Multi-stakeholder technical-economic analysis of the design of a waste heat recovery system on district heating networks

Analyse technico-économique multi-acteurs de la conception d'un système de valorisation de chaleur fatale sur réseau de chaleur

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Energy communities for collective self-consumption: frameworks, practices and tools
Session 3 – June 16, 2020
Which skills and tools to support energy communities?

Outline

Aim of this study : *To illustrate the application of a multi-actor approach on a real case study at urban scale, in order to optimize the design of a waste heat recovery system.*

Objectives of our communication

- Identify the most promising actor configuration.
- Identify the selection criterion that facilitates most agreements between actors.
- Identify the globally most promising design.
- Suggest some information visualization tools to facilitate actor-based negotiations.

Structure of this presentation

- Introduction.
- System description.
- Method.
  - Generic aspects.
  - Specific approach for each actor.
- Results.
  - Energy/economy analysis for each actor.
  - Actor/Actor interactions.
- Conclusions and perspectives.

Introduction

Evolution of energy networks

New generations (3rd and onwards)

New sources (renewables, energy recovery)

Diversity of sources and applications

Diversity of actors in the projects

Need for multi-actor approaches

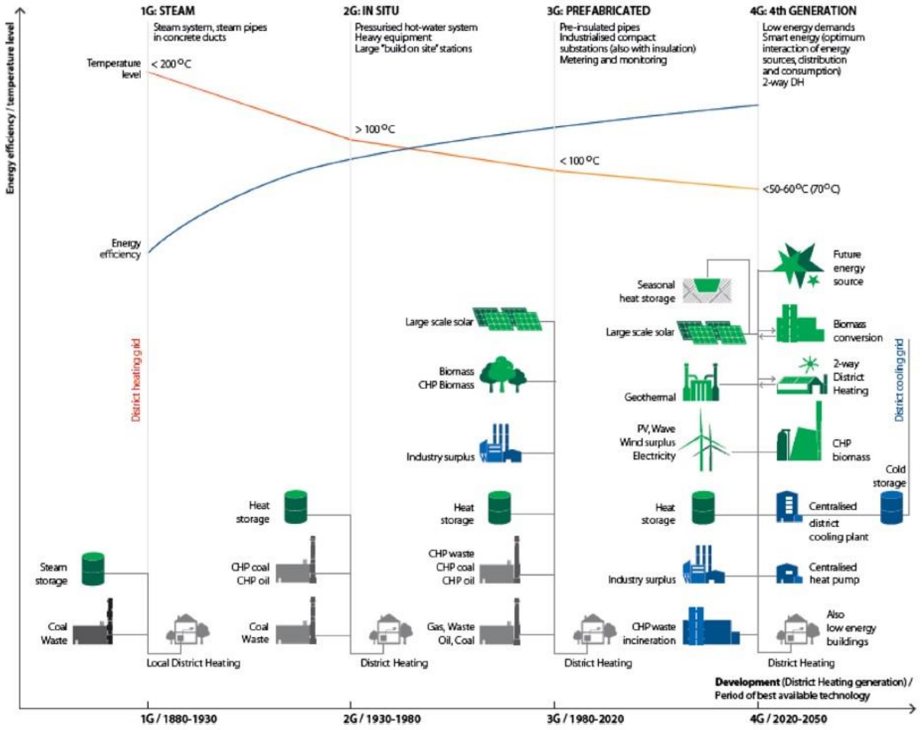


Fig. 2. Illustration of the concept of 4th Generation District Heating in comparison to the previous three generations.

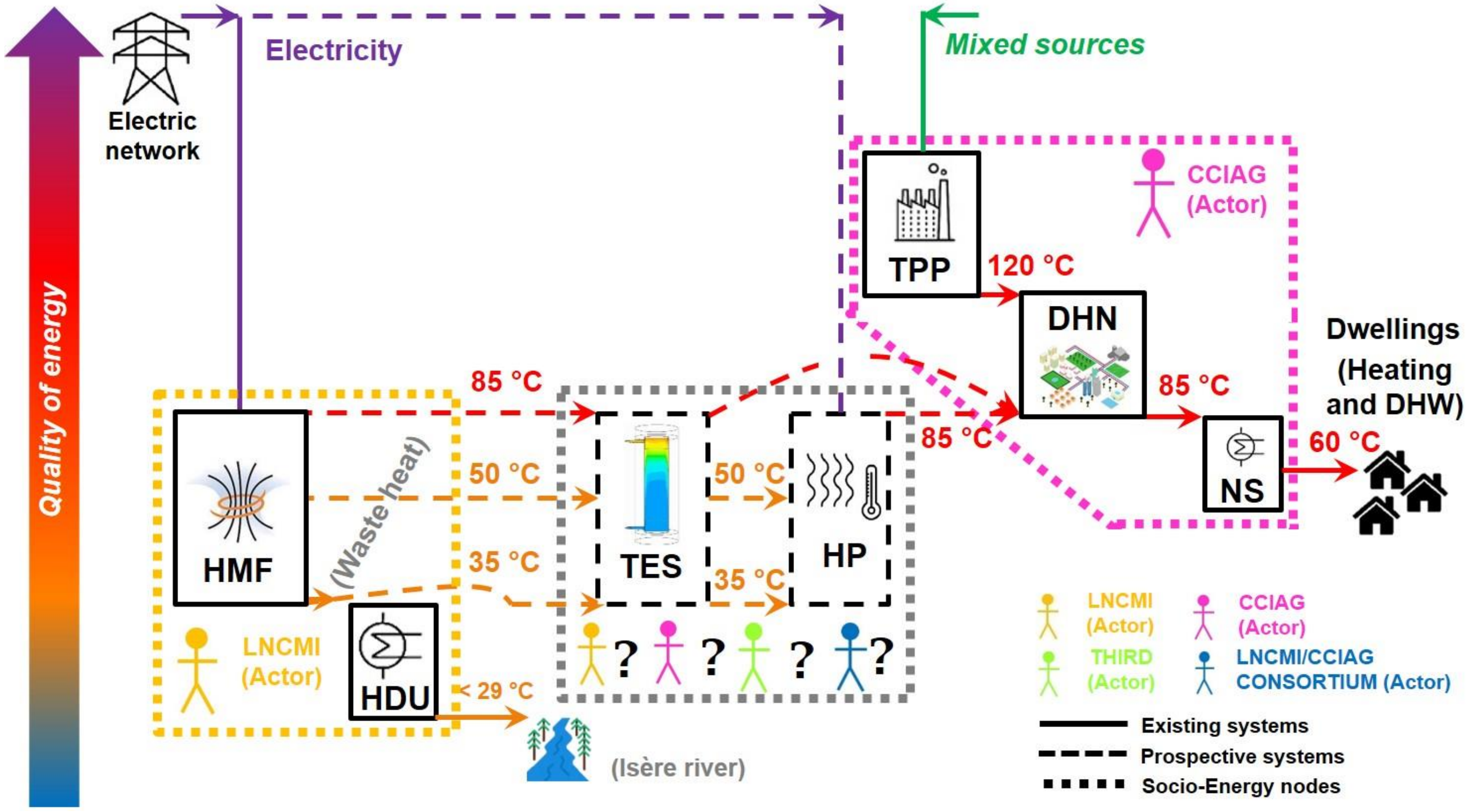
Source: Lund et al, 2014, Energy *vol. 68 pp. 1-11.*

Socio-technical optimality gap (Hinker)

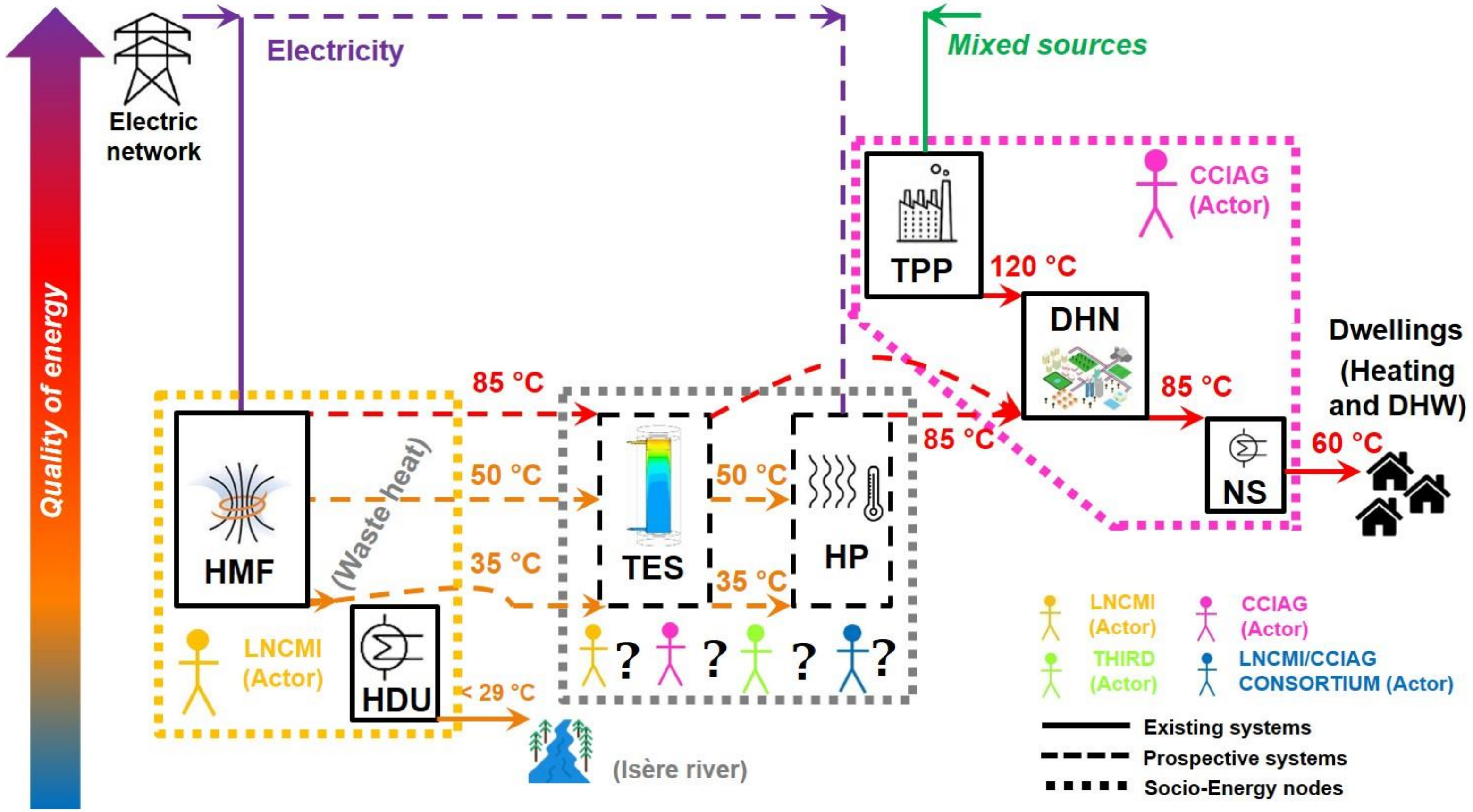
- ❖ A new system unit may be linked to several energy units.
- ❖ Area of responsibility is different for each actor.
- ❖ Several performance indicators for each actor.
- ✓ Assemblage of Socio-Energy Nodes (Debizet and Tabourdeau)

System description – Case study in Grenoble

- Main Existing actors/systems
  - LNCMI : high electricity consumer
  - CCIAG : City Heating Utility
- Prospective system for recovery of industrial waste heat made up of:
  - Thermal storage (STOCK)
  - Heat pump (if needed) (PAC)
- 4 ownership scenarii:
  - LNCMI or CCIAG
  - A consortium between the two
  - A third party (external)

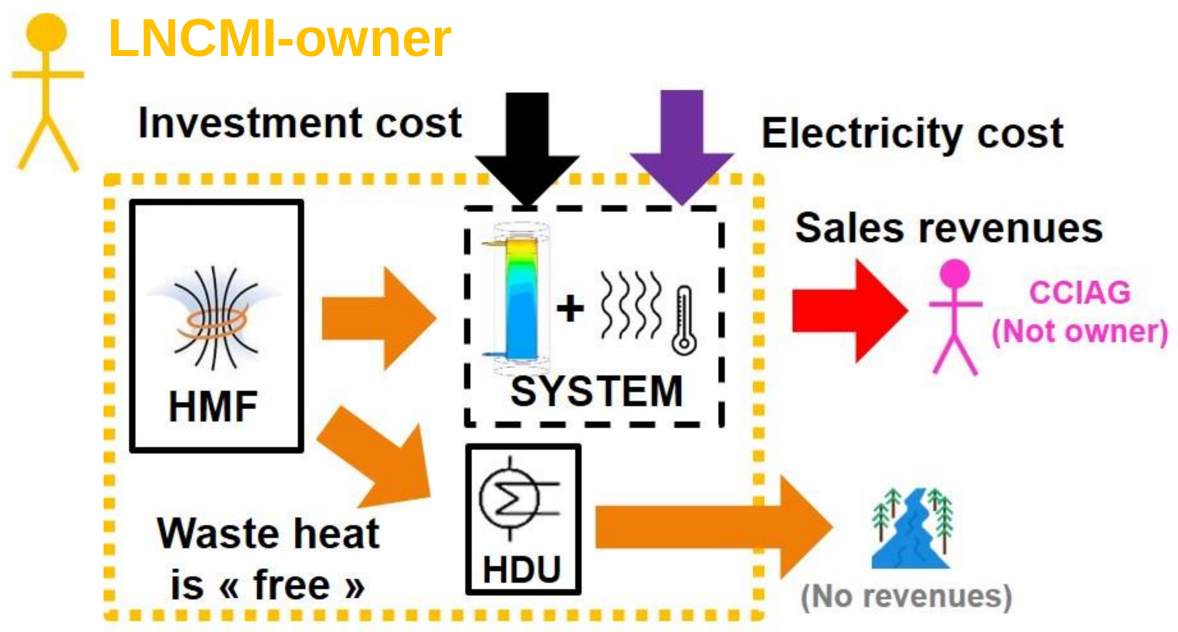


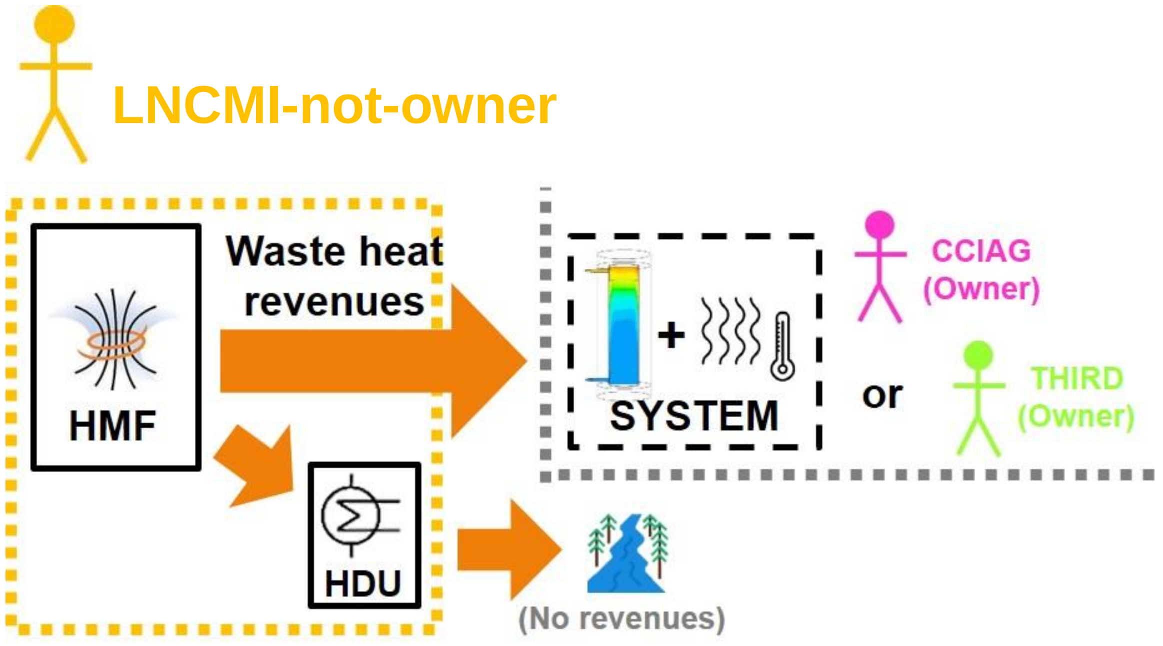
Method – Generic aspects



- Yearly simulation.
- Mixed-integer linear programming.
- Energy balance on each unit:
  - High Magnetic Fields (HMF).
  - Heat Dissipation Unit (HDU).
  - Thermal Energy Storage (TES).
  - Heat Pump (HP).
  - Thermal Production Plant (TPP).
  - District Heating Network (DHN).
  - Network's Sub-stations (NS).
- Cost flow balance on each unit.
- Optimize design by choosing from
  - 3 waste heat temperatures.
  - 5 thermal storage capacities.
- 2 criteria: Energetic and Economic.
- Specific indicators for each actor.

Method – Specific approach for LNCMI





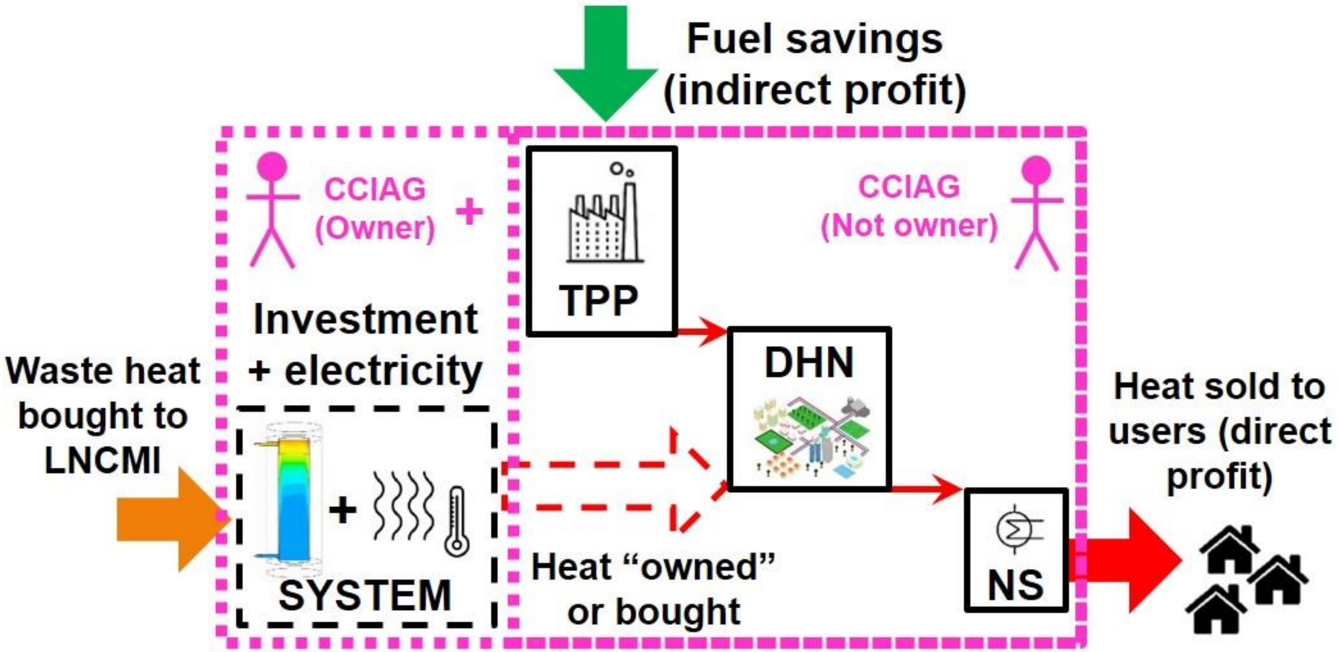
$$NPVO_{LNCMI} = \frac{C_{SYSTEM}^{Q,out} - C_{HP}^{elec,in} - \dot{Z}^{M}}{CRF} - Z^{Inv}$$

$$NPVN_{LNCMI} = \frac{C_{LNCMI}^{wh,sold}}{CRF}$$

Energetic indicator:
(Whether owner or not)

$$Recovery\ Factor\ (RF) = \frac{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{SYSTEM}^{in}(t) \cdot \Delta t}{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{LNCMI}^{wh}(t) \cdot \Delta t} \cdot 100$$

Method – Specific approach for CCIAG



Energetic indicator (whether owner or not)

$$Coverage\ Factor\ (CF) = \frac{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{SYSTEM}^{out}(t) \cdot \Delta t}{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{DHN}^{load}(t) \cdot \Delta t} \cdot 100$$

Economic indicator

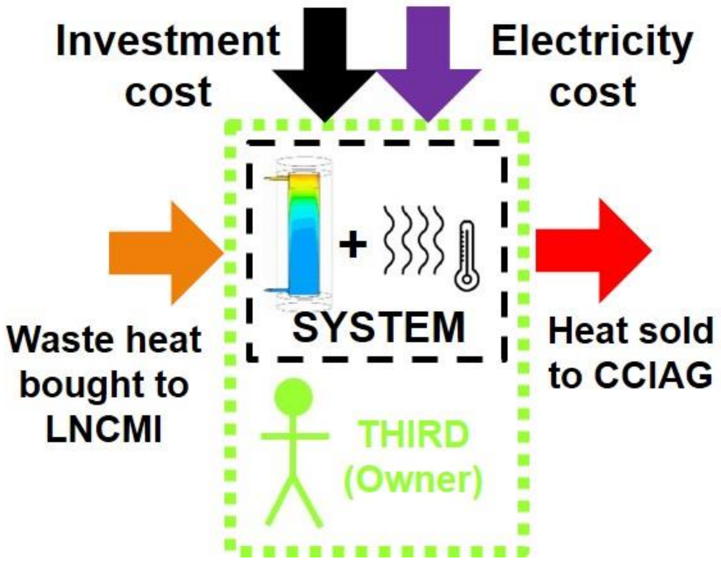
Owner :

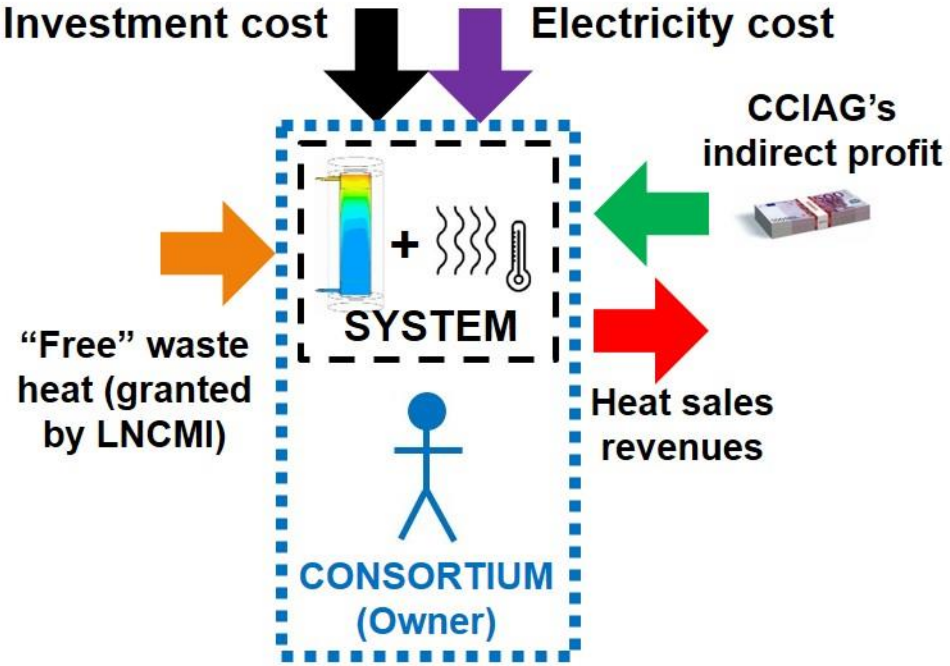
$$NPVO_{CCIAG} = \frac{\left(Q_{SYSTEM}^{out} \cdot c_{SYSTEM}^{Q,out} + c_{TPP}^{En,in} \cdot \left(En_{TPP}^{in,REF} - En_{TPP}^{in}\right) - C_{LNCMI}^{wh} - C_{SYSTEM}^{elec,in} - \dot{Z}^{M}\right)}{CRF} - Z^{Inv}$$

Not-owner :

$$NPVN_{CCIAG} = \frac{\left[Q_{SYSTEM}^{out} \cdot \left(c_{NS}^{Q,out} - c_{SYSTEM}^{Q,out}\right) + c_{TPP}^{En,in} \cdot \left(En_{TPP}^{in,REF} - En_{TPP}^{in}\right)\right]}{CRF}$$

Method -- Approaches for THIRD and CONSORTIUM





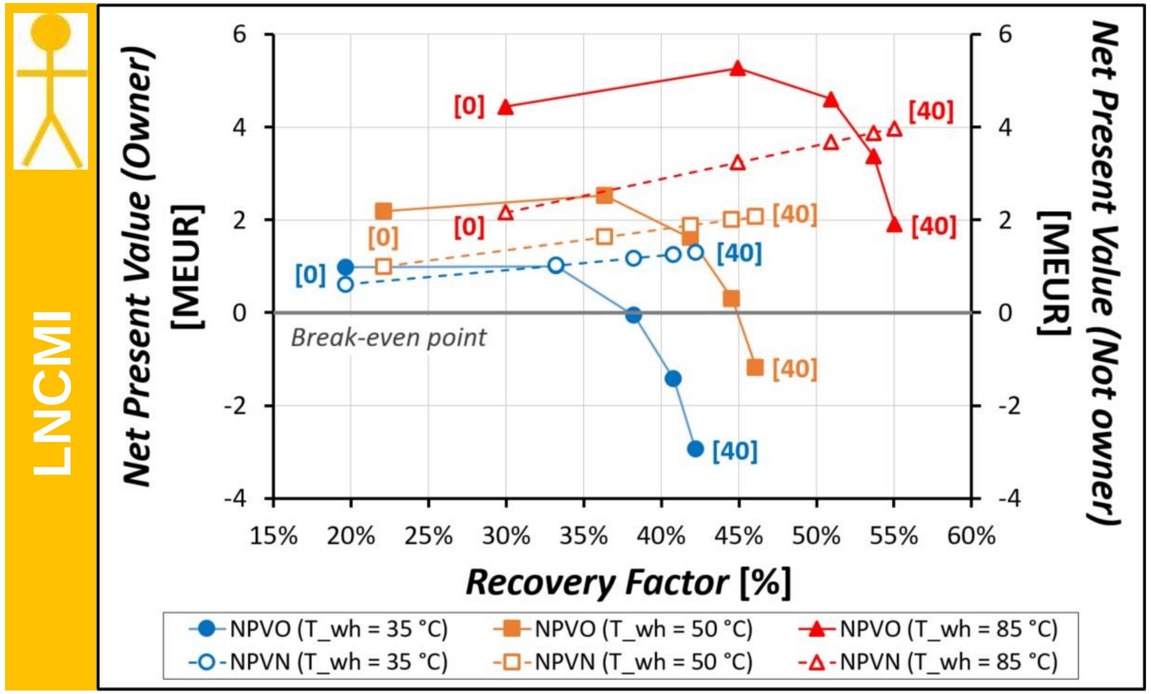
$$Valorization\ Factor\ (VF) = \frac{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{SYSTEM}^{out}(t) \cdot \Delta t}{\sum_{t=t_{ini}}^{t=t_f} \dot{Q}_{LNCMI}^{wh} \cdot \Delta t} \cdot 100$$

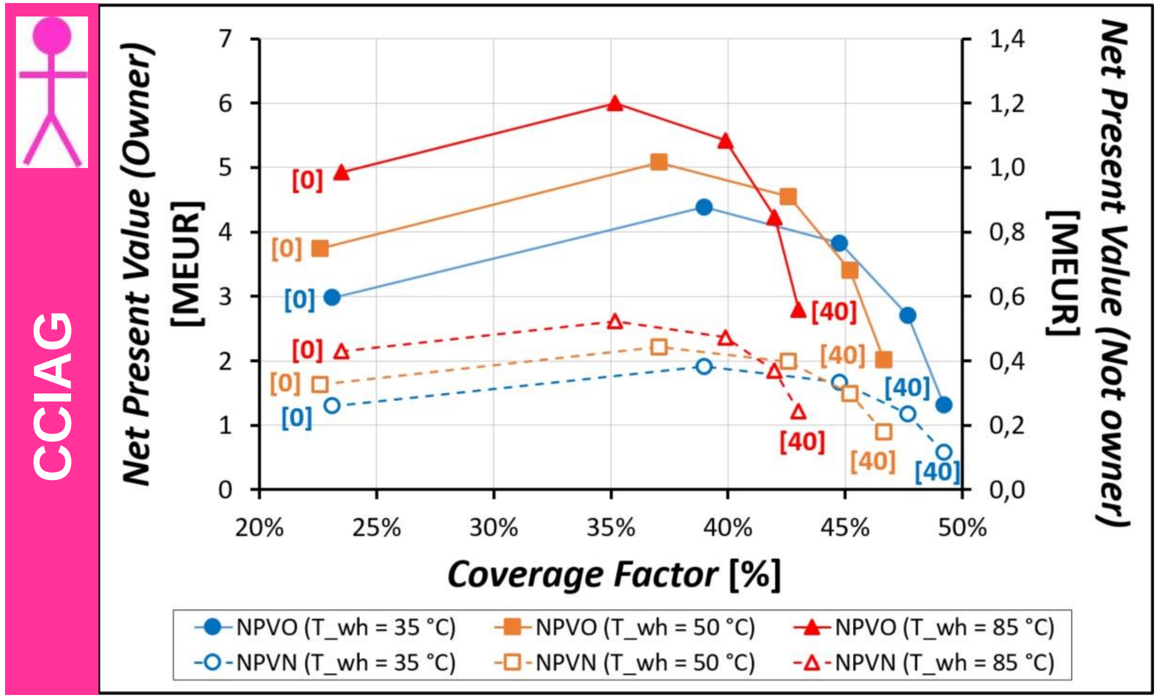
$$Recovery\ and\ Coverage\ Factor\ (RACF) = RF \cdot CF$$

$$NPVO_{THIRD} = \frac{C_{SYSTEM}^{Q,out} - C_{LNCMI}^{wh,out} - C_{SYSTEM}^{elec,in} - \dot{Z}^{M}}{CRF} - Z^{Inv}$$

$$NPVO_{CSRT} = \frac{C_{SYSTEM}^{Q,out} + C_{TPP}^{fuel\ savings} - C_{SYSTEM}^{elec,in} - \dot{Z}^{M}}{CRF} - Z^{Inv}$$

Results – Energy/economy for LNCMI and CCIAG

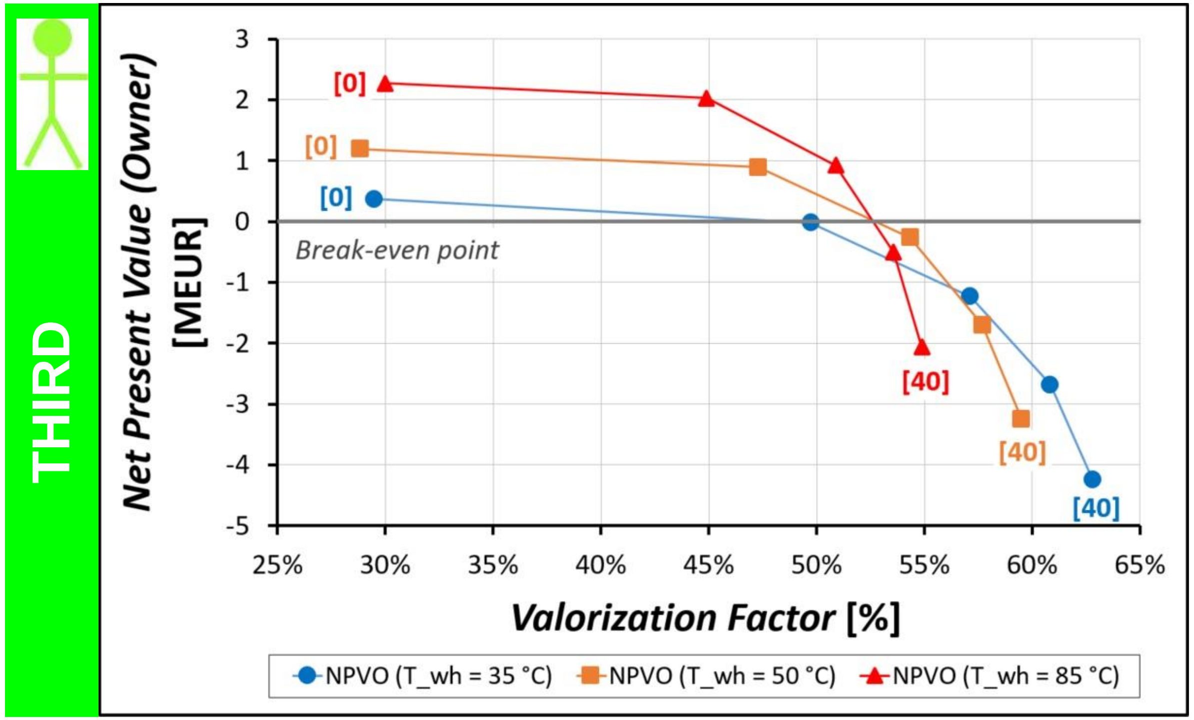


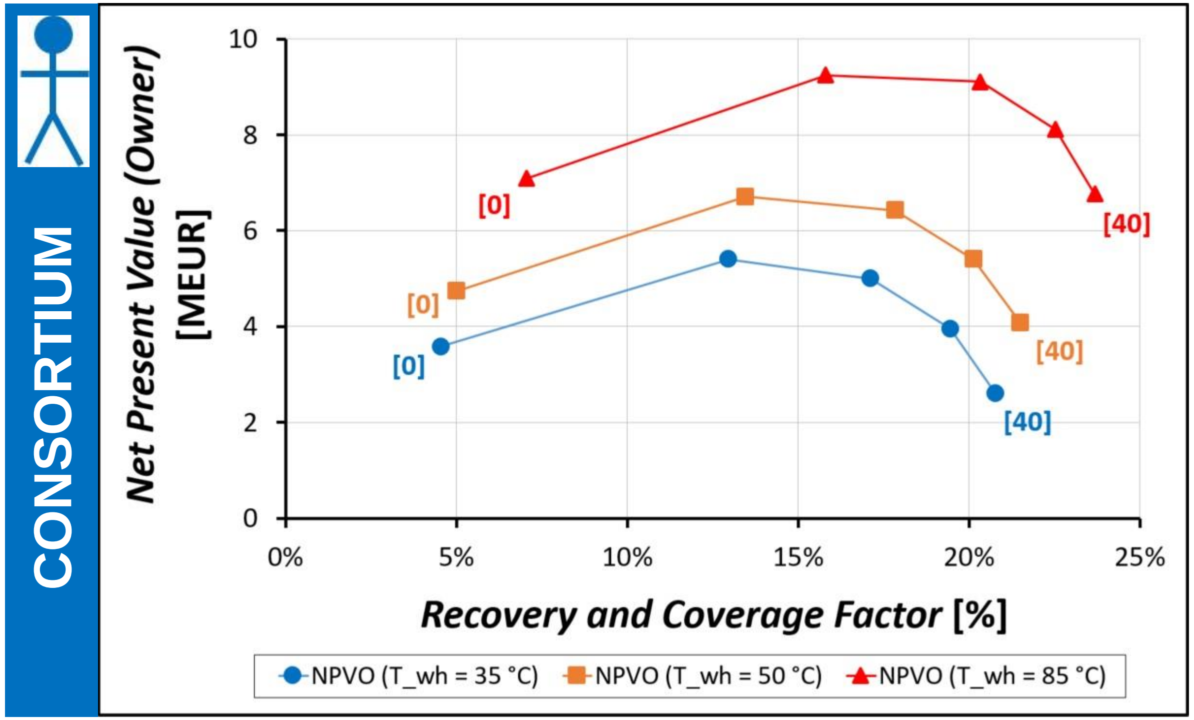


- ❖ Not always profitable if owner.
  - ❖ (Marginal investment outweighs additional revenues)
- ✓ Energy-optimal: **85 °C**, **40 MWh** (Owner or not).
- ✓ Economy-opt.: **85 °C**, **10 MWh** (Owner) / **40 MWh** (Not owner).
- ✓ Pareto-optimal solutions from 10 MWh to 40 MWh if owner.

- ✓ Always profitable, whether owner or not owner.
  - ✓ (Fuel savings in heat production plants)
- ✓ Energy-optimal: **35 °C**, **40 MWh** (Owner or not).
- ✓ Economy-optimal: **85 °C**, **10 MWh** (Owner or not).
- ✓ Pareto-optimal solutions between 10 MWh and 40 MWh.

Results – Energy/economy for LNCMI and CCIAG





- ✓ Energy-optimal : **35 °C, 40 MWh** (**but not rentable**).
- ✓ Economy-optimal : **85 °C, 0 MWh** (close for 10 MWh).
- ❖ Not profitable in many scenarios -> Complex negotiations.
  - ❖ Negotiate with LNCMI for waste heat price.
  - ❖ Negotiate with CCIAG for valorized heat price.

- ✓ Energy-optimal: **85 °C, 40 MWh**.
- ✓ Economy-optimal: **85 °C, 10 MWh**.
- ✓ Project is always profitable.
  - ✓ Waste heat is “free” (LNCMI is in the Consortium).
  - ✓ Fuel savings are “mutualized” (CCIAG).

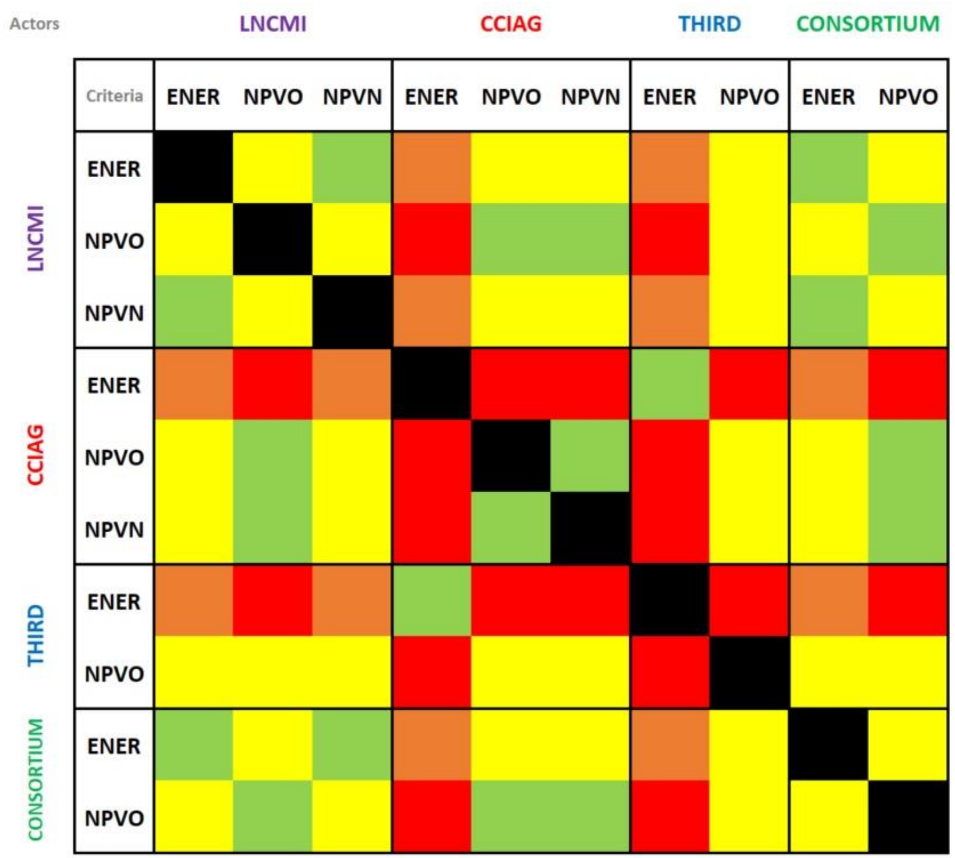
Results – Actor/actor analyses

4 unique monocriterion-optimal solutions identified

Criterion \ Actor	LNCMI	CCIAG	THIRD	CONSORTIUM
Energetic	85 °C, 40 MWh	35 °C, 40 MWh	35 °C, 40 MWh	85 °C, 40 MWh
NPV (Owner)	85 °C, 10 MWh	85 °C, 10 MWh	85 °C, 0 MWh	85 °C, 10 MWh
NPV (Not owner)	85 °C, 40 MWh	85 °C, 10 MWh	N/A	N/A

Direct agreement
Negotiations over storage capacity
Negotiations over temperature
Negotiations over both

Cross-analysis matrix



- Energetic criterion is controversial for CCIAG and THIRD.
- THIRD has the most complex negotiation scenario.
  - Double-bound by LNCMI's and CCIAG's price constraints.
- CONSORTIUM satisfies existing actors to an extent.
  - LNCMI -> Energy- and economy-wise.
  - CCIAG -> Economy-wise.
- Economic criterion brings most agreements.
  - Promising, because it contains the energy criterion in some way.

Conclusions and perspectives

Objectives

- Most promising actor configuration?
- Most conciliating criterion?
- Most promising design?
- Tools to facilitate negotiations?

Conclusions

- ✓ LNCMI/CCIAG CONSORTIUM.
- ✓ Economy.
- ✓ 85 °C with 20 MWh (refer to manuscript).
- ✓ Cross-analysis matrix.

Limitations

- ❖ Optimize energy & economy in operation?
- ❖ In-depth negotiation analysis?
- ❖ Increase model robustness?

Perspectives

- ➢ OMEGAlpes.
- ➢ Constraints relaxation, choices and changes of assemblages.
- ➢ Additional criteria (exergy, exergoeconomy, environment…), additional actors.

Bibliography

[1] Farías I, Bender T. Urban assemblages: How Actor-Network Theory Changes Urban Studies. London and New York: Routledge; 2010. doi:https://doi.org/10.1080/02723638.2013.779486.

[2] Hampikian Z. De la distribution aux synergies ? : Circulations locales d'énergie et transformations des processus de mise en réseau de la ville. Université Paris-Est, 2017. doi:https://pastel.archives-ouvertes.fr/tel-01586025/document.

[3] Debizet, Gilles, Antoine Tabourdeau, Caroline Gauthier, et Philippe Menanteau. 2016. « Spatial processes in urban energy transitions: considering an assemblage of Socio-Energetic Nodes ». Journal of Cleaner Production, Special Volume: Transitions to Sustainable Consumption and Production in Cities, 134 (octobre): 330 41. https://doi.org/10.1016/j.jclepro.2016.02.140.

[4] Hinker J, Hemkendreis C, Drewing E, März S, Hidalgo Rodríguez DI, Myrzik JMA. A novel conceptual model facilitating the derivation of agent-based models for analyzing socio-technical optimality gaps in the energy domain. Energy 2017;137:1219–30. doi:10.1016/j.energy.2017.06.038.

[5] Fitó J, Hodencq S, Ramousse J, Wurtz F, Stutz B, Debray F, et al. Energy- and exergy-based optimal designs of a low-temperature industrial waste heat recovery system in district heating. Energy Convers Manag 2020;211:Article number 112753. doi:10.1016/j.enconman.2020.112753.

[6] Pajot C, Morriet L, Hodencq S, Delinchant B, Wurtz F, Reinbold V, et al. An Optimization Modeler as an Efficient Tool for Design and Operation for City Energy Stakeholders and Decision Makers. (HAL Id : hal-02285954). 16th IBPSA Int. Conf., Rome (Italy): 2019.

[7] Morriet L, Pajot C, Delinchant B, Marechal Y, Wurtz F, Debray F, et al. Optimisation multi-acteurs appliquée à la valorisation de chaleur fatale d ' un acteur industriel flexible. Conférence Francoph. l'International Build. Perform. Simul. Assoc. Garantie performances., 2018.

[8] Pajot C. OMEGAlpes : Outil d'aide à la décision pour une planification énergétique multi-fluides optimale à l'échelle des quartiers. Doctoral Thesis. Université de Grenoble (France), 2019. doi:https://tel.archives-ouvertes.fr/tel-02520569.

[9] Dorotić H, Pukšec T, Duić N. Economical, environmental and exergetic multi-objective optimization of district heating systems on hourly level for a whole year. Appl Energy 2019;251:113394. doi:10.1016/j.apenergy.2019.113394.

[10] Ahmed N, Elfeky KE, Lu L, Wang QW. Thermal and economic evaluation of thermocline combined sensible-latent heat thermal energy storage system for medium temperature applications. Energy Convers Manag 2019;189:14–23. doi:10.1016/j.enconman.2019.03.040.

[11] Guelpa E, Verda V. Thermal energy storage in district heating and cooling systems: A review. Appl Energy 2019;252:113474. doi:10.1016/j.apenergy.2019.113474.

THANK YOU VERY MUCH FOR YOUR ATTENTION!

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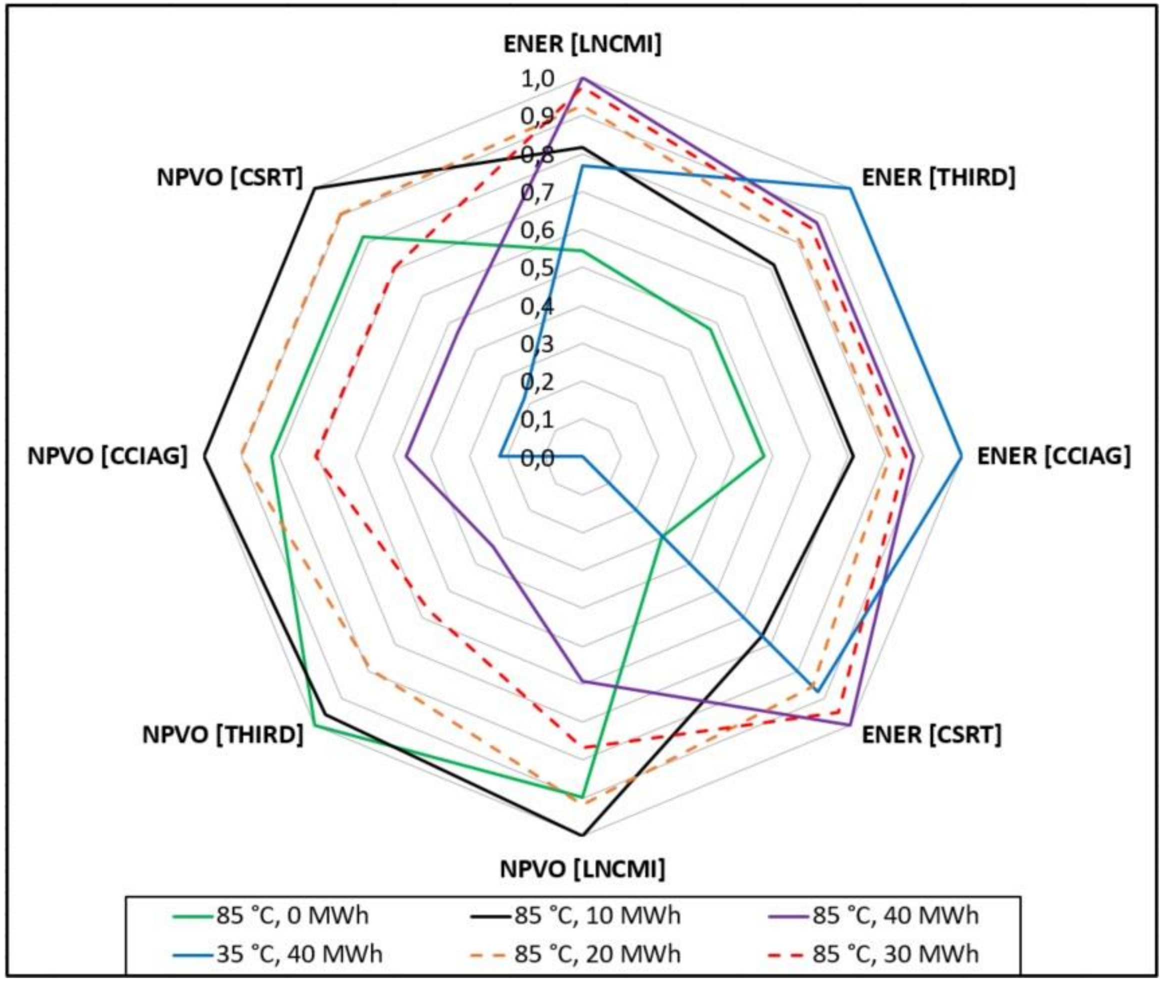
Extended Results – Multi-actor compromise



Multi-actor & Multi-criteria radar

- Energetic & economic criterion, 4 actors.
- Opposite vertices correspond to the same actor.
- Continuous lines : Monocriterion-optimal solutions.
- Discontinuous lines : Pareto-optimal solutions.
- Larger storage capacities prioritize energy.
- Smaller storage capacities prioritize economy.
- **85 °C with 20 MWh** seems the most balanced design.