ETH zürich

Distributed multi-energy-hubs: *a review and techno-economic model to assess viability and potential pathways*

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S.4c: Energy System Analysis and Modelling

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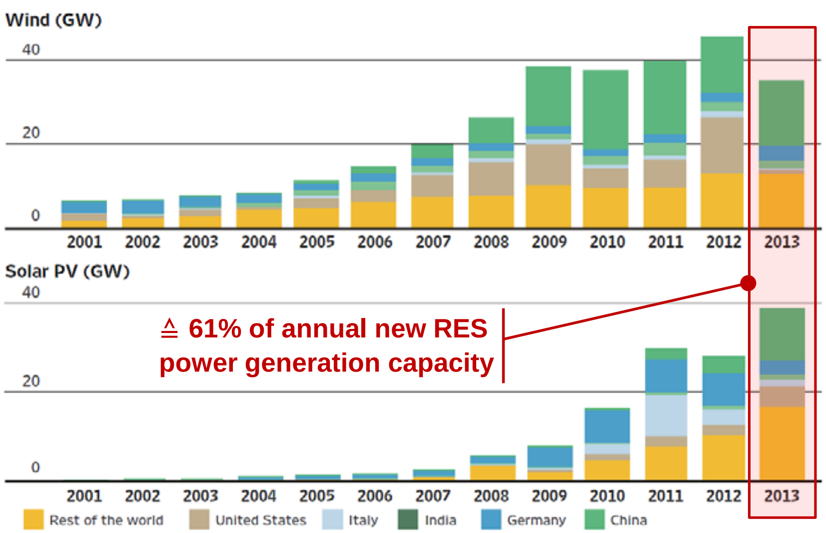
D MTEC Departement Management, Technology, and Economics

Group for Sustainability and Technology

Distributed solutions on district level as promising lever to cope with the increasing share of decentralized, intermittent power generation

Increasing decentralized power generation …

Global new capacity additions for wind & solar PV p.a.



Source: IRENA (2015)

… calls for innovative, integrated solutions

- Need for flexibility measures to decouple energy supply and demand
  - Operational flexibility of generation capacity
  - Transmission & distribution grid extension
  - Storage technologies (e.g. batteries, P2G)
  - Demand side management
- Distributed, decentralized solutions as a lever to
  - increase self-consumption
  - match local production and consumption on neighborhood / district scale

Current Project

- Overview on distributed solutions with different techn. configurations on district level
- Assessment of techno-economic performance of “Multi-Energy-Hubs”

Agenda

- Concept of Multi-Energy-Hubs
- Multi-Energy-Hubs in Practice
- Techno-Economic Model
- Outlook

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- **Concept of Multi-Energy-Hubs**
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What is a Multi-Energy-Hub?
Existing terminologies / concepts in literature and our understanding

Terminology in literature

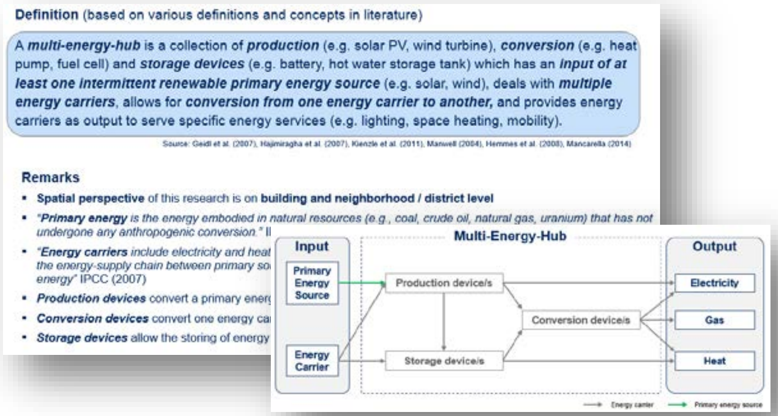
Selected publications

- Fabrizio et al. (2010)
- Geidl et al. (2007)
- Hemmes et al. (2007)
- Mancarella (2014)
- Manwell (2004)
- Maroufmashat et al. (2014)

Our understanding / definition

Based on a literature review of different definitions and concepts, we are approaching multi-energy-hubs by their specific application. Thus, our understanding is as follows:

> ***A multi-energy-hub allows to match intermittent renewable power production with district level energy demand.***


Definition (based on various definitions and concepts in literature)

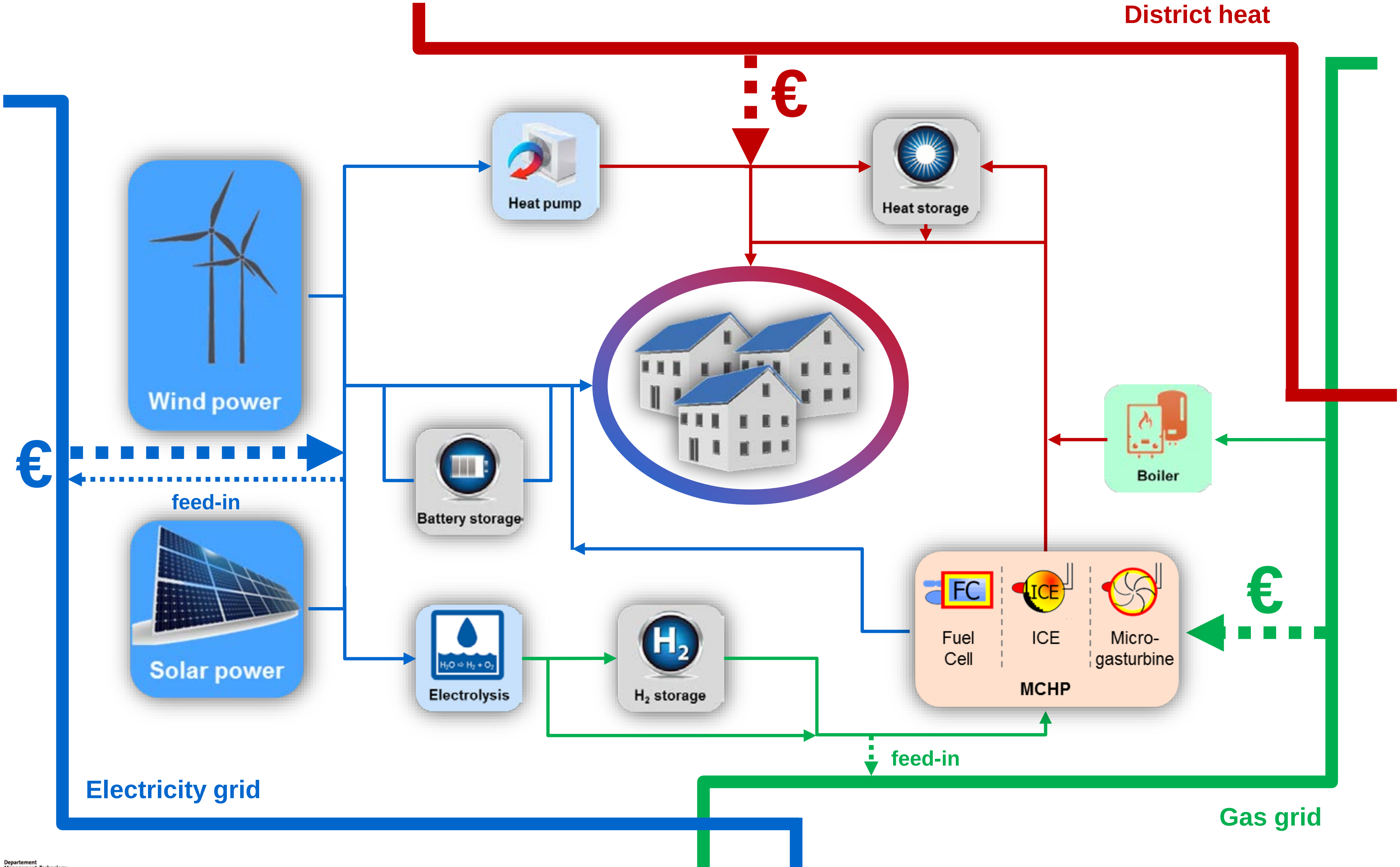
A ***multi-energy-hub*** is a collection of ***production*** (e.g. solar PV, wind turbine), ***conversion*** (e.g. heat pump, fuel cell) and ***storage devices*** (e.g. battery, hot water storage tank) which has an ***input of at least one intermittent renewable primary energy source*** (e.g. solar, wind), deals with ***multiple energy carriers***, allows for ***conversion from one energy carrier to another,*** and provides energy carriers as output to serve specific energy services (e.g. lighting, space heating, mobility).

Source: Geidl et al. (2007), Hajimiragha et al. (2007), Kienzle et al. (2011), Manwell (2004), Hemmes et al. (2008), Mancarella (2014)

Remarks

- **Spatial perspective** of this research is on **building and neighborhood / district level**
- *"**Primary energy** is the energy embodied in natural resources (e.g., coal, crude oil, natural gas, uranium) that has not undergone any anthropogenic conversion."* II
- *"**Energy carriers** include electricity and heat* … *the energy-supply chain between primary so*… *energy"* IPCC (2007)
- ***Production devices*** convert a primary energ…
- ***Conversion devices*** convert one energy ca…
- ***Storage devices*** allow the storing of energy …

What is a Multi-Energy-Hub?
Our simplified depiction of the concept with P2G on district level



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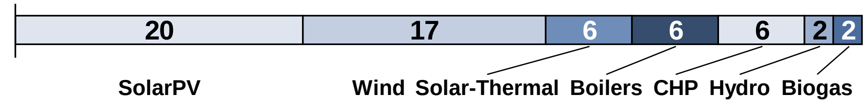
To add market perspective, we are currently compiling important insights on existing/planned multi-energy-hub projects in a database

Containing information on …

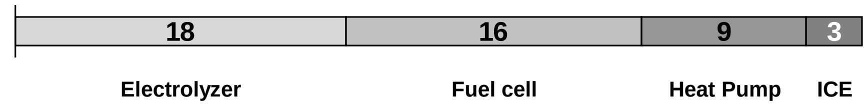
- **Location**
- **Technologies integrated**
  - Type (e.g., PV, heat pump, battery)
  - Rating (e.g., capacity, efficiency)
  - Manufacturer
- **Ownership model**
  - Type
  - Name
- **Schedule**
  - Operating status
  - Construction date
- **Funding**
  - Source
  - Amount
- **Grid connectivity**
- **Motivation, drivers / barriers**
- **Current / future market services**

Split of technologies across projects, in

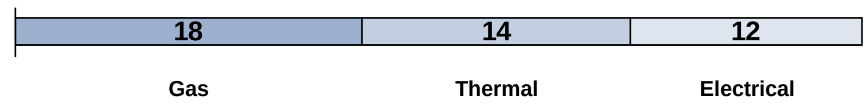
Production technologies



Conversion technologies[1)]



Storage technologies[1)]

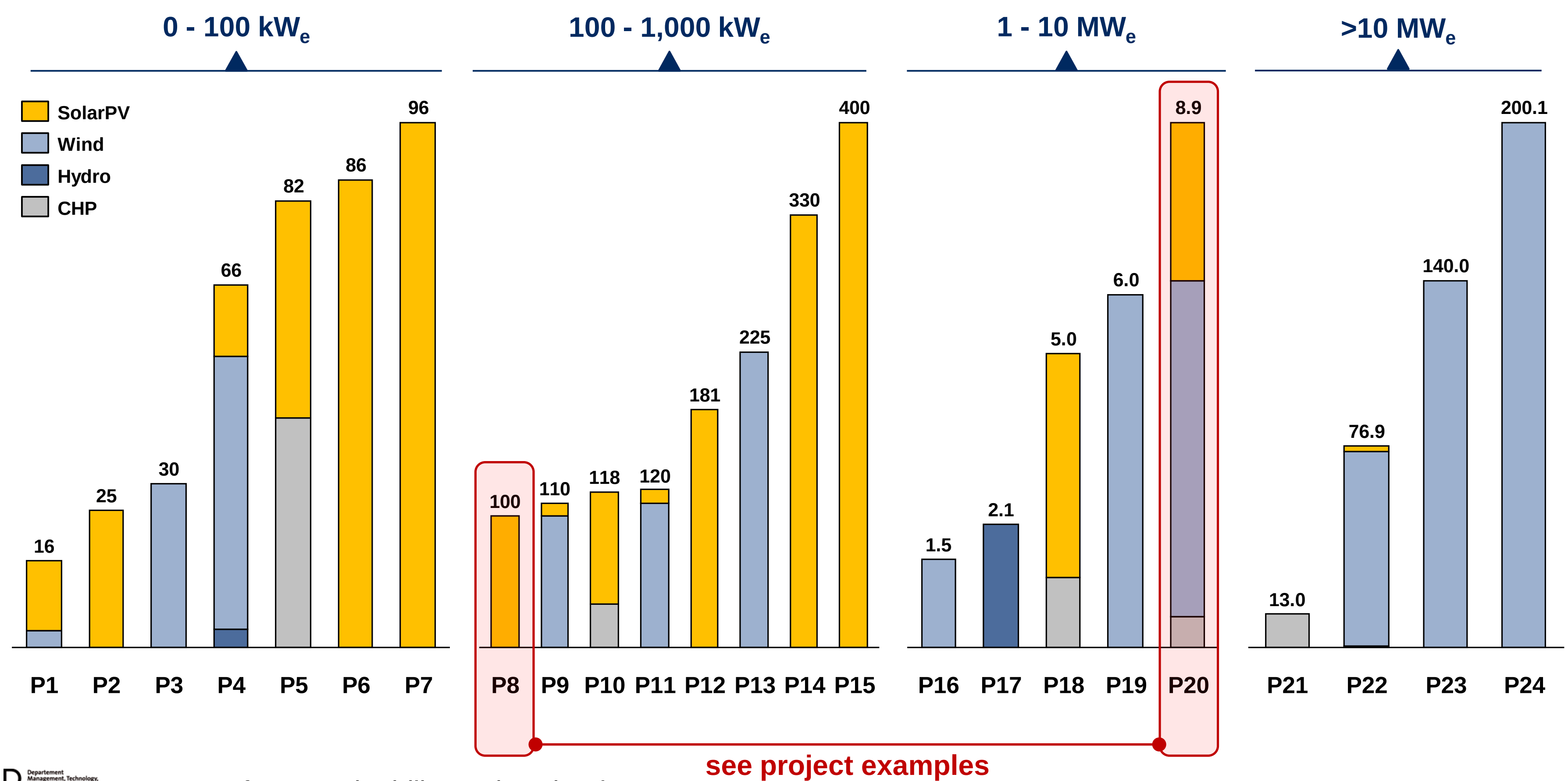


- **Total # of 29 projects added to date**
- **Geographical focus: USA & Europe**

1) Biased, as primary focus on P2G projects

According to hub size, clusters emerge with different production technologies in use (preliminary sample analysis of project database)

Project split across installed electric production capacity, 24 projects



A deep-dive into two selected projects reveals the differences of multi-energy-hubs in terms of e.g., size, technologies, motivation

P8 Energieautarkes MFH Brütten

- Demonstration project for a grid independent Multi-Family-House (MFH), under construction since 2015, scheduled operation for 2016
- Supplies residential heat and electricity demand for a MFH with 9 residential units, no grid connectivity for electricity, gas and heat
- Integrated technologies
  - Production: Solar PV (100 MWh/yr)
  - Conversion: Electrolyzer, MCHP (fuel cell), and heat pump
  - Storage: Battery (tbd.), hydrogen storage (in vessels), and thermal storage
- Innovative pricing scheme, i.e., no direct energy cost but energy budget incl. bonus/malus system

P20 SmartRegion Pellworm

- Demonstration project to achieve maximum utilization of local intermittent renewable energy sources (wind and solar), in operation since 2014
- Supplies residential heat and electricity demands of Pellworm but grid-connected to mainland, GER
- Integrated technologies
  - Production: Solar PV (2.7 MW_p), wind turbine (5.7 MW), and biogas-CHP (0.5 MW_e)
  - Conversion: Heat pumps
  - Storage: Battery (lithium-ion, 1 MW), battery (redox-flow, 0.2 MW), and thermal storage
- Project consortium consists of 8 members coordinated by E.ON SE, involving private, government and university partners

SmartRegion Pellworm

Source: Public available project data and interview data

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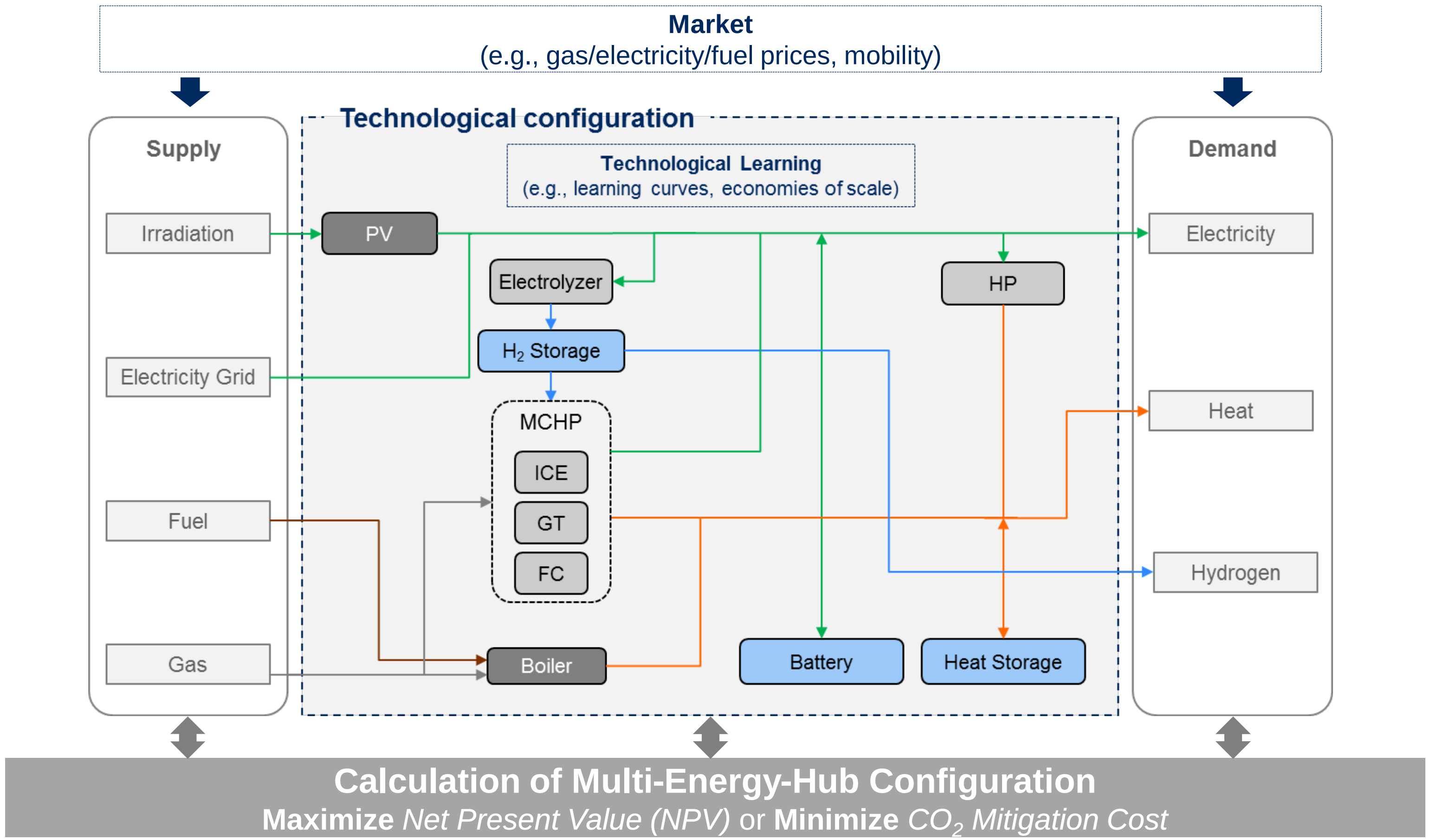
Structural overview on the techno-economic model

External Environment (conditioned by **Policy**, e.g., incentives, taxes, subsides)



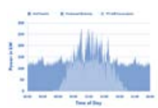
Production technology | Conversion technology | Storage technology

Fuel, Electricity, Heat, Hydrogen, Gas

Model implementation: Input and output parameters using MATLAB

Input Parameters

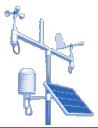
Load curves electricity & heat



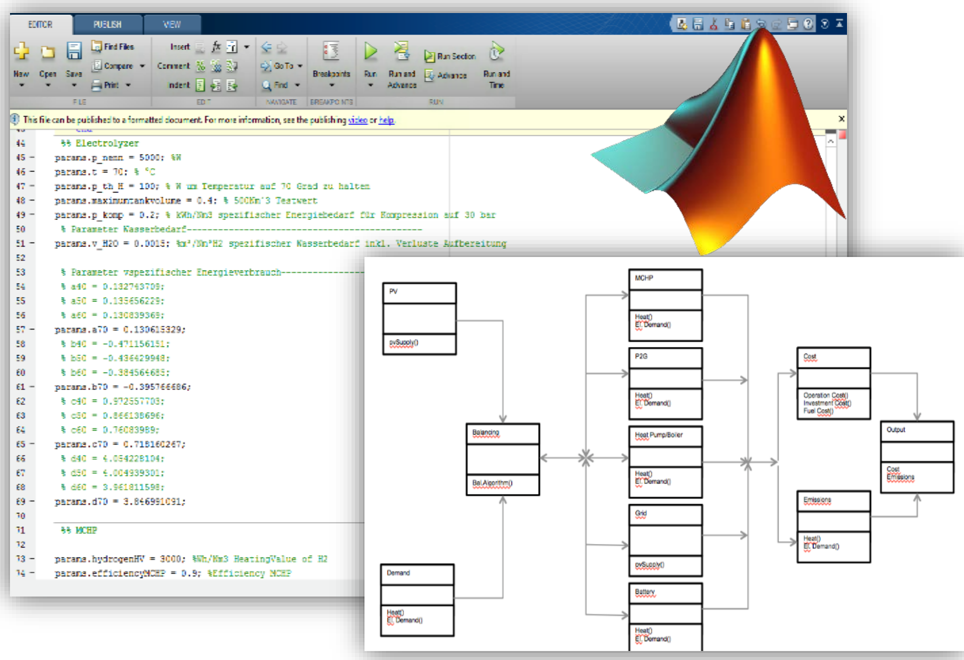
Financial & market data

Technology & economic data

Weather data



Building features



Output Parameters

Economic viability

System efficiency

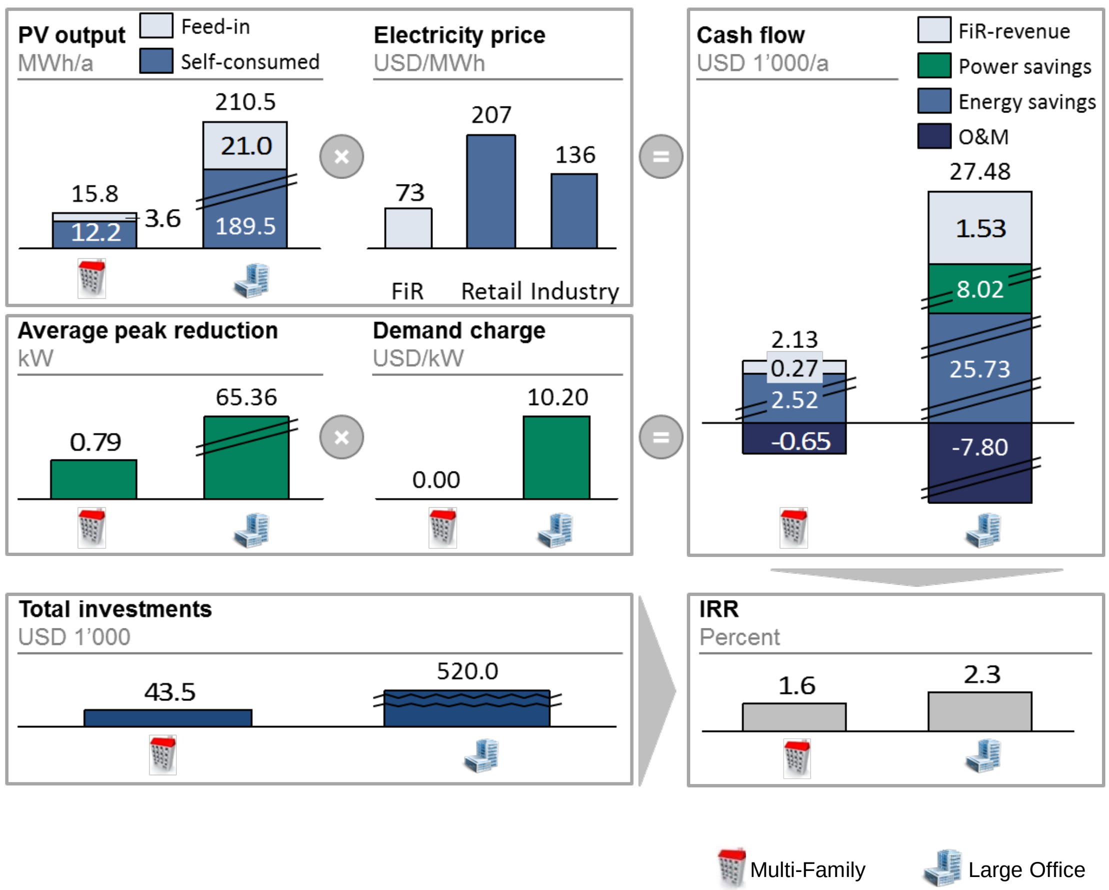
Hub & techn. sizing

As we are currently finalizing the development of the model, first results are expected this summer

Expected results / findings

- Current cost barriers and major cost drivers
- Overview on key performance indicators
  - NPV with cash flow calculation (investment, O&M, savings)
  - CO_2 mitigation cost
- Ideal techn. configurations and sizing for different hub types and applications
- Share of self-sufficiency (cost to be grid independent)
- Influence of techn. learning potential and market dynamics
- Spatial differences for locations in scope (DE, CH, AT, IT)

Previous research: Self-consumption (PV + Battery)



Source: Lang et al. (2015)

In a second step, the techno-economic model is refined by adding both scenario and sensitivity analyses

Scenario Analysis

Testing of model results under different scenarios, e.g.,

Technological configurations
- "High RES share"
- "Battery-only"
- …

Economic environment
- "Zero-subsidies"
- "High gas/ electricity price"
- …

Table 4: Electricity price scenarios used in model simulations

Scenario	Assumption	Electricity Wholesale Price Scenario	Electricity Retail Price Scenario
S1	Unlimited access of household to wholesale market	High: +3% per year (real)	High: + 2% per year (real)
S2		Low: -1% per year (real)	
S3		Medium: + 1.5% per year (real)	Medium: + 1% per year (real)
S4		High: +3% per year (real)	Low: + 0% per year (real)
S5		Low: -1% per year (real)	
S6	No access of household to wholesale market	Constant: 0 EUR/kWh	High: + 2% per year (real)
S7			Medium: + 1% per year (real)
S8			Low: + 0% per year (real)

Sensitivity Analysis

Testing of model results by varying input parameters, e.g.,

- Sizing of PV, storage, hub
- Plant lifetime
- Capex / Opex
- Efficiency
- Discount rates
- …

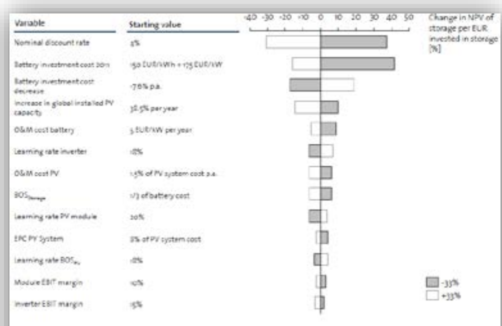


Figure 13: Sensitivity analysis of the most important input parameters under scenario S3

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Outlook & next steps: Results from the techno-economic model are expected by July, the database will be further complemented too

Techno-economic model

- Finalization of **integration** of **remaining technologies** and economic aspects
- **Validation of model assumptions** / preliminary results by **real test cases** and **experts**
- **Results** on **techno-economic assessment** in different technological configurations
- **Addition** of second model step with **scenario** and **sensitivity analyses**

Database on market installations

- **Addition of more projects** to the database **to achieve comprehensiveness**
- **Detailed analysis** of **selected projects** to gain deeper, qualitative understanding
- **Evaluation** of **overall data** to obtain insights, e.g., predominant technical configurations, rationale / motivation, barriers

Organizational implications

- Compiling of **qualitative interviews** with multi-energy-hub owners, operators, tech. manufacturers to **understand barriers/drivers** at the **individual** and **firm level**
- **Derivation** of **policy implications**, i.a. instruments to foster the implementation of multi-energy-hubs

Thank you for your kind attention!

Appendix

Literature

Fabrizio, E., Corrado, V., & Filippi, M. (2010). A model to design and optimize multi-energy systems in buildings at the design concept stage. Renewable Energy, 35(3), 644–655. doi:10.1016/j.renene.2009.08.012

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What is a Multi-Energy-Hub? Definition according to different concepts in literature

Definition (based on various definitions and concepts in literature)

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- *"**Energy carriers** include electricity and heat as well as solid, liquid and gaseous fuels, occupy intermediate steps in the energy-supply chain between primary sources and end-use applications. An energy carrier is thus a transmitter of energy"* IPCC (2007)
- ***Production devices*** convert a primary energy source into an energy carrier (e.g. solar PV, wind turbine, biogas plant)
- ***Conversion devices*** convert one energy carrier to another energy carrier (e.g. electrolyzer, fuel cell, heat pump)
- ***Storage devices*** allow the storing of energy carriers (e.g. battery, hot water storage tanks, hydrogen storage tanks)