pilots) are resource consuming
  - Ethical arguments
- Objective of the modelling exercise
  - To identify transition pathways towards a low-carbon electricity system, based on distributed renewable production
  - To test governance strategies for the transition
  - To support participation of stakeholders in scenario processes

Agent-based Modelling (ABM) – A methodology for analyzing complex social and natural systems

- Self-organized systems
  - E.g. ecosystems, residential patterns, speculative market bubbles, innovation and technological change
  - Self-organized systems are characterized by (partial) non-predictability, non-linearity, path-dependence, bifurcations, emergence
  - Missing information about dynamic equations on macro scales
- Agent-based Modelling
  - Adopts a rule-based micro-approach to describing SOS
  - Is appropriate to simulate social behavior
  - Renders emergence on the macro-level possible
  - Is increasingly accepted in social science

ABM – Basic elements and features



- Agents are intelligent
  - Autonomous
  - Heterogeneous
  - Social
  - Reactive
  - Proactive

  (Wooldridge and Jennings 1995)

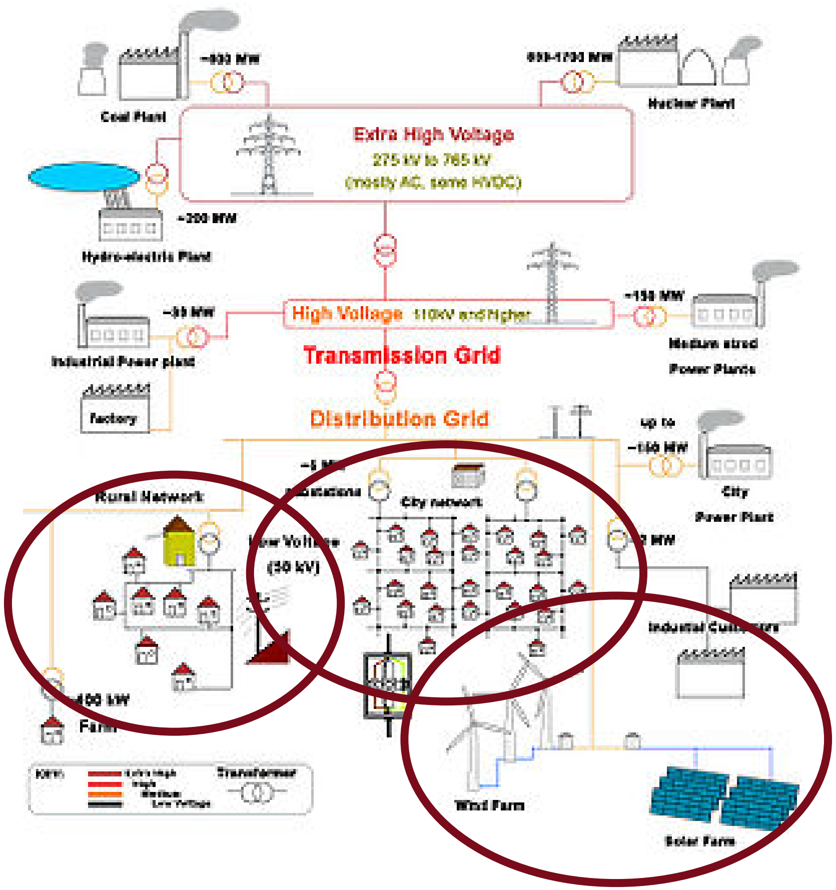
- "*Everything can be Agent!*"
  (Kubera et al. 2010)

Core functionality of the Multi-Agent-Model

- Heterogeneous, distributed agents take investment decisions
  - Consumption technology (smart)
  - Generation technology (intermittent)
  - Grid capacity & topology
  - Storage technology
- Agents optimize utility under bounded rationality
  - Utility functions
- Agent decisions are interrelated through
  - Technical constraints
  - Social relations and dynamics
  - Institutional arrangements (ownership, cells Gehrke & Kosek 2012)
  - Regulatory environment (Brunekreeft 2010, Glachant 2012)

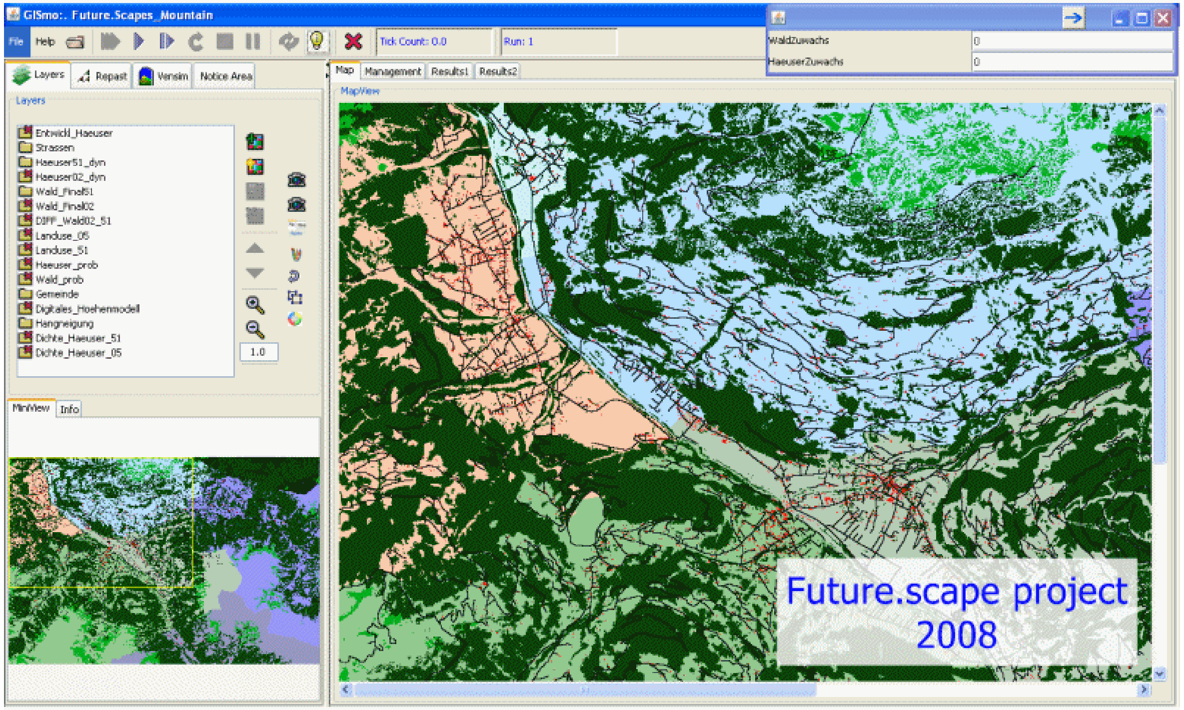
Focus of the conceived model

- Infrastructure investment
  - Timescale = lifetime of the technology
  - Investment products
- Agent types
  - Producers, grid operators, retailers, storage providers, consumers, new actors (e.g. flexibility operators)
- Distribution network and subnetworks
- Different regional specifications
  - Grid topology
  - Actor population

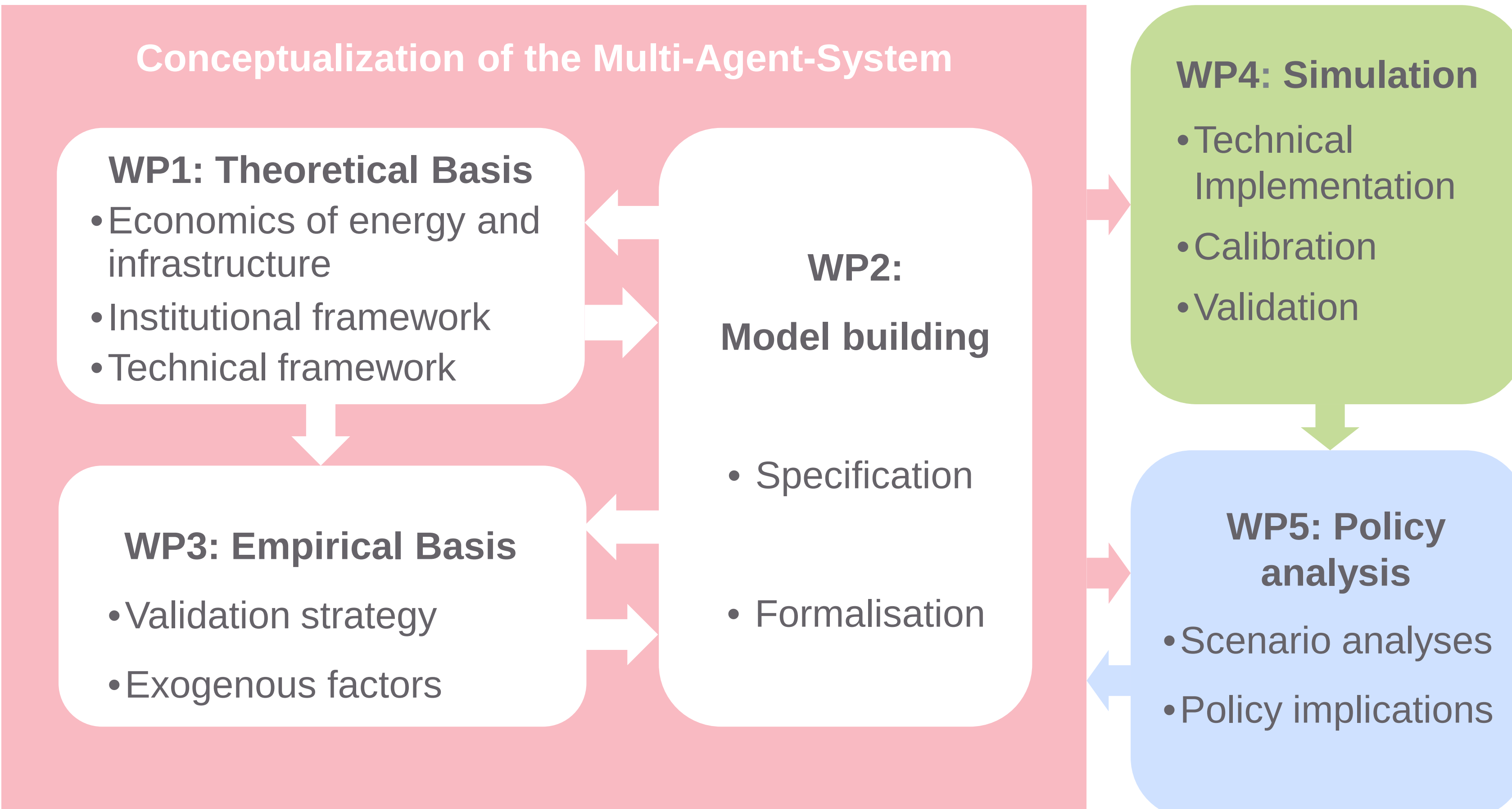


Tools

- MASGISmo: Multi-paradigm Agent-based System Dynamics GIS modelling platform - Java-based Platform and GUI developed at F&PD (Gebetsroither 2008, 2010)
- NetLogo
- Java/Repast



INFRASET – a project in AIT-F&PD



Conclusions and outlook

- From the broader view of climate change and energy policy, the main impact of Smart Grid technologies will be through renewable generation, storage and efficiency gains
- Technology is inherently socio-technical
- The transition from the hierarchical, demand driven electricity system to a distributed, active system of prosumers is a complex socio-technical process with uncertain outcome
- Agent-based models can help to identify transition pathways to a desired low-carbon electricity system
- Focus on infrastructure investments is relevant for policy in the fields of energy innovation and carbon reduction
- AIT-F&PD develops a modelling tool focusing on social, market and policy aspects

Thank you for your attention!

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