IPESE
INDUSTRIAL PROCESS AND
ENERGY SYSTEMS ENGINEERING

SCCER – FURIES
Shaping the FUtuRe SwIss Electrical InfraStructure

In cooperation with the CTI
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Swiss Competence Centers for Energy Research
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Investment planning of energy systems in an urban context

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Future Energy
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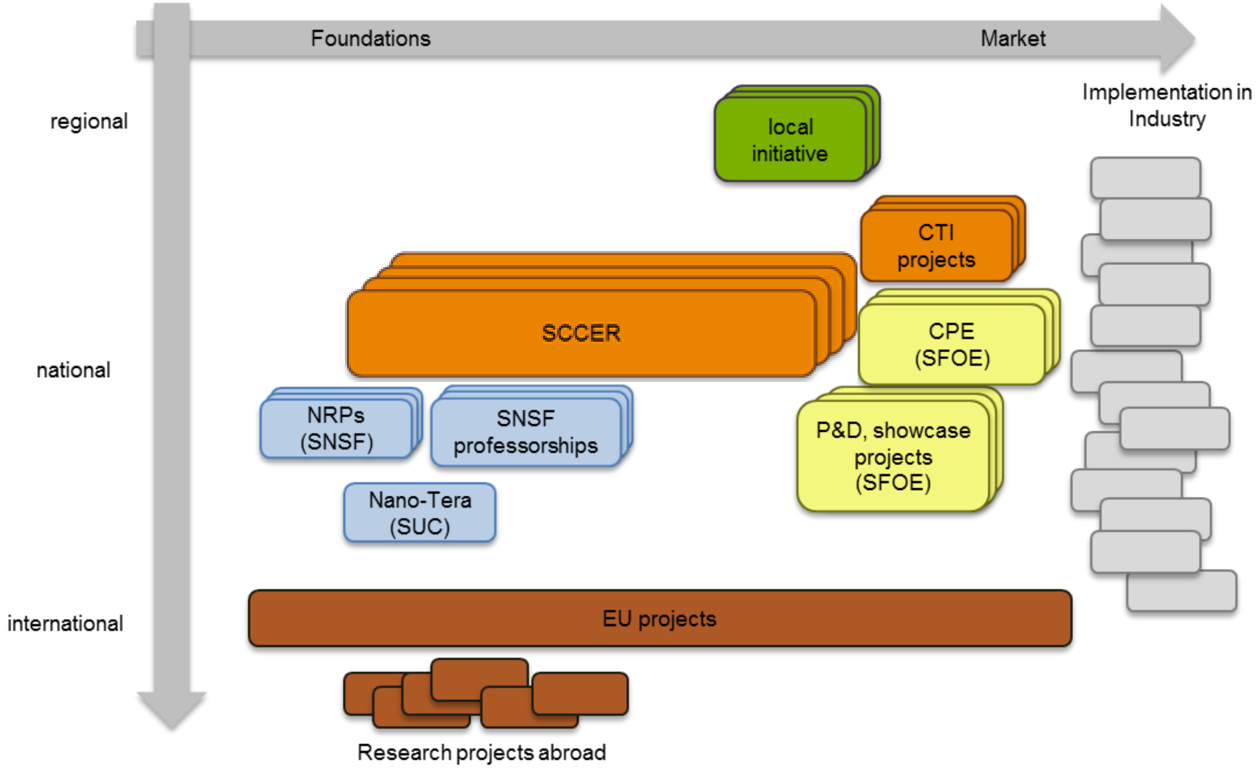
International Seminar on
"Towards Smart Sustainable Cities – Integrated Approaches"

Outline

- Introduction
- Problem
- Model
- Application to case study
- Conclusion & Outlook

Introduction

- The Swiss Competence Centres for Energy Research (SCCERs) have been established in support of the Swiss government's energy strategy for 2050 and funded by the Commission for Technology and Innovation (CTI)

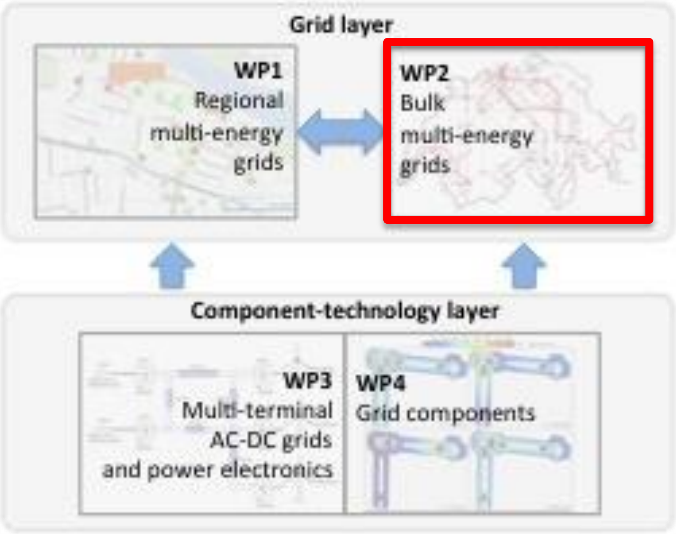


Introduction

- There are 8 SCCERs established covering the entire value chain of the energy sector namely:
  1a. SCCER-Future Energy Efficient Buildings & Districts (SCCER FEEB&D)
  1b. SCCER- Efficiency of Industrial Processes (SCCER EIP)
  2. Future Swiss Electrical Infrastructure (SCCER FURIES)
  3. Heat Electricity Storage (SCCER HaE)
  4. Supply of Electricity (SCCER SoE)
  5. Competence Center for Research in Energy, Society and Transition (SCCER CREST)
  6. Efficient Technologies and Systems for Mobility (SCCER Mobility)
  7. Biomass for Swiss Energy Future (SCCER BIOSWEET)

Introduction

- SCCER-Furies structure



WP2

- Develop a model of the Swiss bulk energy system for planning and operation
- Provide advice to decision makers when planning the future Swiss energy system

Goal of this study	Develop a decision support tool for the long term investment planning of district energy systems and networks

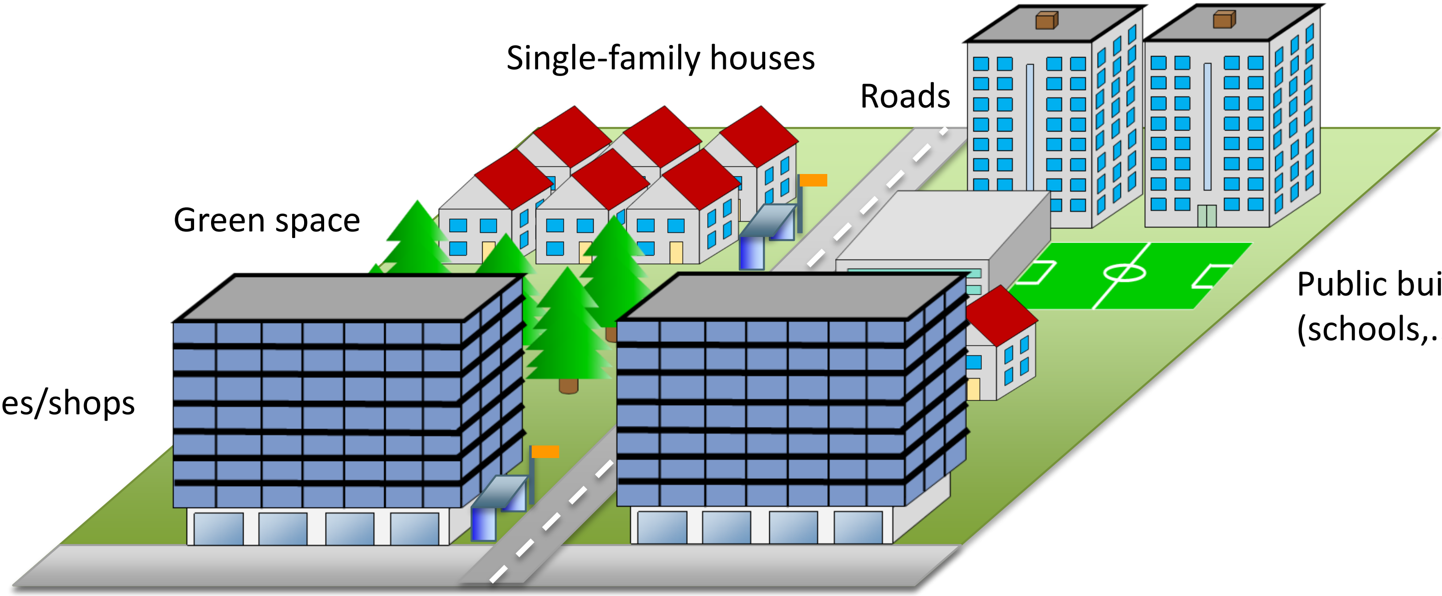
Problem

Problem

Development of a new district

Energy services to provide

Heating Cooling Electricity Transportation



Multi-family houses

Single-family houses

Roads

Green space

Public buildings (schools,...)

Offices/shops

Public transport

Problem

Questions

Energy services to provide

Heating Cooling Electricity Transportation

Limit costs and impact

\$ CO_2

Which energy systems to choose?

Gas boilers

Geothermal heat pumps

Solar PV

Biomass boilers

...

Which networks to develop?

Electricity

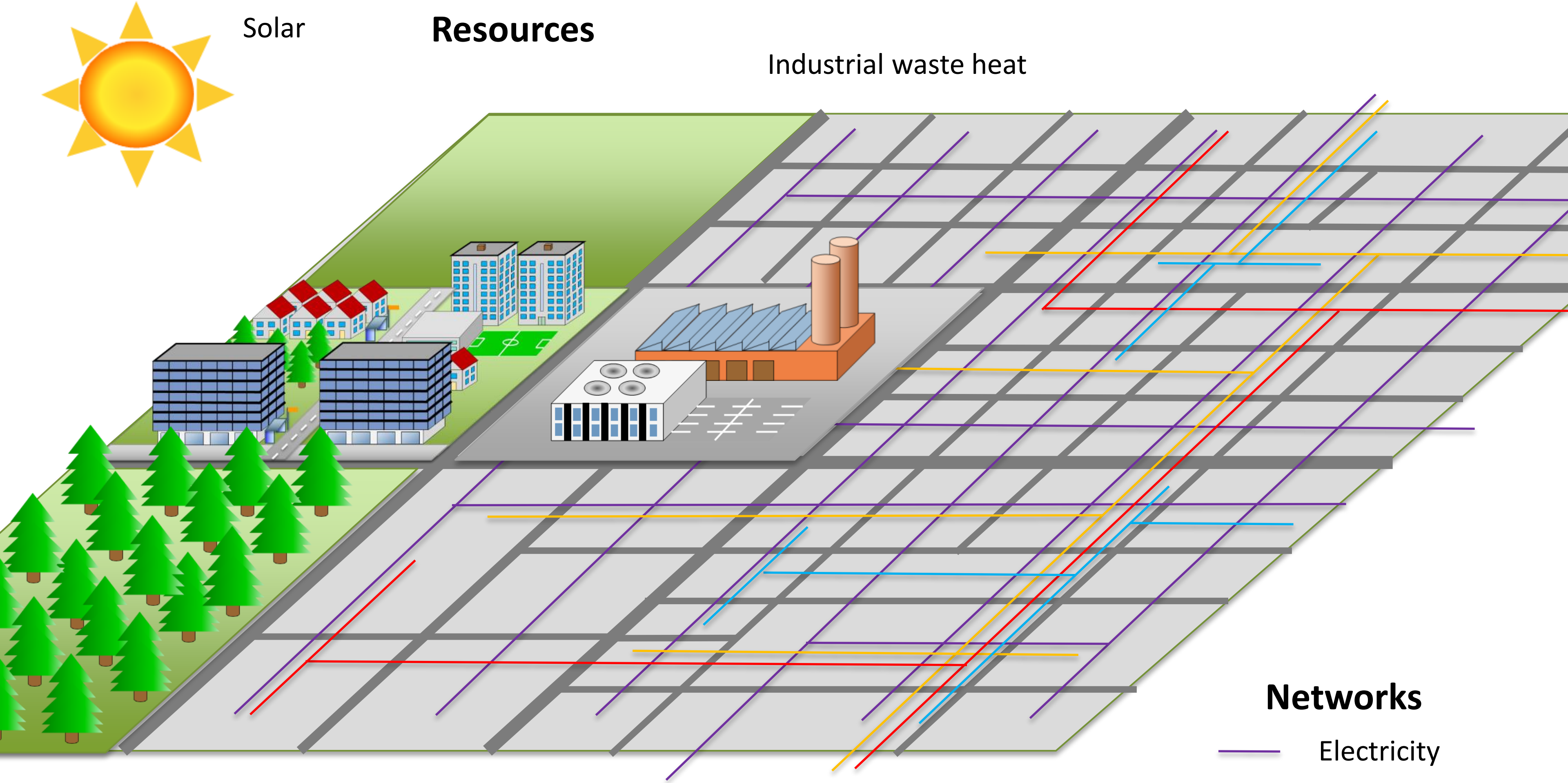
Gas

District heating

District cooling

Problem

Local resources and infrastructure



Solar

Resources

Industrial waste heat

Biomass

Geothermal

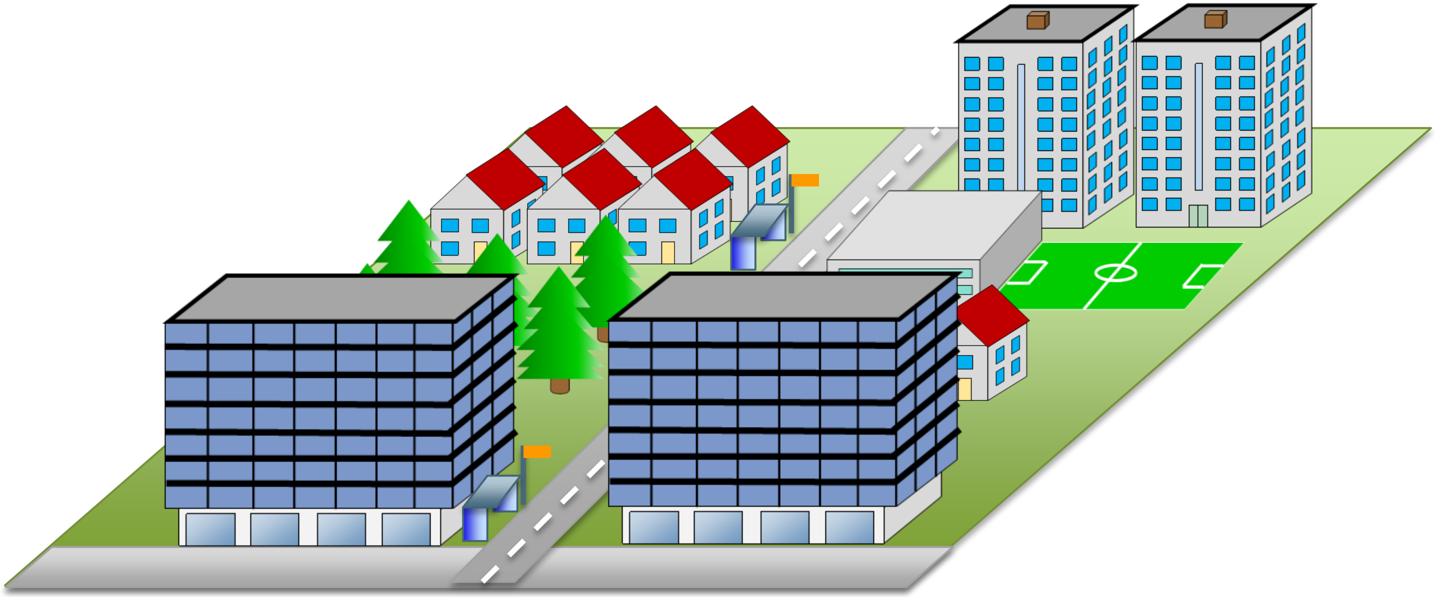
Networks

- Electricity
- Gas
- District heating
- District cooling

Problem

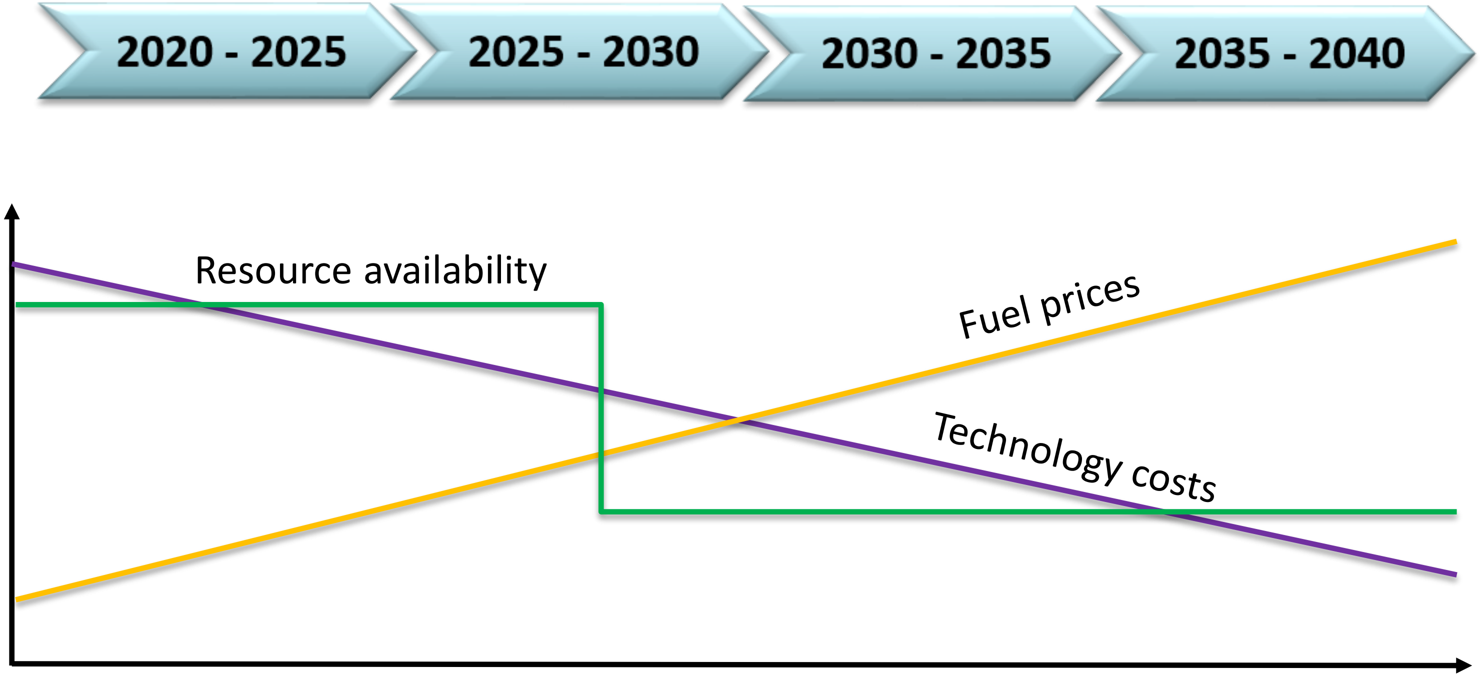
Phasing of construction

2020 - 2025 | 2025 - 2030 | 2030 - 2035 | 2035 - 2040



Problem

Evolving costs and resource availability



Model

Model

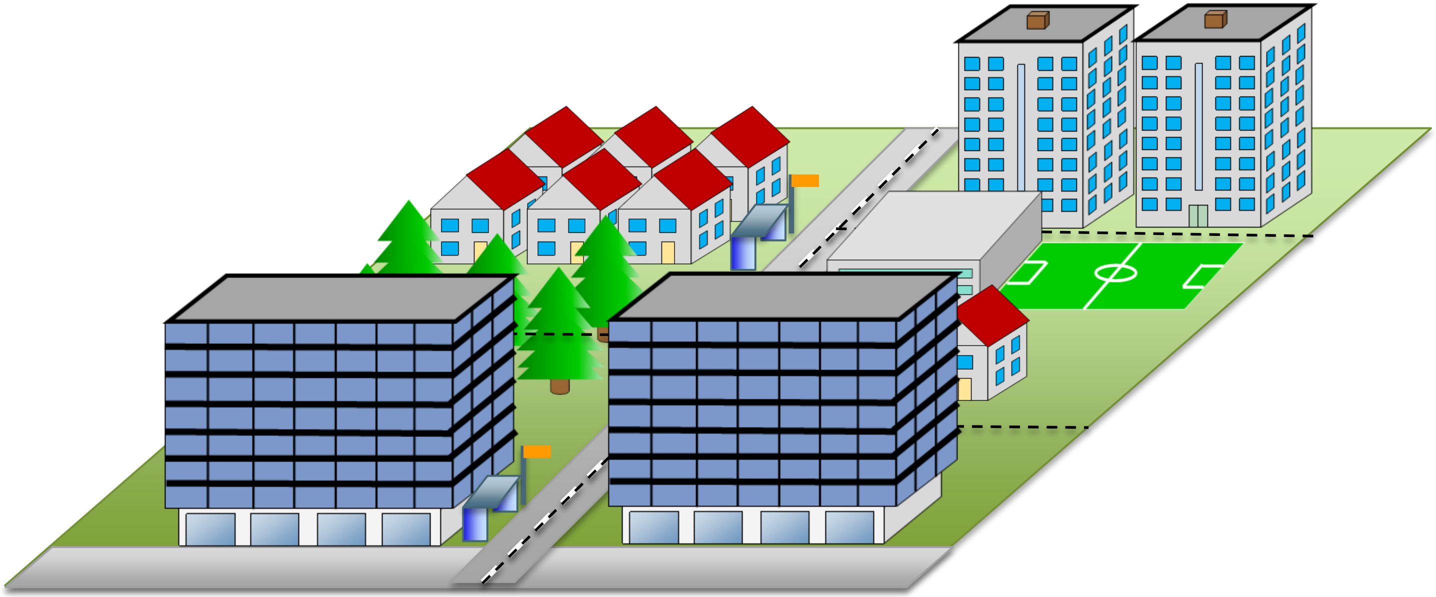
Goal

- Develop a decision support tool for the long term investment planning of district energy systems and networks
- Based on optimisation using Mixed Integer Mathematical Progamming (MILP)
- Minimising economic costs and environmental impact
- Taking into account
  - Energy demand profiles
  - Local resources
  - Existing infrastructure in surrounding area
  - Phasing of construction
  - Evolving fuel and technology costs
  - Evolving resource availability

Model

Energy model

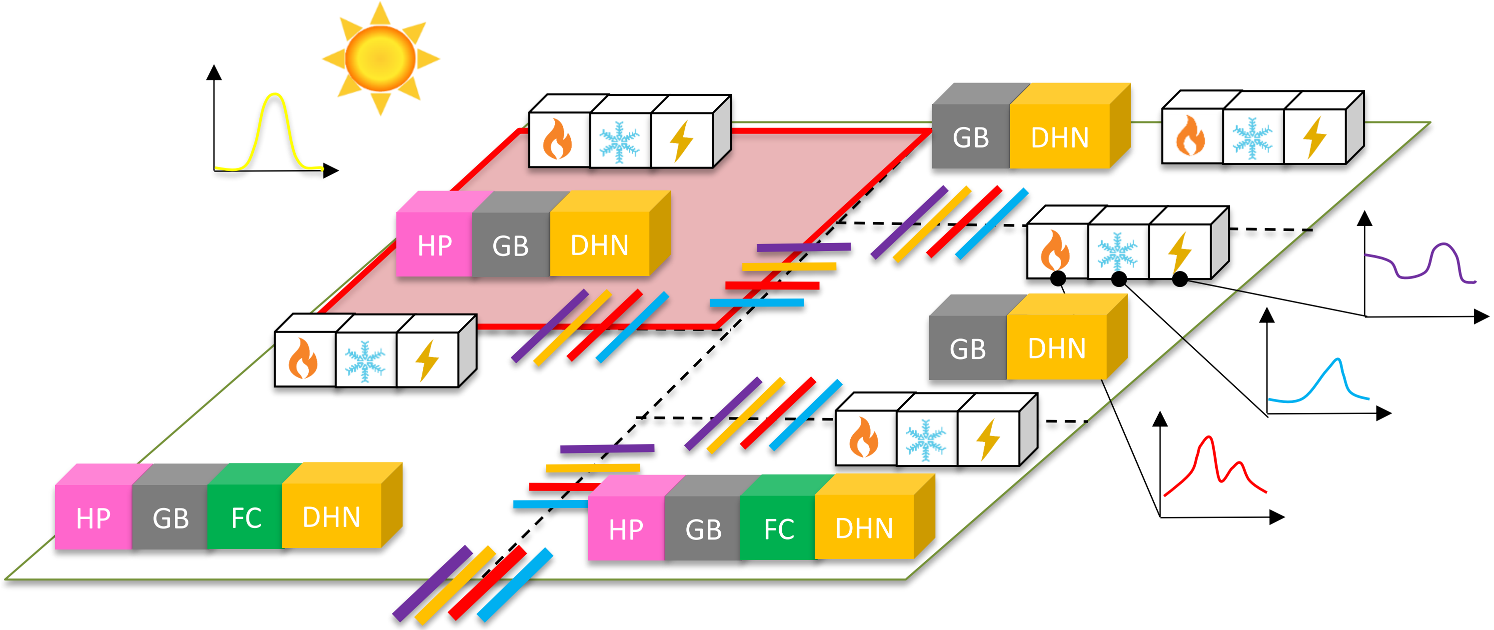
- District divided in zones



Model

Energy model

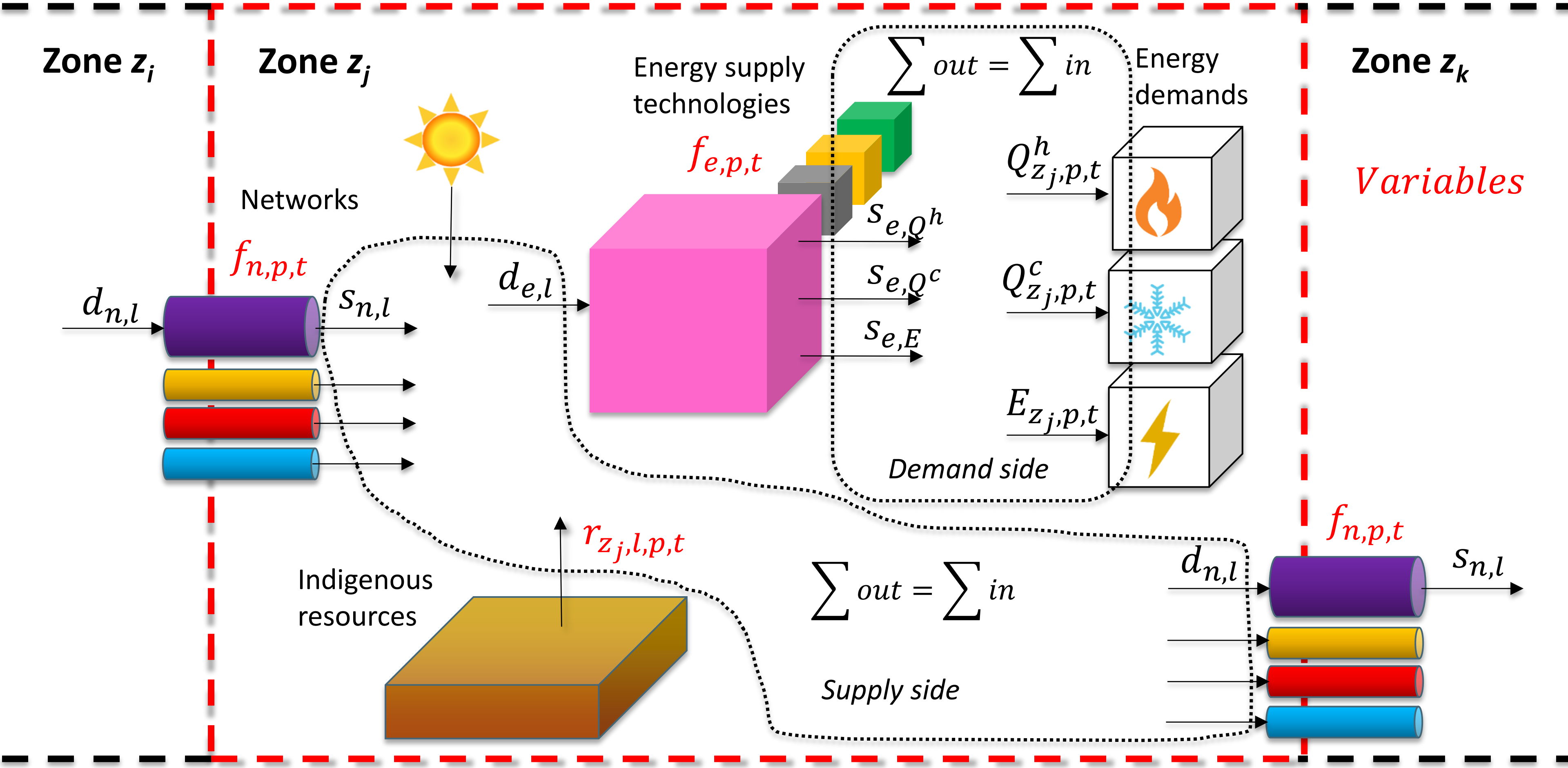
- District divided in zones
- Energy demand profiles for each zone
- Energy supply technology choices in each zone
- Network connection options (type & capacity)
- Indigenous resources



Model

Energy model

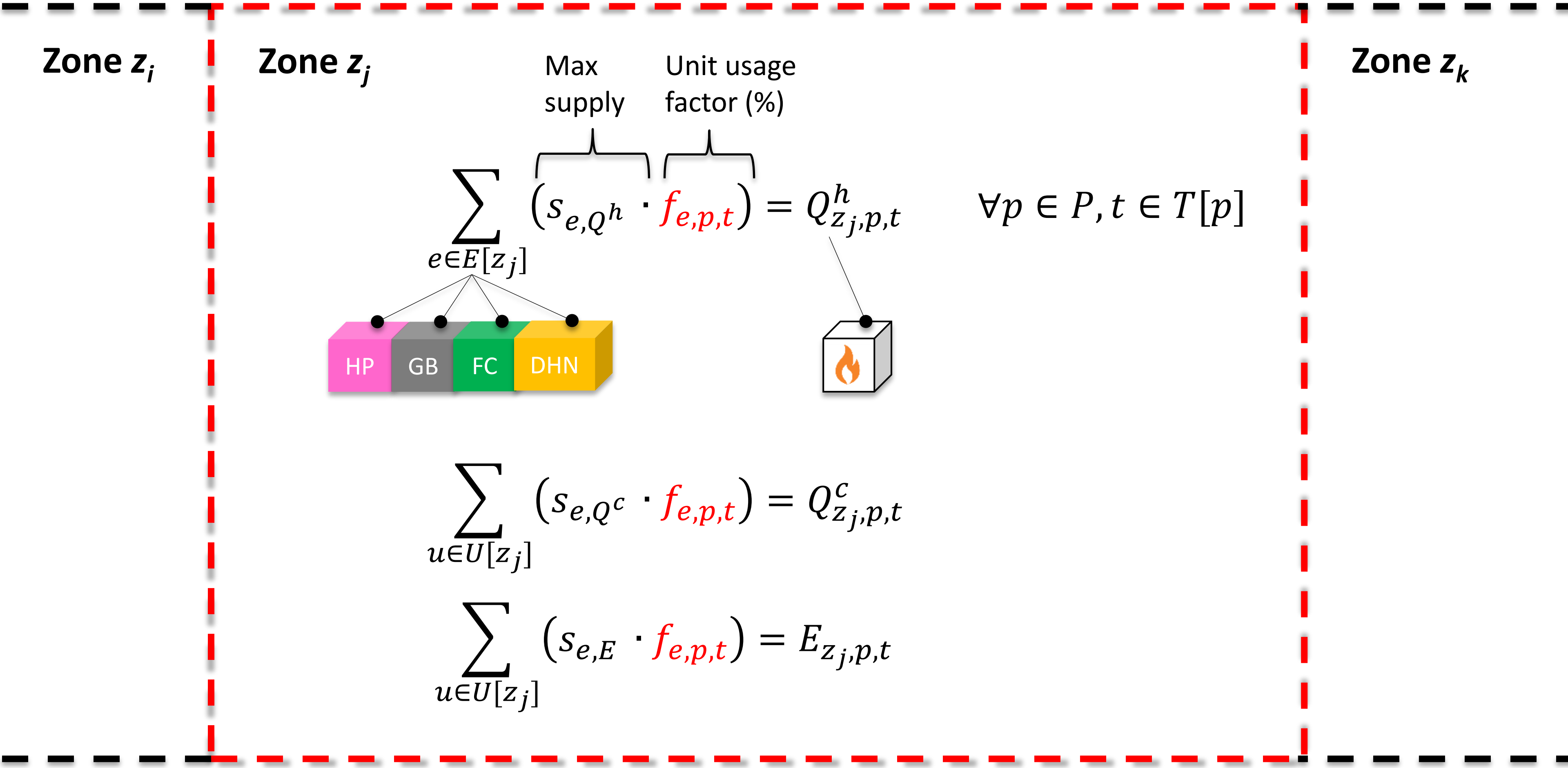
- **Energy balance inside a zone** $\forall p \in P, t \in T[p]$



Model

Energy model

- Energy balance inside a zone (demand side)



$$\sum_{e\in E[z_j]} \left(\overbrace{s_{e,Q^h}}^{\text{Max supply}} \cdot \overbrace{f_{e,p,t}}^{\text{Unit usage factor (\%)}}\right) = Q^h_{z_j,p,t} \qquad \forall p \in P, t \in T[p]$$

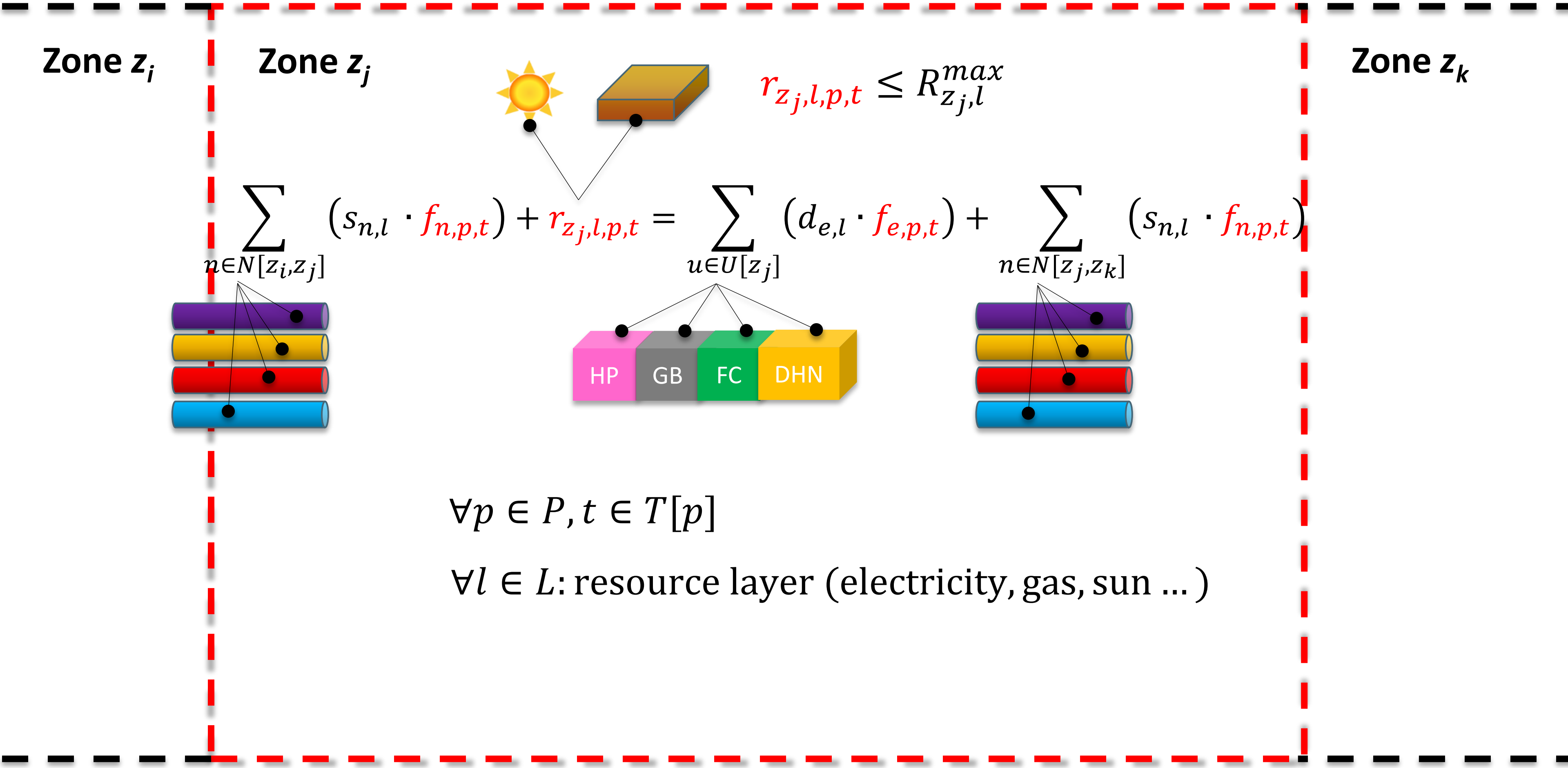
$$\sum_{u\in U[z_j]} \left(s_{e,Q^c} \cdot f_{e,p,t}\right) = Q^c_{z_j,p,t}$$

$$\sum_{u\in U[z_j]} \left(s_{e,E} \cdot f_{e,p,t}\right) = E_{z_j,p,t}$$

Model

Energy model

- Energy balance inside a zone (supply side)



$$r_{z_j,l,p,t} \leq R_{z_j,l}^{max}$$

$$\sum_{n\in N[z_i,z_j]} \left(s_{n,l} \cdot f_{n,p,t}\right) + r_{z_j,l,p,t} = \sum_{u\in U[z_j]} \left(d_{e,l} \cdot f_{e,p,t}\right) + \sum_{n\in N[z_j,z_k]} \left(s_{n,l} \cdot f_{n,p,t}\right)$$

$$\forall p \in P, t \in T[p]$$

$$\forall l \in L: \text{resource layer (electricity, gas, sun ...)}$$

Model

Energy model

- Unit sizing

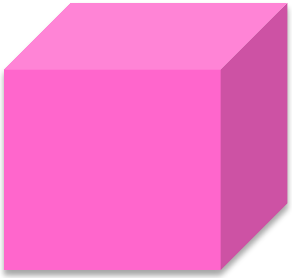
Zone z_i

Zone z_j

$$f_{e,p,t} \leq \overbrace{y_{e,p,t}}^{\text{Unit activation (0/1)}} \cdot \overbrace{F_u^{max}}^{\text{Max size of unit}} \qquad \forall u \in U[z_j], p \in P, t \in T[p]$$

$$f_{e,p,t} \leq F_{e,p}: \text{size of unit in period } p$$

$$y_{e,p,t} \leq Y_{e,p}: \text{existence of unit in period } p$$



$f_{n,p,t}$

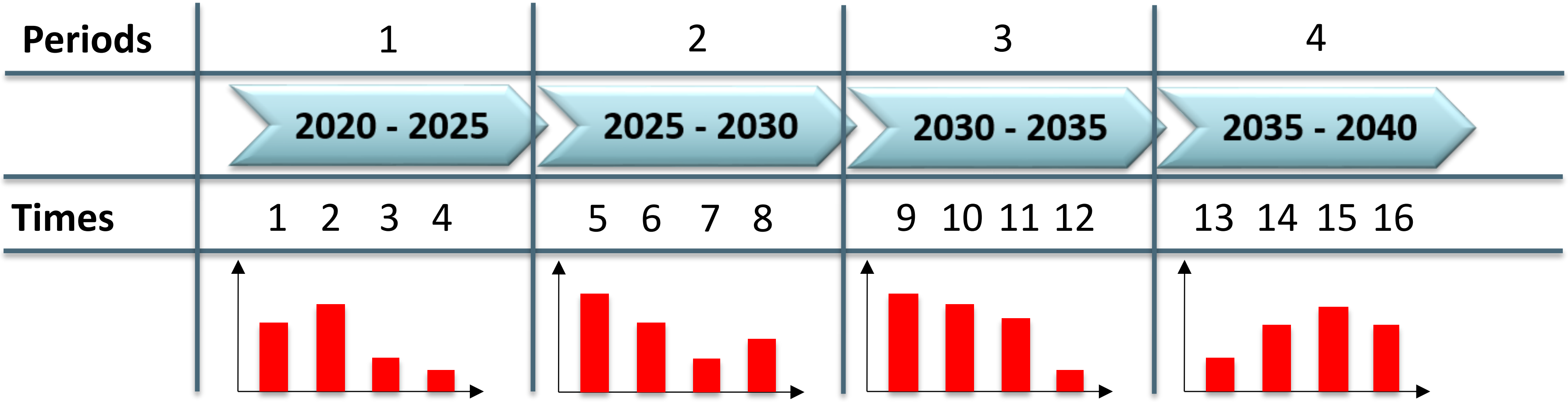
Same equations for networks

Zone z_k

Model

Economic model

- Periods represent investment stages
  - Buildings (input) and energy system configuration (output) are fixed inside each period
- Times represent different operating conditions inside each period
  - Energy demands and supply technology/network usage is defined for each time
  - Energy balance is solved for each time



Periods	1	2	3	4
	2020 - 2025	2025 - 2030	2030 - 2035	2035 - 2040
Times	1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16

Model

Economic model

- **Maximise Net Present Value (objective)**

Number of periods

Cash flow

$$\max NPV = \sum_{p=1}^{n_p} \frac{CF_p}{(1+d)^p} - Inv^0$$

Discount rate

Initial investment
(in period 0)

$$CF_p = Rev_p - Inv_p + Dis_p$$

Revenues

Investment

Disposal value

Model

Economic model

- **Revenue**

$$Rev_p = -\sum_{u \in U} \sum_{t \in T[p]} \left(C^{fix}_{u,p,t} \cdot y_{u,p,t} + C^{var}_{u,p,t} \cdot f_{u,p,t}\right)$$

Units: energy supply technologies, networks, demands, imports (grid, biomass...)

Fixed cost

Variable cost (<0 if selling)

- **Investment**

$$Inv_p = -\sum_{u \in U} \left(I^{fix}_{u,p,t} \cdot y_{u,p,t} + I^{var}_{u,p,t} \cdot f_{u,p,t}\right)$$

Fixed investment

Variable investment

Model

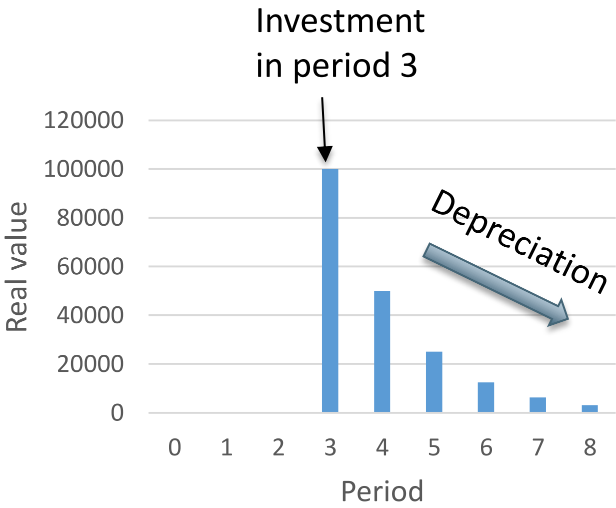
Economic model

- Disposal value
  - Disposal value of asset (=unit) is recovered a) when unit is sold or b) at the end of the project (residual value)
  - Disposal value is equal to the real value (RV) of the unit

$$Dis_{u,p} = RV_{u,p}$$

$$RV_{u,p} = (1 - \delta_u) \cdot RV_{u,p-1} + Inv_{u,p}$$

Depreciation rate



Application to case study

Application to case study

Presentation of case study

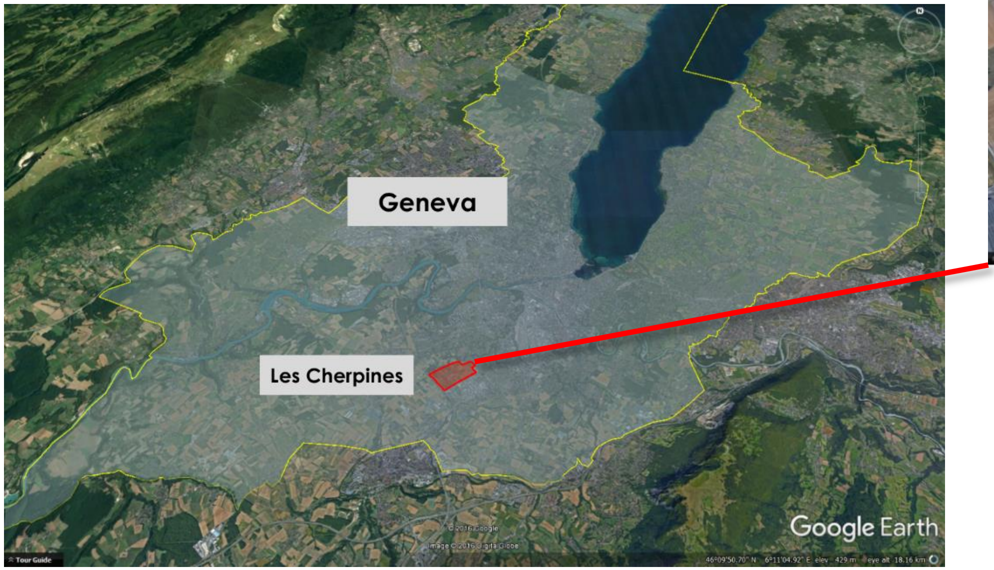
Canton of Geneva

Population: 490,578 (mostly urban)

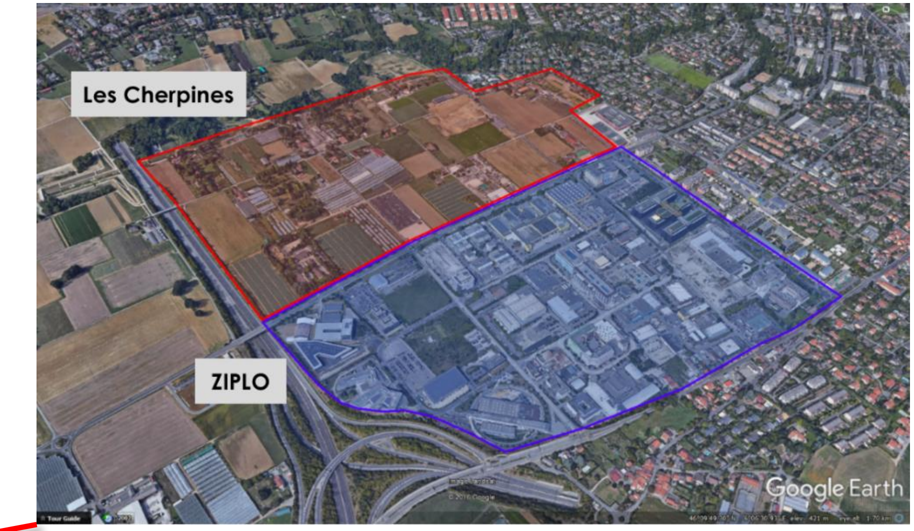
Area: 282 km^2

Density: 1740 inh./km^2

Climate: temperate oceanic



Source: Google Earth



Source: Google Earth

Les Cherpines

Mixed use «eco-distict»

3000 dwellings, 2500 jobs

560,000 m^2 floor area

58 ha greenfield

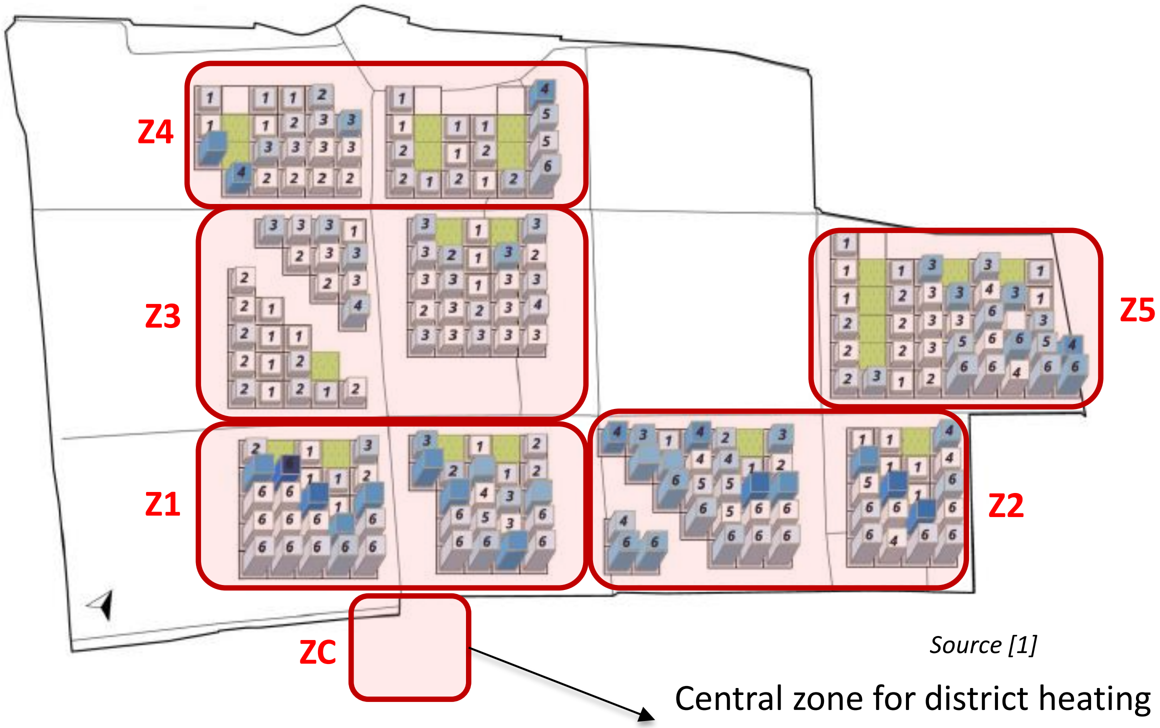
Construction: 2018-2035

Neighbouring industrial zone «ZIPLO»

Application to case study

Case study definition

- District layout
  - 11 building blocks modelled as 5 zones + central zone



Source [1]

Central zone for district heating central plant & grid connection

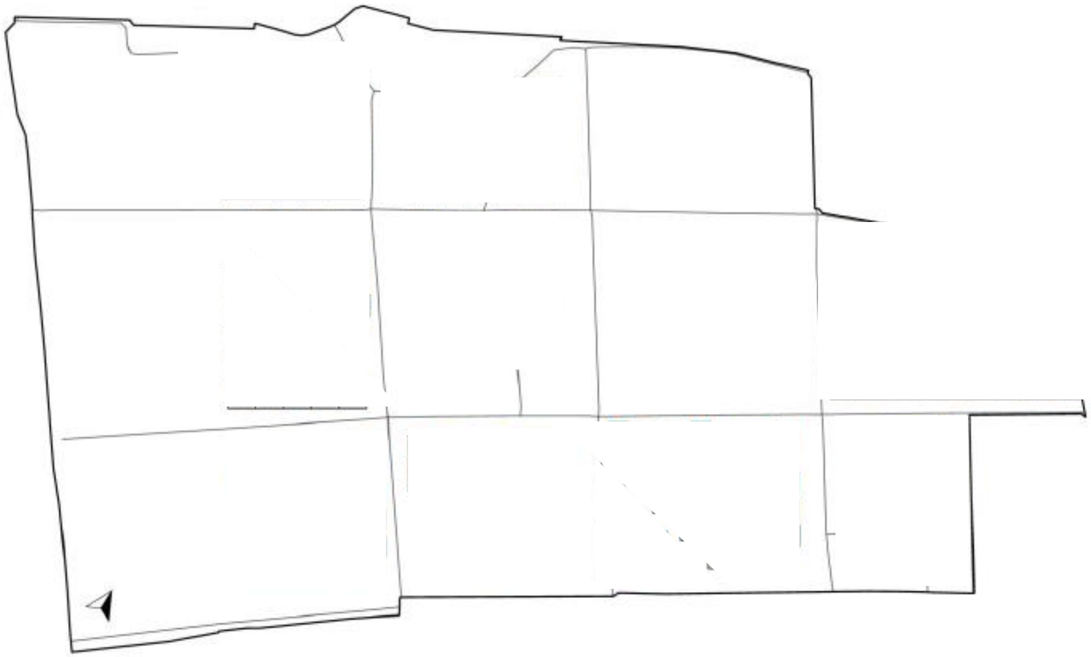
[1] Sébastien Cajot , Nils Schüler, Markus Peter, Andreas Koch, François Maréchal "Interactive optimization for the planning of urban systems", accepted at CISBAT 2017 International Conference Future Buildings & Districts Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Application to case study

Case study definition

- Construction phases

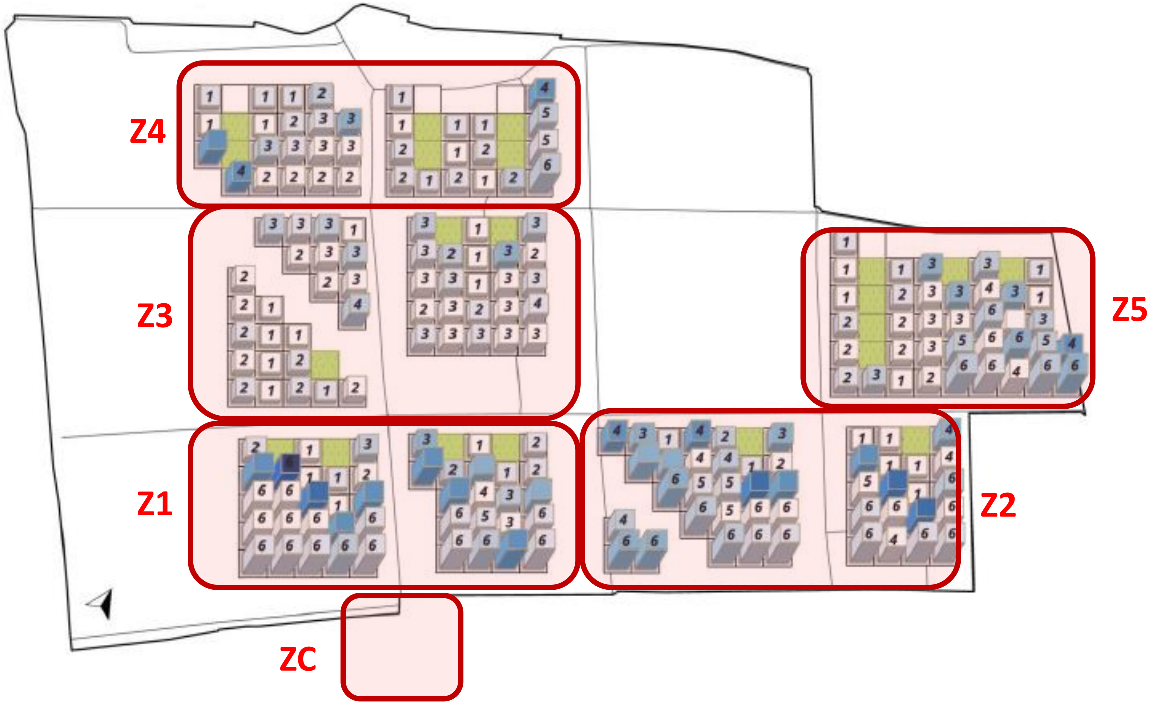
2018 → 2020 → 2022 → 2023 → 2025 → 2026 → 2028 → 2029 → 2030 → 2033 → 2035



Application to case study

Case study definition

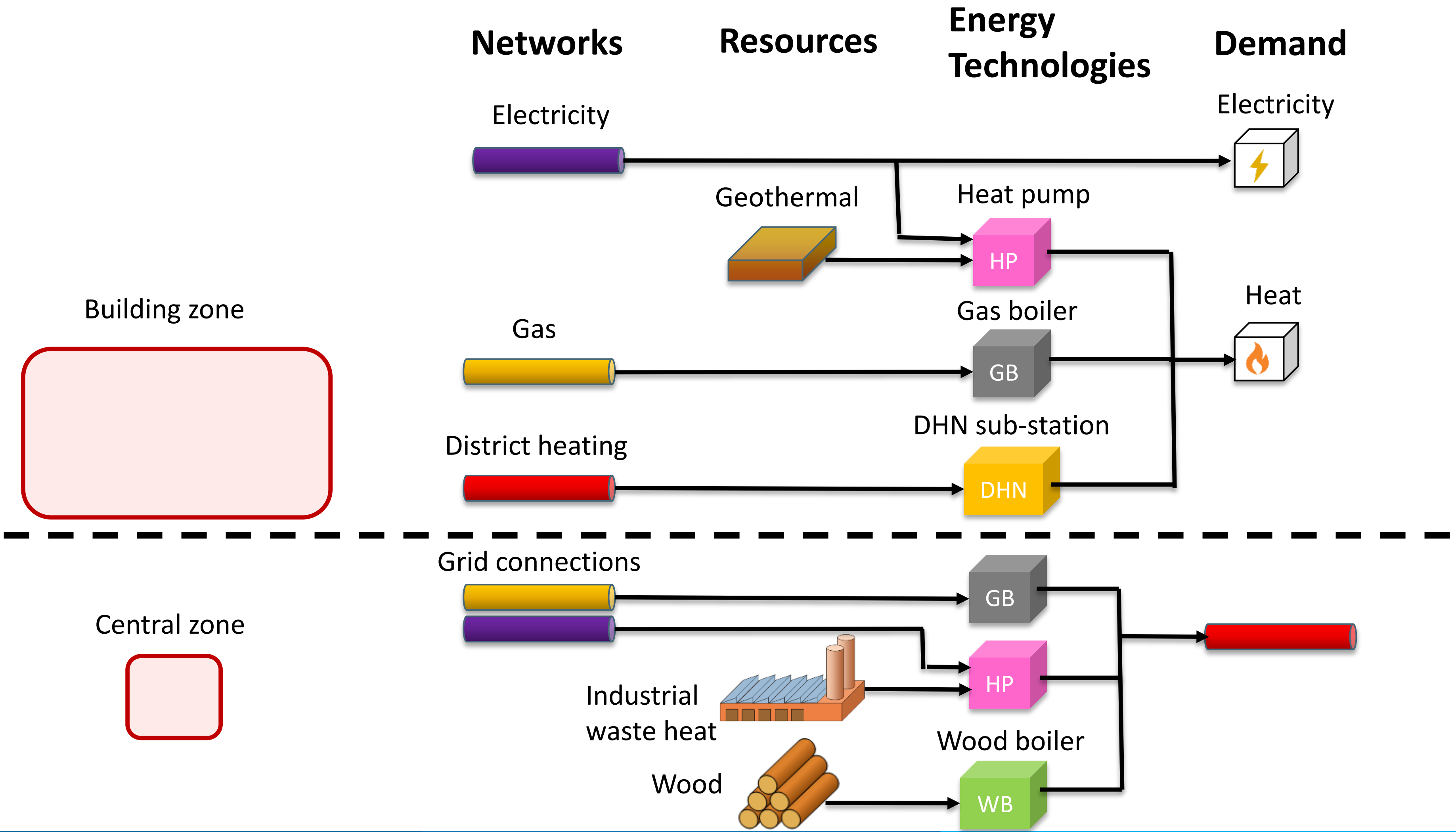
- Energy systems considered



Application to case study

Case study definition

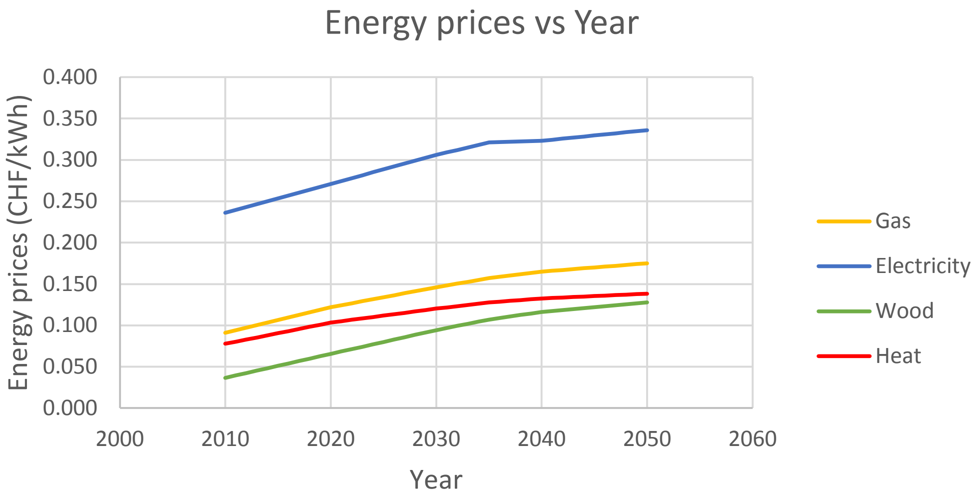
- Energy systems considered



Application to case study

Case study definition

- 30 periods (1 period = 1 year)
- 3 time-steps in each period (➔ summer, winter, mid-season)
- Energy prices

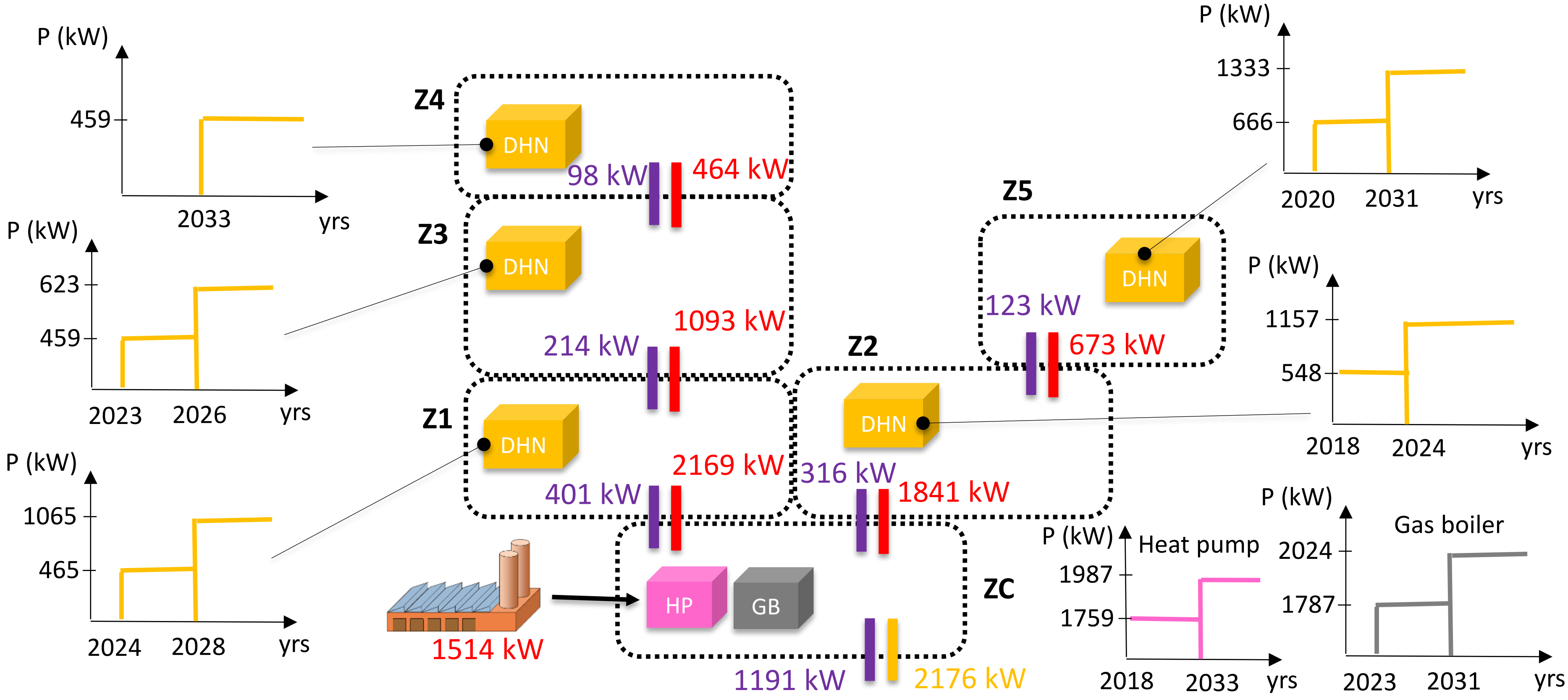


- Economic parameters
  - Discount rate = 6 %
  - Project lifetime = 30 years

Application to case study

Results

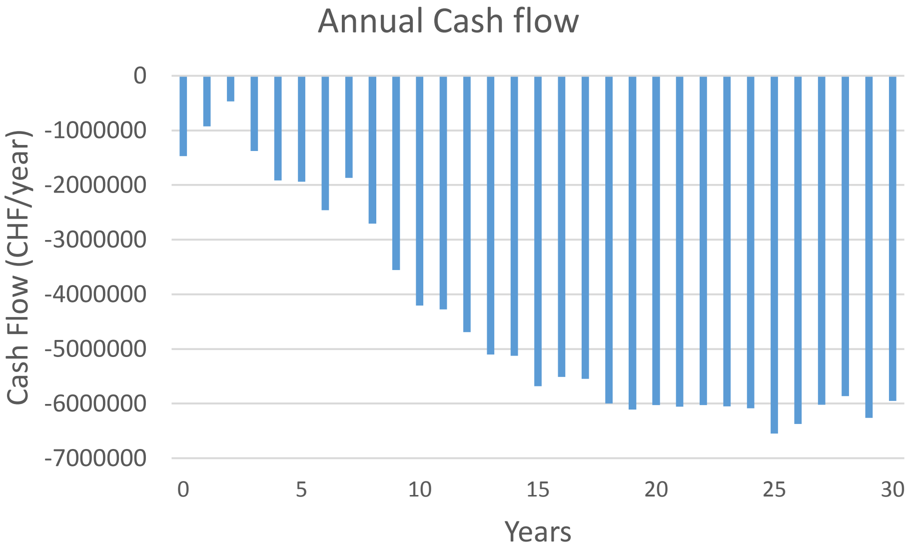
- All zones are connected to district heating network (no decentralised system)
- Central system consists of heat pump (→ industrial waste recovery) and gas boiler for peak (in winter)



Application to case study

Results

- Cash Flow is always negative → due to an error in energy selling price to final consumers (positive instead of negative)
- Should not affect the results (configuration) since these costs are constant in all cases



NPV = -51914 kCHF

Conclusion & Outlook

Conclusions

- A MILP model was developed to optimise long term investment planning of district energy systems and networks
  - Model can help identify which networks and energy systems to invest in
- Can serve as a basis for a future decision support tool for urban planners, utility system managers, etc.
- Model was applied to a case study in Geneva (new district development)
  - Promising first results but some data needs to be further corrected or refined
- Major drawback
  - Model takes a long time to converge (if it does at all)

Outlook

- Ascertain some model constraints
- Correct data in case study
- Run case study for different scenarios (costs, district density, resource availability etc.)
- Apply uncertainty analysis
- Apply model to larger case studies
- Find a way to improve the calculation time

Acknowledgements

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Merci

Danke

Thank you for your attention!

Спасибо

Рахмет