Multi-energy systems optimization: a new formulation with linear programming for temperatures and magnitudes of thermal power flows in heating systems

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1 Research aim

1. The motivation behind this work is the need to address the impact of the recent COVID-19 crisis and the Ukrainian war on the European Union's energy landscape, pushing for sustainable smart energy solutions.

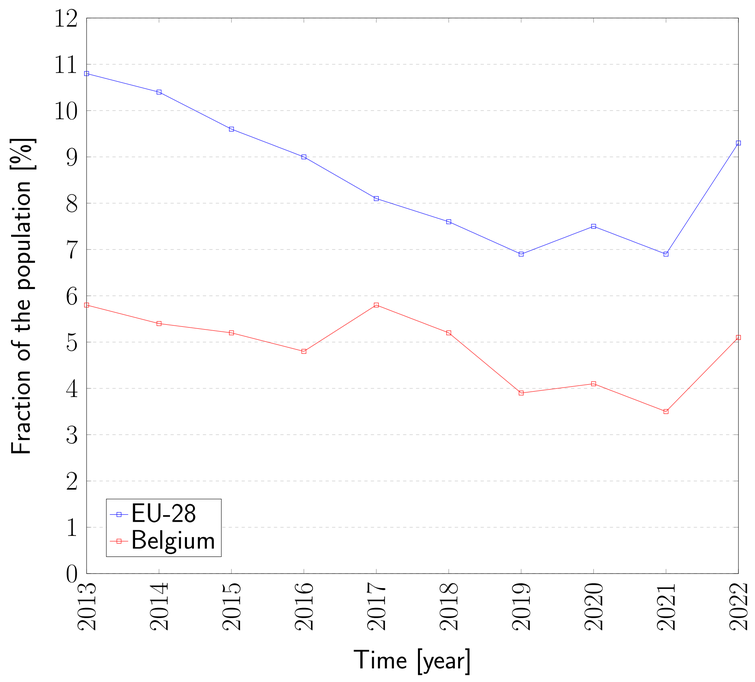


Figure 1: Fraction of the population that was unable to keep their homes adequately warm during the last ten years. A steady decline is observed at European level with an increase in 2022 related to the economical crisis the European population was exposed to.

2. The primary issue at hand is the optimization of equipment sizing for technologies like District Heating Network, Heat Pump, Thermal Energy Storage, and Photovoltaic Panels, particularly in the context of low-temperature DHNs.
3. Our approach tackles this challenge by employing a novel formulation based on temperature levels, which effectively enhances the Coefficient of Performance of Heat Pumps and increases the energetic density of Thermal Energy Storage.
4. The results of our methodology are exemplified through a case study of a housing unit equipped with solar panels, linked to a 5th generation DHN. The findings show impressive metrics, including 28% electric autoproduction, a seasonal COP of 4.1, and an 81% electric autoconsumption rate.
5. This work holds significant implications for the future of energy systems in the EU, as it demonstrates a promising avenue for optimizing low-temperature DHNs. By considering equipment performance sensitivity to network temperatures, it enables the maximization of renewable energy utilization, marking a crucial step towards more sustainable and cost-effective energy solutions.

2 Methodology

Linear Programming

$$\min_{x \geq 0} \quad c^{\mathrm{T}} x \tag{1}$$

$$\text{s.t.} \quad Ax = b \tag{2}$$

Node Formulation

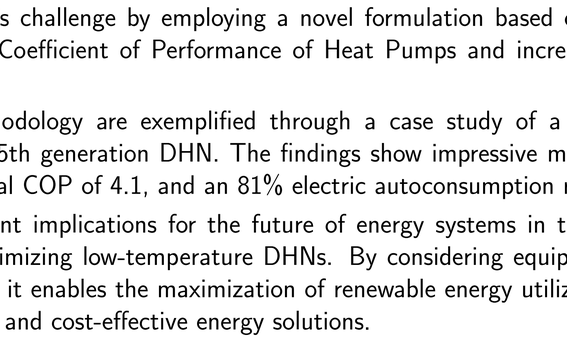


Figure 2: A node exchanging energies (positive values)

Multi-energy system

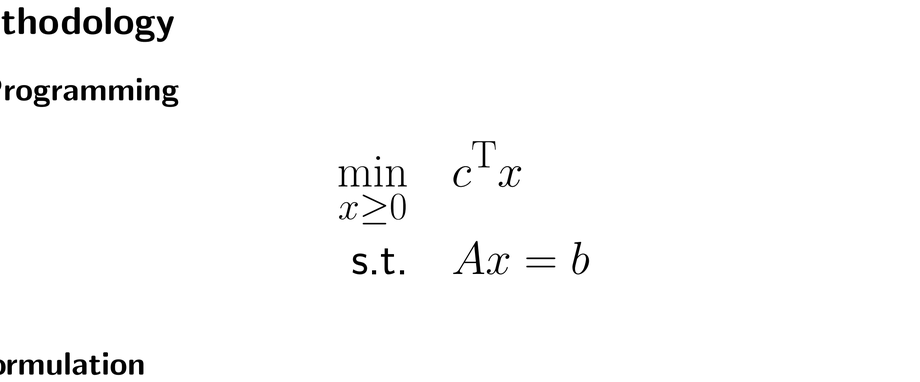


Figure 3: A system composed of two energy networks

3 Case Study

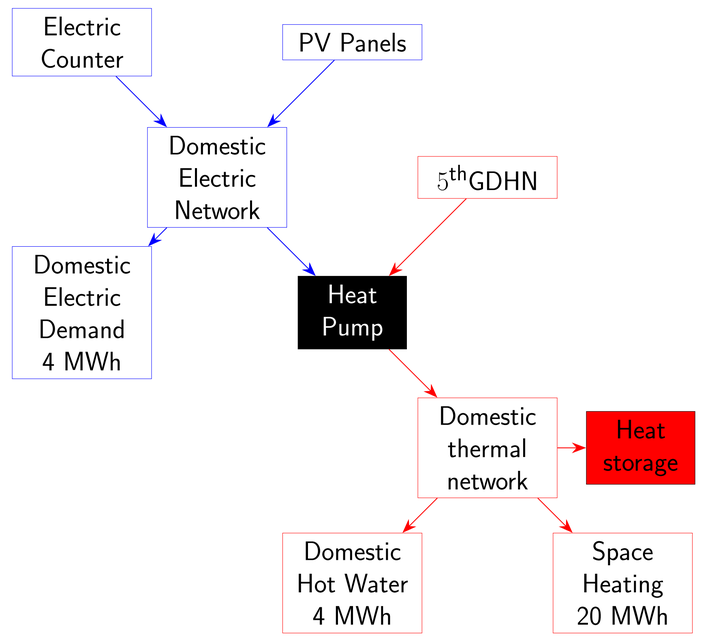
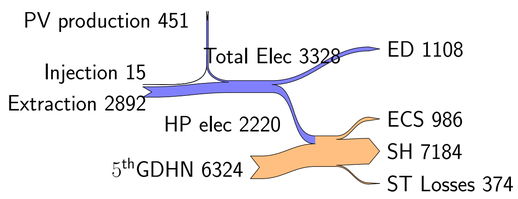
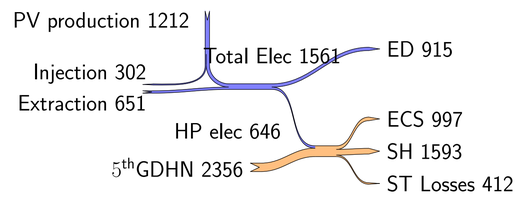


Figure 4: An optimized household

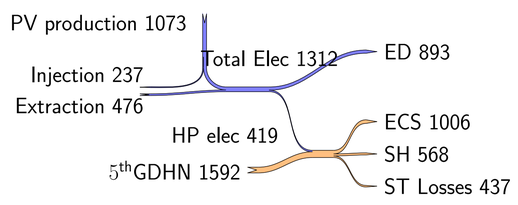
4 Results



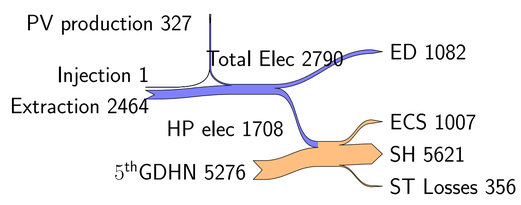
(a) Electricity and heat flow 1st trimester 2018



(b) Electricity and heat flow 2nd trimester 2018



(c) Electricity and heat flow 3rd trimester 2018



(d) Electricity and heat flow 4th trimester 2018

Figure 5: Sankey diagrams for operations over 2018

Table 1: Extracted and injected electric energy and related cost and benefit for the case study (expressed in kWh)

period	extraction [kWh]	injection [kWh]	extraction [EUR]	injection [EUR]
Jan - Mar	2892	16	637	1
Apr - Jun	651	302	133	11
Jul - Sep	476	237	100	9
Oct - Dec	2464	1	541	0
year	6483	556	1411	21

Table 2: Indicators for 2018

period	SCOP	Autcons	Autoprod
Jan - Mar	3.84	0.96	0.13
Apr - Jun	4.64	0.75	0.58
Jul - Sep	4.79	0.78	0.63
Oct - Dec	4.08	0.99	0.12
year	4.10	0.81	0.28

5 Conclusions

- A novel approach using temperature levels and linear programming was developed to optimize multi-energy systems with flexible temperature, simultaneously on their operational and design level.
- The model itself takes advantages of the flexibility provided via the temperature levels. However, those also come at a cost in terms of complexity, with variable count higher than 225 times the number of variables of a fixed temperature formulation.
- Accuracy and optimality of linear programming in heating network applications is limited by the method complexity and by approximation errors.