# Integrated Thermo-economic Modeling of Geothermal Resources for Optimal Exploitation Scheme Identification

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ÉCOLE POLYTECHNIQUE
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# Context

- Development of geothermal energy usage
  - Deliver simultaneous energy services
    - Electricity, district heating, cooling
- Conceptual process system design
  - Efficient and economic use
  - Site conditions
    - Specificities of geothermal resources

➡ Need for a systematic methodology to design geothermal energy conversion systems

# Objectives

- Develop a systematic methodology that accounts for:
  - Services to be supplied and seasonal variation
  - Potential geothermal resources with geological characteristics
  - Energy conversion technologies

➡ Identify optimal configurations and exploitation schemes for given setting

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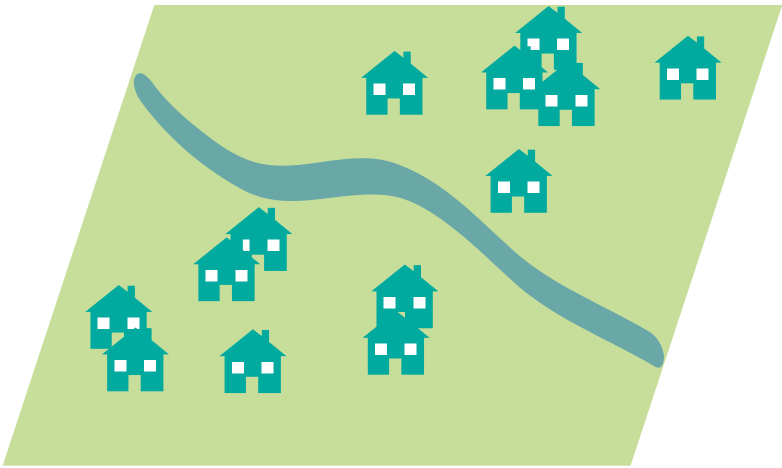

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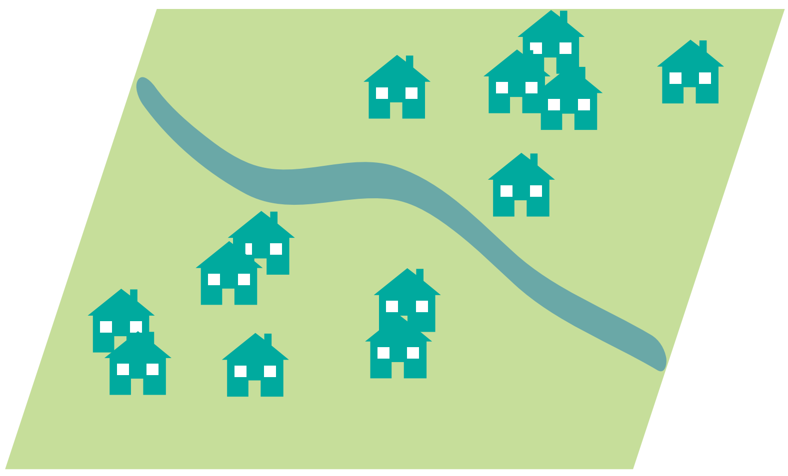

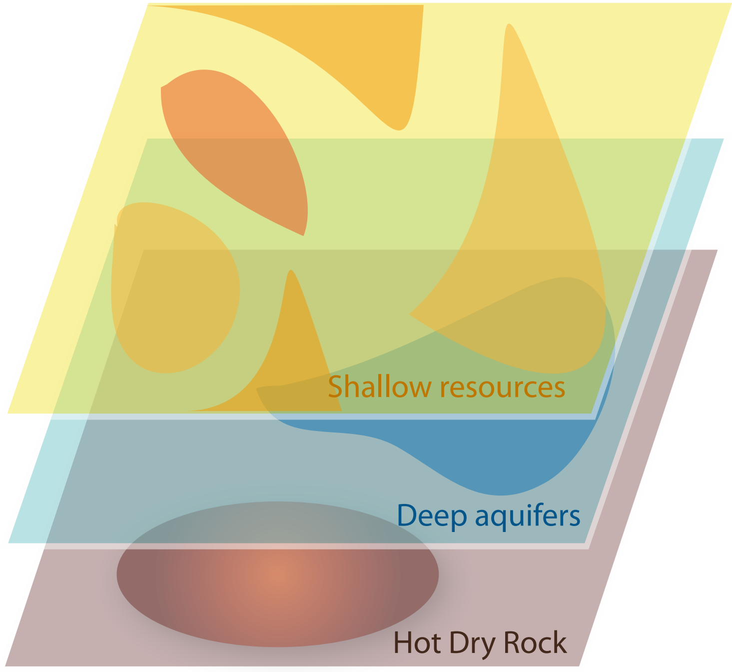

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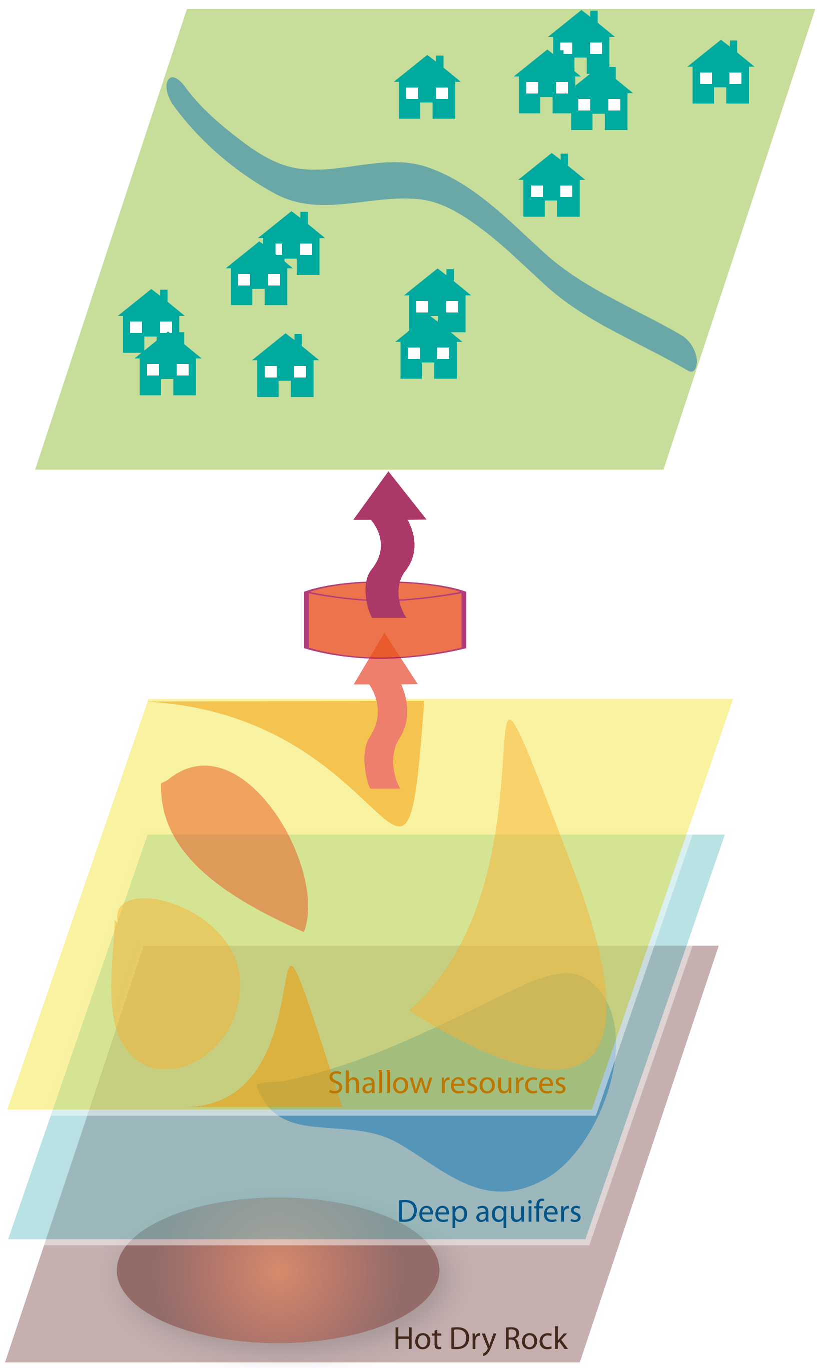

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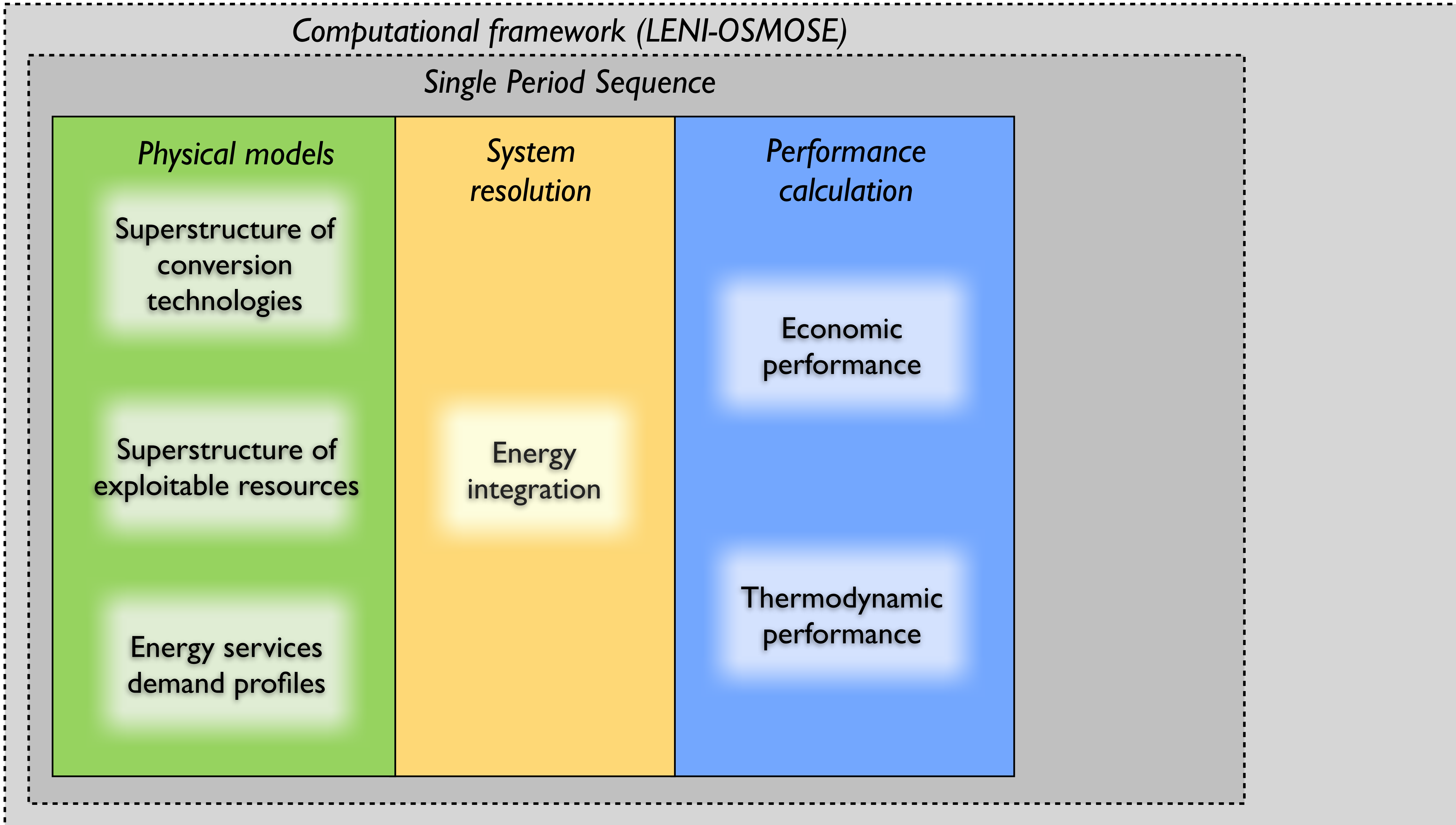

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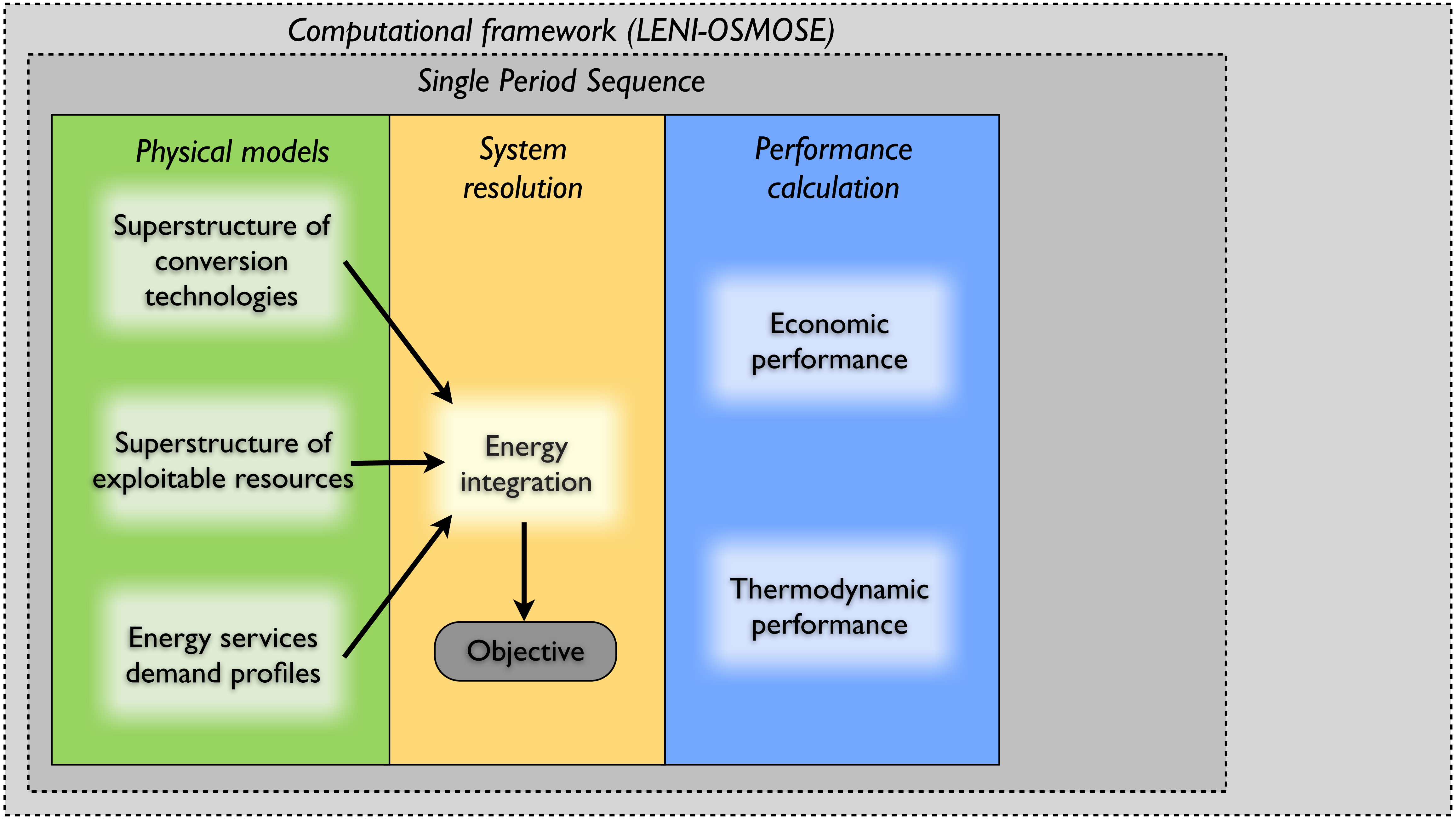

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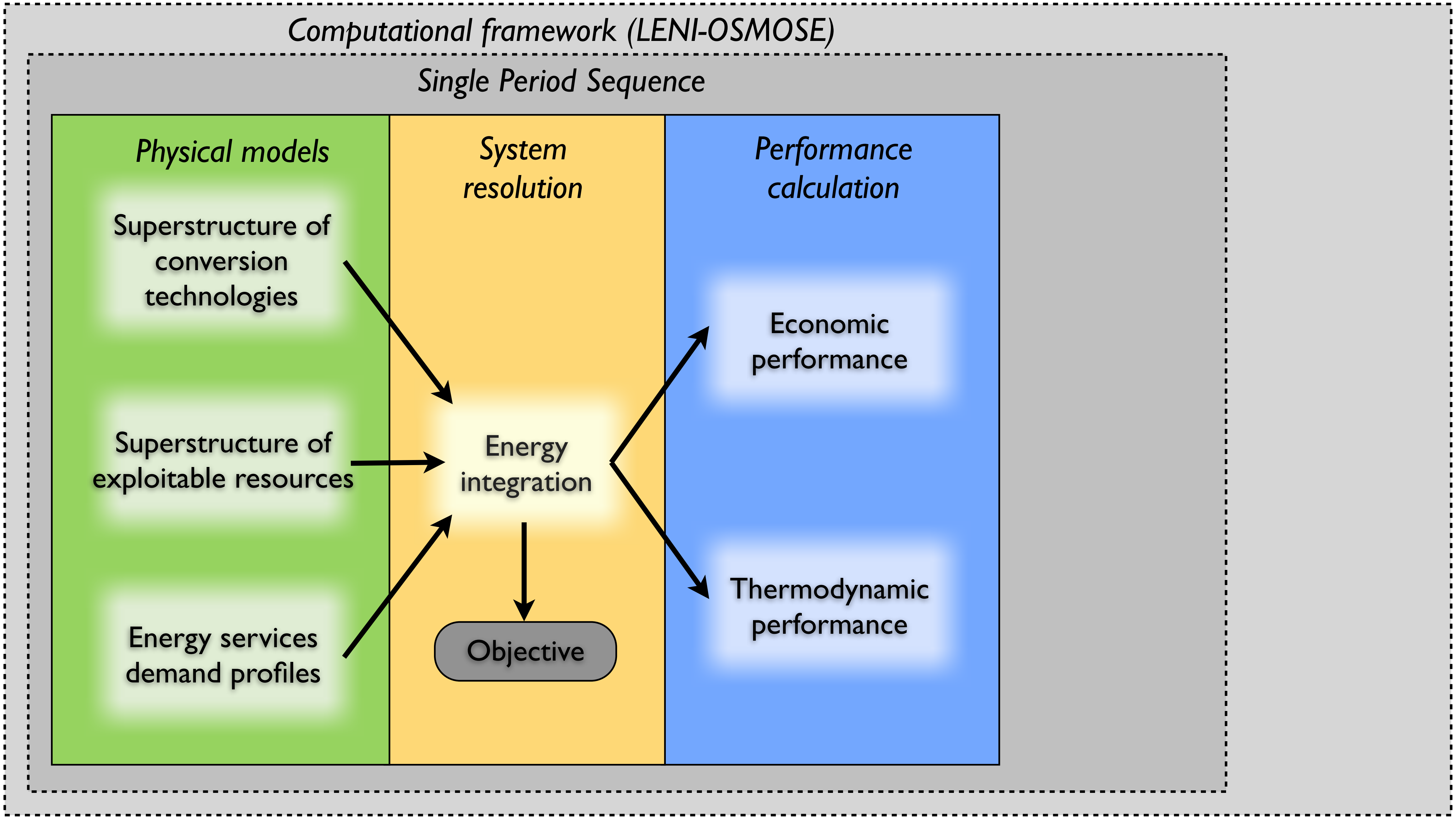

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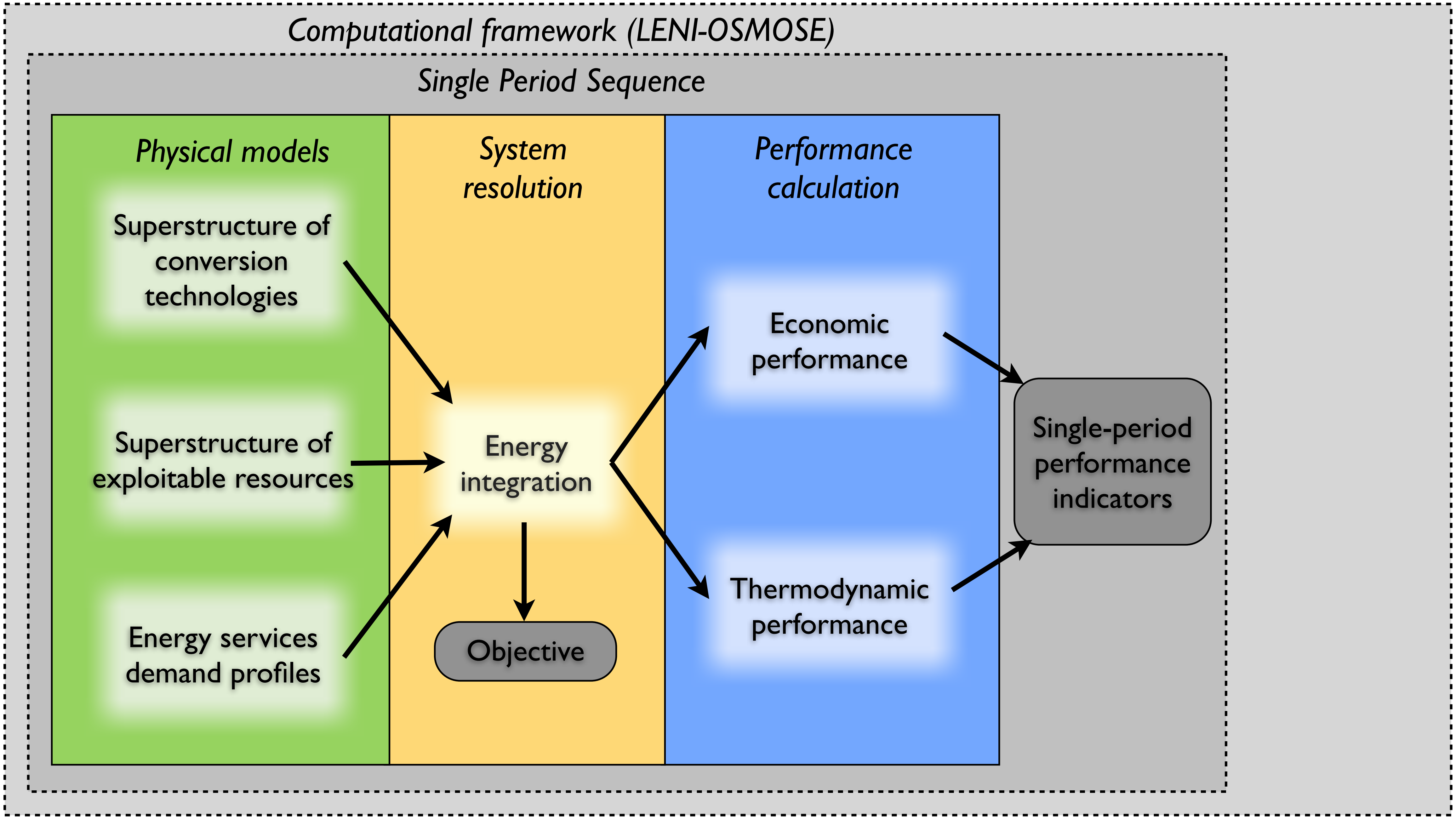

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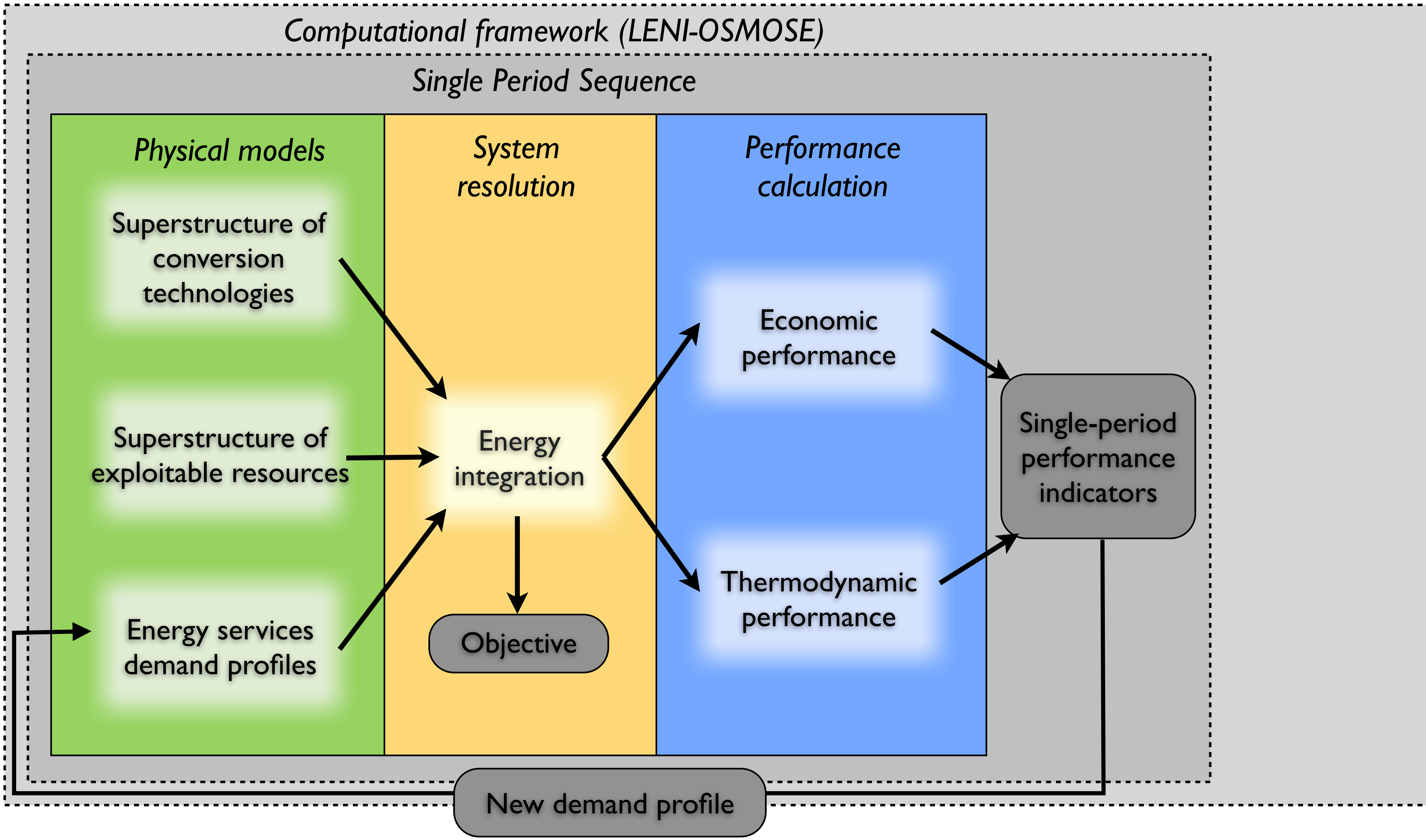

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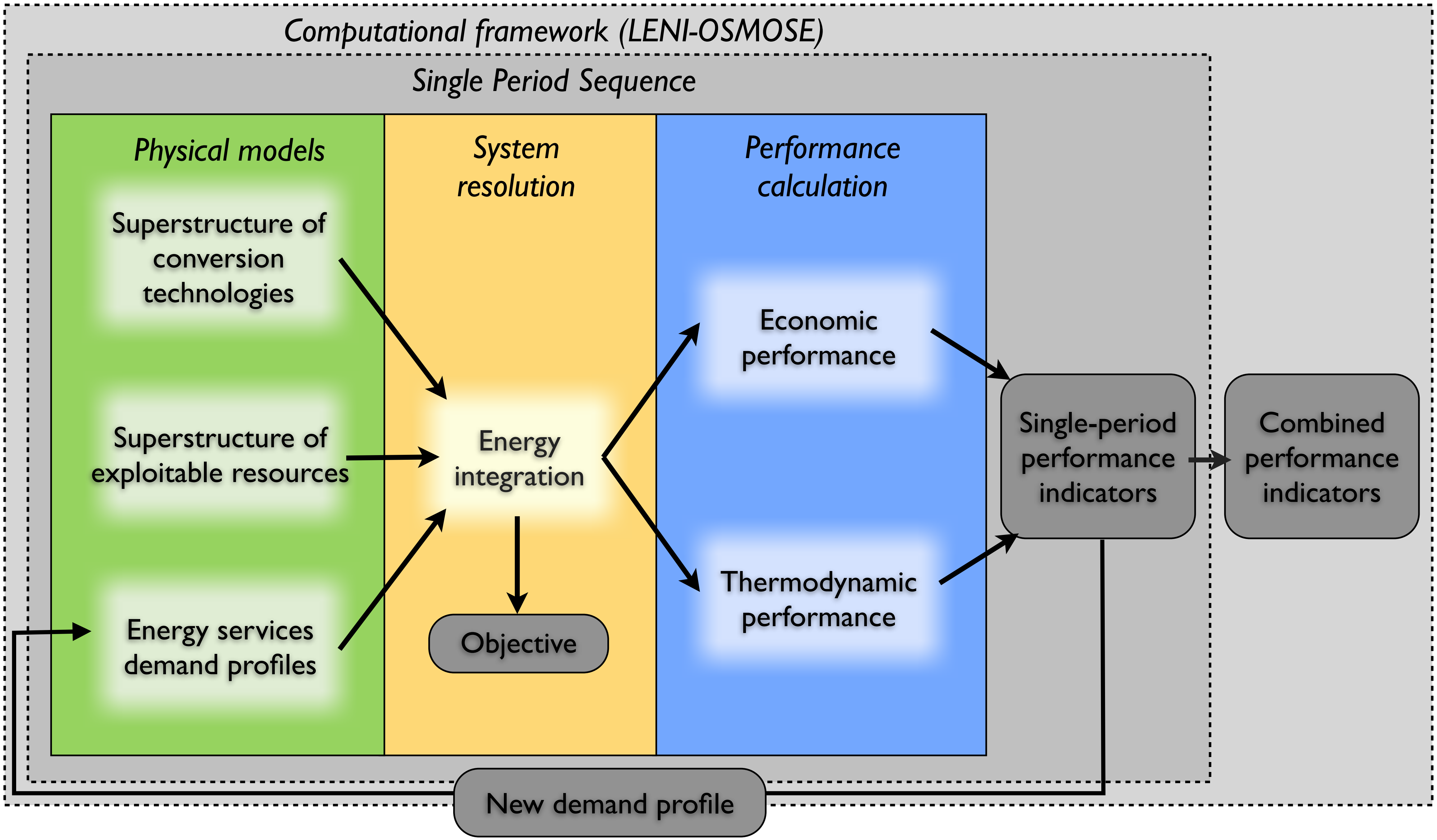

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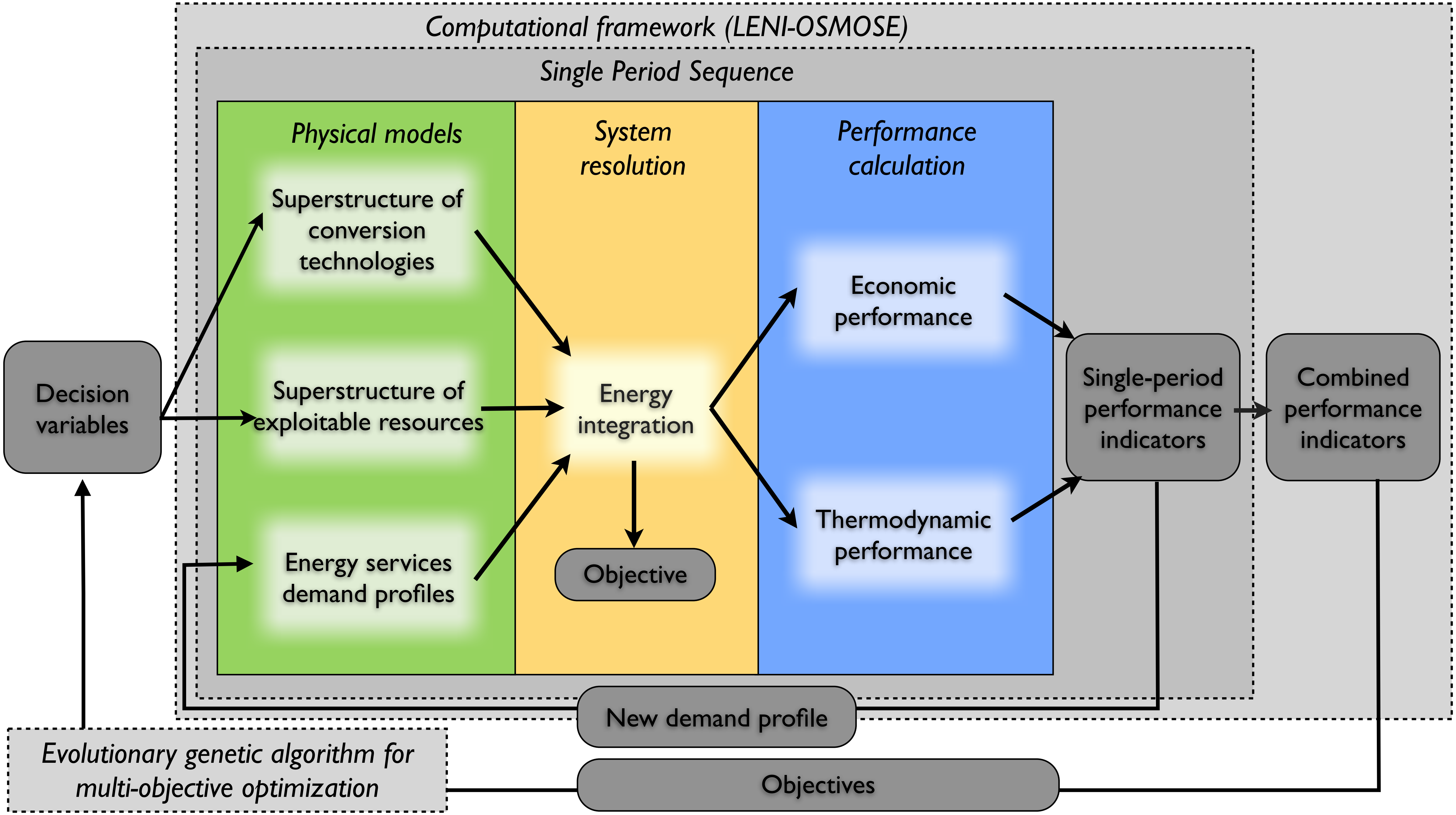


# Resource models characteristics

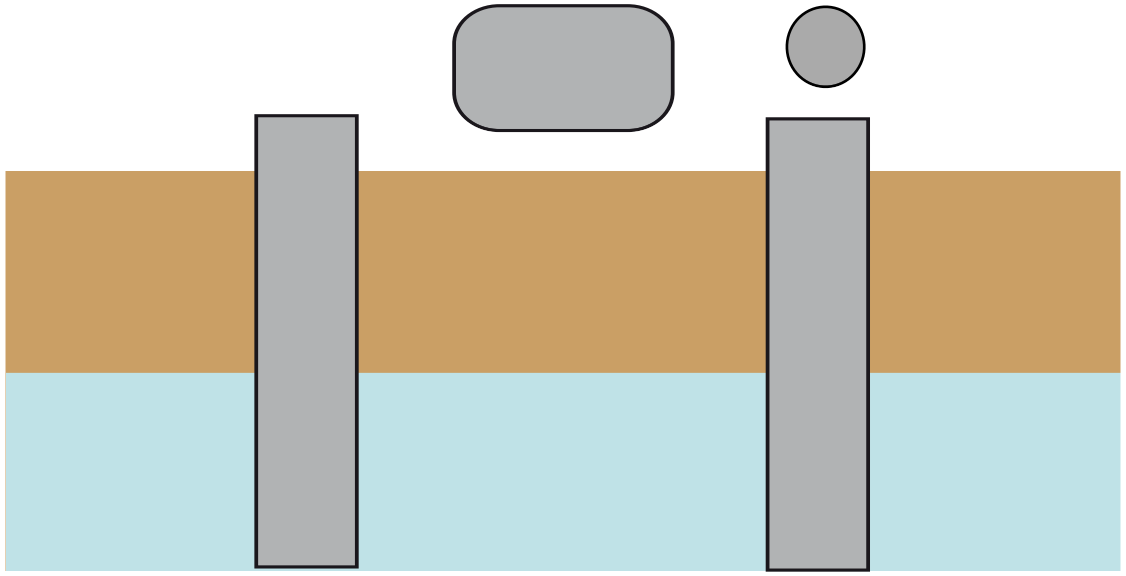
- Models based on geological data to calculate Q&T

Shallow aquifers

Deep aquifers

Enhanced Geothermal Systems

$$\dot{Q}^{+} = \dot{m} \cdot c_p \cdot (T_{in} - T_{out})$$



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$$T_{in} = 12C$$
$$\dot{m} = 15kg/s$$
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$$T_{in} = 65C$$
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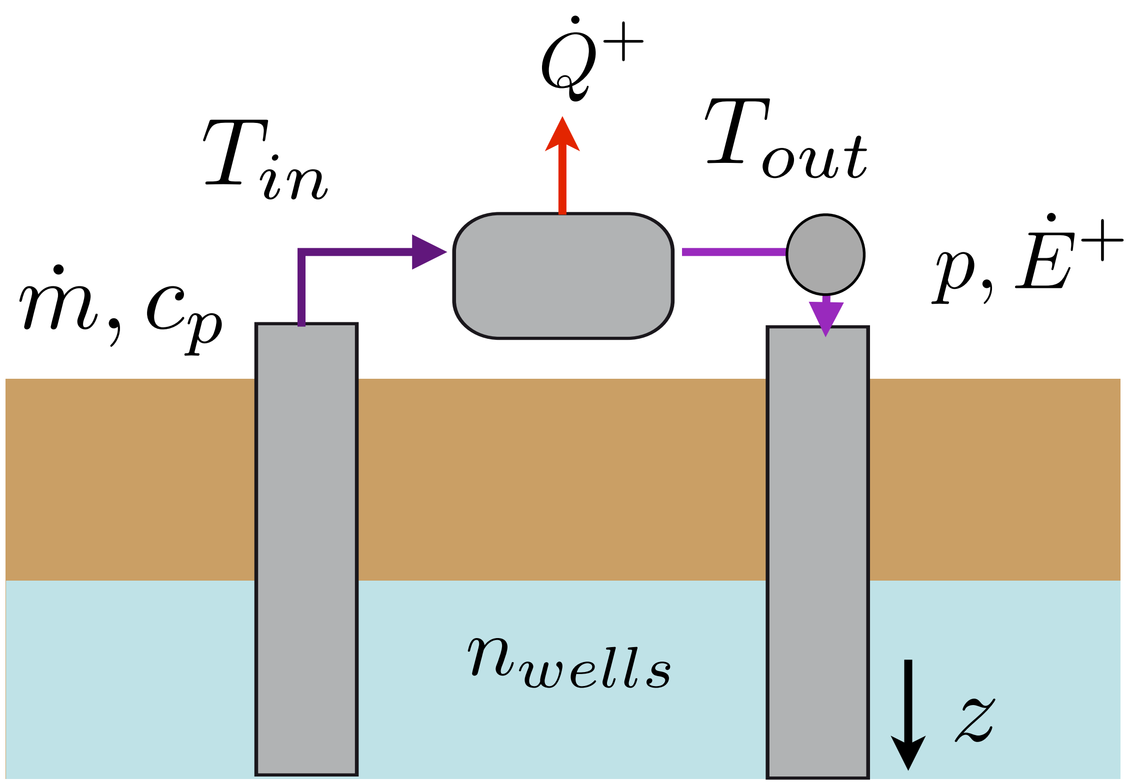

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$$T_{in} = 180C \quad \dot{m} = 45kg/s \quad z = 5000m \quad p = 115bar$$

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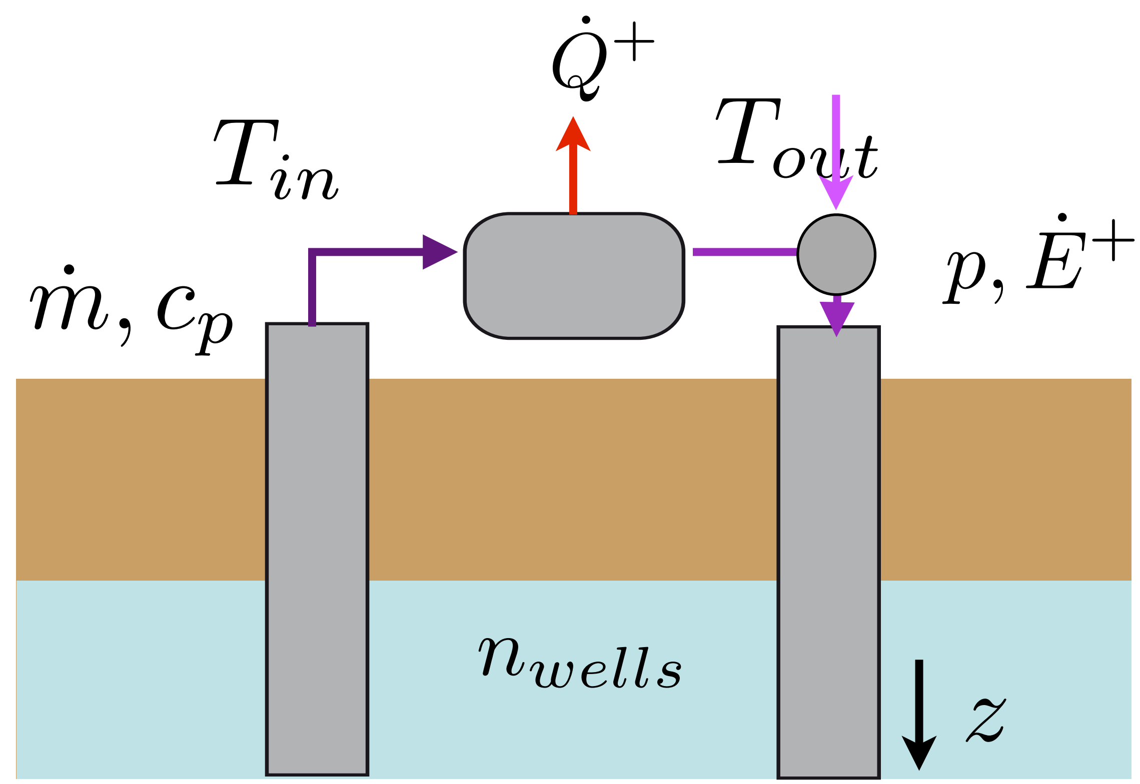

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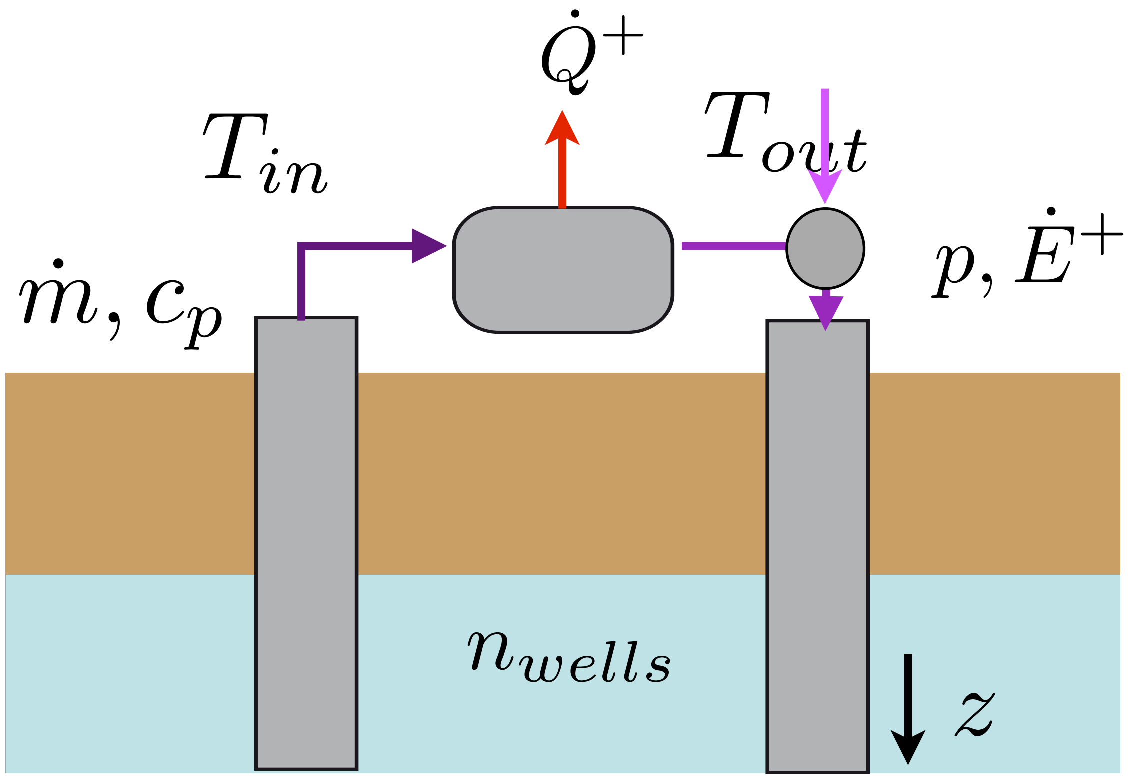
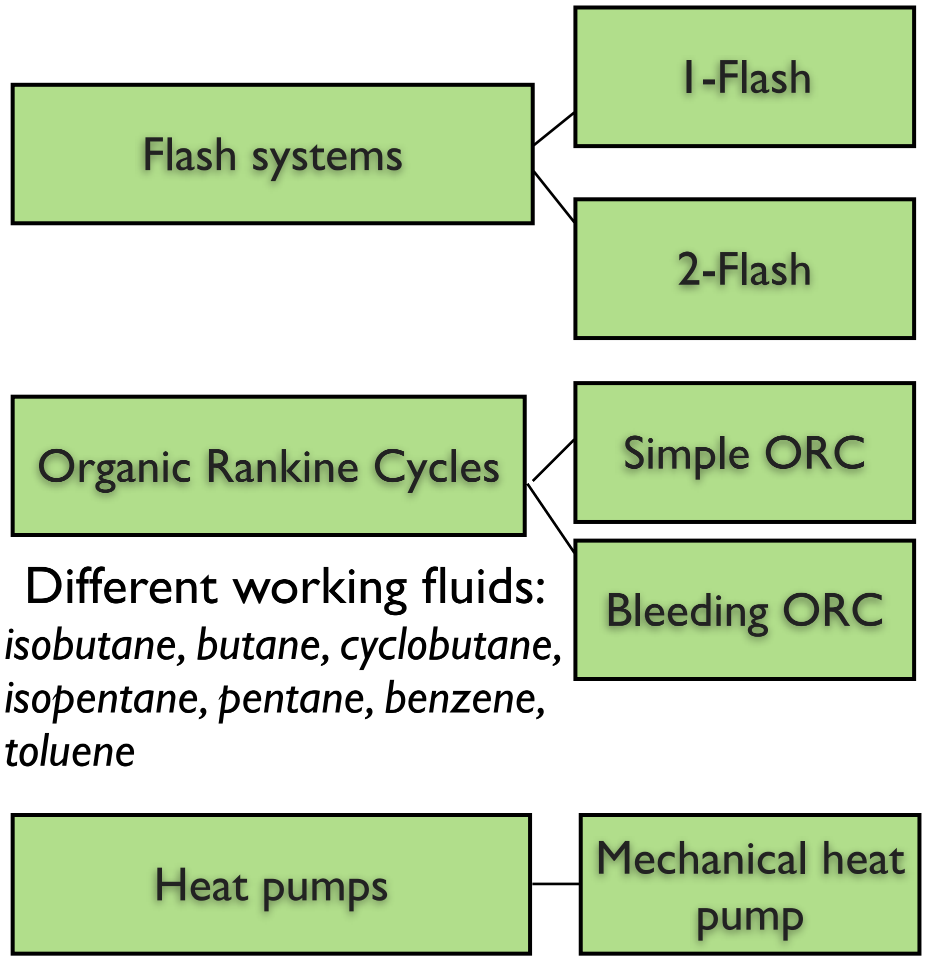



➡ *Similar models, different characteristics!*

# Conversion technologies models

- Use of flowsheeting software (Belsim-Vali) to simulate operating conditions




➡ *Calculation of heat loads and produced/consumed power, no design of HEX network*

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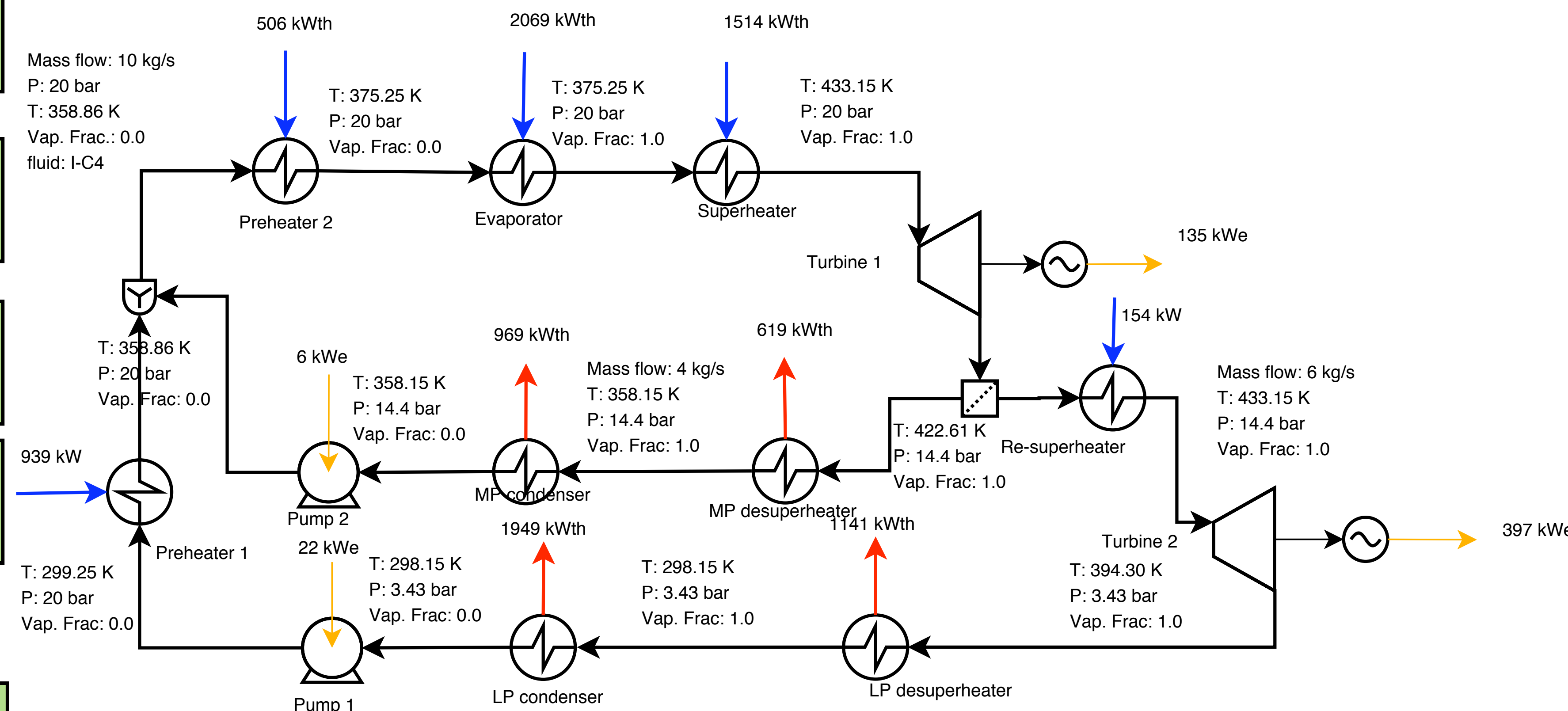
  - 1-Flash
  - 2-Flash
- Organic Rankine Cycles
  - Simple ORC
  - Bleeding ORC

Different working fluids: *isobutane, butane, cyclobutane, isopentane, pentane, benzene, toluene*

- Heat pumps
  - Mechanical heat pump

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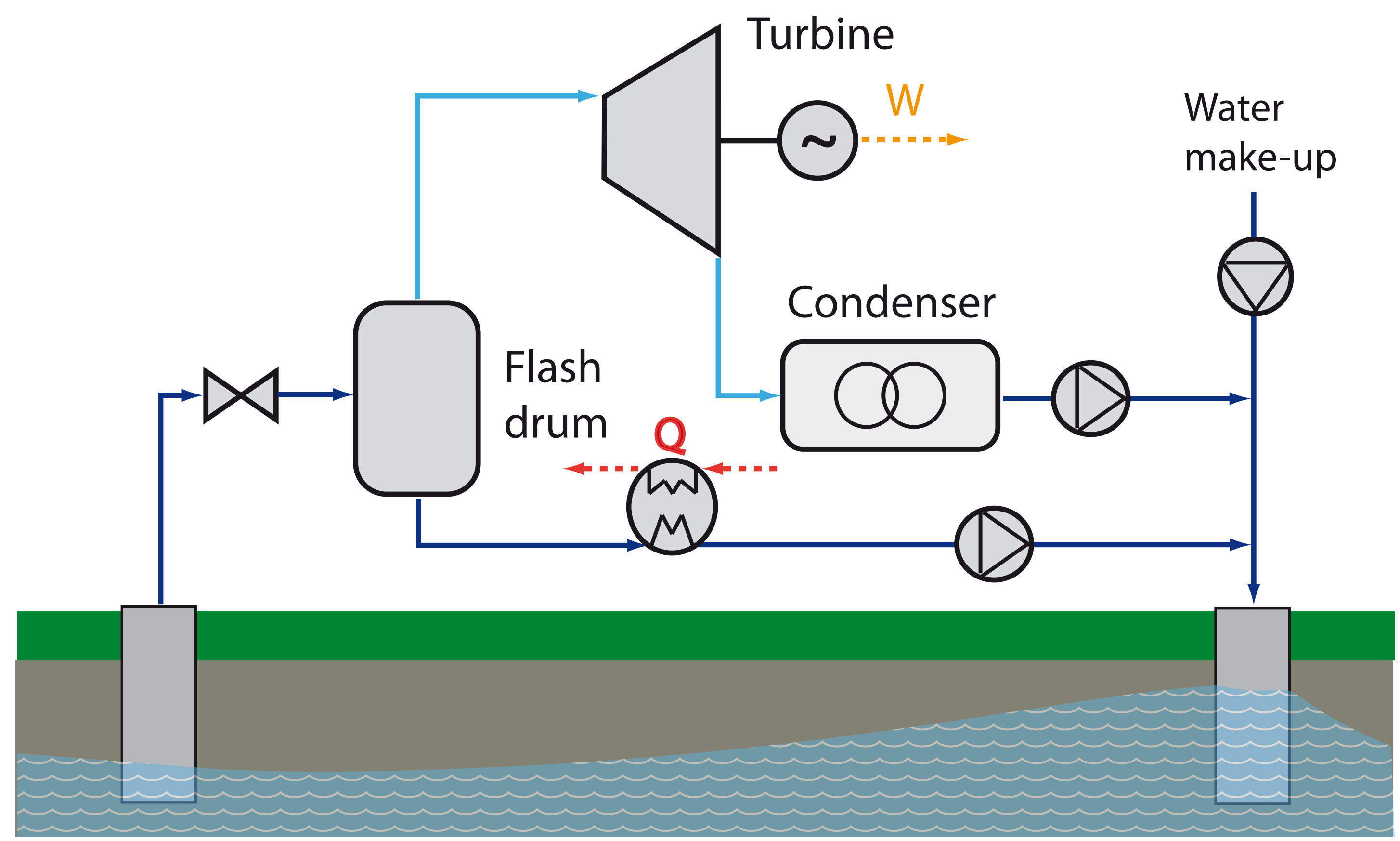


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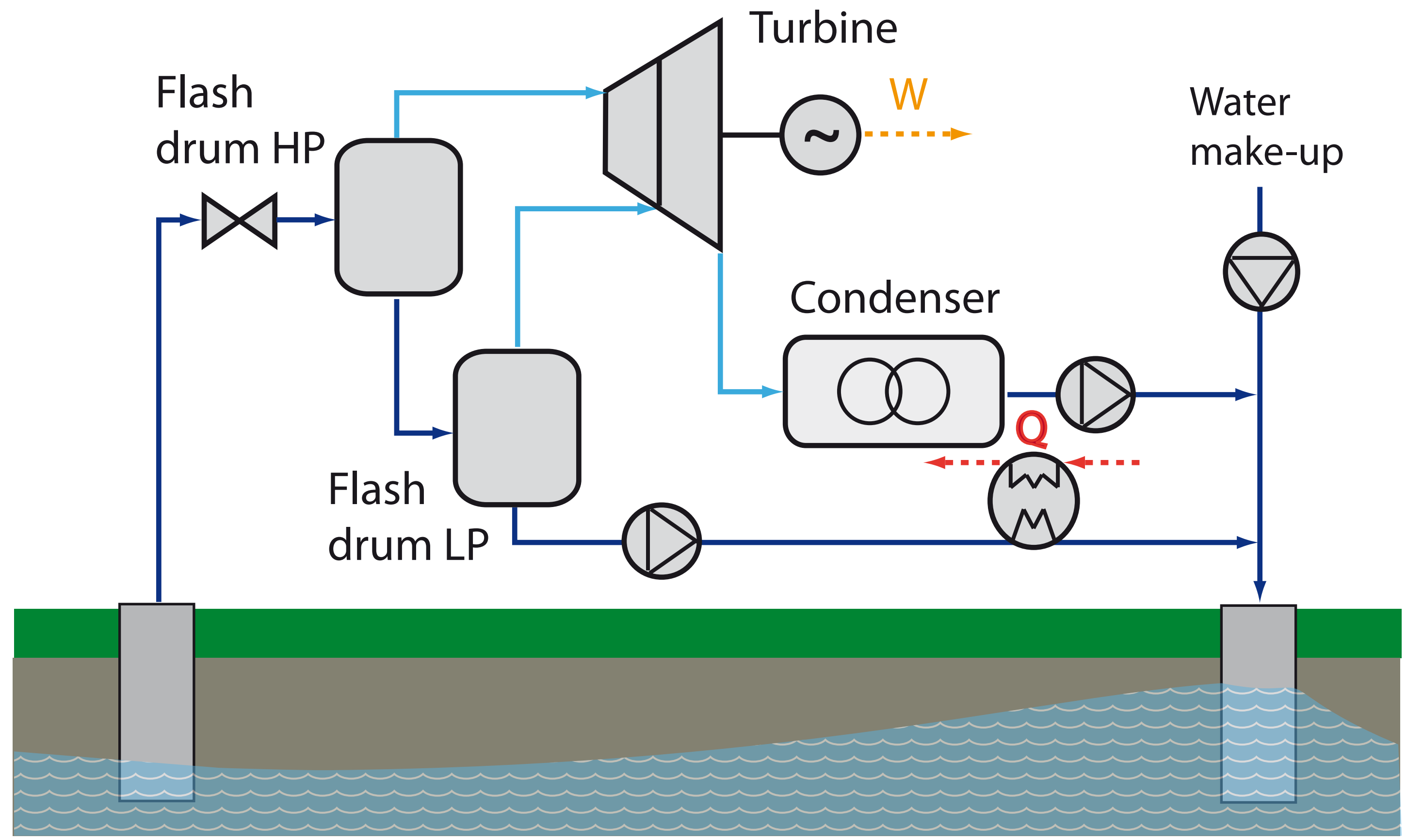


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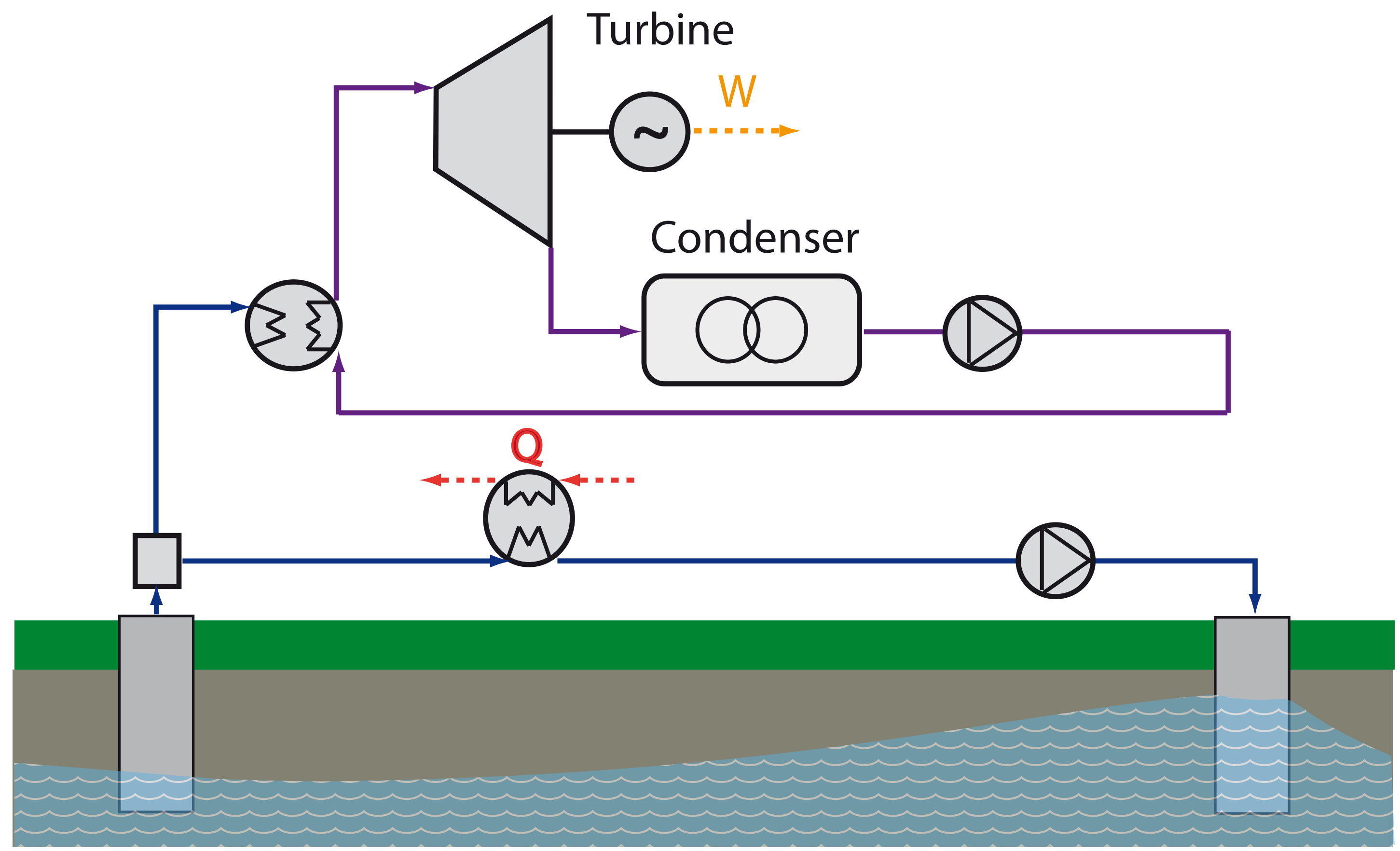


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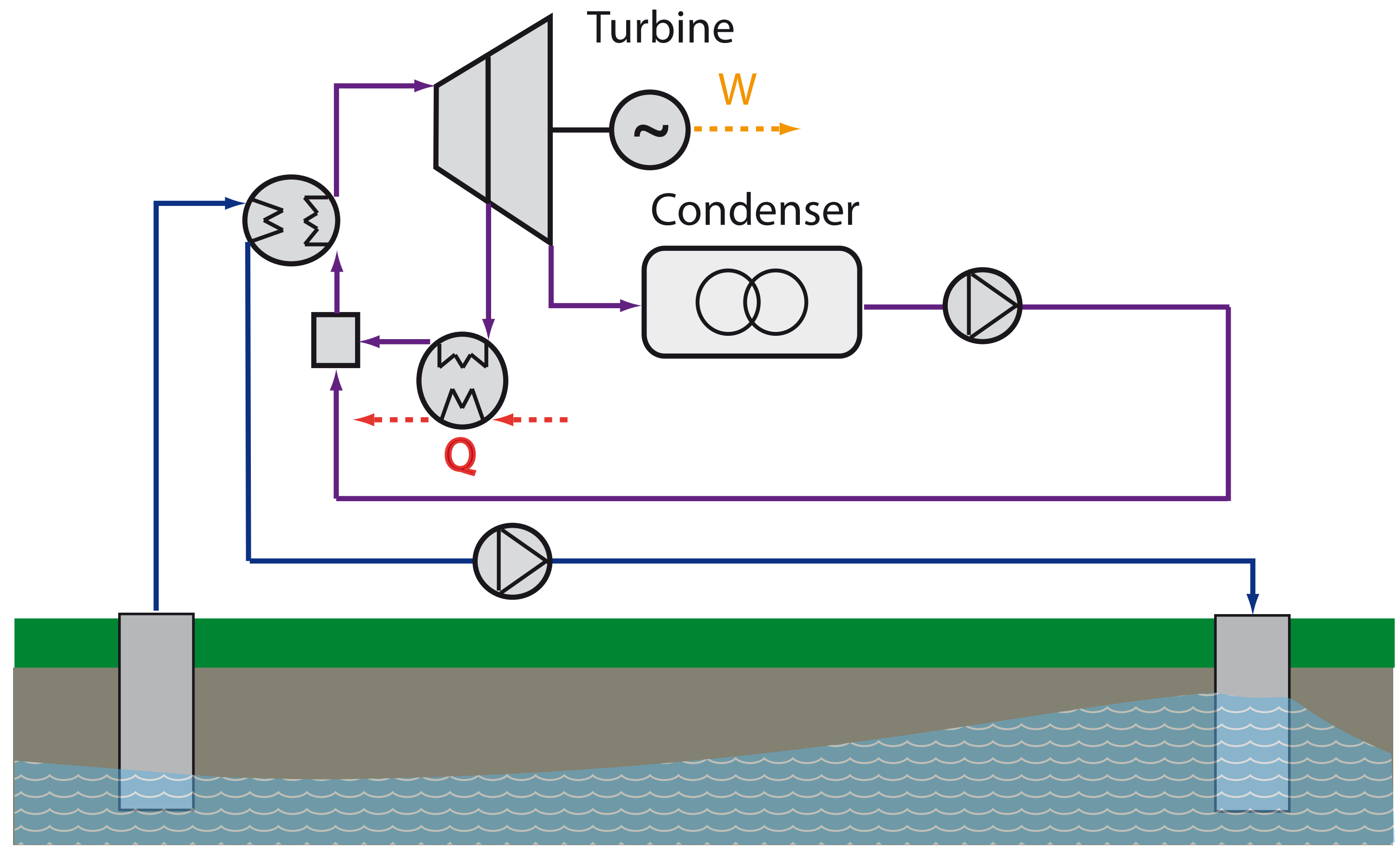


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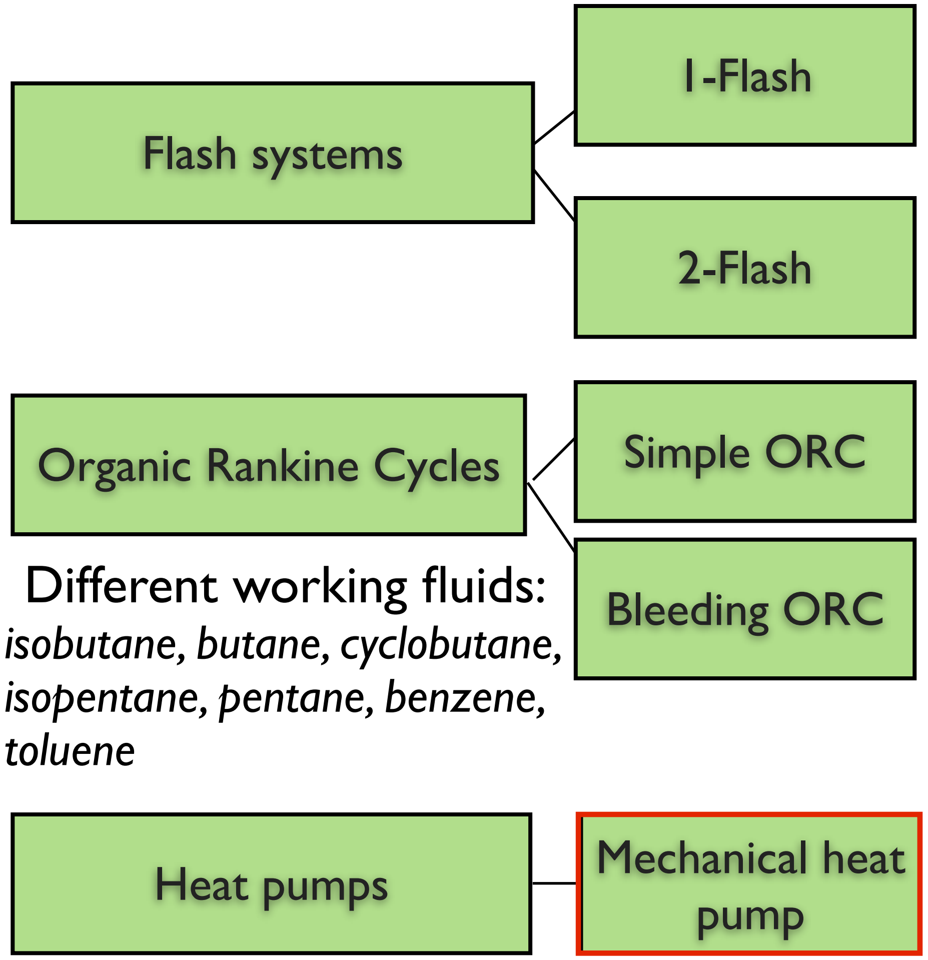


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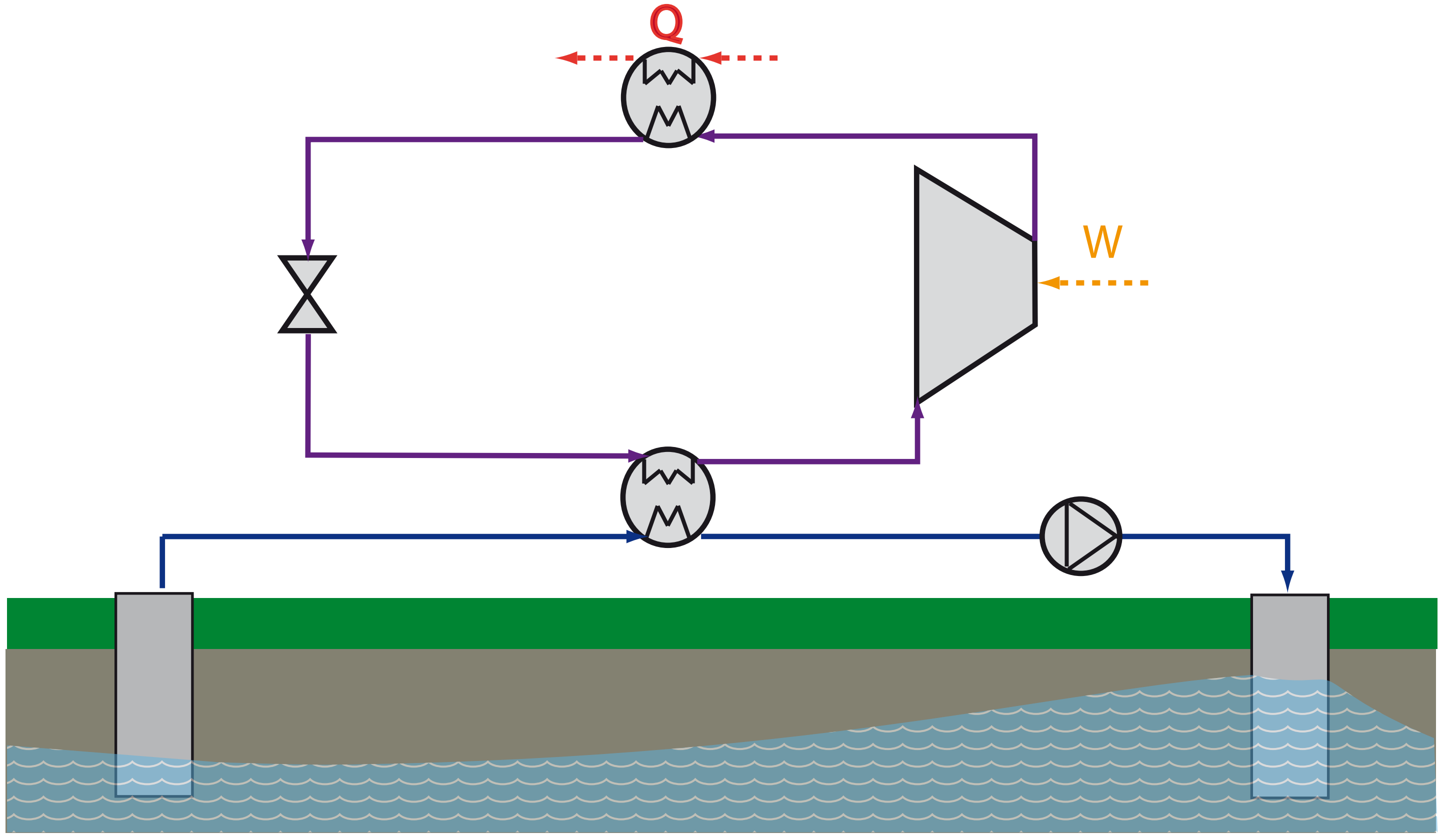


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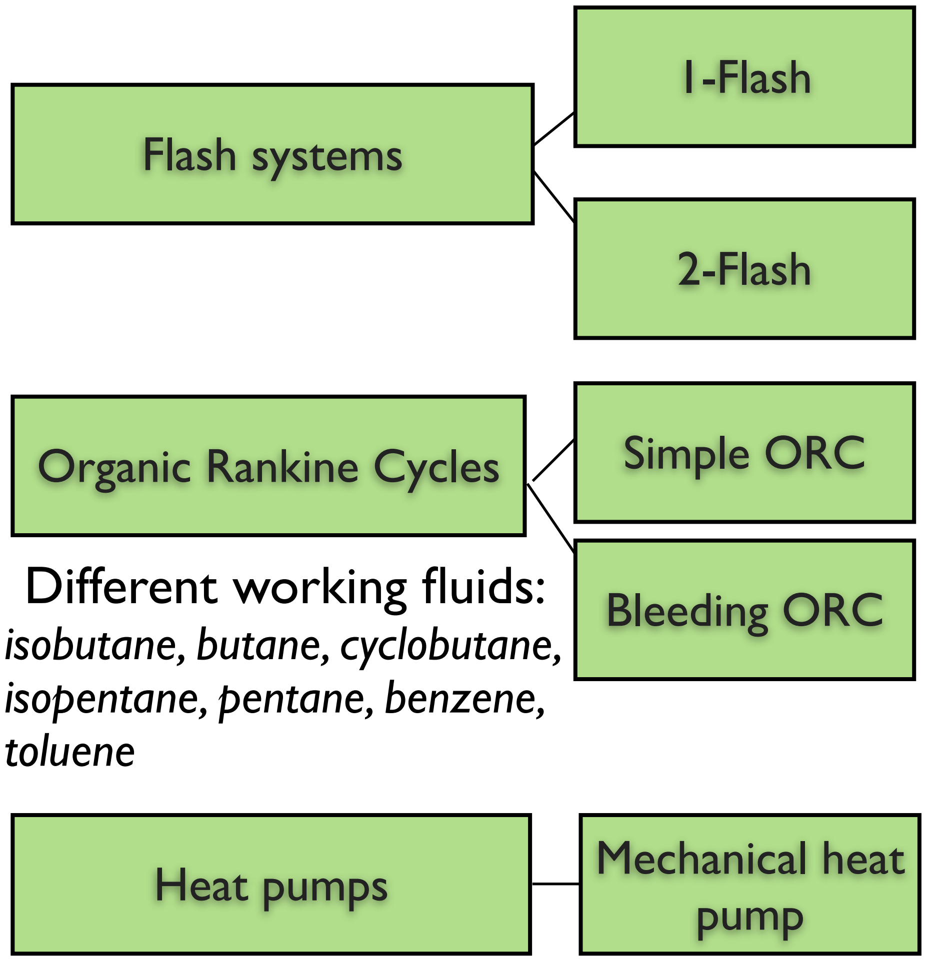
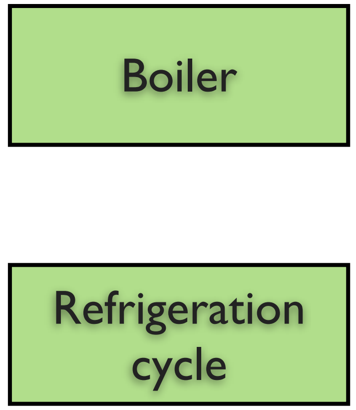


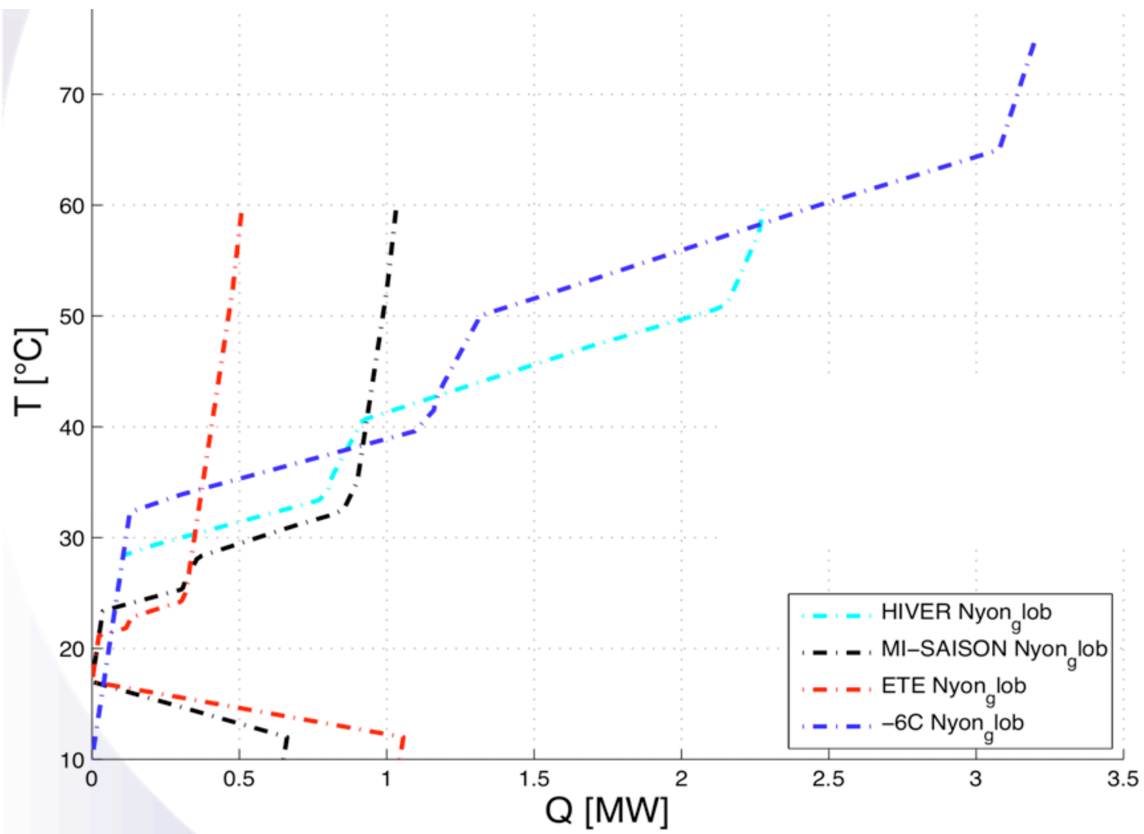




Back-up technologies

➡ *Calculation of heat loads and produced/consumed power, no design of HEX network*

# Demand profiles

- GIS-based data for seasonal demand in urban areas (1)
  - Allows to calculate Q&T
  - District heating & Cooling




*Examples profiles*
➡ *4 demand periods (full year)*
➡ *Constraints on DH & DC*

(1): Girardin et al., A geographical information based system for the evaluation of integrated energy conversion systems in urban areas, ECOS 2008

# System resolution

- Optimal integration of energy conversion system, resources and demand
  - Selection of resources and technologies
  - Sizing of technologies
  - Total heat exchanger network area

➡ Process integration techniques (pinch analysis) to solve MILP problem

  ➡ Single objective: operating cost/investment cost/mechanical power

  ➡ Use of energy flows calculated at previous step

- System design for each period

# Performance indicators

- Thermodynamic performance indicators
  - energy efficiency
  - exergy efficiency

$$\epsilon_p = \frac{\dot{E}_p^- + \sum_{i=1}^{n_{serv}} \dot{Q}_{i,p}^-}{\dot{E}_p^+ + \sum_{i=1}^{n_{geo}} \dot{Q}_{i,p} + \sum_{i=1}^{n_{bkp}} \dot{Q}_{i,p}}$$

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# Performance indicators

- Economic performance indicators
  - Investment costs
  - Operating costs
  - Total annualized costs

➡ net profit

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$$CI_{tot} = \sum_{i=1}^{n_{geo}} C_{drill,i} + \sum_{i=1}^{n_{tech}} C_{equip,i} + \sum_{i=1}^{n_{serv}} C_{distrib,i} + DC + IC$$

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  - Operating costs

$$CO_p = C_{maint_p} + C_{man_p} + C_{fuel_p} + C_{E_p^+} - (\sum_{i=1}^{n_{serv}} R_{i,p})$$

  - Total annualized costs

$CO_p < 0$ ➡ *Revenue*

➡ net profit

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$CO_p < 0$ ➡ *Revenue*

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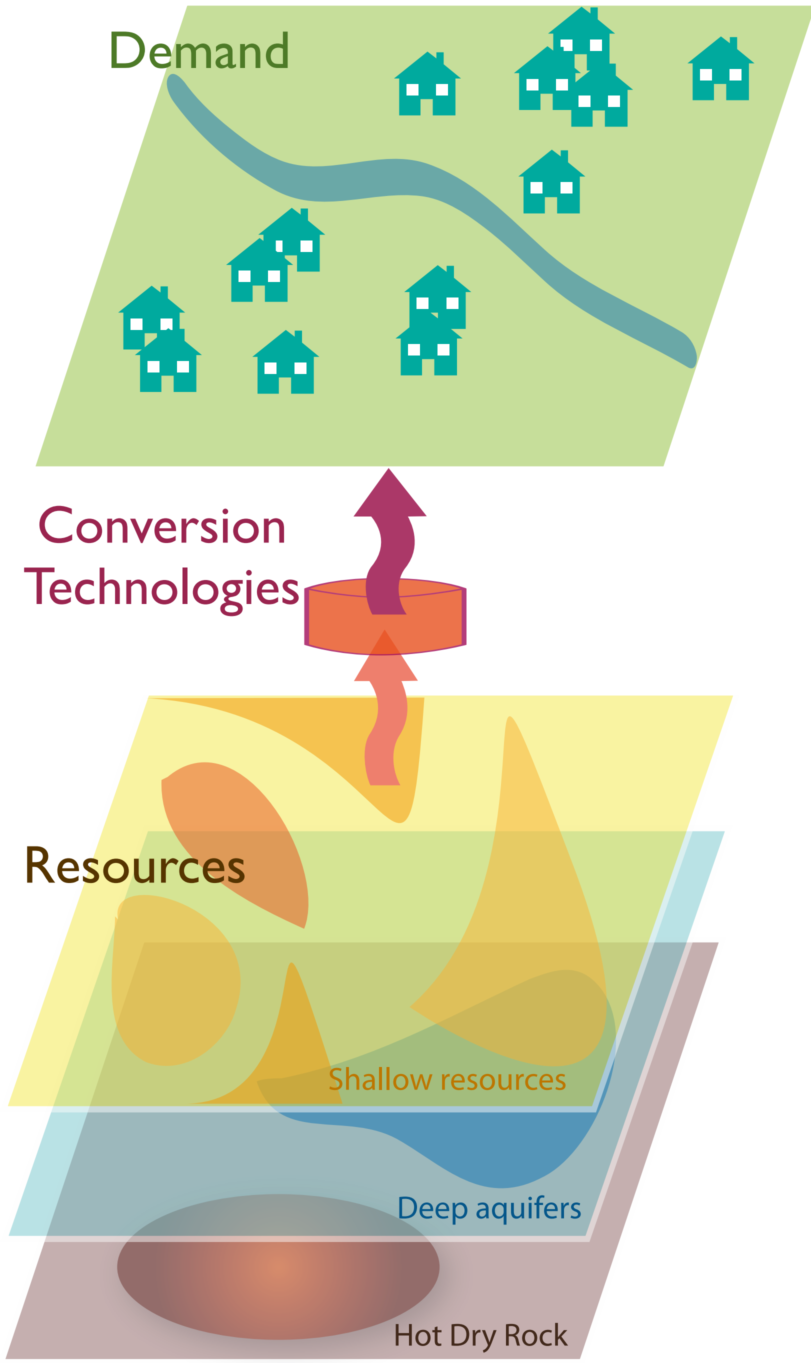
$$C_{annual} = CI_{annual}(i, yr) + \sum_{p=1}^{n_{periods}} CO_p \cdot t_{op,p} + F$$

$C_{annual} < 0$ ➡ *Profitable system*

# Example case study



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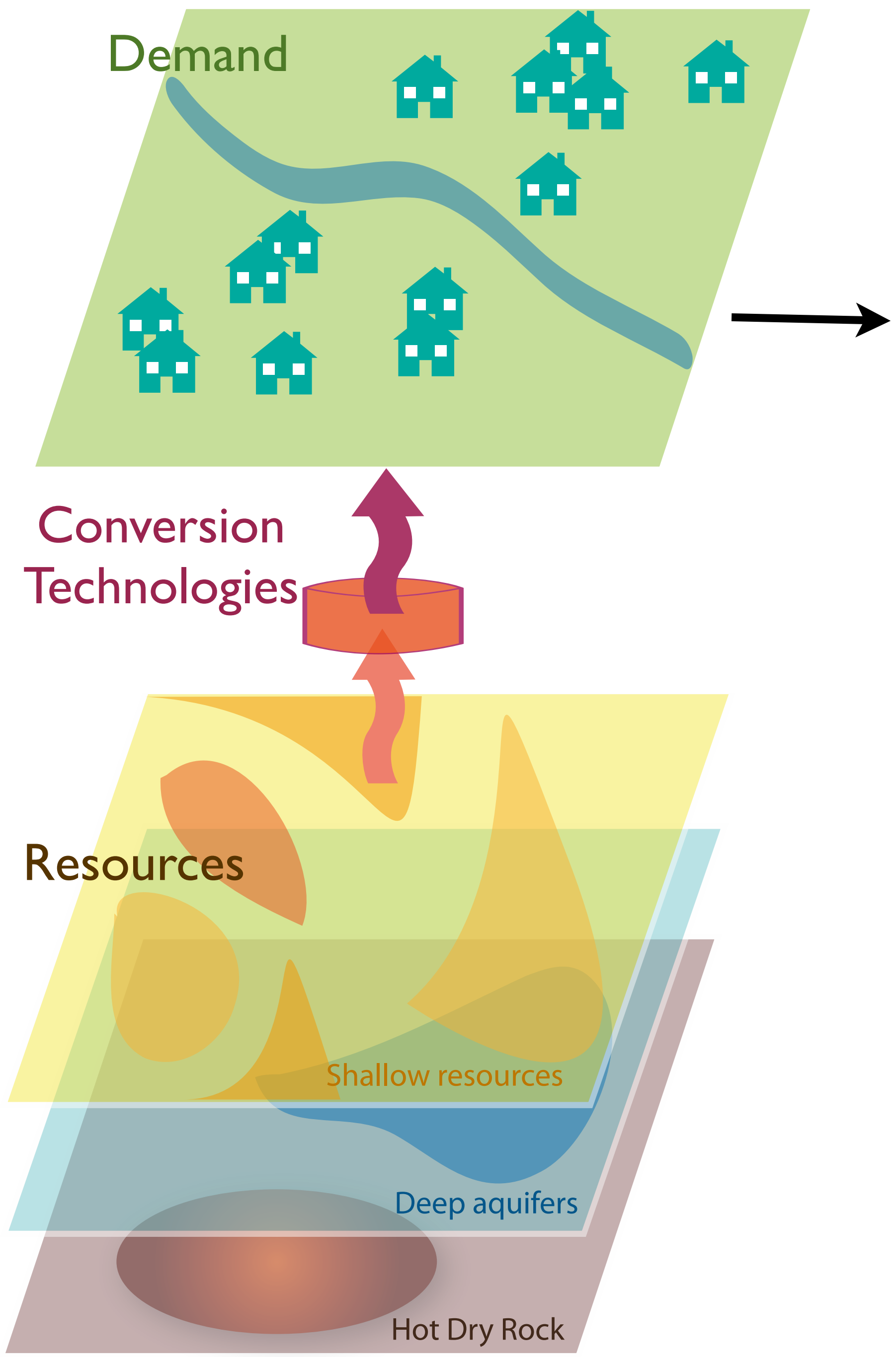


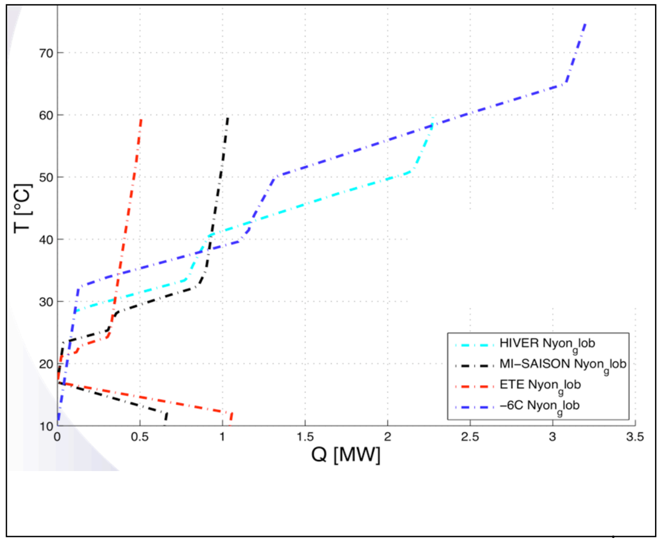


- *Winter (4205 h)*
- *Extreme winter (88 h)*
- *Summer (525 h)*
- *Interseason (3942 h)*

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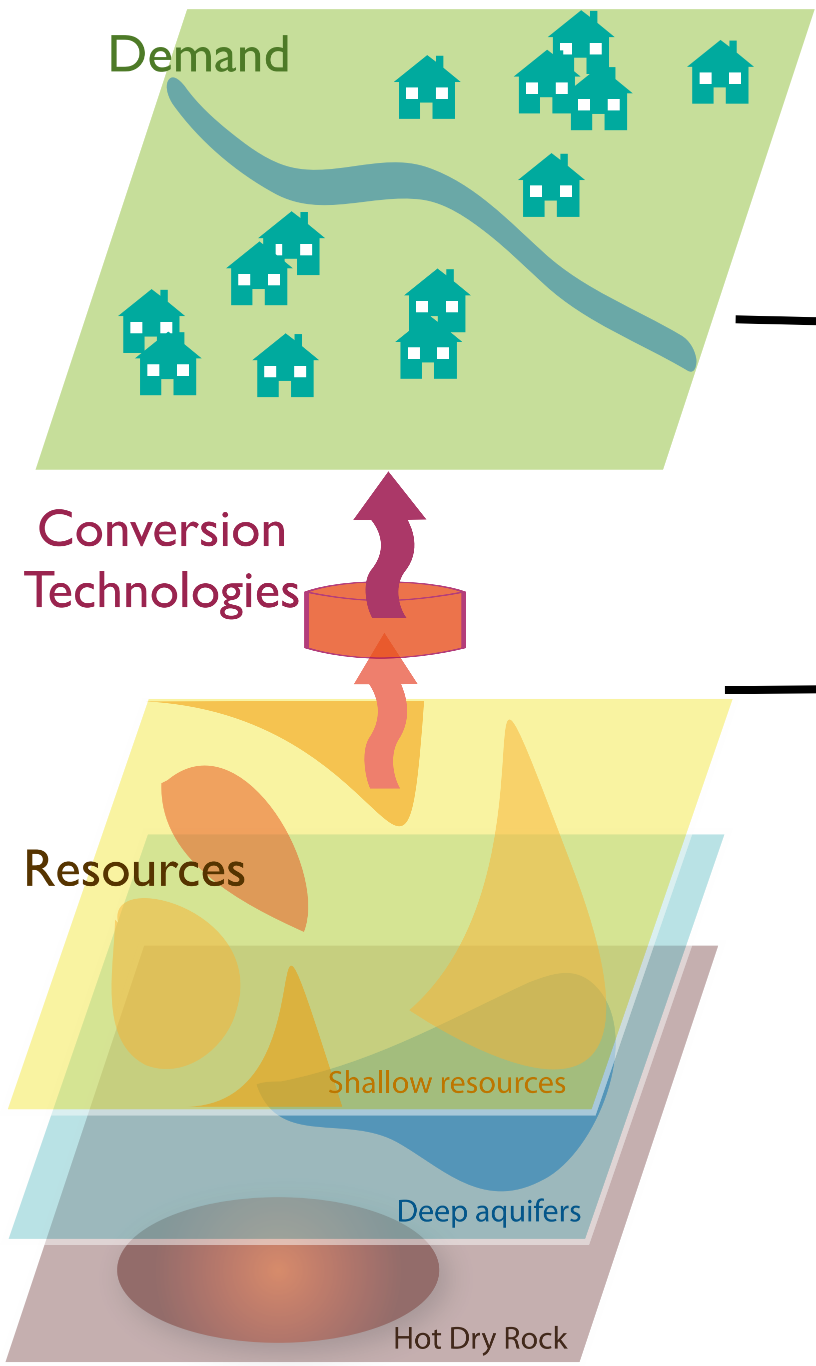


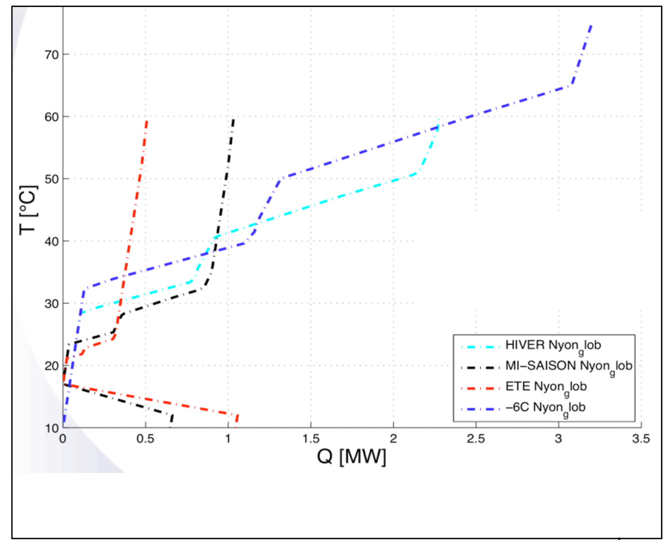


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Bleeding ORC

Heat pump

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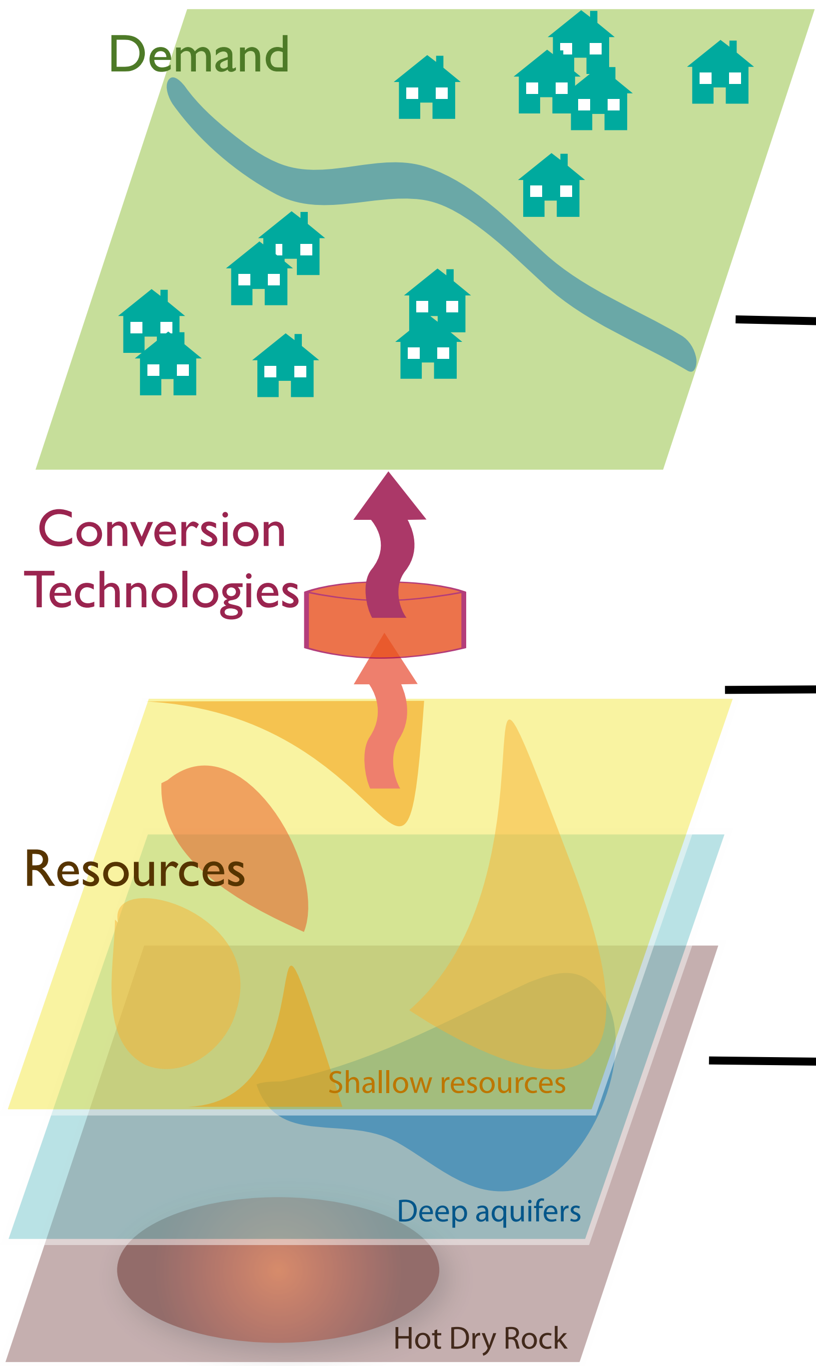


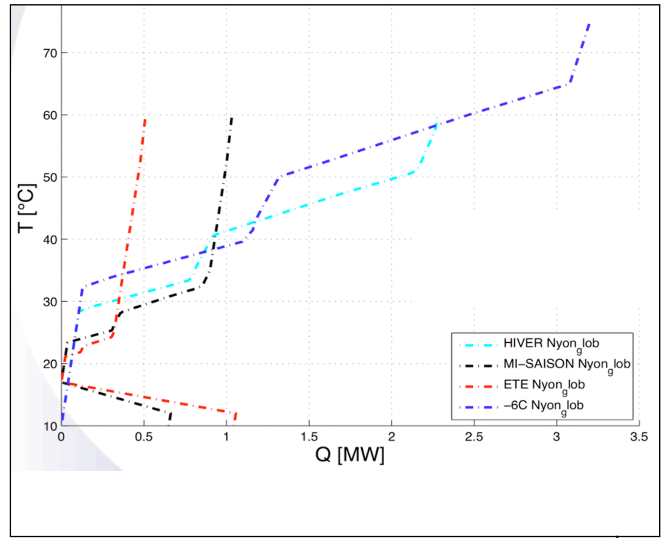


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Enhanced Geothermal System → $T_{in} = 180C, T_{inj} = 100C$

$\dot{m}_{max} = 45kg/s, z = 5000m$

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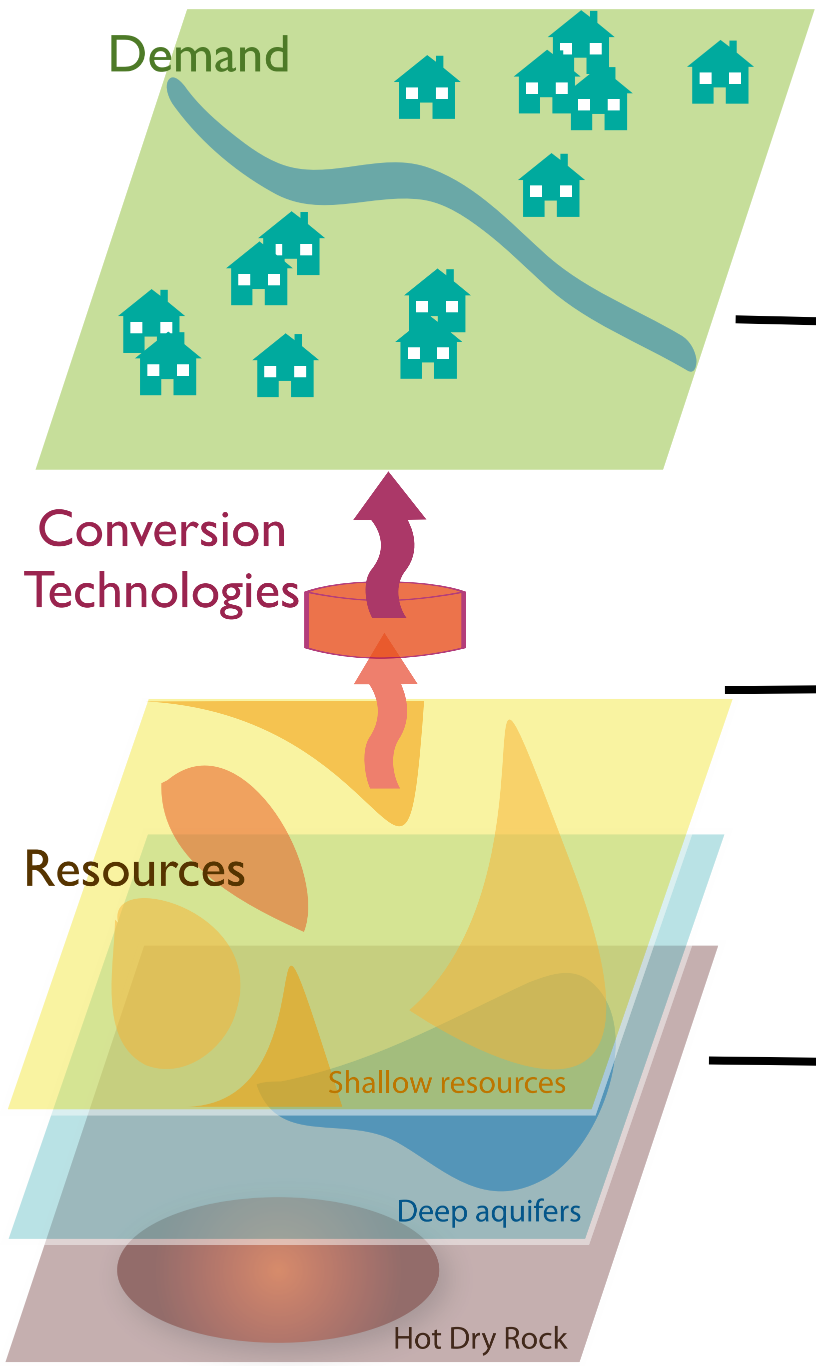


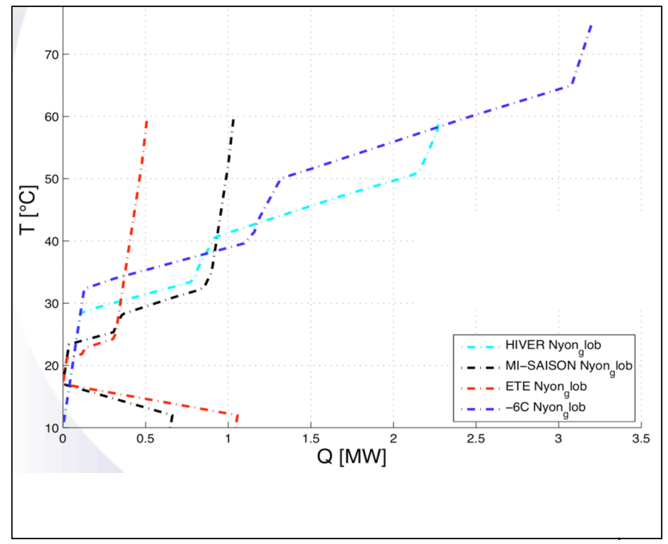


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- *Interseason (3942 h)*

Simple ORC

Bleeding ORC

Heat pump

## Goals:

*1. Satisfy demand with geothermal resources*

*2. Maximize geothermal power production*

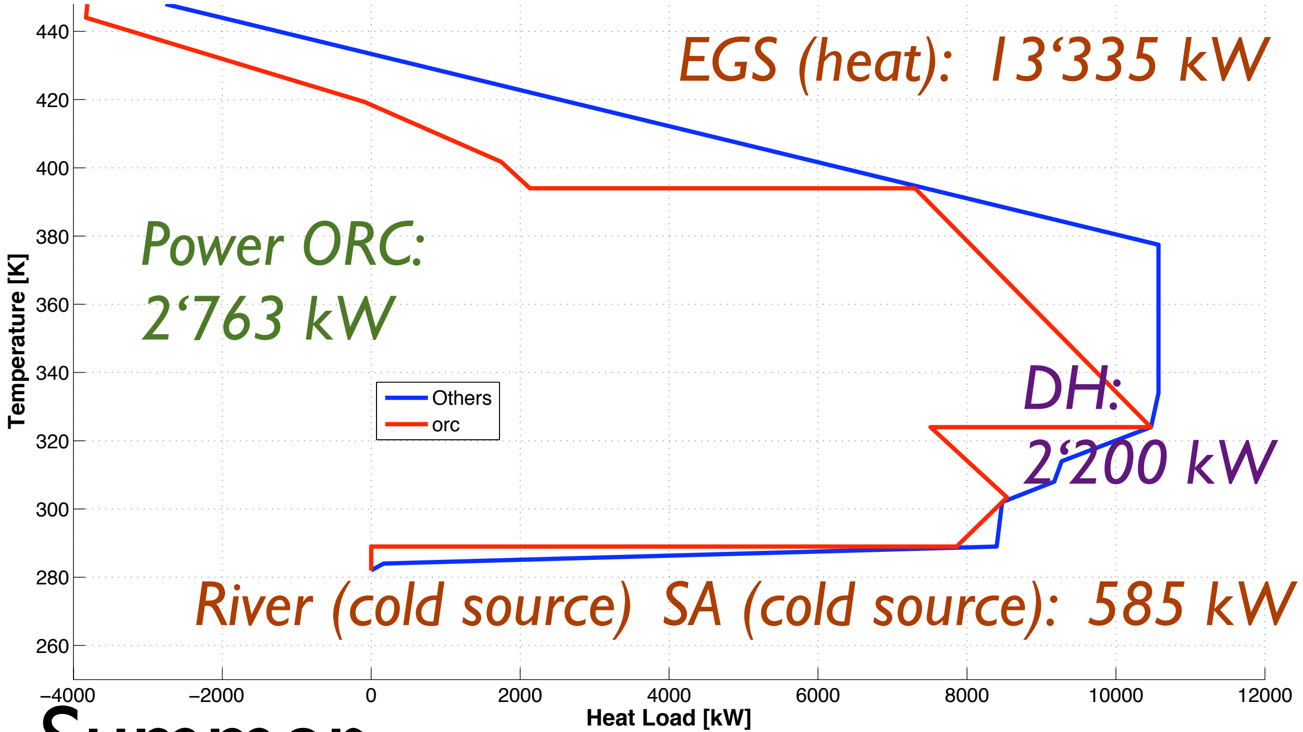
Shallow aquifer → $T_{in} = 8C, \dot{m}_{max} = 20kg/s, z = 300m$

Deep aquifer → $T_{in} = 70C, \dot{m}_{max} = 100kg/s, z = 2000m$

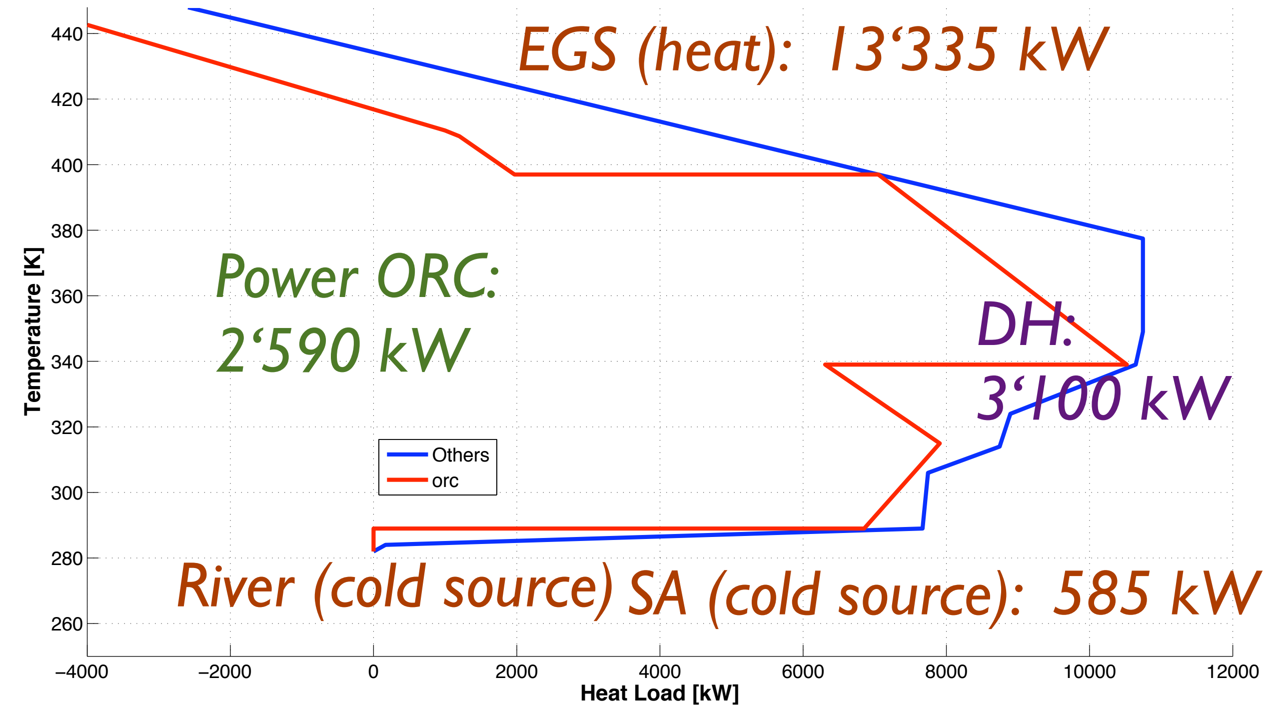
Enhanced Geothermal System → $T_{in} = 180C, T_{inj} = 100C$
$\dot{m}_{max} = 45kg/s, z = 5000m$

# Energy integration results

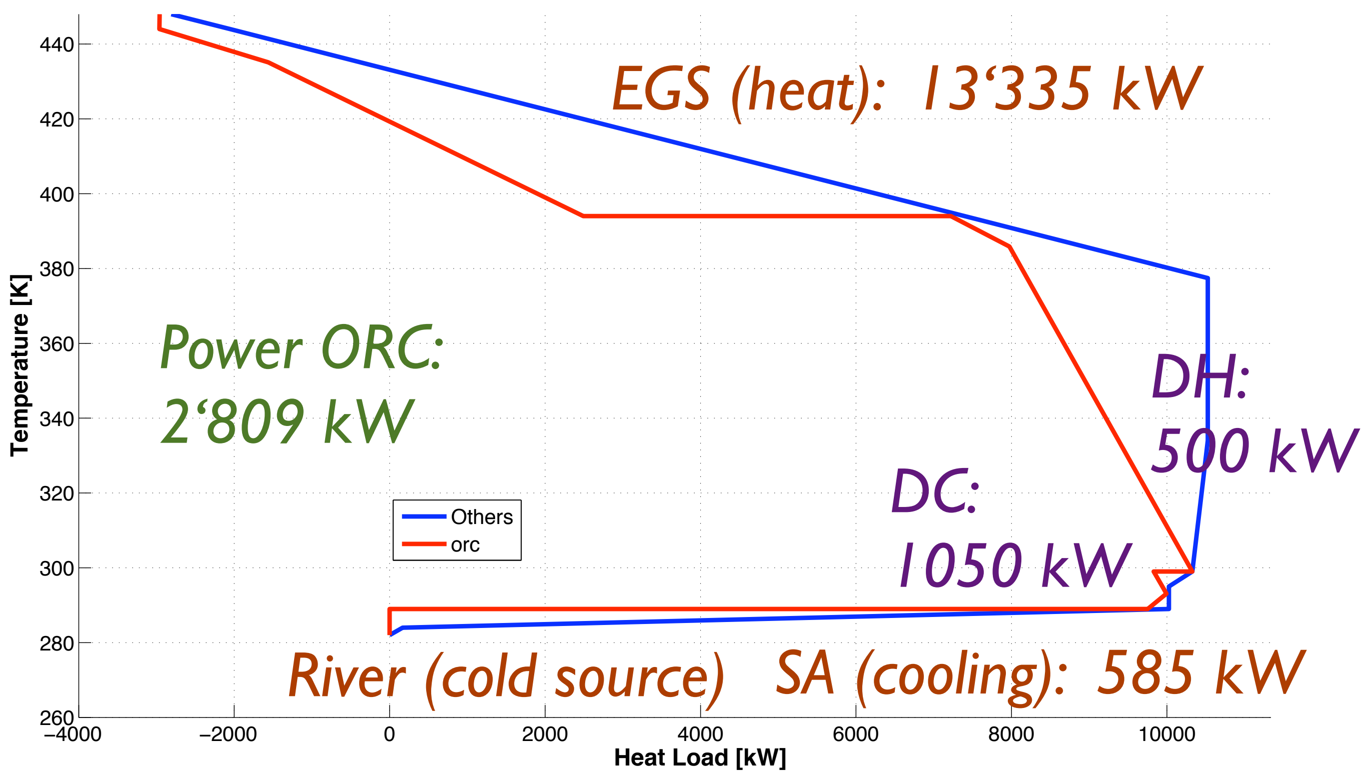
## Winter



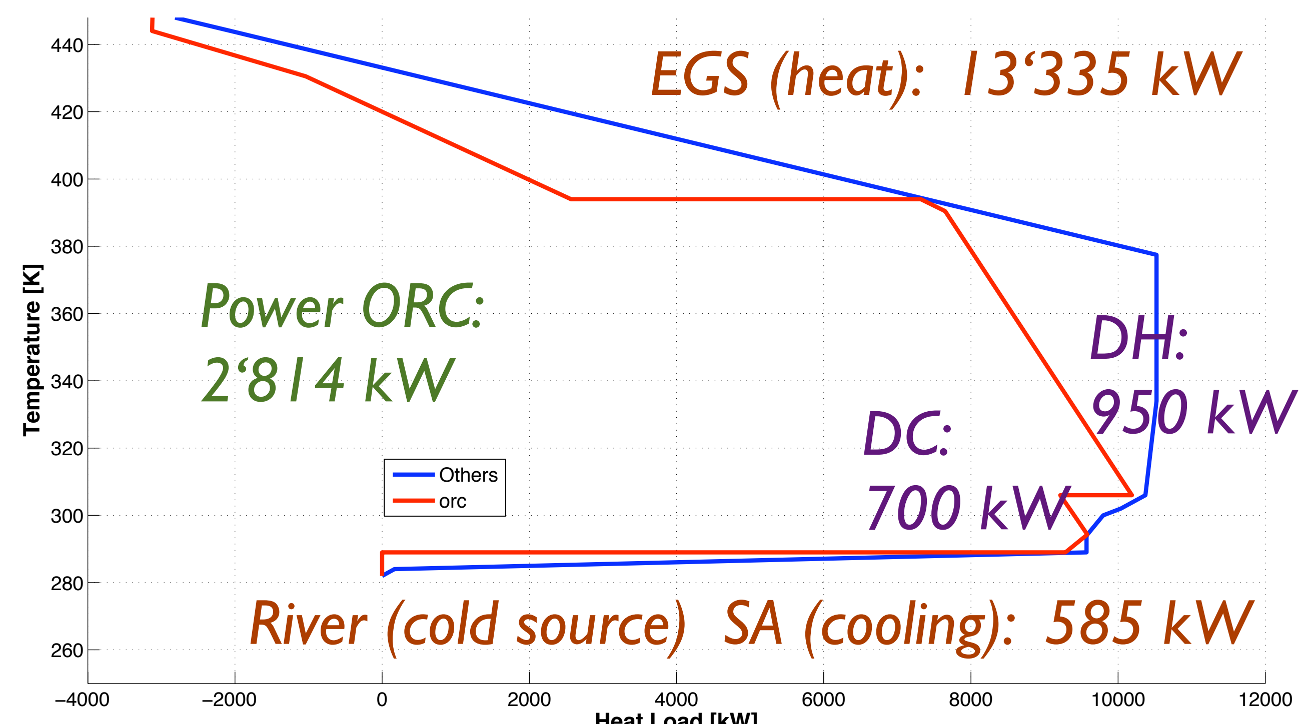

## Extreme winter




## Summer




## Interseason



# Energy integration results

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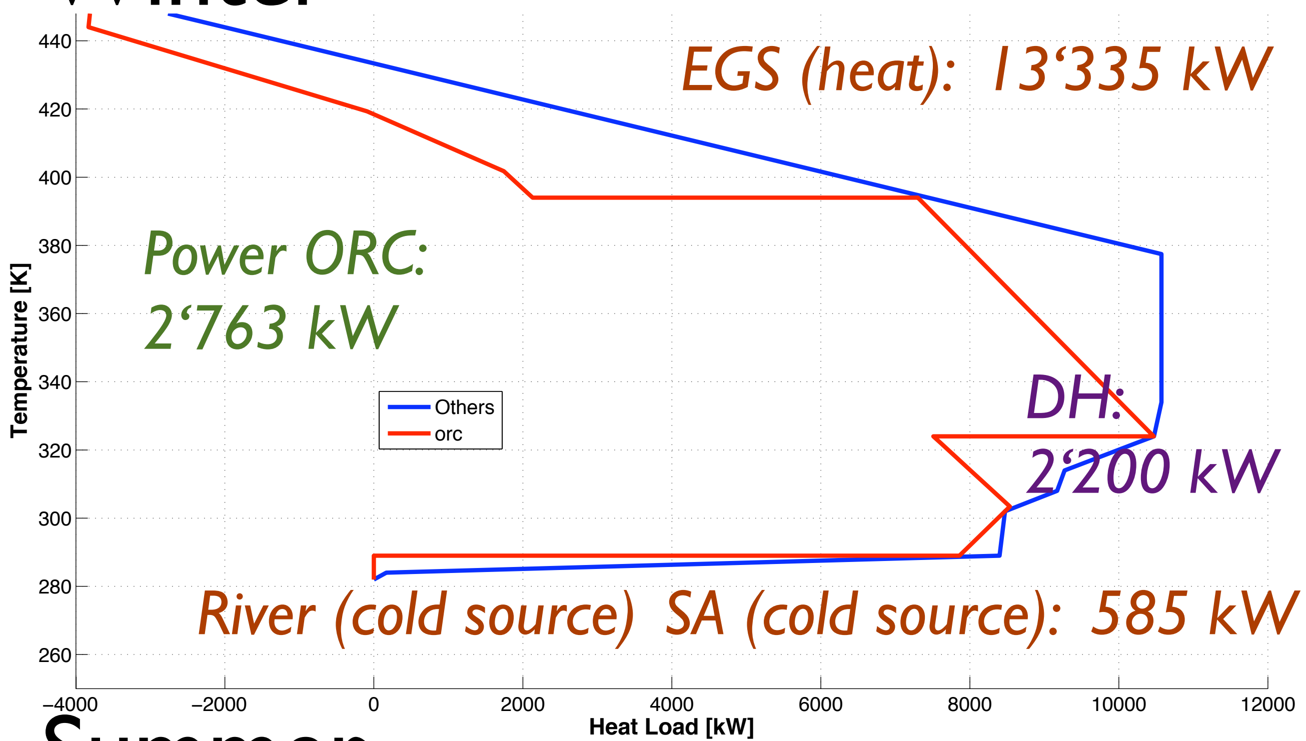


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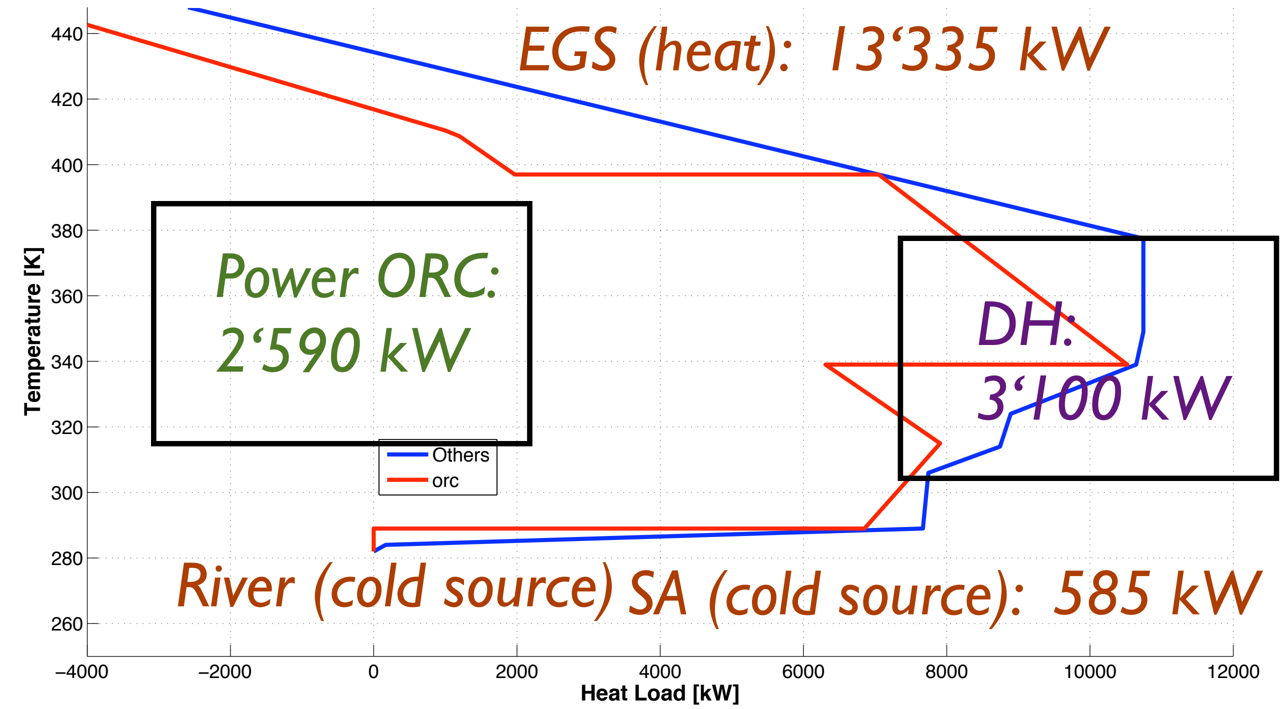


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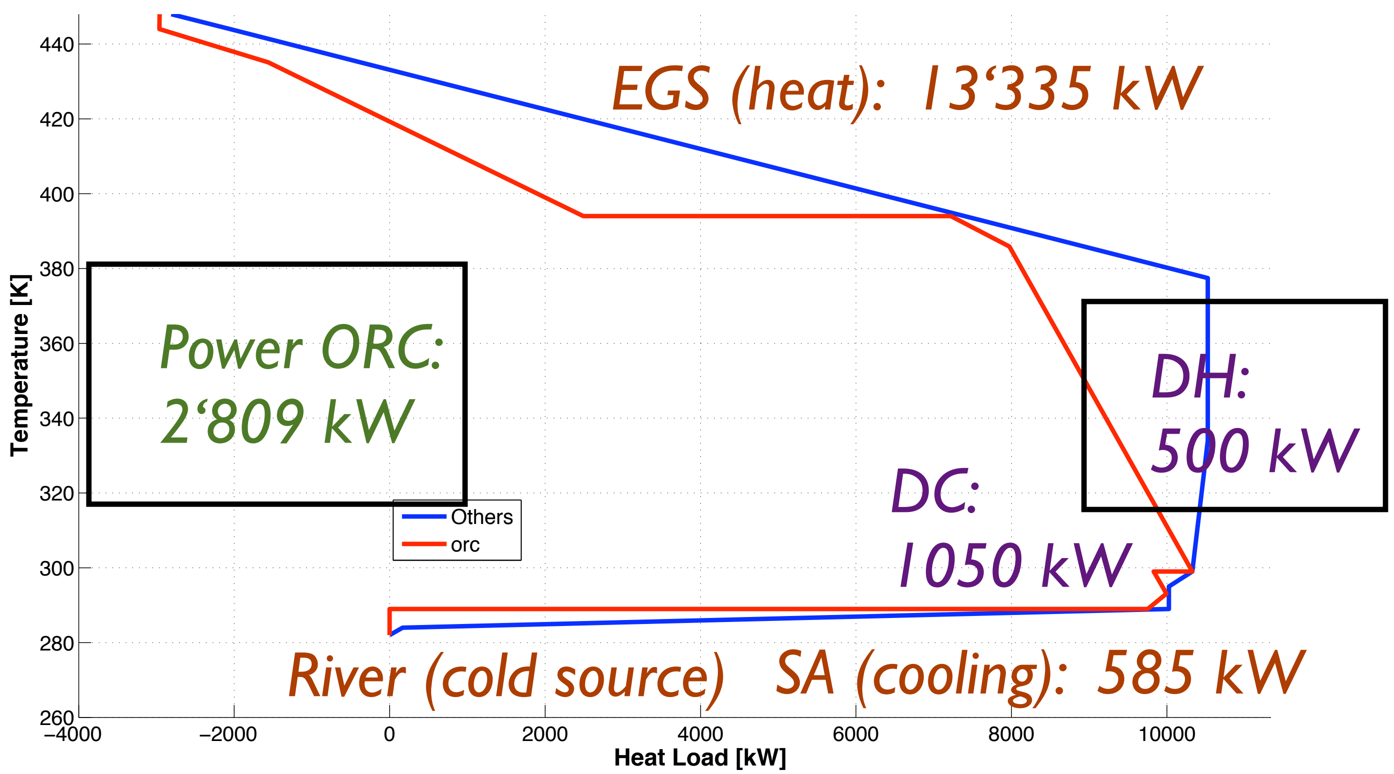


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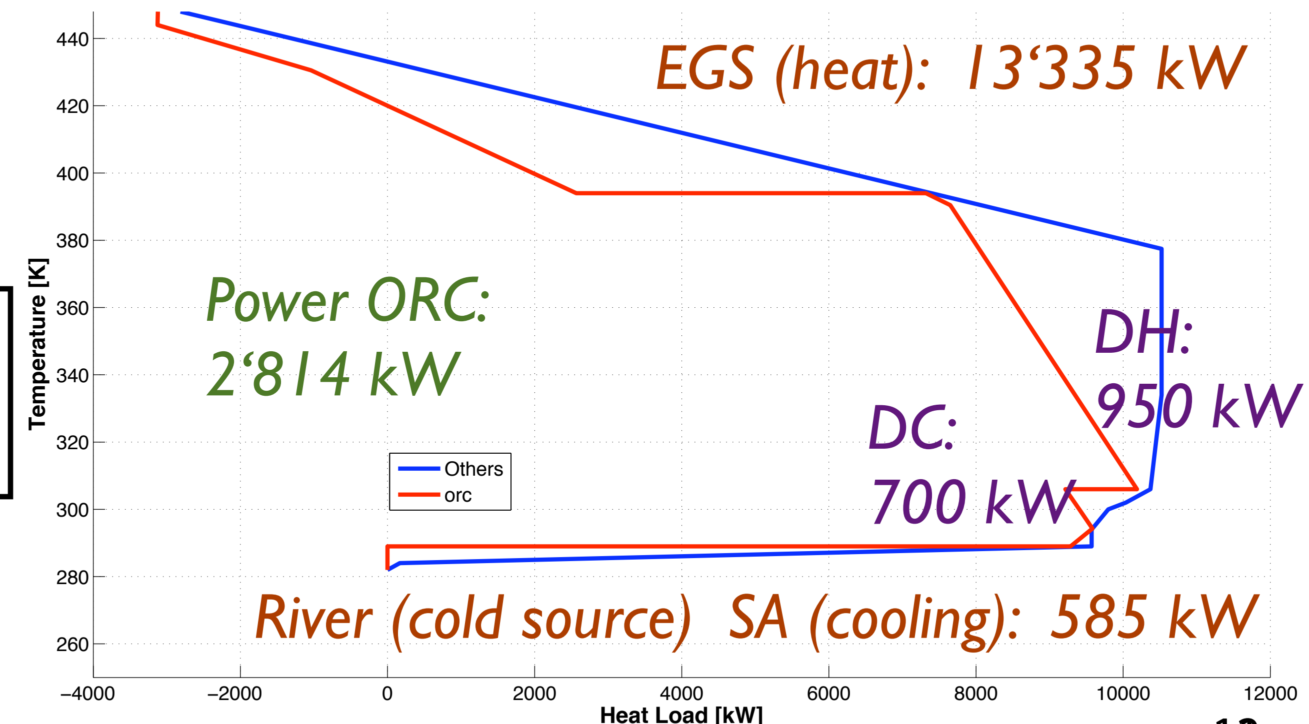
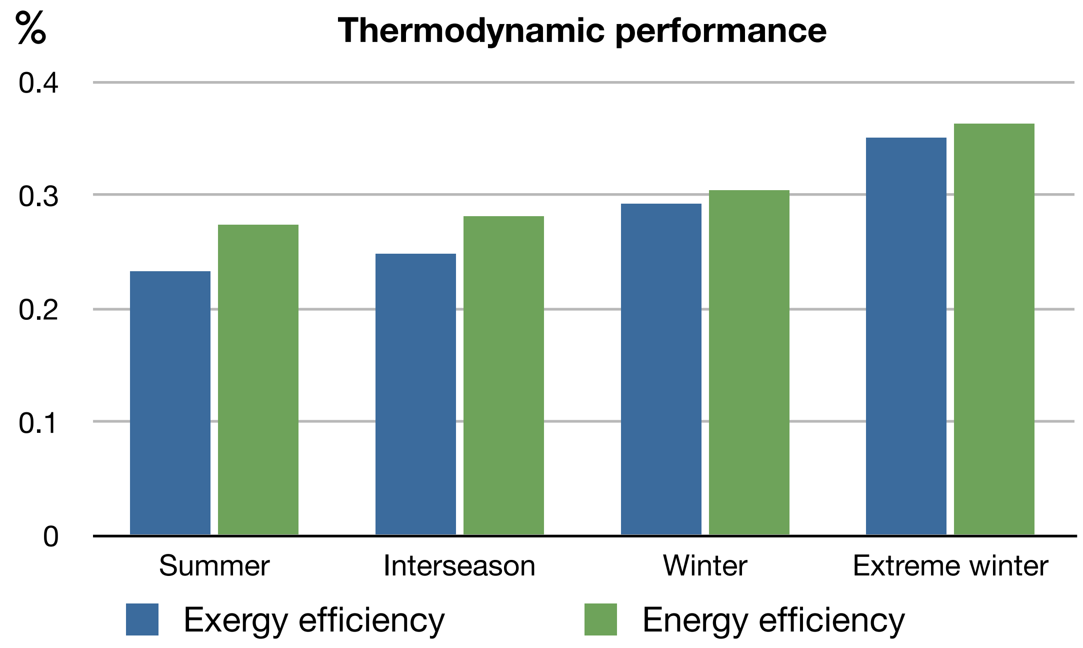
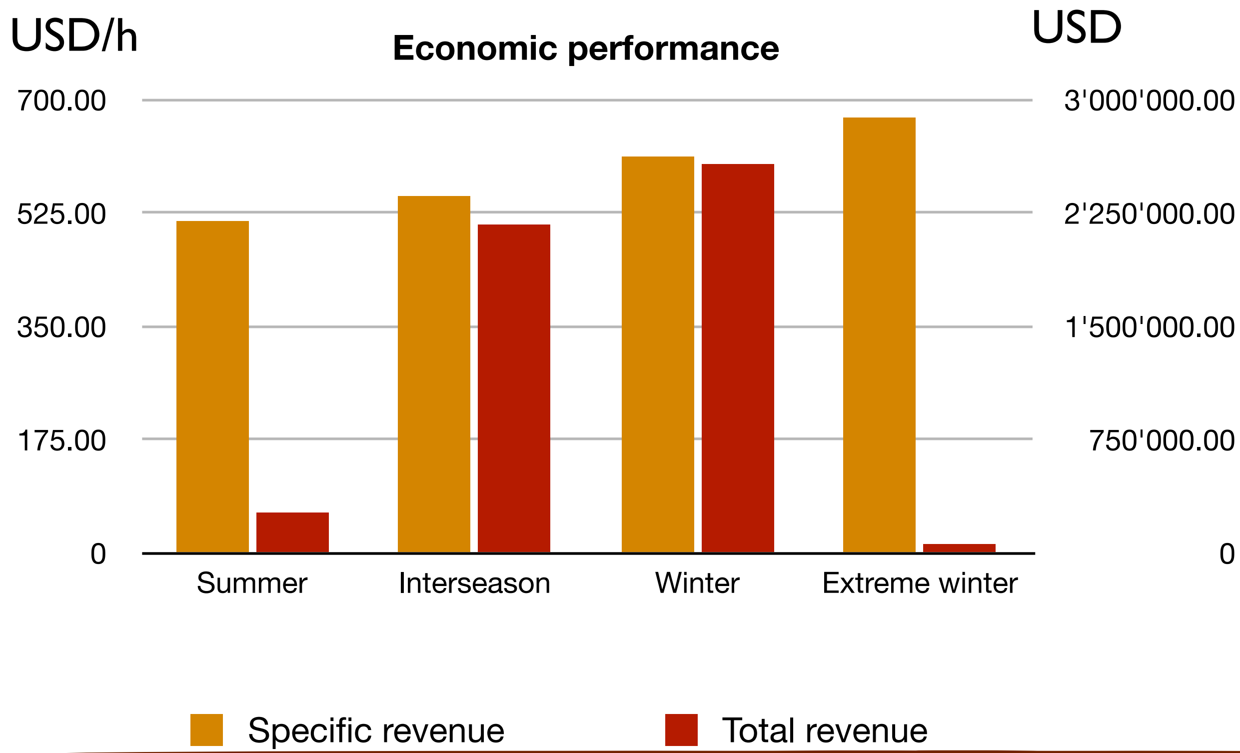


# System performance




Exergy efficiency, average: 27.0%

Energy efficiency, average: 29.3%

Net profit, accounting for all costs: 395'438 $/yr

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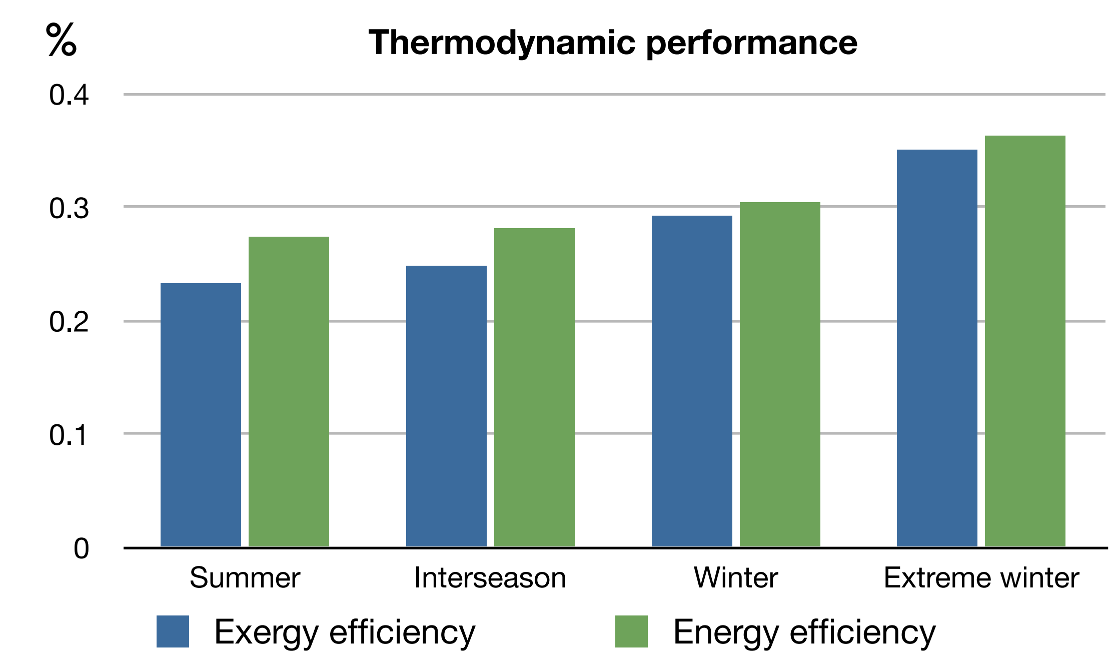


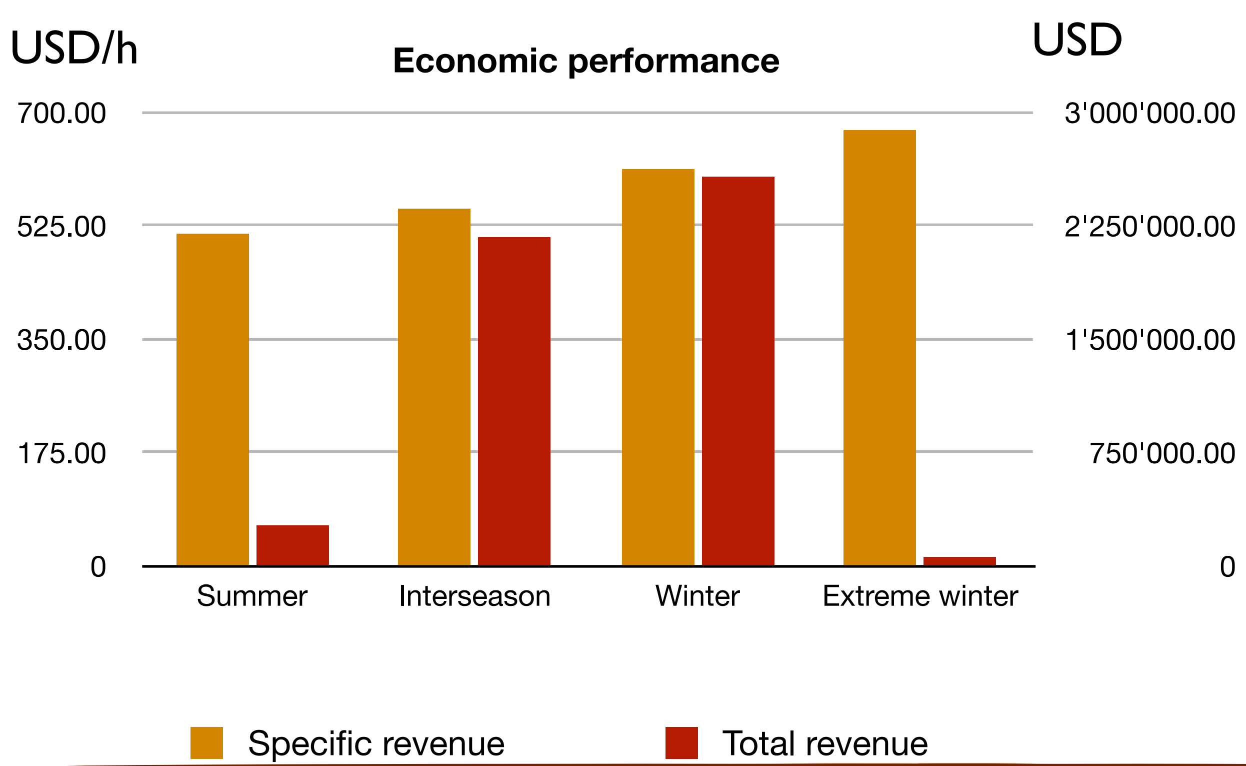


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- *Parasitic power (530 kW for EGS!)*
- *More potential for district heating*

Net profit, accounting for all costs: 395‘438 $/yr

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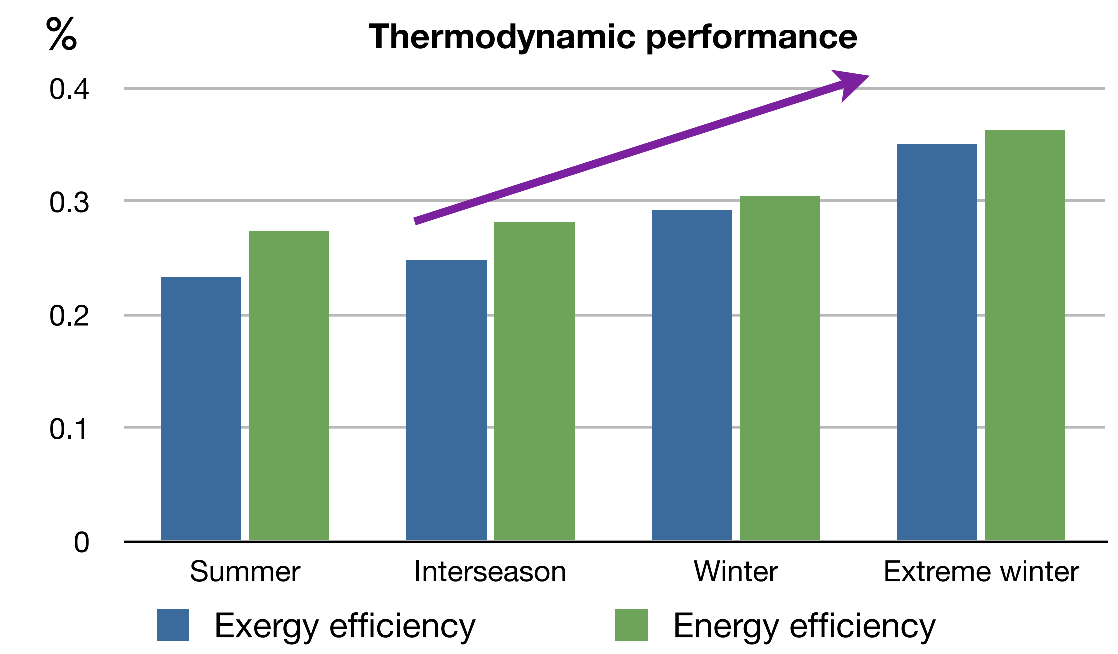


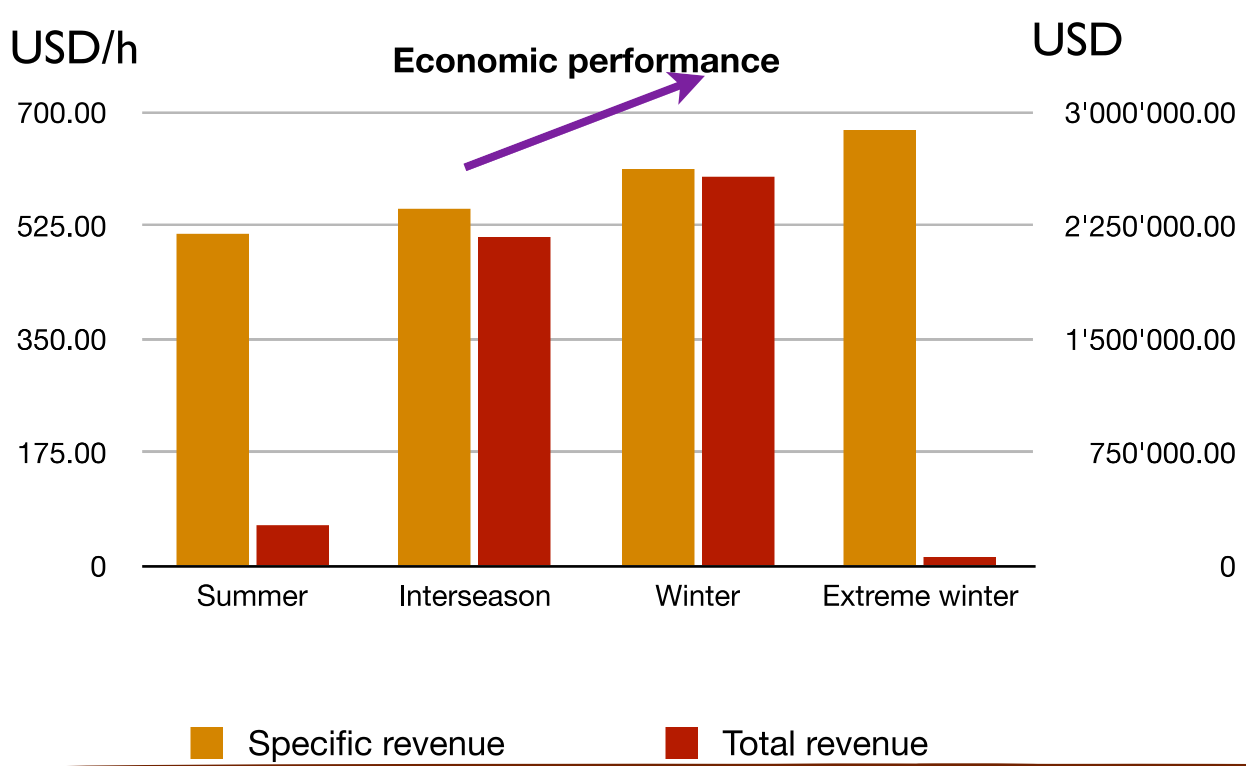


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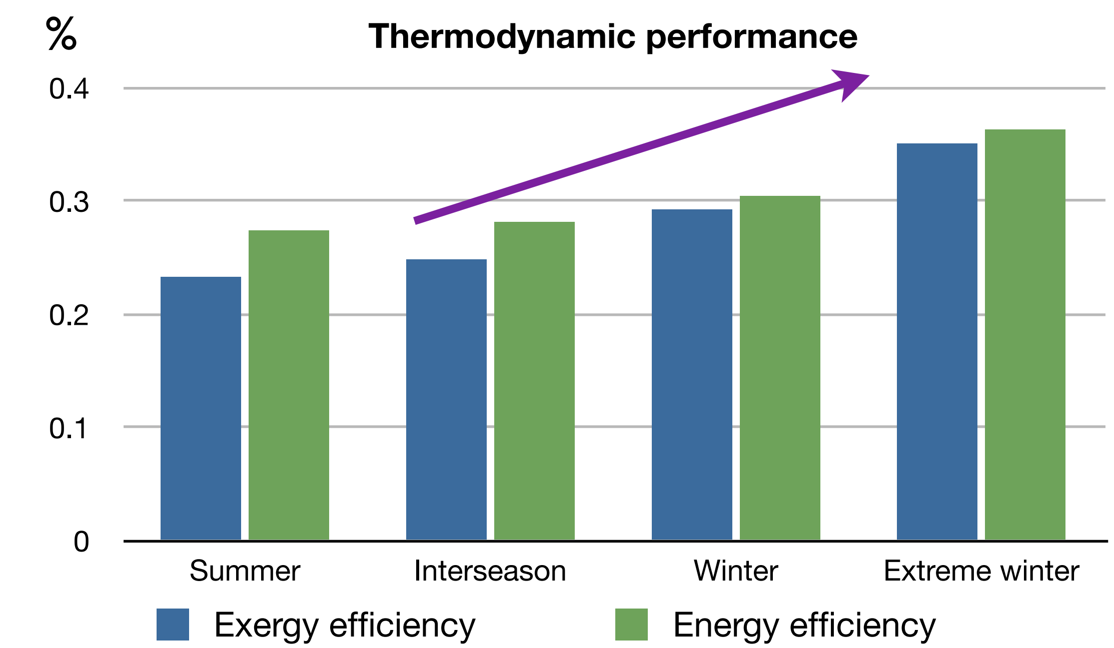


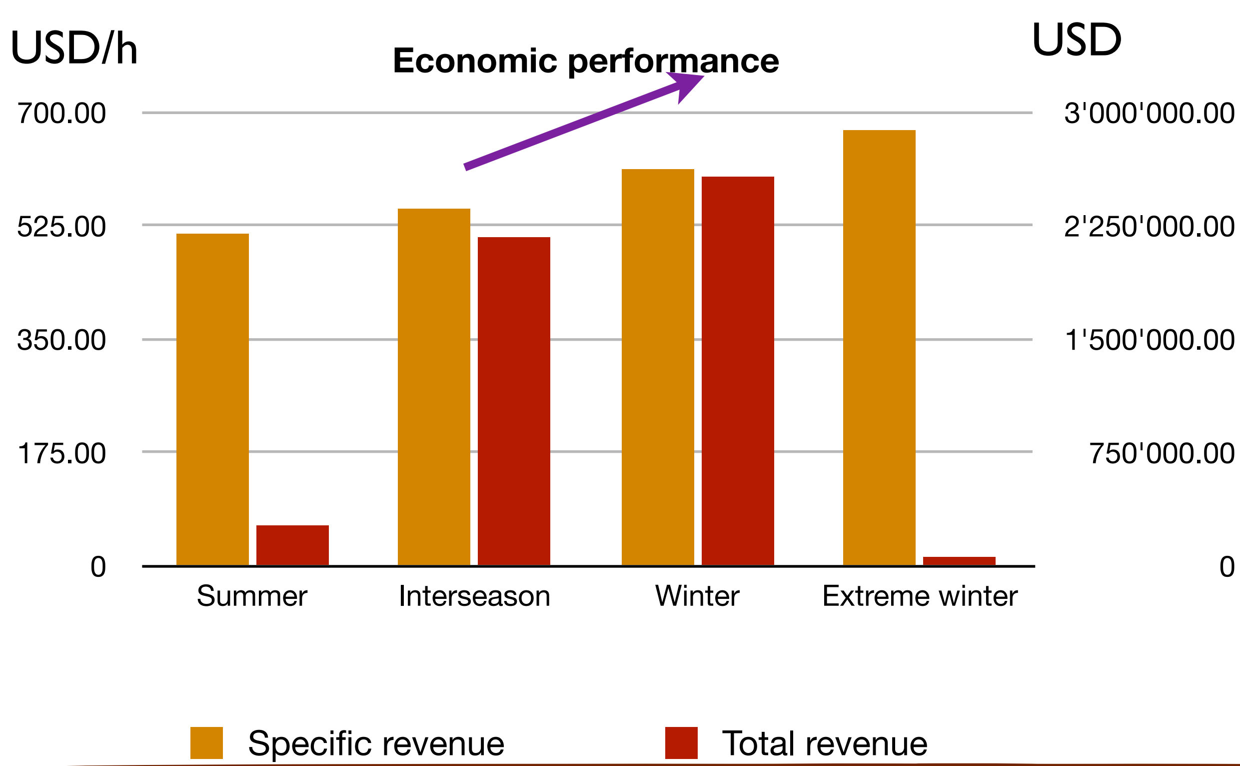


| | |
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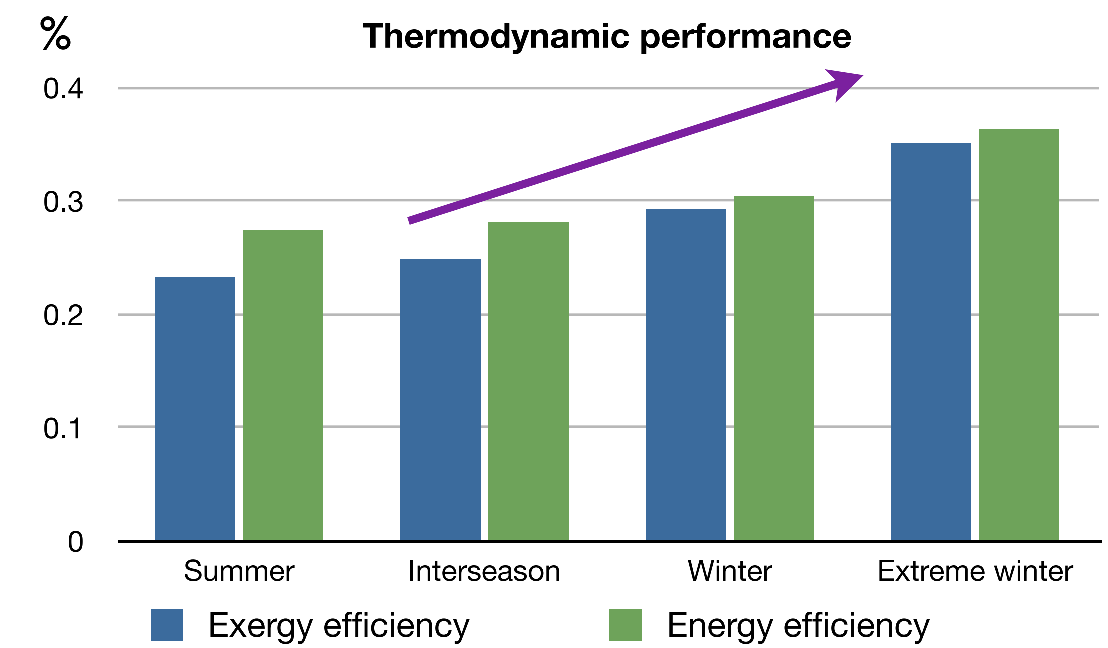


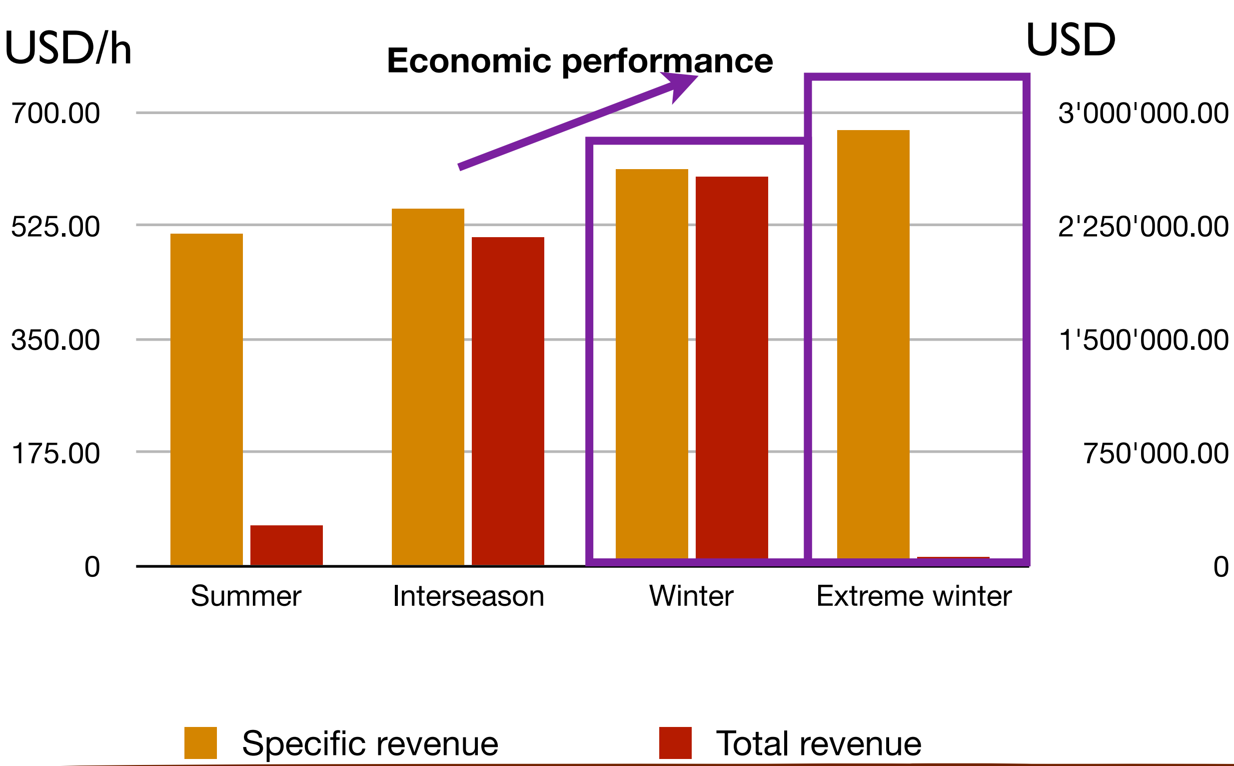


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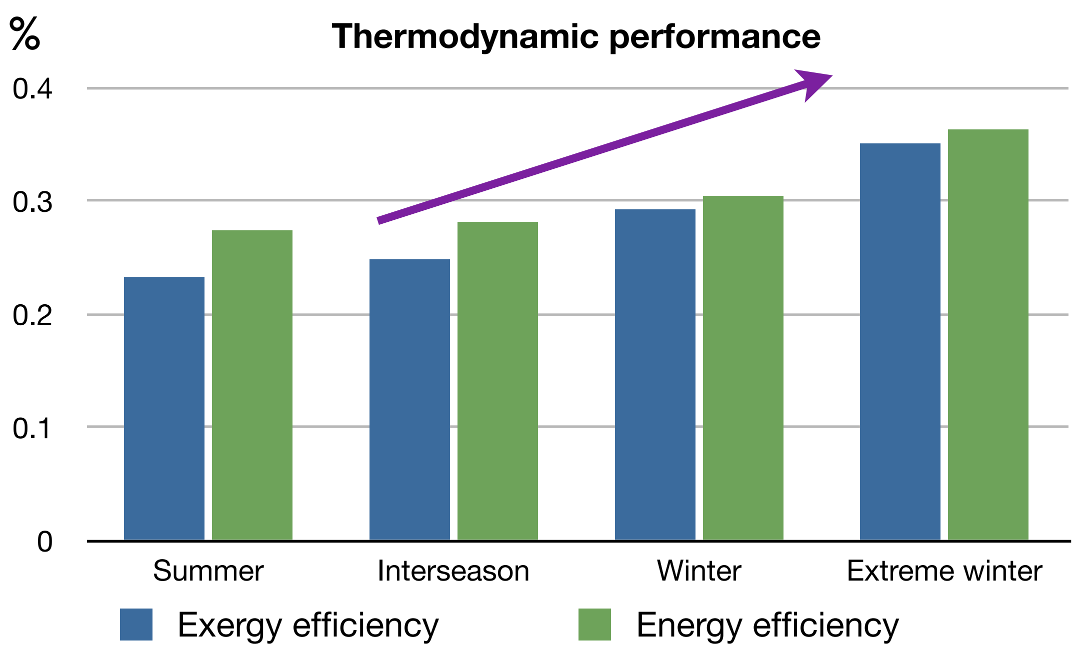


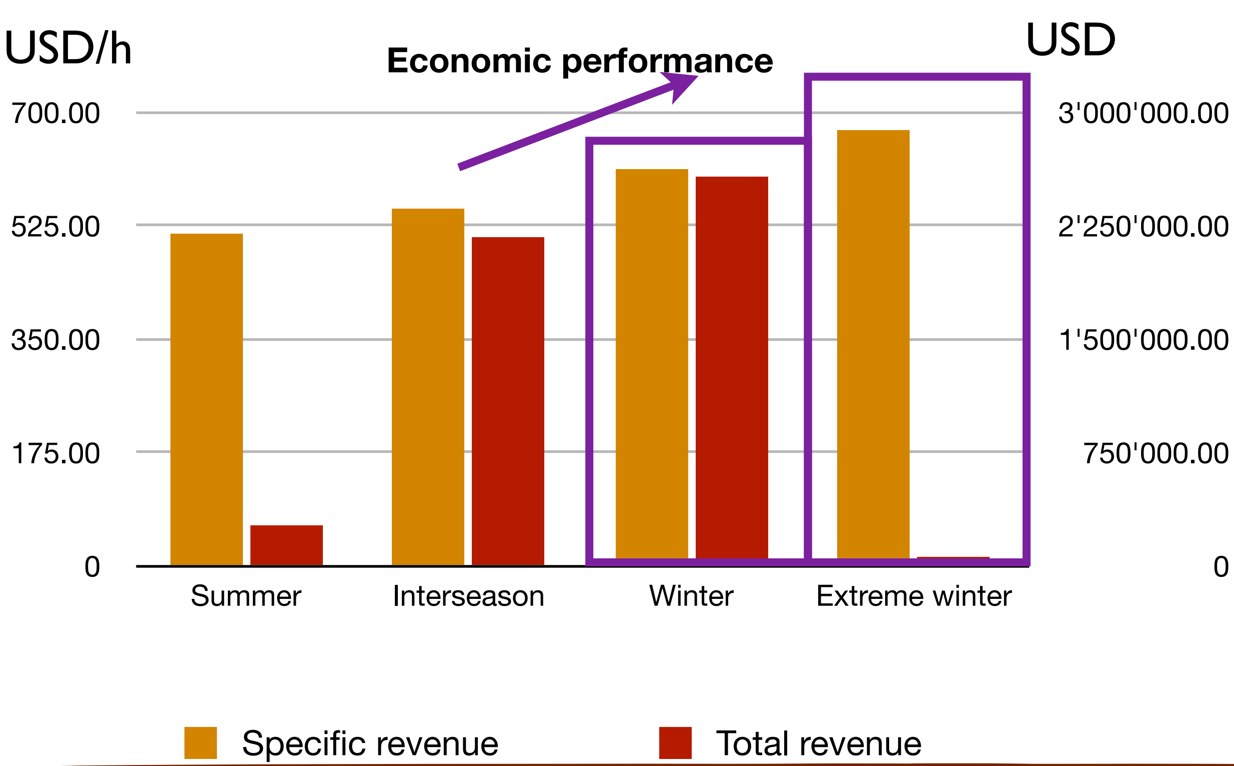


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➡*Importance of site conditions (demand and climate)*

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# Conclusions

- Integration of 3 components allows for accurate system description
  - Accounts for site specificities
- Importance of the multi-period approach
  - Seasonal variation in demand
    - Influences system design
  - Allows to identify potentials for seasonal storage
- Cogeneration to improve efficiency of geothermal resource usage

# Perspectives

- Optimal process design
  - Multi-objective optimization
- Integration of environmental performance indicators using LCA
- Integration of seasonal heat storage possibilities
  - Geothermal residual heat valorization
  - Solar thermal energy storage

Thank you for your attention!