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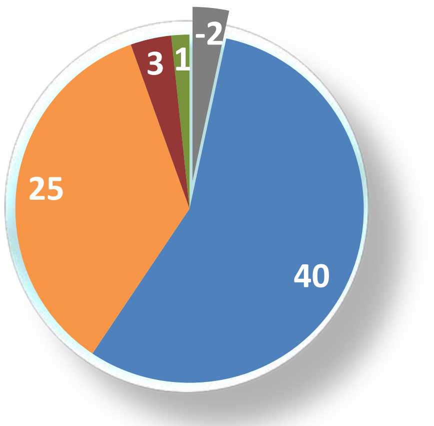
Can the decentralised CHP generation provide the flexibility required to integrate intermittent RES in the electricity system?

Introduction

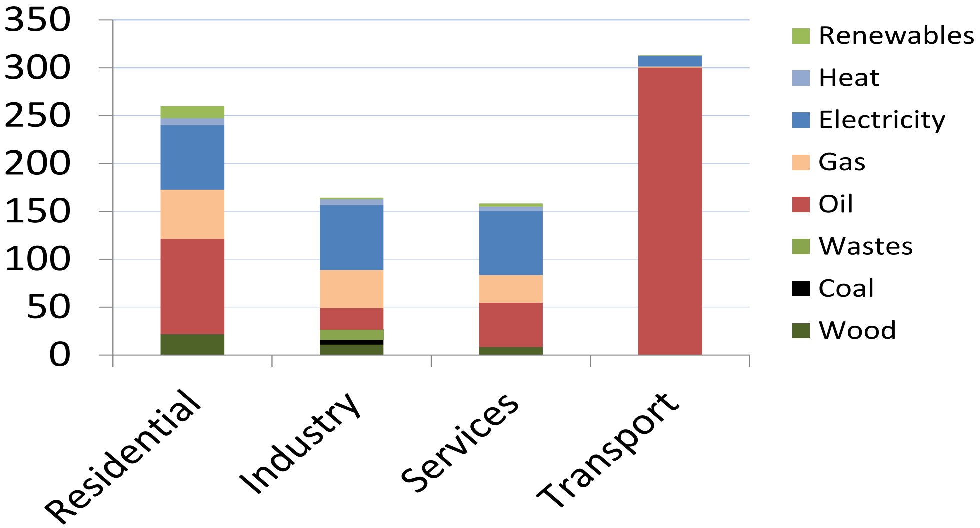
- Swiss energy system & Swiss energy strategy to 2050 objectives
- The concept of dispatchable biogenic CHPs (electricity-driven)
- Extensions on Swiss Times Electricity Model (STEM-E)
  - Challenges in modelling
- Preliminary results from model testing
- Conclusions

Swiss energy system in 2013

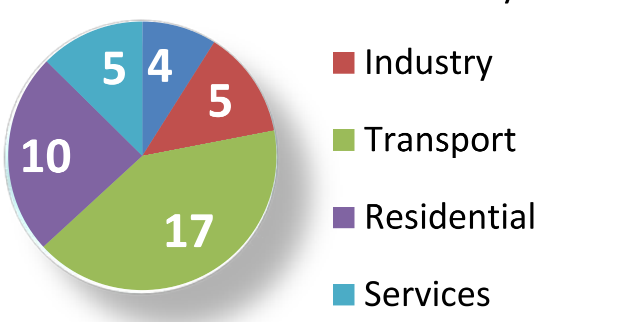
- Electricity production: 66 TWh



- Final energy consumption: 896 PJ



- CO_2 emissions 41 Mtn:

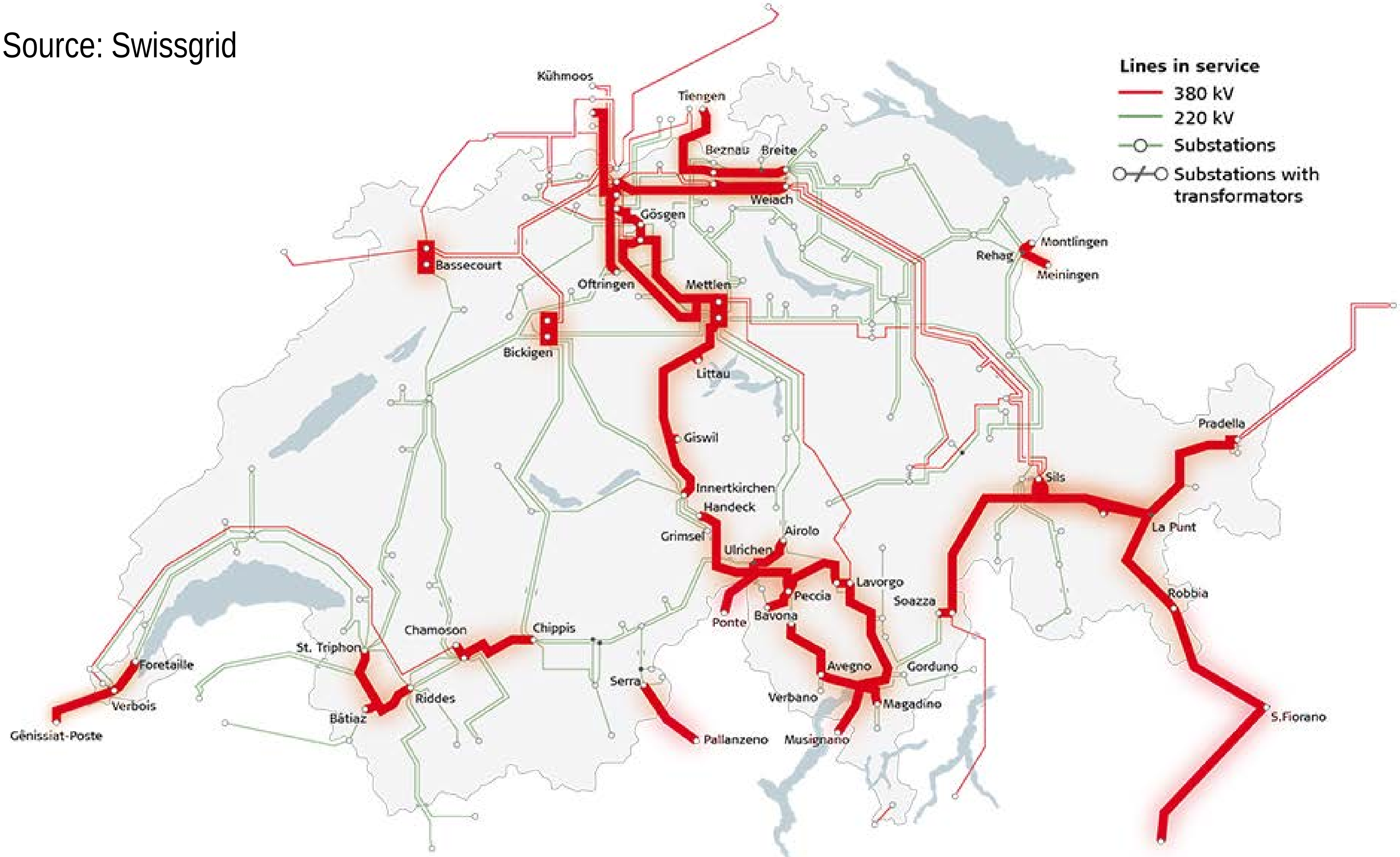


- Energy Strategy 2050 key objectives:
  - Enhancement of energy efficiency
  - Unlocking new RES (wind, solar, biomass)
  - Withdrawal from nuclear energy
  - Imports and fossil to meet residual electricity demand
  - Extension of electricity grid

Dams south, Nuclear north

Swiss grid congested lines

Source: Swissgrid

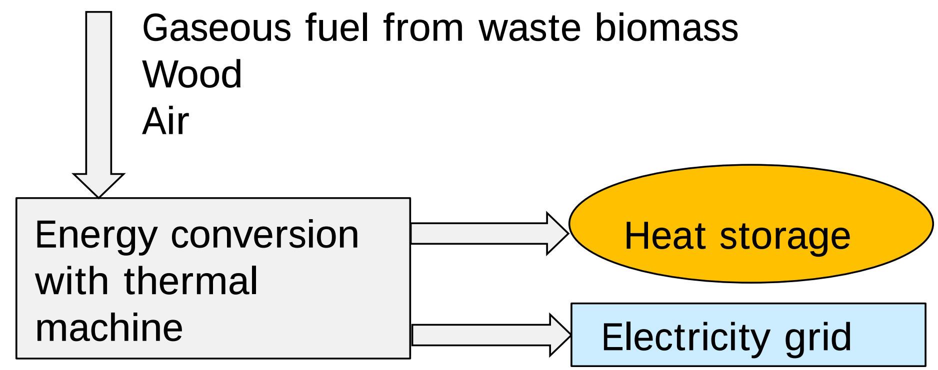


2/3 of the grid was built between 1950 and 60s with focus on ensuring regional supplies from nearby plants

The concept of biogenic CHP Swarm

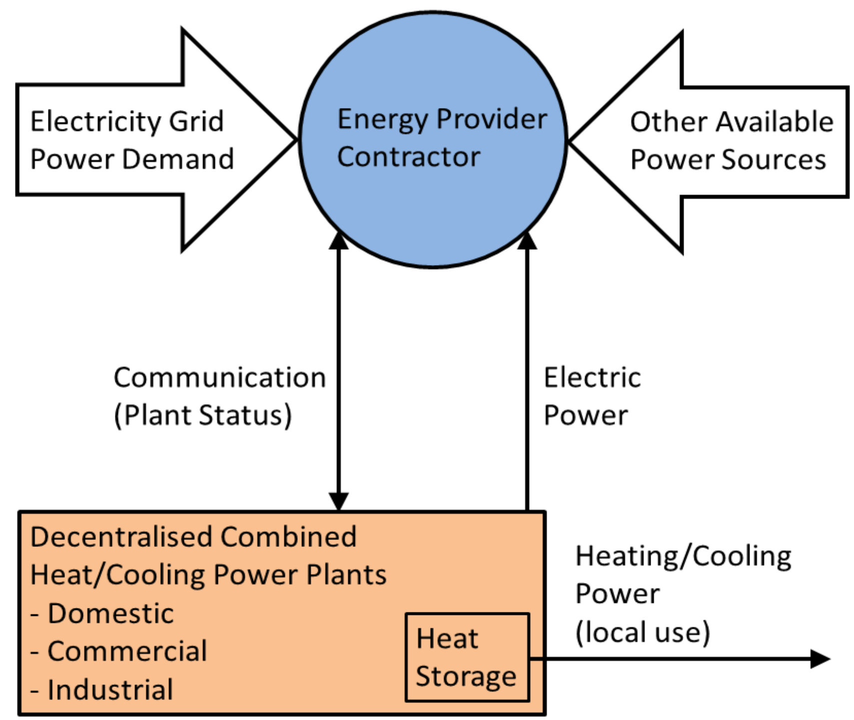
Running project ETH/PSI sponsored by BFE and Swisselectric Research

- Combined Heat and Power plant



- Specifications for grid stabilisation:
  - Fast response power generation
  - Temporal independent production of electricity and heat

- A contractor (electricity utility) could operate a CHP swarm by remote:
  - Dispatchable, scalable and decentralised power plant
  - Balancing power is sold at high price levels on the market



Assessing the potential of CHP Swarms

- A biogenic flexible CHP can participate in the following markets:
  a) Electricity supply, on-site or distributed
     → competition with power plants
     → competition with electricity grid price
  b) Heat supply for space and water heating, on-site or distributed
     → competition with boilers and heat pumps
     → competition with district heating networks
  c) Provision of grid balancing services at a grid distribution level:
     → competition with on-site solutions e.g. batteries
     → competition with services provided by pump hydro, PtG, etc.
- However, the technology is resource-constrained:
  → it uses biogas or upgraded biogas injected to gas grid
  → needs access to gas pipelines
  → competition with other biogas uses

Challenges in TIMES modelling

- To implement biogenic flexible CHPs in TIMES, to assess its potential and to identify barriers and competitors we need in the model at least:

  - Representation of **decentralised power generation**
  - **High time resolution** to account for demand and resource fluctuations
  - Introduction of **dispatchability features** (e.g. ramp-up constraints)
  - Representation of **heat supply and demand sectors**
  - Representation of **electricity & heat storage technologies**
  - Representation of **alternatives**, such as power-to-gas pathways
  - Representation of **bio-methane production options**
  - Representation of **demand for balancing services**

Swiss Times Electricity Model

2012 **FROM STEM-E to STEM-HE** 2014

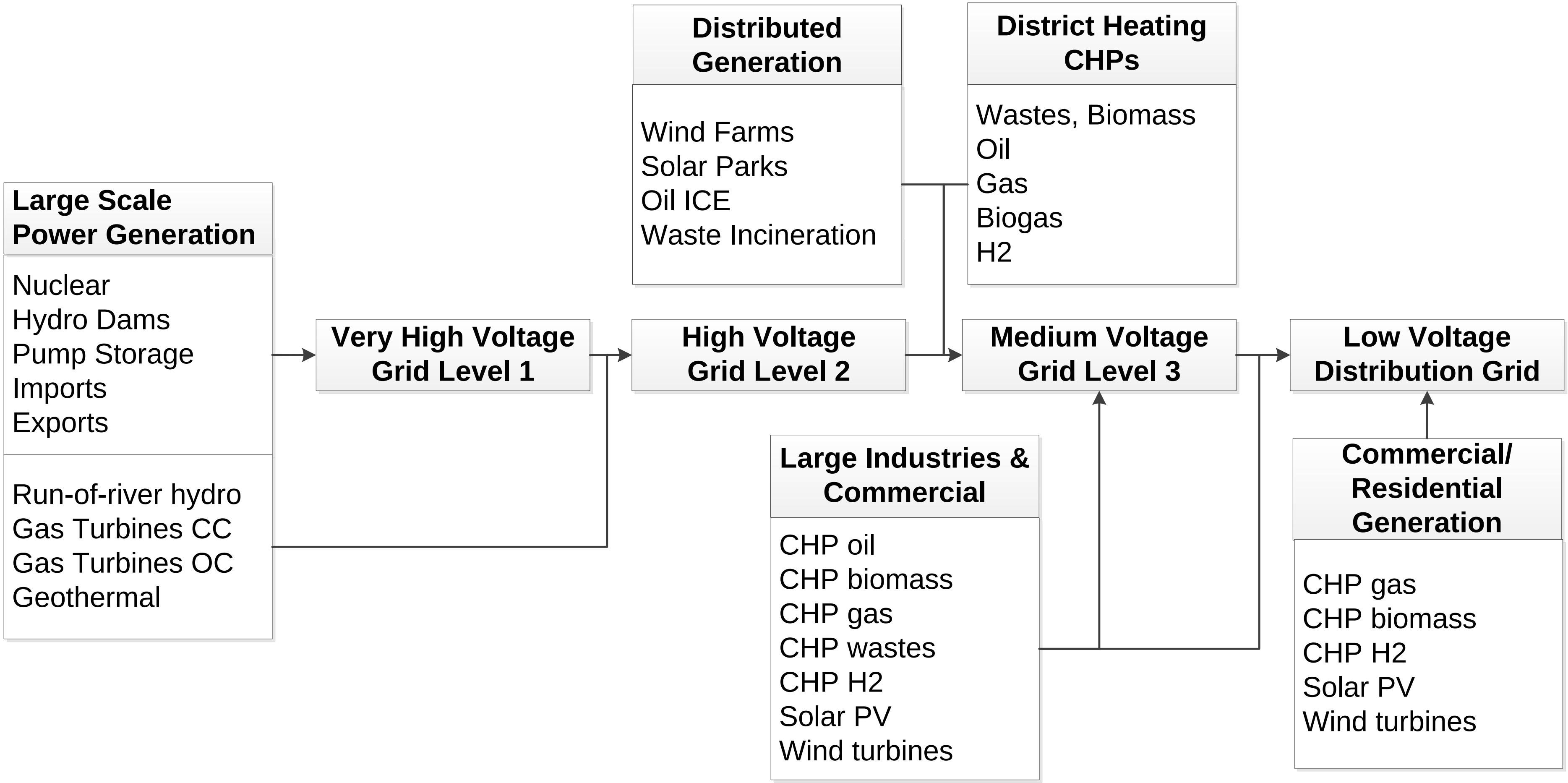
STEM-E:

- Swiss Electricity Model
- 288 time slices:
  4 seasons X 3 days X 24h
- Exogenous electricity demand linked to economic activity
- Electricity load profiles
- Different types of power plants
- Resource potentials

STEM-HE:

- All STEM-E plus:
- Decentralised generation
- Heat demands & load profiles
- Heat supply options
- Storage for electricity & heat
- Power-to-gas / gas-to-power
- Upgraded biogas production
- Ramping constraints
- Balancing services

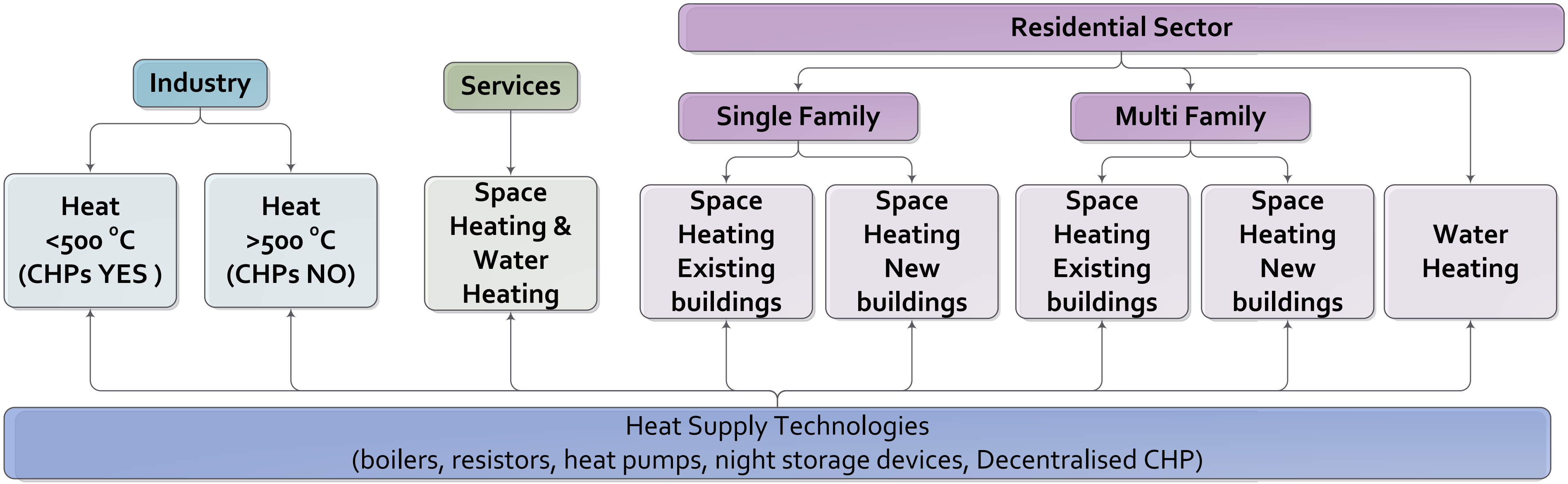
Representation of decentralised sector



- 4 different grid voltage levels are represented
- Allows for compensation of RES generation that is fed into grid
- Similar structure with TIMES-PET (and perhaps with other models)
- Not always straightforward assignment of power plants to each level

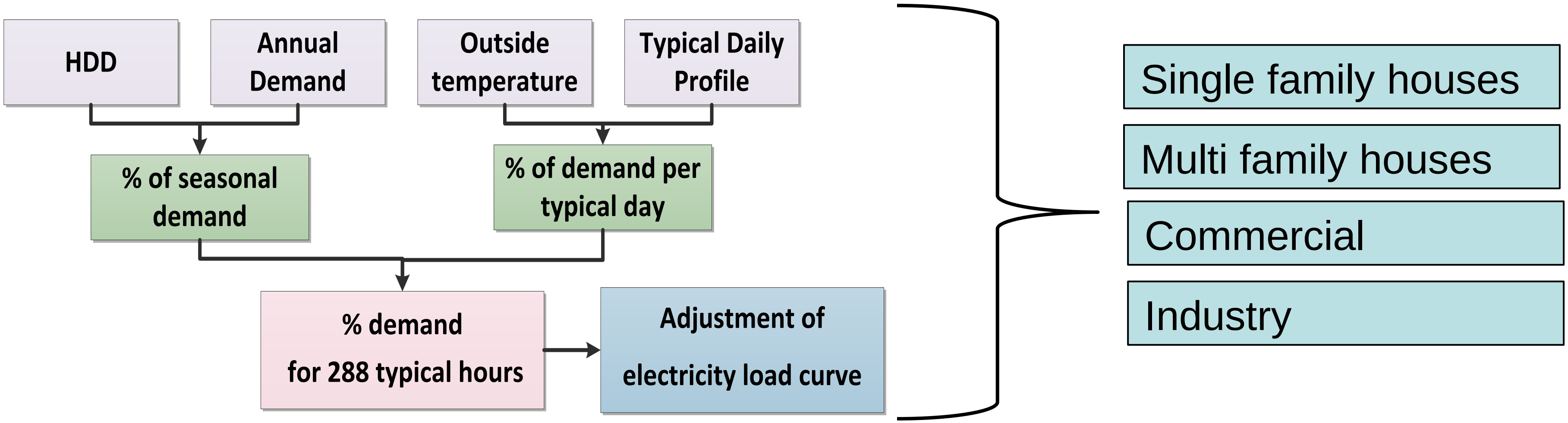
Heat demand sector

- To reduce complexity the focus is on heat that can be supplied by CHPs
- Space and water heating in buildings and commercial sectors
  - Differentiation between different types of houses
- Two classes of heat in industrial sectors: <500 °C, >500 °C



Heat demands and load profiles

- Statistical estimation of consumer behaviour from surveys [1]



- Data reconciliation to minimise the deviation between actual and calculated annual heat demand from the profiles:

$$\min \sum_{t} \left(w_{1,t}(D_t - F_t)^2 + \sum_{ts} w_{2,t}(x_{ts} - y_{ts})^2 \right)$$

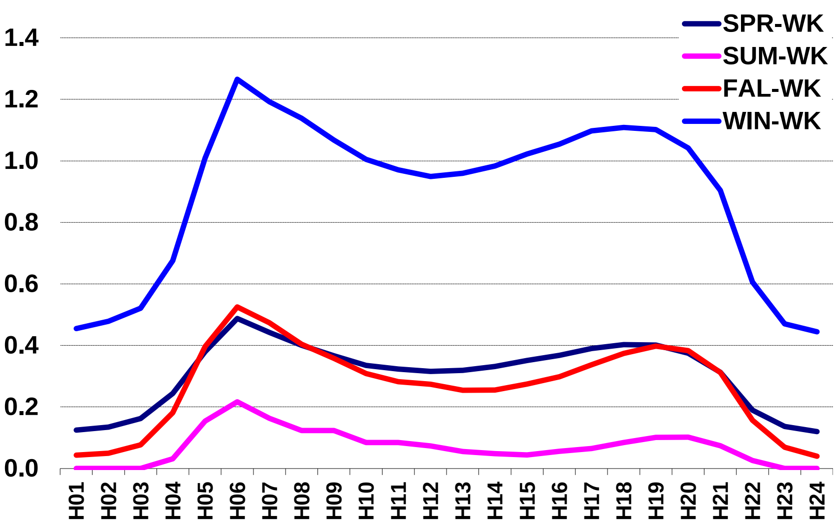
$$F_t(x_1 \ldots . x_n) = 0$$

$$C_k(x_1 \ldots . x_n) = 0$$

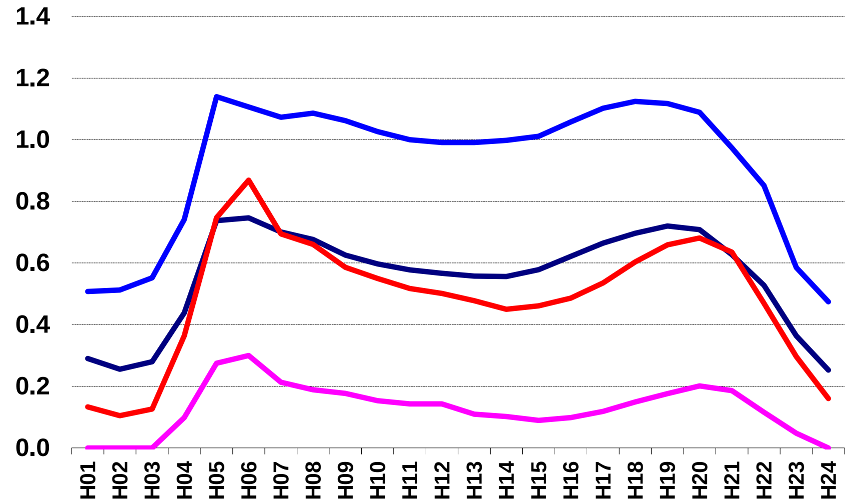
$\boldsymbol{w}$	weights, user defined
$\boldsymbol{y}$	Initial hourly profiles
$\boldsymbol{x}$	Adjusted hourly profiles
$\boldsymbol{F}$	Calculated annual heat demand
$\boldsymbol{D}$	Actual annual heat demand
$\boldsymbol{C}$	Other constraints that must hold

Examples of obtained heat profiles

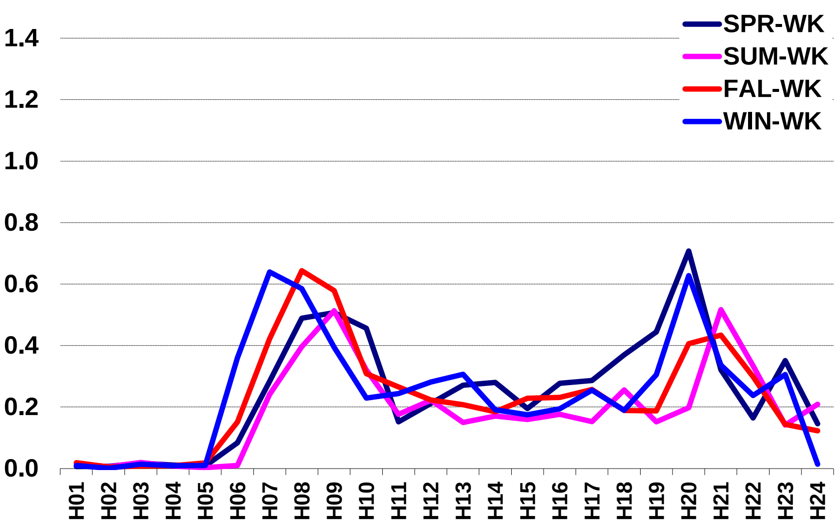
Existing single family houses – Space heating in PJ



Existing multi family houses – Space heating in PJ



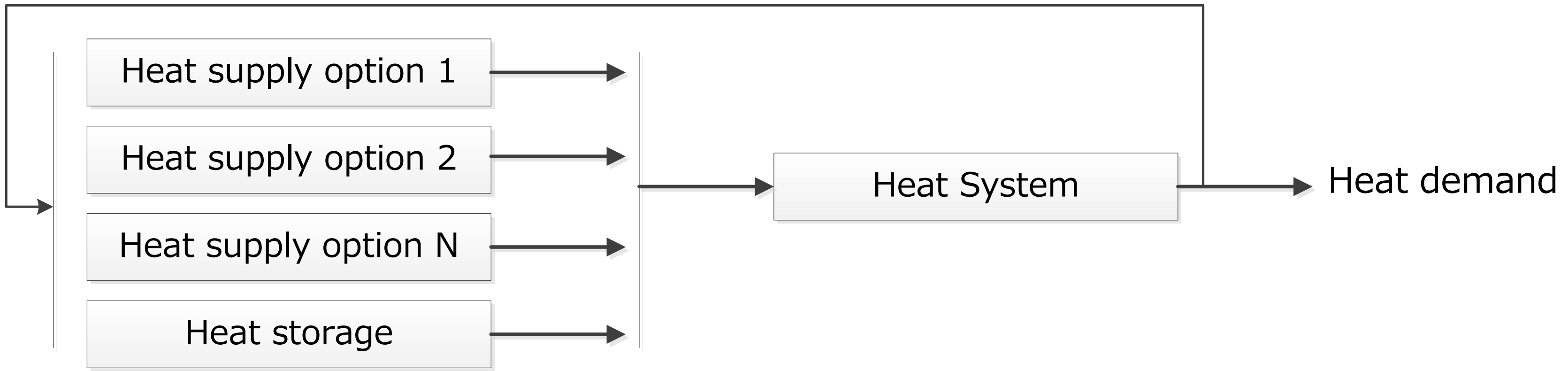
All households– Water heating in PJ



- Space heating: morning peak followed by a long day-time plateau and a smaller evening peak
- Water heating: sharp variations depending on use

Representation of heat systems [2]

- Combinations of primary and secondary heating systems is possible via user constraints:



$$a_{p,t} \cdot X_{p,t}^{NCAP} + b_{pp,t} \cdot X_{pp,t}^{NCAP} = c_{1,t}$$

Fixed capacity ratio: e.g. solar thermal and gas boiler

$$a_{p,t} \cdot X_{p,t}^{NCAP} + b_{pp,t}^{MAX} \cdot X_{pp,t}^{NCAP} \leq c_{2,t}$$

$$a_{p,t} \cdot X_{p,t}^{NCAP} + b_{pp,t}^{MIN} \cdot X_{pp,t}^{NCAP} \geq c_{3,t}$$

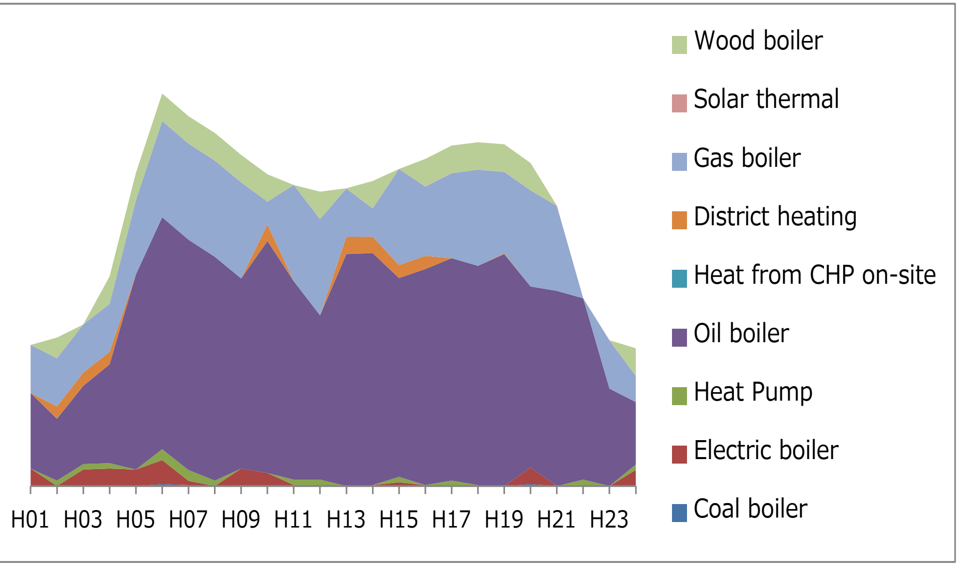
Upper and lower bounds on capacity ratios: e.g. micro CHP and gas boiler

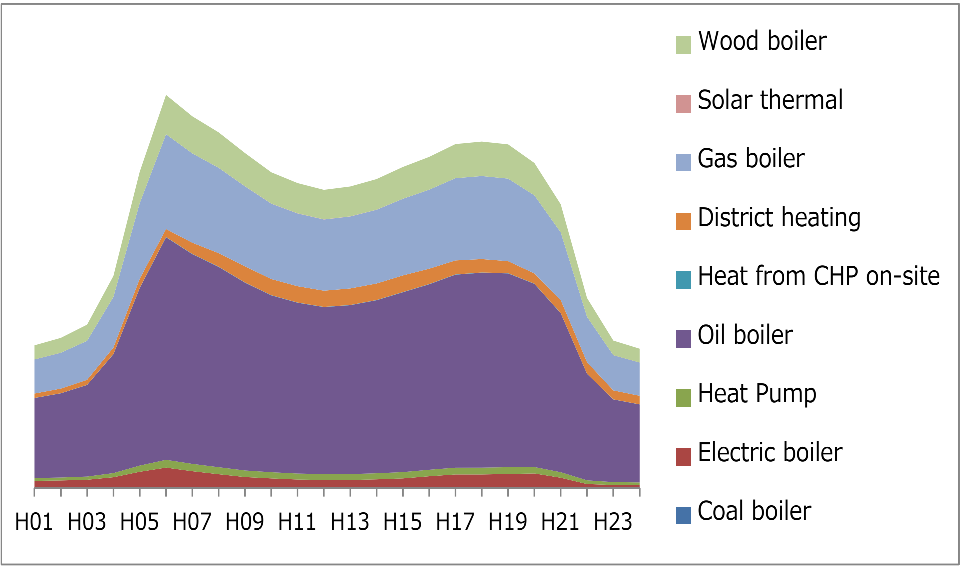
$$\sum_{p \in P_{PRI}} X_{p,t}^{CAP} \geq demand_{t,ts\_peak}$$

Match demand capacity requirement with the capacity of the primary heat supply systems

$\forall p \in P_{PRI}$; $pp \in P_{SEC \cup STG}$; $t \in T$; $ts\_peak \in TS$; $a_{p,t}, b_{p,t}, c_{1,t}, c_{2,t}, c_{3,t}$ const

Avoiding technology mix in heat supply





- No individual technology optimisation is applicable for heat supply systems:

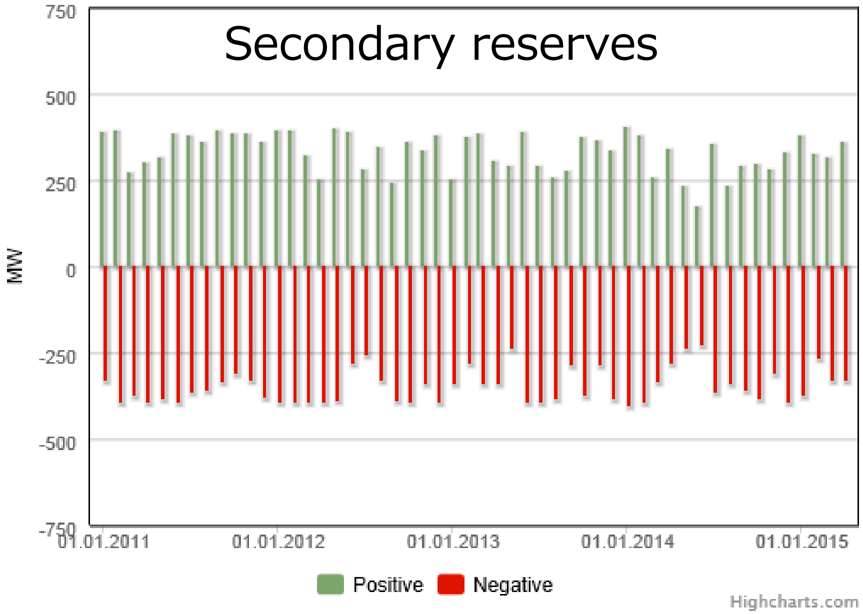
a) Go for MIP by ensuring that only one heat system will supply a heat demand class [2] (not directly supported in TIMES)

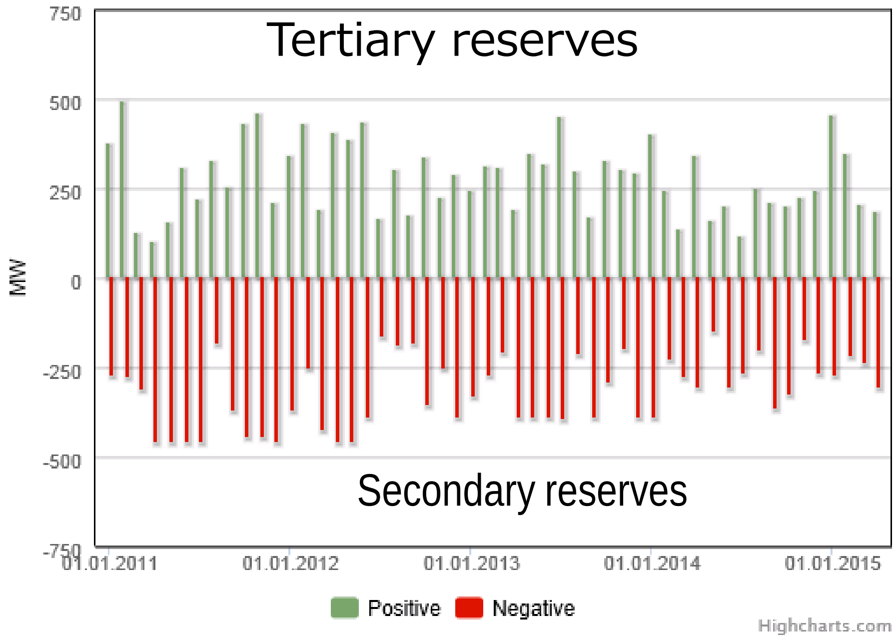
OR:

b) Introduce a utilisation curve for each heat supply system with NCAP_AF(UP) and ACT_UPS(FX) in accordance with the demand curve

Introducing balancing services

- Primary reserves react to frequency deviations within 30 seconds
- Secondary reserves are activated just slightly after the primary reserves and maintain a balance between generation and demand within each balancing area (duration from 1 to 60 minutes)
- Tertiary reserves are called only after secondary control has been used for a certain duration, to free the secondary reserves for other purposes



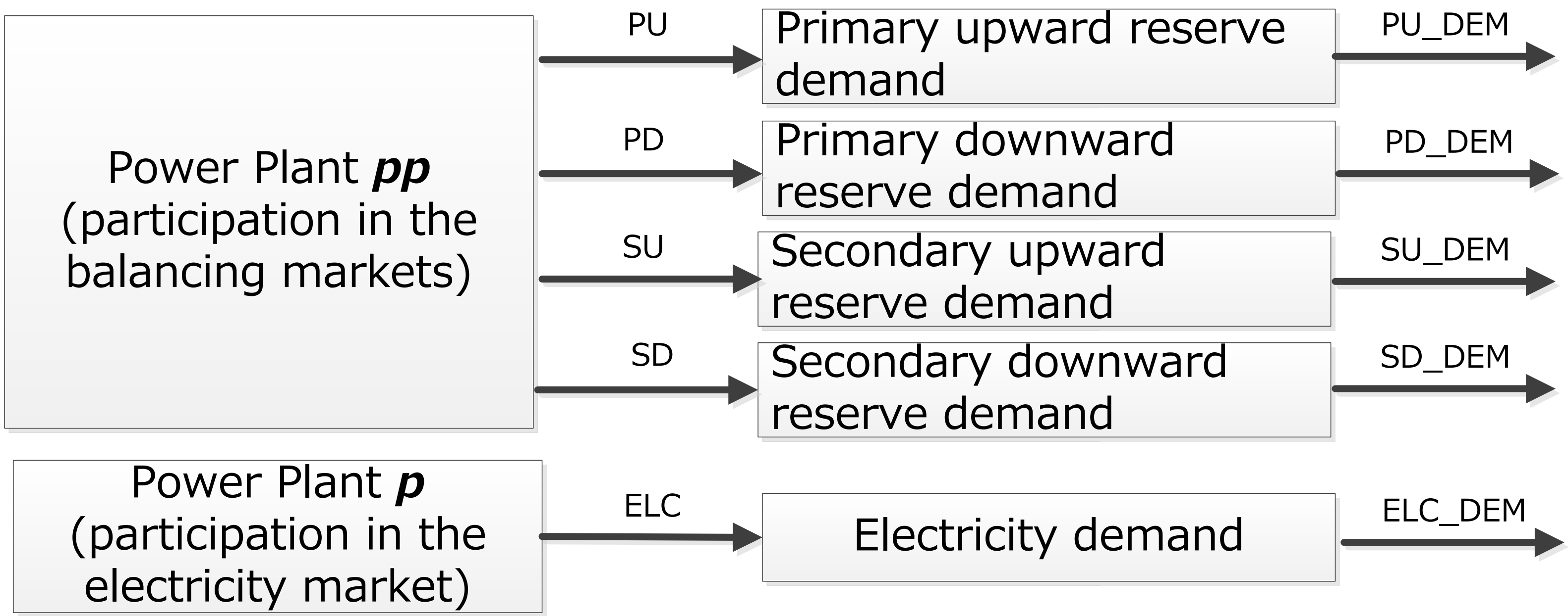


Source: Swissgrid

Porting OSEMOSYS methodology [3]

- Each power plant is producing 4 additional commodities related to the primary & secondary upward and downward reserves
- The set of the attributes of a power plant is augmented by:
  - Its minimum stable operation
  - The % of total capacity available for primary and secondary upward and downward reserves
  - The ramp-up and ramp-down rates
- We can also provide the % of upward reserve met by online plants to avoid unrealistically provisions of upward reserves from offline technologies
- The additional equations for balancing services:
  - Can be introduced as UC (takes time to enter the constraints in EXCEL)
  - Can be implemented as TIMES extension in GAMS (prone to errors)

Porting OSEMOSYS methodology



- Each power plant eligible for participating in the balancing markets is divided into two parts
- A capacity transfer UC ensures that the capacity-related costs are paid only once: $X_{p,t}^{CAP} = X_{pp,t}^{CAP}$
- Demand for balancing services: $3 * \sqrt{\sigma_D^2 + \sigma_G^2 + K}$

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Key equations for balancing services [3]

$X_{p,t,ts}^{CAPON} = X_{p,t,ts}^{ELC} / (capact_p \cdot yrfr_{t,ts})$:online capacity of process p

Downward reserve:

$$X_{pp,t,ts}^{k} \leq X_{p,t,ts}^{CAPON} \cdot max_{k,pp} \cdot capact_{pp} \; : \; k \in \{PD, SD\}$$

Upward reserve for a fast ramping plant: ($\boldsymbol{max_{k,pp} \geq stableop_{pp}}$)

$$X_{pp,t,ts}^{k} \leq X_{pp,t}^{CAP} \cdot af_{pp,t,ts} \cdot max_{k,pp} \cdot capact_{pp} : \; k \in \{PU, SU\}$$

$$X_{pp,t,ts}^{PD} + X_{pp,t,ts}^{SU} \leq X_{p,t,ts}^{ELC}$$

$$X_{p,t,ts}^{ELC} \leq X_{p,t,ts}^{CAPON} \cdot capact_p$$

Upward reserve for a slow ramping plant: ($\boldsymbol{max_{k,pp} \leq stableop_{pp}}$)

$$X_{pp,t,ts}^{k} \leq X_{p,t}^{CAPON} \cdot af_{pp,t,ts} \cdot max_{k,pp} \cdot capact_{pp} : \; k \in \{PU, SU\}$$

$$X_{pp,t,ts}^{PD} + X_{pp,t,ts}^{SU} + X_{p,t}^{CAPON} \cdot stableop_{pp} \cdot capact\_p \leq X_{p,t,ts}^{ELC}$$

$$X_{p,t,ts}^{ELC} + X_{pp,t,ts}^{PD} + X_{pp,t,ts}^{SU} \leq X_{pp,t,ts}^{CAPON} \cdot capact_{pp}$$

Key equations for balancing services [3]

Minimum online upward reserve ($k \in \{PU, SU\}$)

$$\sum_{pp} X^{k}_{pp,t,ts} \geq DEM_{k,t,ts} \cdot minonline_{t}$$

All reserve from online plants when $\max_{k,pp} \leq stableop_{pp}$:

$$X^{k}_{pp,t,ts} = X^{ONLINE_k}_{p,t,ts} \cdot capact_{p}$$

Share of reserve from online plants when $\max_{k,pp} \geq stableop_{pp}$:

$$X^{k}_{pp,t,ts} \geq X^{ONLINE_k}_{p,t,ts} \cdot capact_{p}$$

Upward reserve is limited by online capacity minus power output:

$$X^{CAPON}_{p,t,ts} - X^{ELC}_{p,t,ts} \geq \left(X^{ONLINE_{PU}}_{pp,t,ts} + X^{ONLINE_{SU}}_{pp,t,ts}\right)$$

Upward reserve by online plants limited by their max contribution to upward reserve:

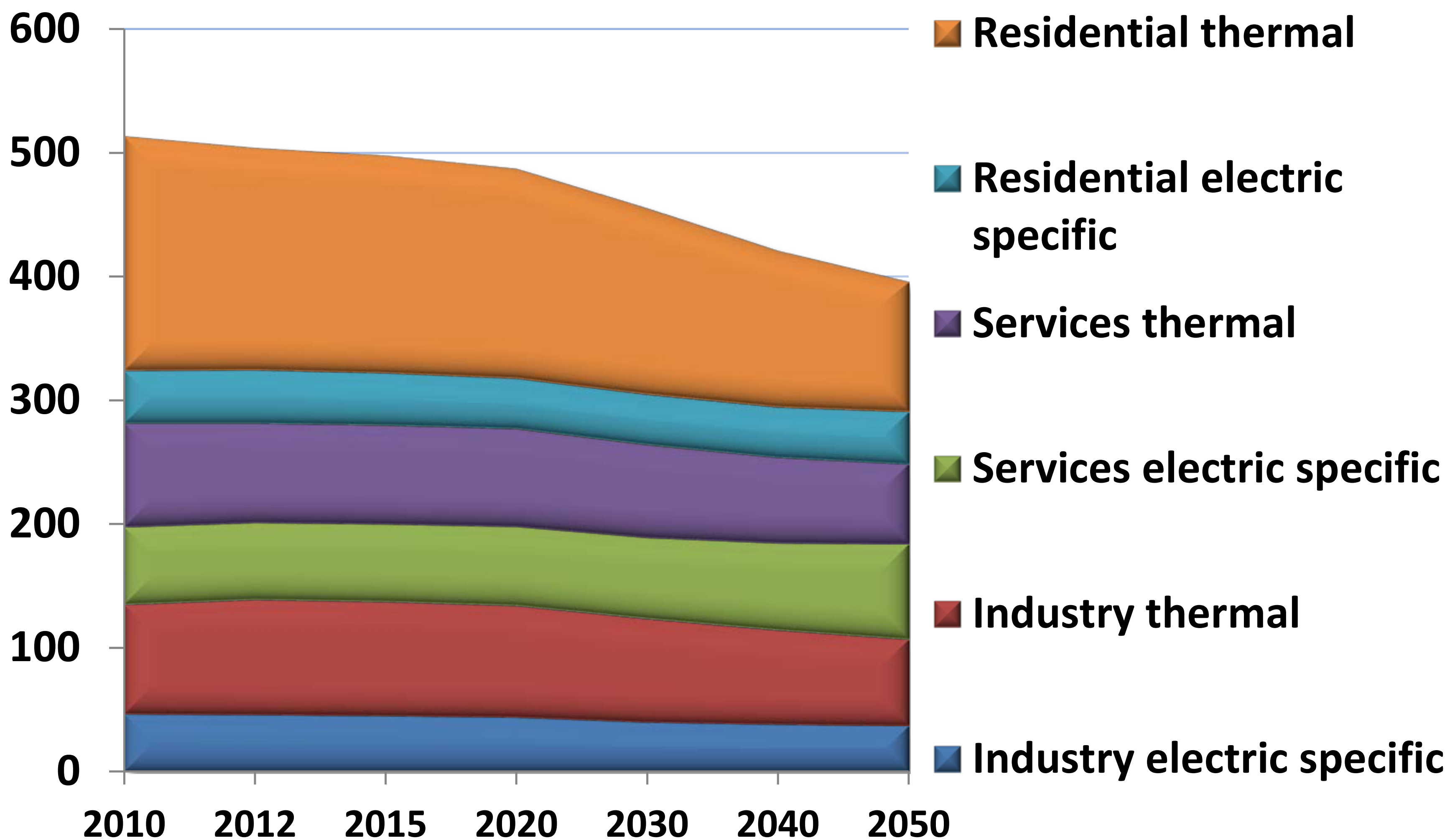
$$X^{CAPON}_{p,t,ts} \cdot max_{k,pp} \geq X^{ONLINE_k}_{p,t,ts}$$

Preliminary results from model testing

- The related to this work project is currently running and we are still integrating information from our partners regarding grid constraints, balancing services, CHP technology characterisation and biomass resource potentials
- “Reference” scenario assumptions used to test the model:
  - Based on the “POM” scenario of Swiss energy strategy 2050, implementing strong efficiency measures
  - Fuel prices from IEA ETP 2014, translated to Swiss border pre-tax prices
  - Nuclear phase out to be completed by 2034
  - No CCS and no coal in electricity generation
  - CO2 price rises to 58 CHF/t CO2 in 2050
  - Solar potential: ~10 TWh, Wind potential: ~3 TWh, Hydro: ~40 TWh

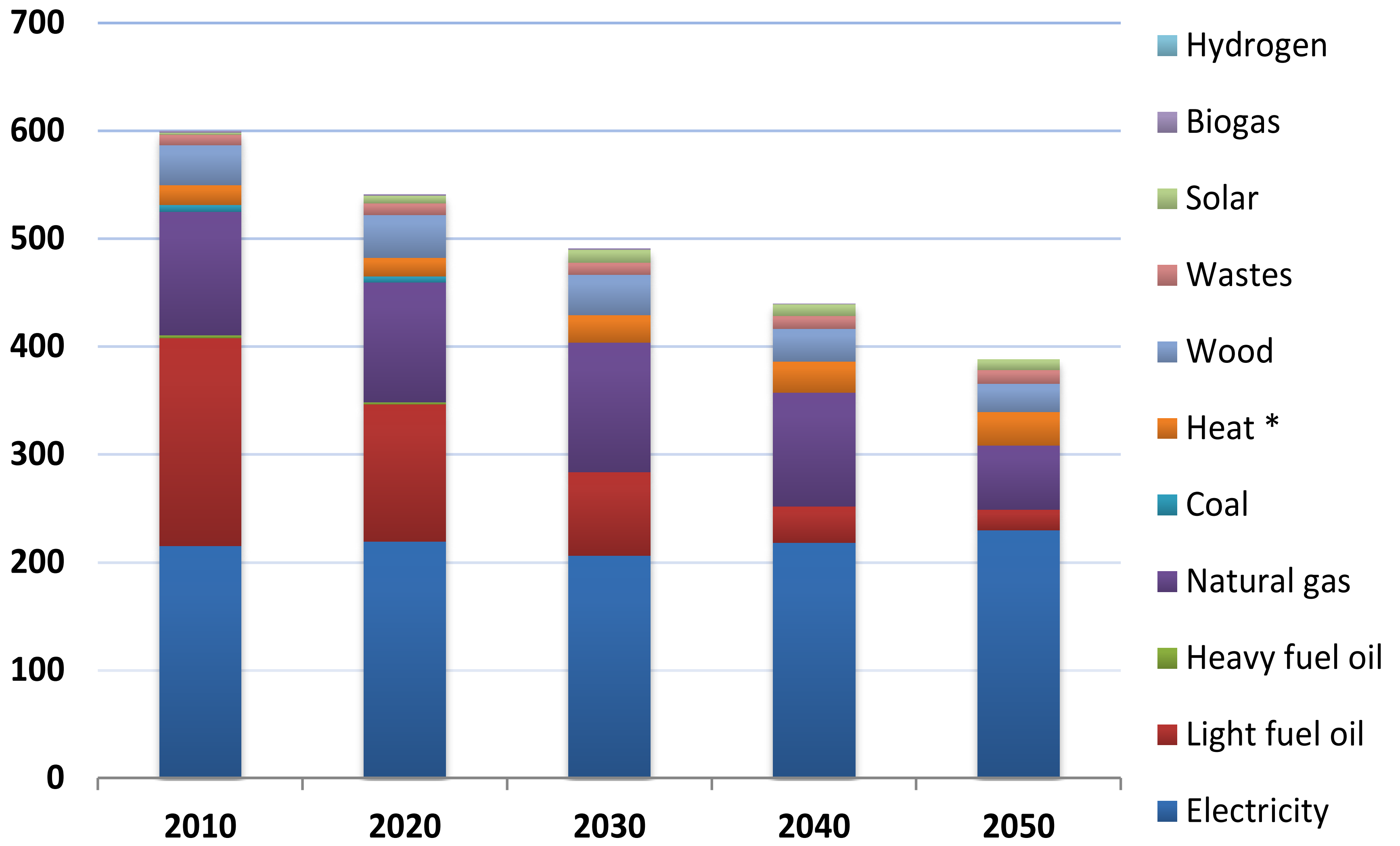
Forecast of demands

Energy service demands in PJ

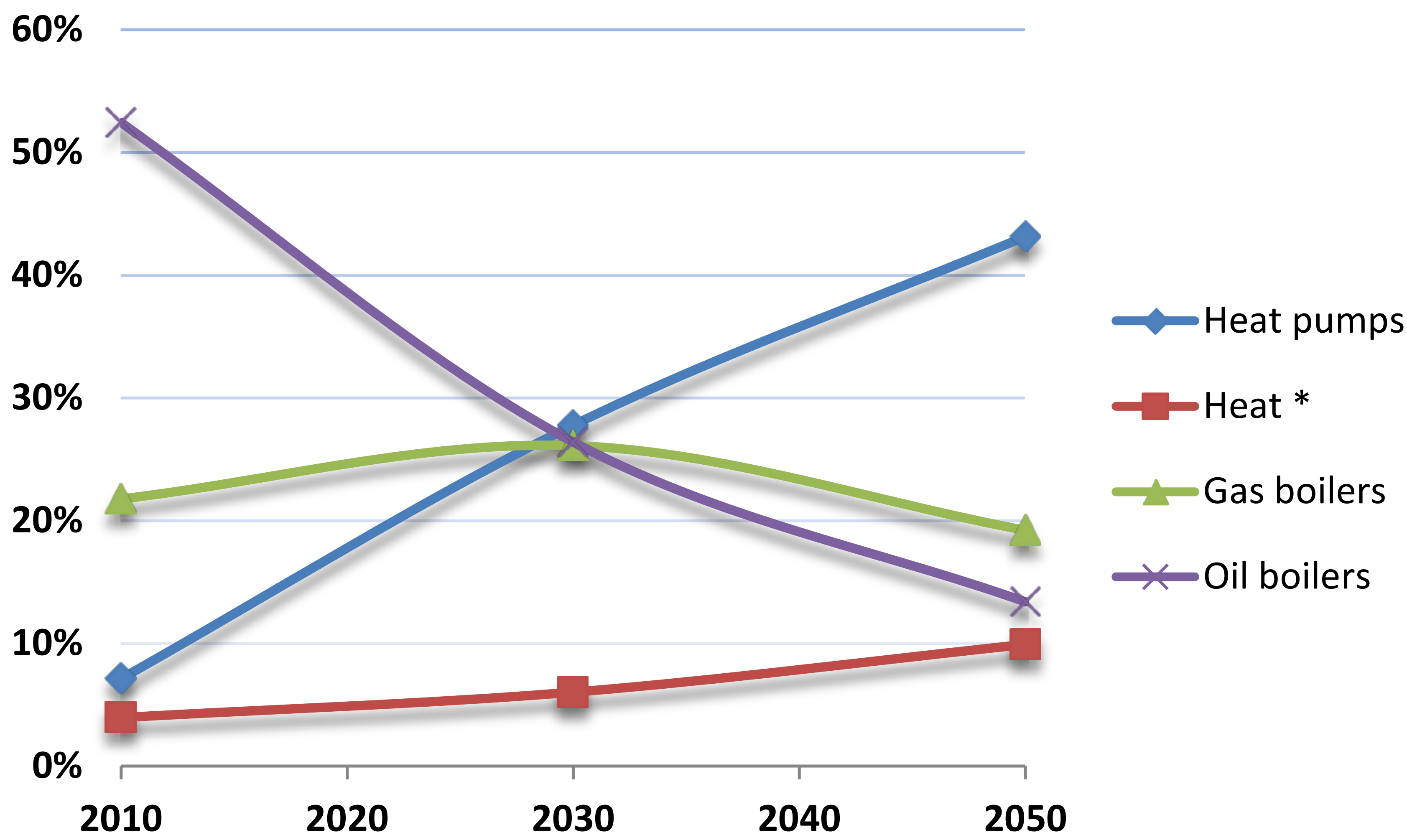


Final energy consumption in PJ

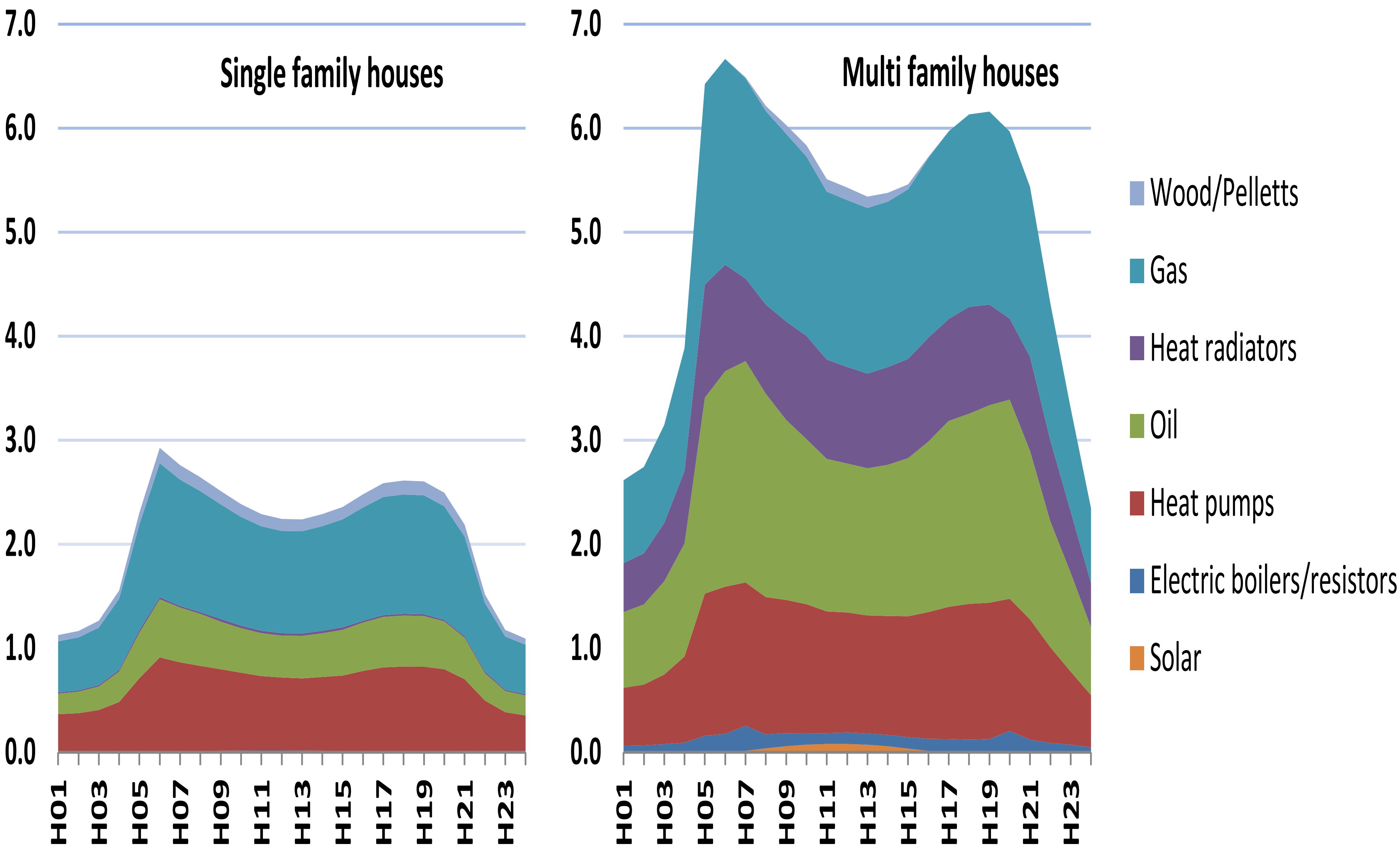
(excl. transport)



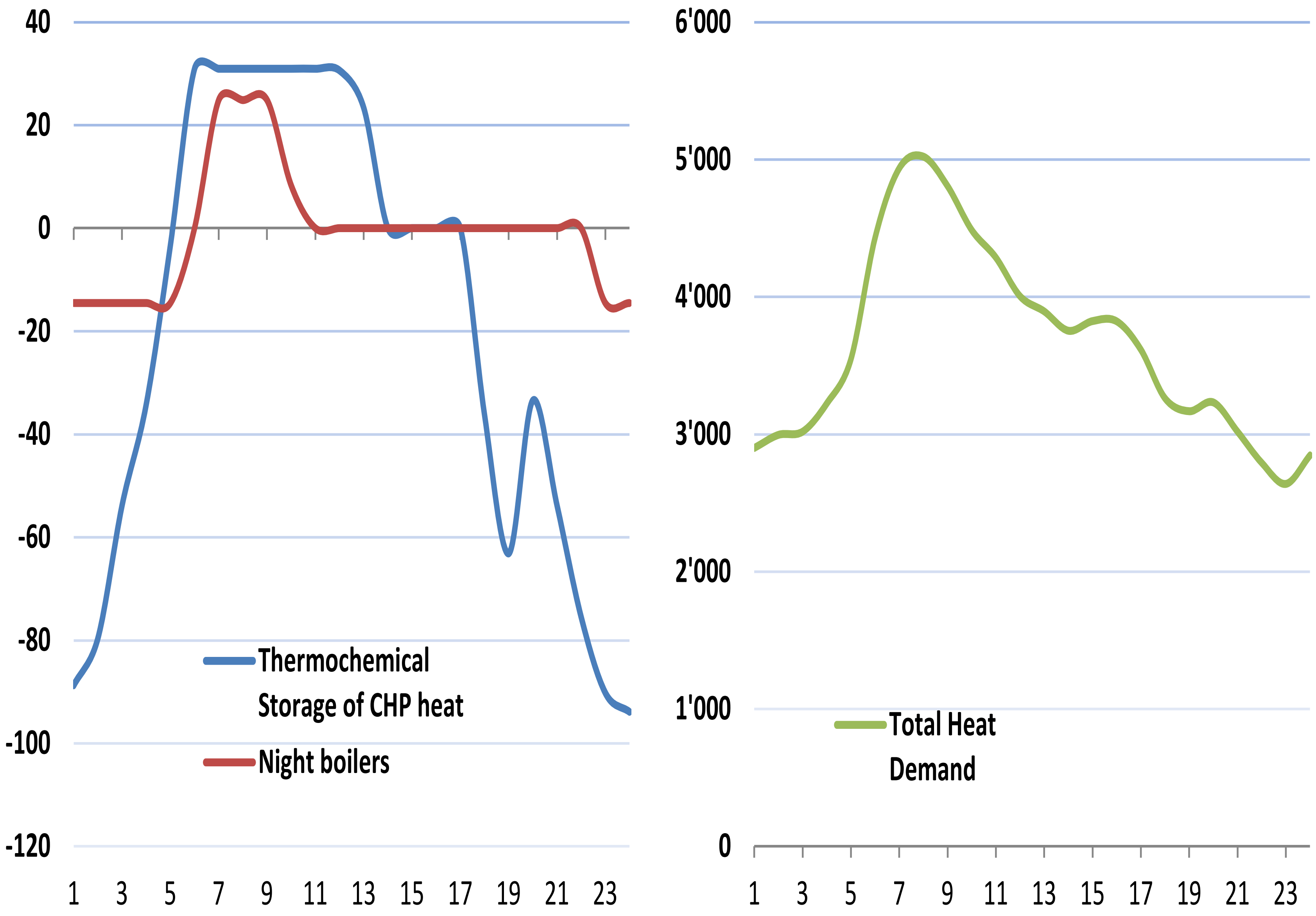
Share of technologies in residential heat



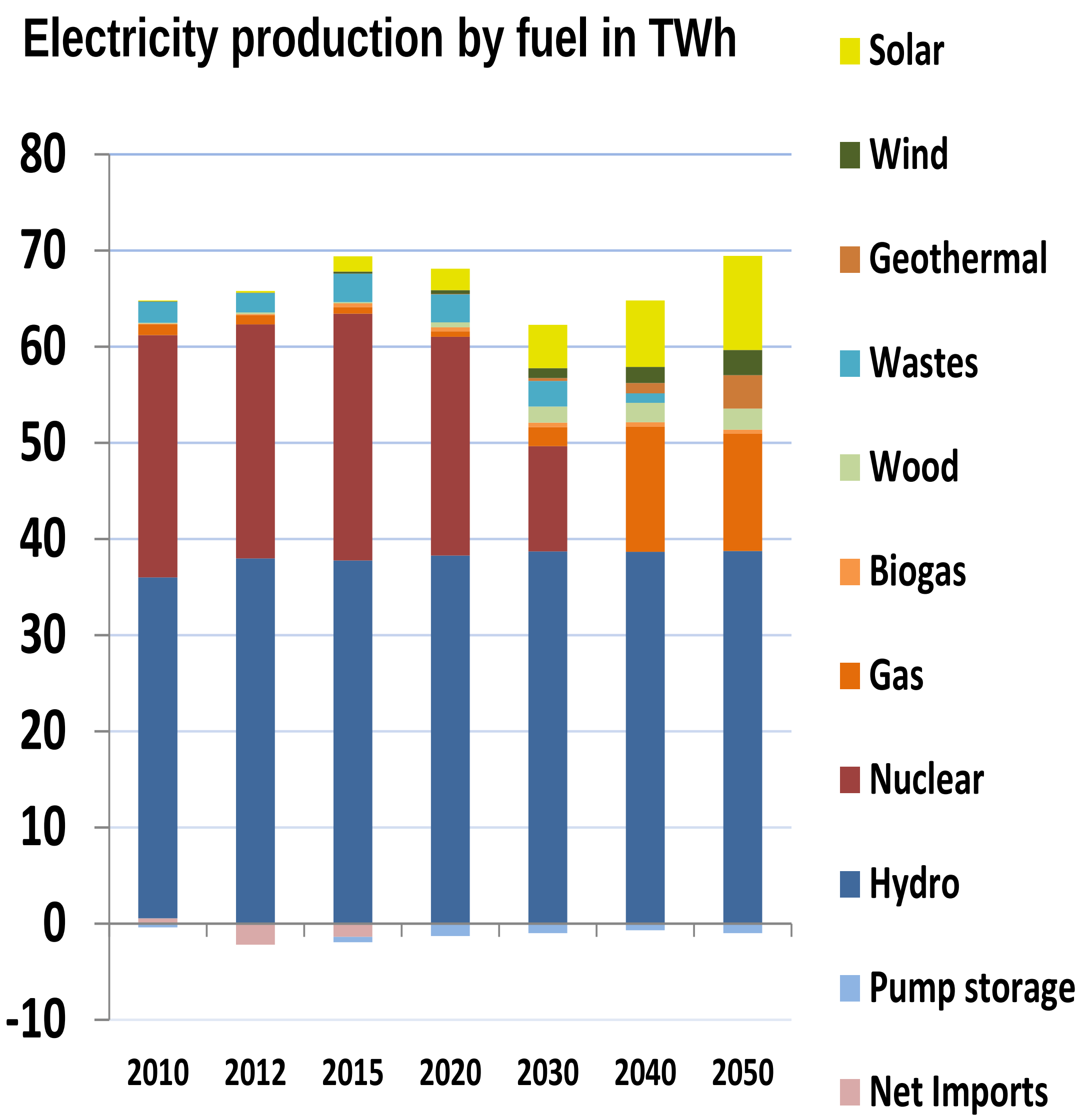
Operational profiles of heat technologies

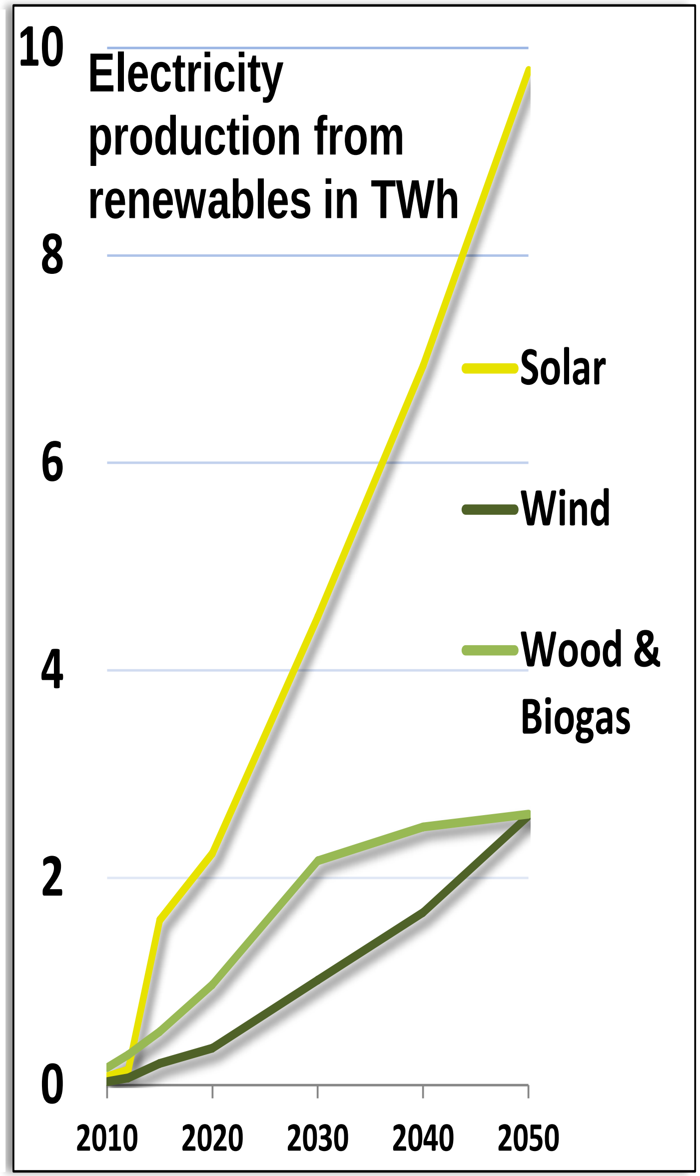


Storage technologies for heat in services



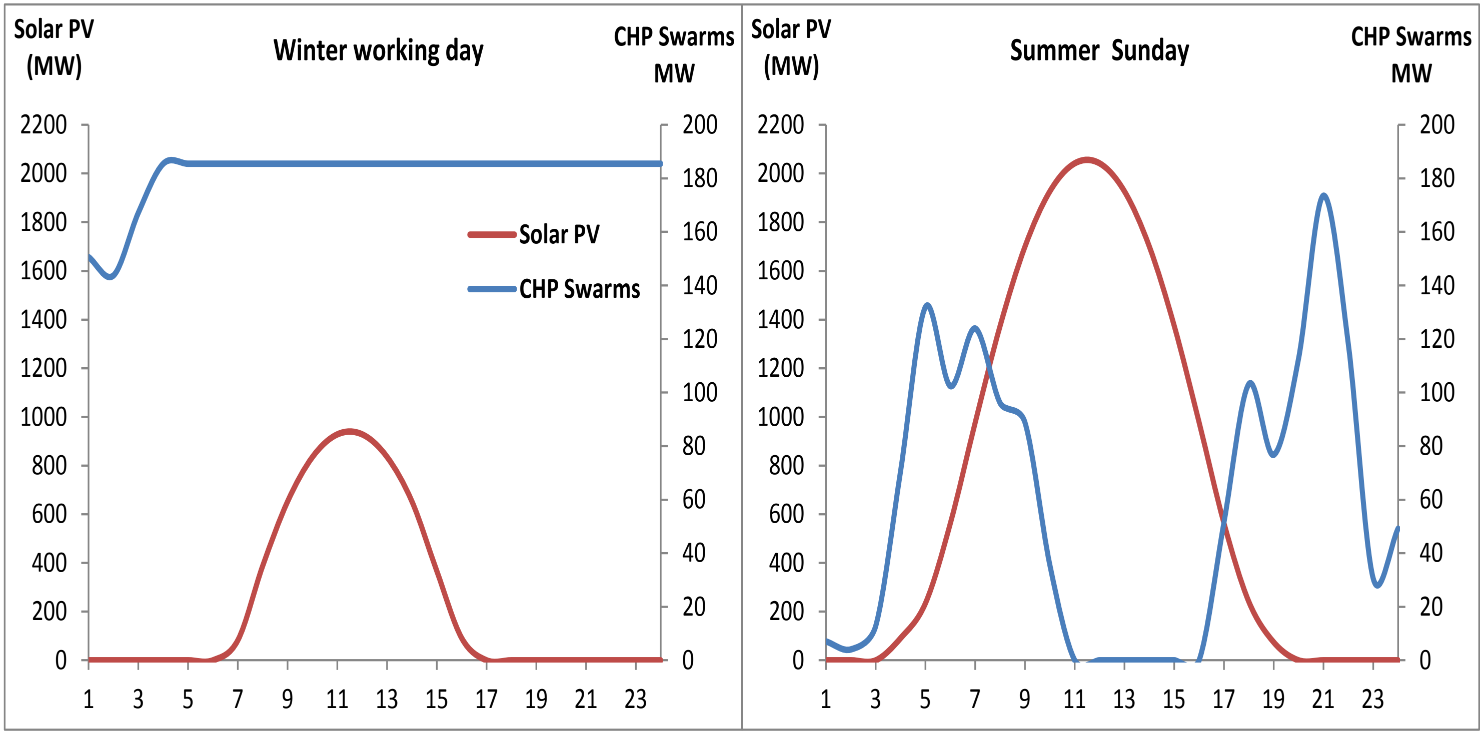
Electricity generation sector





CHP Swarms (capacity & operation profile)

	2020	2030	2040	2050
Capacity (MW)	109	185	124	56
Electricity production (GWh_e)	585	1200	522	415
% of total electricity production	*1%*	*2%*	*1%*	*1%*
% of decentralised thermal only electricity production	*39%*	*80%*	*35%*	*28%*
% of decentralised total electricity production	*17%*	*16%*	*5%*	*3%*
Heat production (GWh_{th})	838	1719	748	595



Conclusions – Further Challenges

- CHP Swarms seems a promising technology for providing flexibility to the electric system
- Potential parameters affecting their uptake include:
  - Developments in the large-scale generation
  - Costs of bio-methane and access competition from other uses
  - Feed-in tariffs for biomass
  - Competition in heat supply from heat pumps
  - Storage costs for storing excess heat from CHP Swarms

- Modelling challenges:
  - No satisfactory solution for the technology mix effect in heat sectors
  - Improvement of the dispatching of the power plant technologies: crucial factor for the balancing services as well

References

[1] Main Sources used for obtaining the heat demand profiles:

- BFE, “Analyse des schweizerischen Energieverbrauchs 2000 - 2012 nach Verwendungszwecken“, 2013
- Rossi Alessandro, “Modelling and validation of heat sinks for combined heat and power simulation: Industry”, 2013
- Ayer Roman, “Modelling of heat sinks for combined heat and power simulation: Households”, 2013
- Federal office of Meteorology and Climatology MeteoSwiss
- Mark Hellwig "Entwicklung und Anwendung parametrisierter Standard-Lastprofile", 2003
- Ulrike Jordan, Klaus Vajen, “Realistic Domestic Hot-Water Profiles in Different Time Scales”, 2001

[2] Modelling heat systems:

- Merkel E., Fehrenbach D., McKenna R., Fichter W., Modelling decentralised heat supply: An application and methodological extension in TIMEs, Energy 73 (2014), 592-605

[3] Modelling balancing services:

- Welsch M., Howells M., et al., Supporting security and adequacy in future energy systems: the need to enhance long-term energy system models to better treat issues related to variability, Int. J. Energy Res. 39 (2015), 377-396

Thank you for the attention !

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