Anhang zum Ergebnisbericht

Smart City MIKROQUARTIERE

Energie- und lebensqualitätsoptimierte Planung und Modernisierung von Smart City–Quartieren

A4 Wissenschaftliche Publikationen

- Leibold, J., Zelger, T.: „Projekt SC- Mikroquartiere - Modellierung verschiedener Nachverdichtungsszenarien und Optimierung bezüglich erneuerbarer Energieversorgung und der Lebensqualität der NutzerInnen“. BauZ! – Wiener Kongress für zukunftsfähiges Bauen, Wien, 25.01.2018
- Leibold, J., Huemer-Kals, V., Zelger, T.: „Smart City Micro Quarters“. International Sustainable Energy Conference - ISEC 2018, Graz, 3. - 5. Oktober 2018
- Fleischhacker, A., Lettner, G., Schwabeneder, D., Auer, H., “*Portfolio Optimization of Energy Communities to meet Reductions in Costs and Emissions*”, Working Paper, Energy, 2018.
- Fleischhacker, A., Lettner, G., Auer, H., “*Multi-objective Optimization of Urban Energy Systems Considering High Shares of Renewable Energy Generation*”, 15th IAEE European Conference 2017 Session 2F: Sector Coupling I, Vienna, 04.09.2017.
- Fleischhacker, A., Lettner, G., Auer, H., „*Pareto Optimization of a Local Urban Energy System considering Costs and Emissions*“, 15. Symposium Energieinnovation/Session A2, Graz, 15.02.2018.
- Fleischhacker, A., „*Pareto Optimization of a Local Urban Energy System considering Costs and Emissions*“, Kolloquium Urbane Energiesystemsimulation / AIT, Wien, 09.04.2018.

Projekt SC- Mikroquartiere

Modellierung verschiedener Nachverdichtungsszenarien und Optimierung bezüglich erneuerbarer Energieversorgung und der Lebensqualität der NutzerInnen

SC microquarters project

Modelling and optimization of different re-densification scenarios with regard to renewable energy supply and quality of life in the framework

Jens Leibold, IBO; Thomas Zelger, FH Technikum Wien

Abstract

Urban planning is a very complex task with many facets and conditions. Because of the lack of resources many opportunities are often left unrecognized and therefore unused. The research project "Smart City micro quarters" has the goal of simply and quickly exploring the potentials (regarding densification, efficiency, use of renewable energies, etc.) of urban renewal of a city area and thus making city planning viable and capable of action. By means of this method the improvement potentials of a district, in terms of ecological, social, economic and urban planning criteria can be determined with little financial and temporal effort..

Zusammenfassung

Stadtplanung ist ein sehr komplexer Aufgabenbereich mit zahlreichen Facetten und Bedingungen. Aufgrund fehlender Ressourcen und zu geringer Transparenz bleiben im Planungsalltag Chancen und Möglichkeiten, einen Stadtteil zukunftsfähig zu gestalten, unerkannt und folglich auch ungenutzt. Das Forschungsprojekt „Smart City Mikroquartiere" hat sich zum Ziel gesetzt, einfach und schnell die Potenziale (hinsichtlich Nachverdichtung, Energieeffizienz, Einsatz erneuerbarer Energien, etc.) einer städtebaulichen Erneuerung eines Stadtareals auszuloten und damit die Stadtplanung zukunfts- und handlungsfähig zu machen. Durch diese Methode sollen die Stadtentwickler mit geringem finanziellen und zeitlichen Aufwand in die Lage versetzt werden, die Verbesserungspotenziale eines Stadtquartiers in Bezug auf energetische, ökologische, gesellschaftliche, ökonomische und städtebauliche Kriterien abschätzen und in der Folge fundiert handeln zu können.

Zu den Kernergebnissen des Projekts zählen:

- Detaillierte Smart City Indikatoren für Mikro- und Stadtquartiere
- Mikroquartiers-Modelle und eine Handlungsanleitung für die Optimierung in Bezug auf Nachverdichtung, Energieeffizienz, Erneuerbare Energie, deren Speicherung, Energienetze und Qualität der öffentlichen Räume
- Kompakte Darstellung der Ergebnisse auf Mikroquartiersebene für Stadtplanung, AnwohnerInnen, Politik, Projektentwicklung etc.

Problematik und Ausgangssituation

Um dem knappen Wohnraum und einer rasch voranschreitenden Zersiedelung in Städten und ihrem Umland entgegenzutreten, ist eine Nachverdichtung der Bestandssiedlungen in Teilen des ländlichen und vor allem dem urbanen Raum unabdingbar. Eine horizontale Verdichtung erhöht die Flächenversiegelung, Teile der Vegetation und sonstige Freiräume gehen verloren. Eine vertikale Nachverdichtung kann zu erhöhter Verschattung und damit einhergehend zu einer schlechteren Besonnungssituation für Bestandsräume und Nachbarn führen. Wird eine Nachverdichtung in Angriff genommen, führt eine Maximierung aus ökonomischen Gründen häufig zu Widerstand bei Anwohnern. Wie könnte aber eine maßvolle Innenverdichtung aussehen, die auf eine breite Akzeptanz trifft, indem die subjektiv empfundene Lebensqualität im Idealfall steigt und gleichzeitig das Klima geschont wird?

Methodik

Im Projekt SC- Mikroquartiere werden Möglichkeiten der Stadtplanung für eine quartiersweise Entwicklung hin zu einer Low-Carbon City mit hoher Lebensqualität aufgezeigt. Dazu werden Stadtareale in Mikroquartiere (MQ) abstrahiert. Diese beinhalten die gesamte städtebauliche Genetik, die ein Stadtquartier prägen, wie z.B. typische Straßenquerschnitte, Qualitäten des öffentlichen Raums, Baustruktur (Entstehungszeit der Gebäude, Bauweise, Nutzung, Dimension, Materialität, etc.), Bauabstände und die techni-

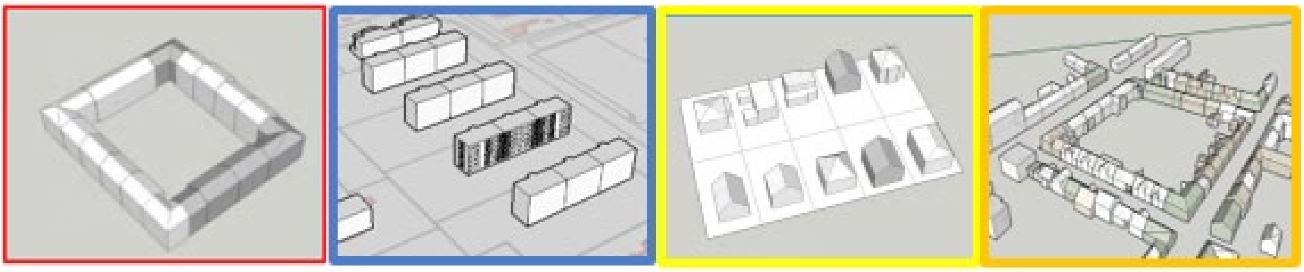


Abb. 1: Betrachtete Mikroquartier-Typologien, Blockrand (rot), Zeile (blau), Einfamilienhaus einzeln (gelb) und Einfamilienhaus Blockrand (orange)

sche sowie soziale Infrastruktur.
Die zum Einsatz kommenden Mikroquartiere sind den Bautypologien Blockrand-, Zeilen- und Einfamilienhaussiedlung zuzuordnen und müssen für jeden Standort angepasst werden, da es zu lokalen Spezifika z.B. der jeweiligen Gebäudehöhe, Gebäudeabstände, usw. kommt. In untenstehender Abbildung sind die Basis- Mikroquartiere exemplarisch für einen betrachteten Standort dargestellt. Die Einfamilienhaussiedlung ist dabei in die Typen EFH einzeln und EFH Blockrand unterteilt.

Für jedes Mikroquartier werden Varianten der Optimierung (das bedeutet nicht zwangsläufig für jeden Standort eine Nachverdichtung) entwickelt. Pro Mikroquartier steht ein Pool aus bis zu 20 baulichen Varianten zur Verfügung, die analysiert und untersucht werden. In nachfolgender Abbildung sind exemplarisch vier Möglichkeiten der Innenverdichtung des MQ „Block" vorgestellt.
Durch Multiplikation der jeweiligen Mikroquartiere können Stadtareale zusammengesetzt werden. In Abbildung 3 ist demonstriert, wie ein ausgewähltes Areal aus den drei MQ- Grundtypen zusammengesetzt wird.

Da es derzeit auf dem Markt keine Simulationssoftware gibt, die alle erwünschten energetischen und Lebensqualitätsparameter auf MQ- Ebene ausgibt, werden unterschiedliche softwarebasierte Simulationswerkzeuge eingesetzt. Die MQ-Varianten sind in SketchUp gezeichnet und die Simulationstools sollten – um den Arbeitsaufwand zu begrenzen – mit diesem Format kompatibel sein.
Die Simulationsergebnisse zeigen die Auswirkungen unterschiedlicher Nachverdichtungsszenarien auf den resultierenden Energiebedarf, die untersuchten Lebensqualitätsparameter und das lokale Potential an erneuerbarer Energieerzeugung auf.
Die Energiebedarfe eines Längs- und eines Eckgebäudes im Mikroquartier werden durch thermische Simulationen mit einem TRNSYS Mehrzonenmodell ermittelt. Dabei werden unterschiedliche Baustandards (Bestand, OIB Mindestanforderungen und Passivhausstandard) sowie vier verschiedene Orientierungen berücksichtigt. Die Hochrechnung des Energiebedarfs für das gesamte Mikroquartier erfolgt durch Hochrechnung über die BGF.
Das lokal zur Verfügung stehende erneuerbare Erzeugungspotential (Solarthermie, Photovoltaik, Erdwärme/kälte, Grundwasserwärme/kälte, Außenluft etc.) wird in verschiedenen Varianten simuliert und dem jeweiligen Energiebedarf gegenübergestellt. Das aktive solare Potential wird in zwei Varianten betrachtet, von Standard Dach bis maximal, d.h. inklusive Vordächer und geeigneten Fassaden. Die kumulierte solare Einstrahlung auf die unterschiedlichen Flächen eines MQ sind in Abbildung 4 für ein Jahr dargestellt.

Varianten der Bedarfsberechnungen und das Deckungspotential an Erneuerbaren Energien sind in Abbildung 5 dargestellt. Dadurch können für die unterschiedlichen Varianten Aussagen zu den erzielbaren Energie-Autonomiegraden getroffen werden.

Die Bestimmung der Lebensqualität setzt sich aus mehreren Bereichen zusammen. Mittels Simulation kann der Bereich Tageslichtsituation und Anzahl der Stunden mit direkter Besonnung für das betrachtete Mikroquartier, bzw. kritische Gebäude, beurteilt werden. Die Abbildung 6 zeigt die Veränderung der Tageslichtsituation zwischen Bestand (links) und der nachverdichteten Variante (rechts). Durch eine Vergrößerung der Glasflächen und anderen Grundrissen könnte eine Verbesserung erzielt werden.

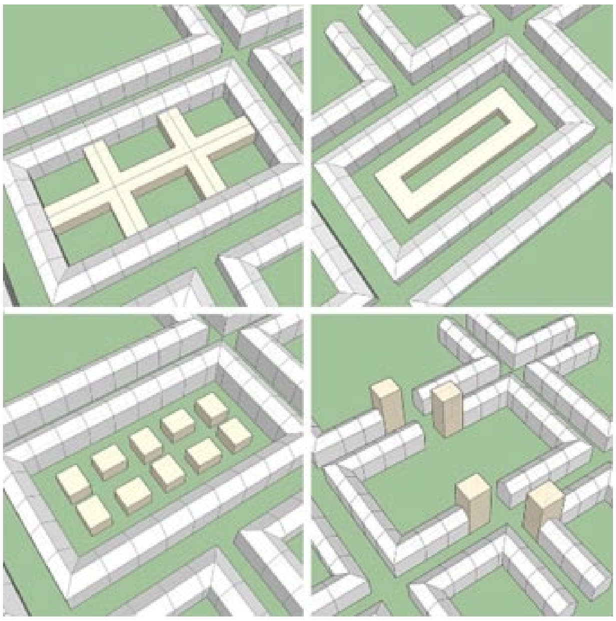


Abb. 2: Nachverdichtungsvarianten am Beispiel Mikroquartier „Block"

Abb. 3: Aufbau eines Areals aus unterschiedlichen Mikroquartieren

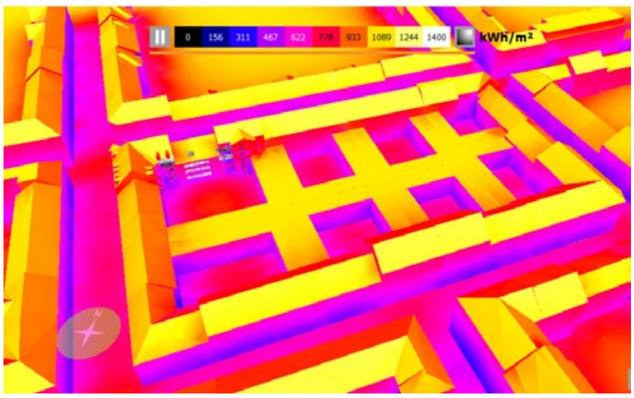


Abb. 4: Solares Potential des Mikroquartiers. (Simulationsergebnisse PVsites)

Die einzelnen Varianten werden zusätzlich primärenergetisch (Betrieb und Gesamt) und anhand der Lebenszykluskosten bewertet. Die Ergebnisse fließen in ein Mikroquartier- Indikatoren Set ein (ca. 100 Indikatoren), das eine umfassende Vergleichbarkeit der Nachverdichtungsvarianten ermöglicht.

Eingesetzte Simulationstools

- Sefaira Plugin für Sketchup Modelle zur Tageslichtbewertung und direkte Besonnungsdauer
- PVsites für dynamische Strahlungswerte, potenzielle PV/ST-Flächen und resultierende Energieerträge
- TRNSYS Mehrzonenmodell: Auf der Grundlage Nutzungsprofile und Einstrahlung werden Bedarfs- und Deckungsprofile berechnet.
- Ecosoft und Lekoecos für Ökobilanz der Gebäude und variablen Bestandteile der Quartiere (Primärenergieinhalt und Global warming potential (GWP))

Ergebnisse

Als zentrales Ergebnis werden für den jeweiligen Standort die idealen Varianten ermittelt.
Es entstehen Modelle und eine Handlungsanleitung für energieoptimierte Mikroquartiere in Bezug auf Nachverdichtung, Energieeffizienz, Einsatz erneuerbarer Energien und Lebensqualität. Dazu wird ein Arbeitsablauf vorgeschlagen, der bereits in der Konzeptphase einer Quartiers/ Energieraum- Planung mit aufeinander abgestimmter Simulationstools die Auswirkungen von Nachverdichtungsvarianten auf den Energiebedarf, die Möglichkeiten der erneuerbaren Energieerzeugung und Lebensqualitätsparameter bestimmen. Diese werden durch Smart City Indikatoren auf Mikro- und Stadtquartiersebene transparent abgebildet und dadurch unterschiedliche Varianten miteinander vergleichbar. Die Verdichtung der ca. 100 Indikatoren in 23 wesentliche Indikatoren werden in einem Sonnendiagramm grafisch aufbereitet. Dadurch werden die Stärken der jeweiligen Variante ersichtlich. In den nachfolgenden zwei Abbildungen ist das Basis Mikroquartier „Block" vor und

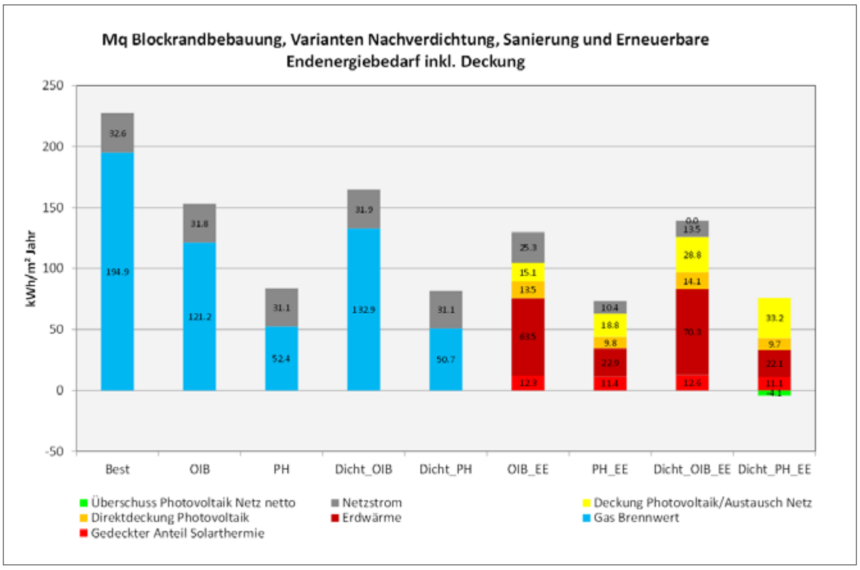


Abb. 5: Varianten Endenergiebedarf und Deckungsszenarien für MQ Blockrand

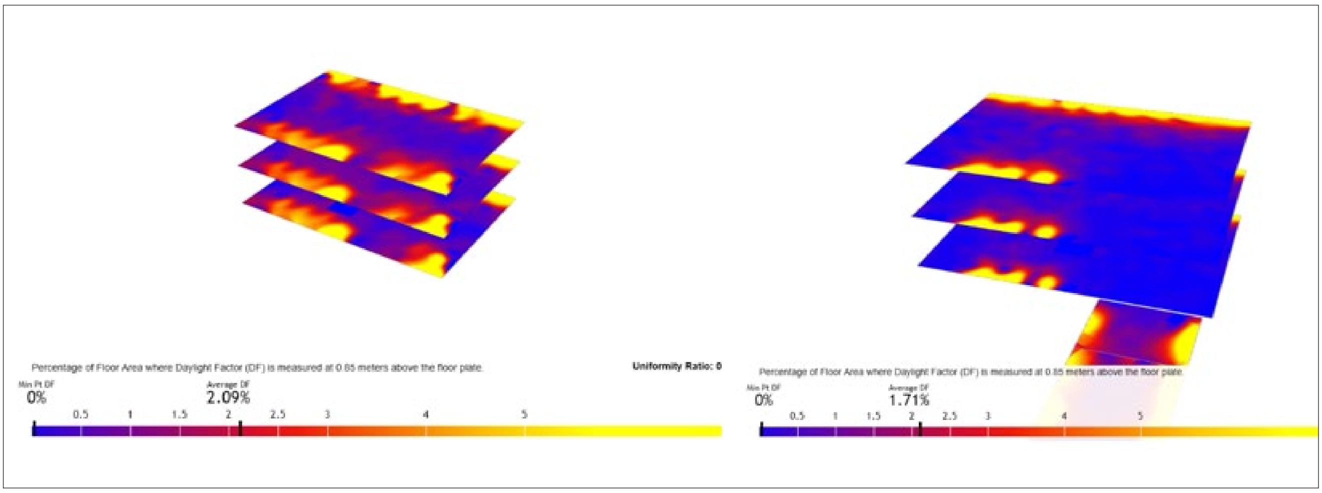


Abb. 6: Simulation des Tageslichtfaktors für das Bestandsgebäude (links) und der nachverdichteten Variante (rechts)

nach der Nachverdichtung mit den begleitenden Maßnahmen dargestellt. Wie deutlich wird, verbessern sich eine Vielzahl der Indikatoren, wobei in diesem Fall ein Parameter, die visuelle Qualität, ungünstiger abschneidet.

Stadtareale

Die im Projekt entwickelte Methode wird auf real existierende Stadtquartiere angewandt. Durch Workshops mit Vertretern der Partnerstädte wird die Methode abgestimmt und praxistauglich gemacht. Partnerstädte, die das Forschungsprojekt unterstützen, sind Baden, Bruck an der Leitha, Graz, Korneuburg und Linz.

Projektpartner und Hauptaufgabenbereiche

- IBO– Österreichisches Institut für Bauen und Ökologie GmbH, Lebenszyklusanalyse, Indikatoren
- Kleboth & Dollnig, Entwürfe zu Bestand- und Nachverdichtung, Wirtschaftlichkeit
- FH Technikum Wien, Potentialanalyse Erneuerbare Energien, Bedarfshochrechnungen und Simulationen
- TU Wien, Energy Economics Group, Energiekonzept auf Arealebene
- Umweltbundesamt GmbH, Mobilitäts- Szenarien und Simulationen (Agentenmodell)

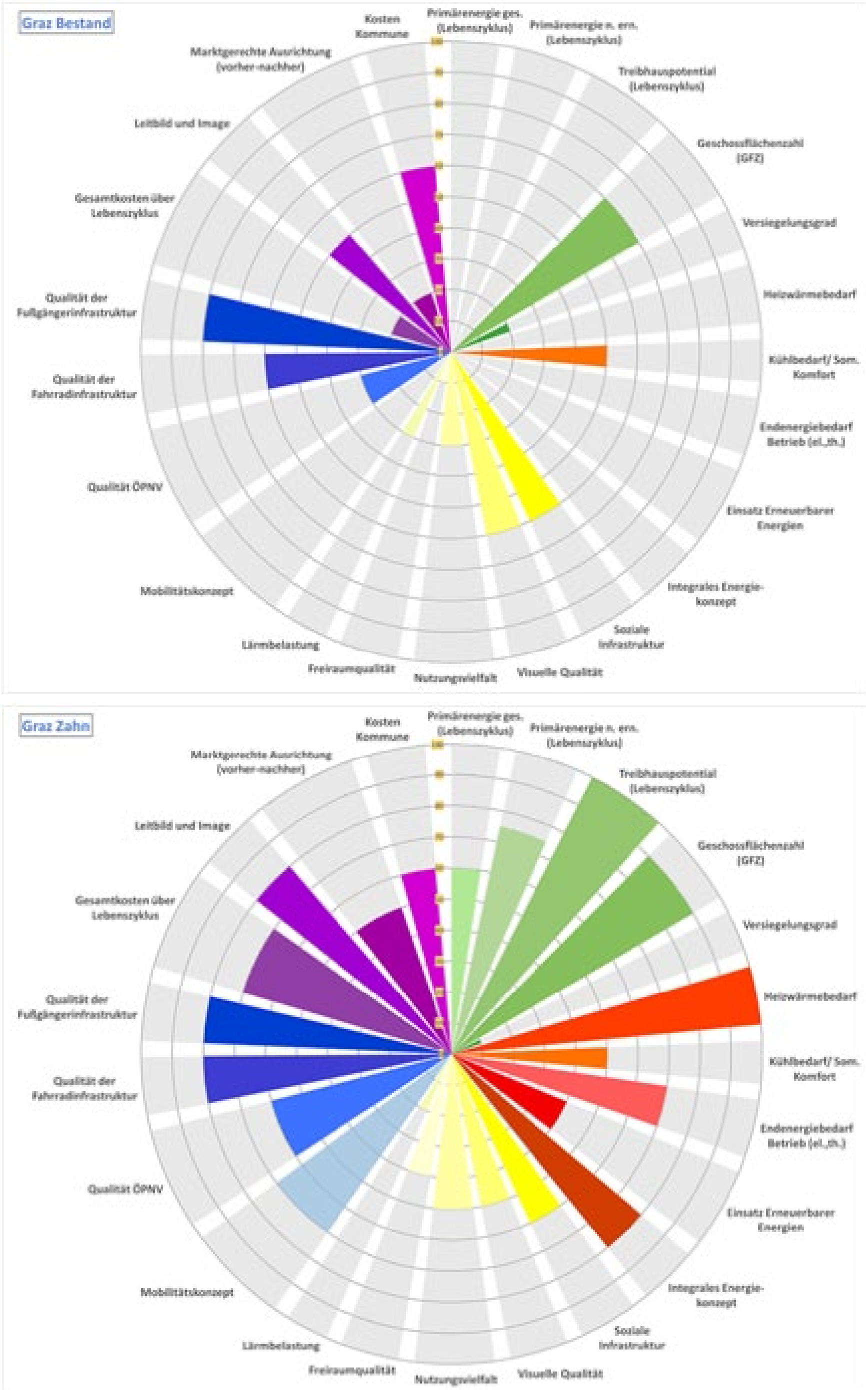


Abb. 7: Grafische Bewertung Bestand (oben) und Nachverdichtungsvariante „Zahn" (unten) für Basis-MQ „Block"

SMART CITY MICRO QUARTERS

Jens Leibold, Veronika Huemer-Kals, Thomas Zelger,
IBO – Österreichisches Institut für Bauen und Ökologie GmbH
Alserbachstraße 5/8, 1090 Wien, Austria
Phone: + 43 (0) 1 319 20 05-50
FH Technikum Wien- Institut für Erneuerbare Energie
Höchstädtplatz 6, 1200 Wien, Austria
E-Mail: jens.leibold@ibo.at

1 SUMMARY

The research project "Smart City Micro Quarters" had the goal of simply and quickly exploring the urban renewal potential (regarding densification, efficiency, use of renewable energies etc.) of a city area and thus making city planning viable and capable of action. For four selected micro quarters, which typically occur in Austrian urban and rural areas, various densification possibilities were analysed. Whole city areas can be represented by multiplying and putting together the micro quarters. One focus was the solar potential in comparison with the energy demand of the variants to reach a high share of local energy autonomy. By means of this method the improvement potential of a district, in terms of energy supply, ecological, social, economic and urban planning criteria, can be determined at the early planning stage with little financial and temporal effort.

2 INTRODUCTION

To counteract the scarcity of housing and rapid urban sprawl in cities and their surrounding areas, densification is essential. A horizontal compaction increases the surface sealing, potential green space and other open spaces are getting lost. Vertical densification can lead to increased shading and a worse daylight situation for existing buildings. Therefore, densification in general often leads to resistance from residents.

In addition, if the ratio of roof area to Gross Floor Area (GFA) is lower, it is more difficult to achieve a high local coverage of the energy consumption with renewable energies. But what could a good compromise look like, that creates housing space, increases the subjectively perceived quality of life and protects the climate by a high rate of local renewable energies?

3 METHOD

3.1 Micro quarters approach in general

In the method developed within the project SC Micro Quarters, possibilities of future city planning for a development towards low-carbon districts are demonstrated. For this purpose, urban areas are abstracted into micro quarters (MQ). These MQ include important urban genetics that characterize the specific city district, like building structure (time of origin of the buildings, way of construction and thermal behaviour, dimension, mix of uses etc.), typical street cross sections, qualities of the public space, construction distances and technical and social infrastructure.

The four MQ that are used can be assigned to the types block, row and single-family housing. For the type single-family housing two variants are used, one open and one closed structure, like it is common in Lower Austria. In Figure 1 the considered types of micro quarters are shown. If there are larger deviations between the so called “Basis- MQ” and the considered one, they should be adapted for each location. Thereby local specifics can be considered like respective building heights, building distance, open space area, gaps between buildings etc.

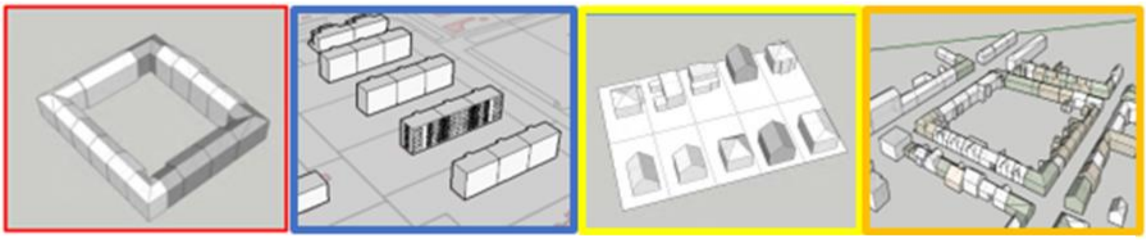


Figure 1: Used types of micro quarters “block” (red), “row” (blue) and “single-family housing” open (yellow) and closed structure (orange)

In a next step variants of densification are developed for each MQ. In the research project, a pool of up to 20 variants per each micro quarter was developed. These were analysed, and strengths and weaknesses displayed. In the following figure, four possibilities of the construction extensions for MQ "Block" are presented.

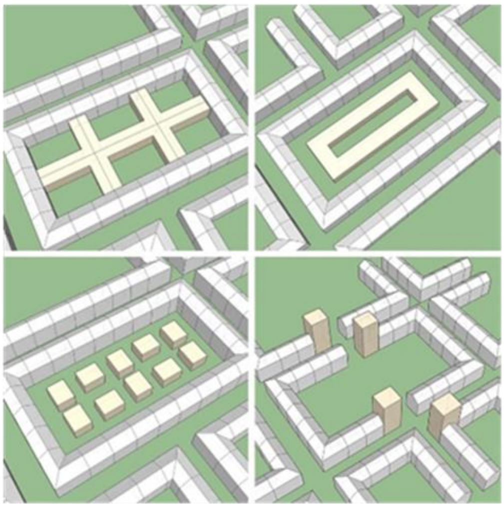


Figure 2: Examples for densification variants for the MQ „Block“

By multiplying the different MQ, whole city areas can be represented. According to the project partners a majority of city areas in Austria can be reproduced by the MQ approach. In Figure 3 it is demonstrated how a chosen city area is replicated by three different MQs.

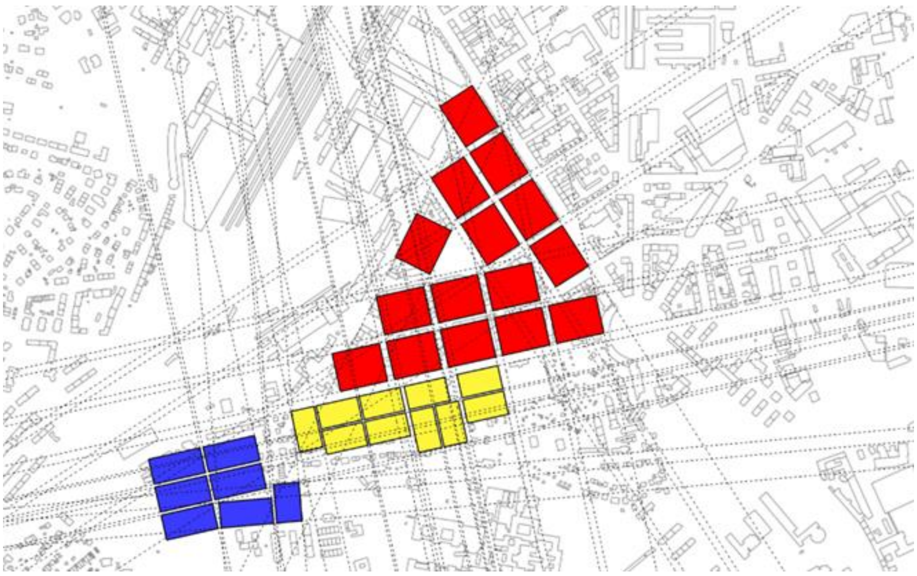


Figure 3: Composition of a city area example by multiplying each of the 3 different MQs

3.2 MQ energy demand and supply calculation

Since there is currently on the market no simulation software available that outputs for a city area or MQ all the desired energy and quality of life parameters, different software-based simulation tools are used. The MQ variants are drawn in SketchUp and the simulation tools should be compatible with this format to limit the amount of work. During the project various simulation tools were checked. In the end for the energy demand and HVAC system TRNSYS were used. For the passive and active solar potential PVsites were chosen.

The simulation results show the effects of different densification scenarios on the resulting energy demand, the examined quality of life parameters and the local potential of renewable energy production.

For each MQ at least one basis building is selected, for the closed structures (Block) a longitudinal and a corner building are analysed. Simulations and calculations to determine the solar potential, energy demand as well as life cycle costs (LCC) will be done for these basis buildings and projected for the whole MQ. Thereby the influence of shadow from neighbouring houses and different orientations are taken into consideration.

Dynamic simulations to determine energy demand are carried out with TRNSYS multi-zone model. Different construction standards (inventory, OIB minimum requirements for building components and passive house standard) as well as four different orientations are considered. The calculation of the energy requirement for the entire micro-district is made by extrapolation through the GFA.

The locally available renewable generation potential (PV, solar thermal, geothermal, groundwater heat / cold, outdoor air etc.) is simulated in different variants and compared to the respective energy requirements. The local renewable energy potential for the MQ within the dense urban context suggests a primary use of solar energy. Therefore, the individual designs are examined for their active solar potential. Figure 4 shows the yearly cumulative solar irradiance of a selected variant. The graphical evaluation serves to pre-select suitable roof areas which should have at least an annual solar irradiation of 700 kWh/m².

The active solar potential is considered in two variants, from standard roof to a maximum version, including balconies, canopies and suitable facades (see Figure 7). In a first step, the roof surfaces were covered with PV modules. Thus, PV yields will be calculated with PVsites on an hourly basis (important for self-consumption determination). PVsites, a software available for free in its current state (beta version) allows users to model and evaluate BIPV projects. Figure 5 shows the PV coverage of the roofs for a considered variant. Due to the different colour design, or more accurate through specific selection of individual PV strings and modules, the resulting solar yield can be optimized.

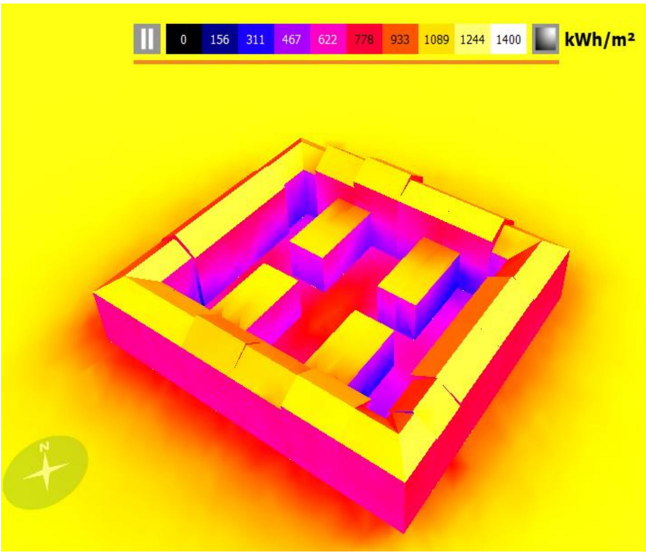


Figure 4: Annual solar irradiation for MQ Block variant "double teeth" (PVsites)

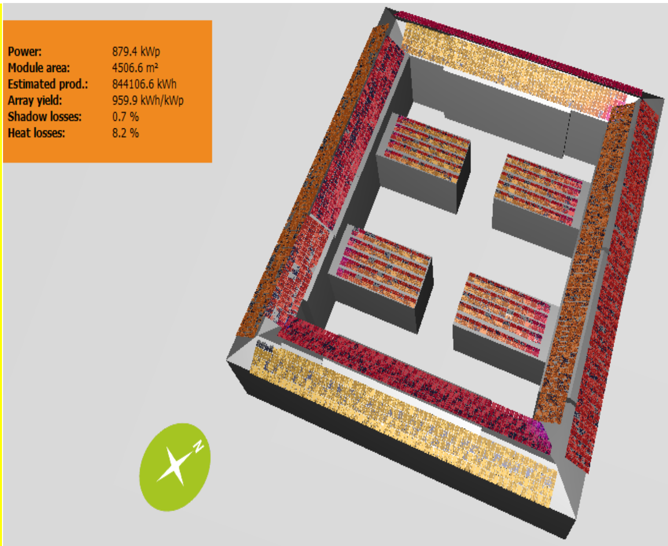


Figure 5: PV allocation "only roof" for MQ Block variant "double teeth" (PVsites)

4 RESULTS

As a central result for each MQ, ideal variants were determined and their strengths and weaknesses were identified. Elaborated Smart City indicators make it possible to compare and evaluate the different variants at the micro and city quarter level. The compression of the chosen 90 indicators from established city area rating systems (DGNB Stadtquartiere, LEED 2009 for Neighbourhood Development, BREEAM Communities, Urban Area Parameters) into 23 essential indicators is graphically processed in a sun chart. The sun chart shows clearly the focus and strengths of each variant. An example is shown in Figure 6 below, on the right side the category "energy" is displayed in detail.

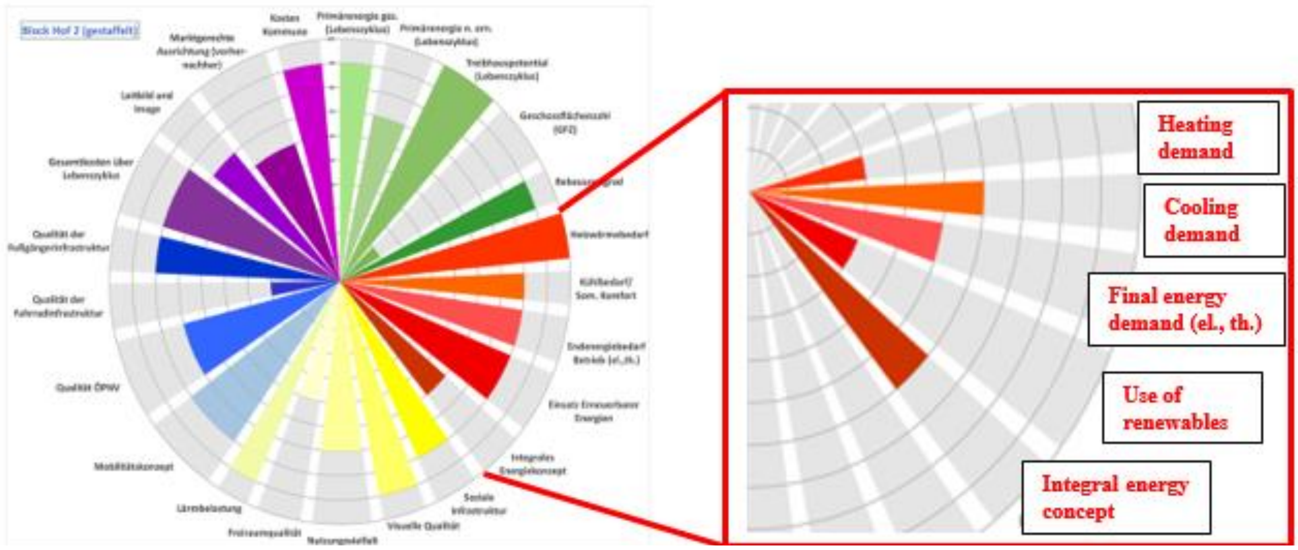


Figure 6: Sun chart with smart city indicators to evaluate variants and the focus "energy" (right side)

Models and guidelines for energy-optimized MQ, in terms of densification, energy efficiency, use of renewable energies and quality of life were developed. For this purpose, a workflow was planned, that determines the effects of the different variants on the energy demand, potential of renewable energy production and quality of life parameters in the concept phase of a MQ. For energy space planning, a workflow with coordinated simulation tools was developed to determine the effects of the different variants on energy demand and potential of renewable energy production. To combine the dynamic results of the energy demand with energy supply and excel tool was developed, which enables determinations regarding degree of autonomy and self-consumption rate under consideration of different PV- and future electromobility scenarios.

Figure 7 shows on the left side an example of the PV occupancy for the base buildings of MQ Block and Single-family house. On the right-hand side, the resulting autonomy and autarchy degrees as a function of the considered PV and e-mobility scenario are shown. The results clearly show that it is also possible to achieve a plus-energy MQ block with the PVmax variant. However, if future e-mobility shares are considered things get more challenging. In the case *emob75*, where 75 % of households are considered to have an electric car, only the MQ Single family house can achieve a plus in the annual balance. These surpluses at city area level is necessary to balance out deficits in the dense MQ "Block" area. For the MQ Single family house also an additional variant was considered, with 1.25 e-cars per household. The result of 99 % autonomy shows why the advanced PVmax variants will become more important in the future to reach at least a yearly zero energy balance.

The energy outputs for the different MQ were put into a simulation tool for the whole city districts to optimize the future energy grid regarding costs and CO_2- emissions. As a result, the electrification for the future energy grid is forecasted (Fleischhacker 2018), which underlines the importance of a high local renewable production to reduce CO_2- emissions, costs and grid capacity.

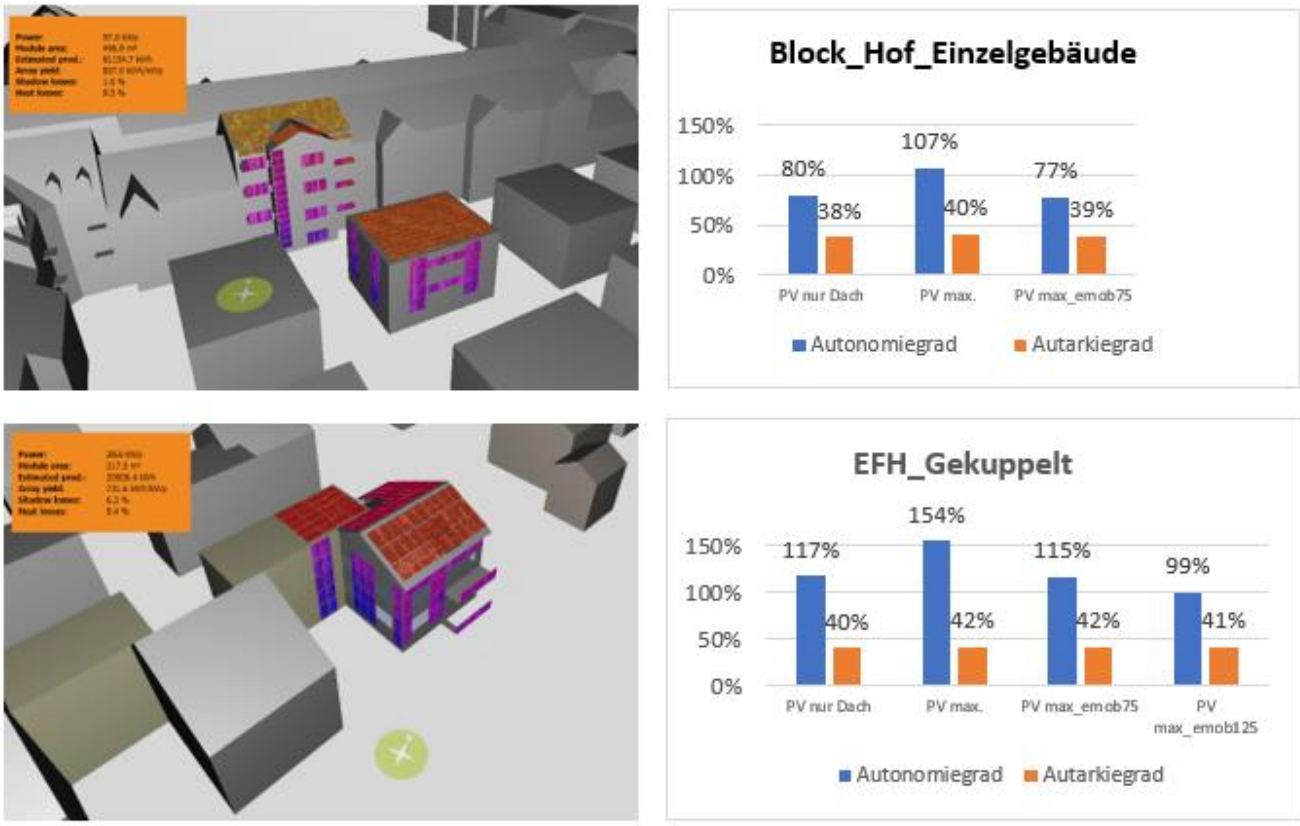


Figure 7: PVmax variants for base buildings MQ Block and Single- family house and the resulting degrees of autonomy and autarchy, depending on the selected PV and e-mobility scenario

5 DISCUSSION

By the MQ method a quick clarification of the potential of a planning area with a reasonable degree of accuracy is possible. The approach requires little preparatory work (low data collection effort), which leads to a short project duration and therefore low cost.

At the beginning of the project, there was the idea to identify an ideal development for each MQ. During the course of the project, several attempts to get an overall rating were carried out, the presented sun chart is one of them. In the end the project partners recognized that the rating within the MQ variants strongly depended on the package of measures (building standard, use of renewables…) and not so much on the differences of the building structures. Therefore, the method in the future will be used as a modular system, which provides for each MQ a pool of construction variants, as well as several measures to guarantee the sustainability and quality of a MQ. The choice of the preferred MQ will take place in a guided process between stakeholders, urban planners and - depending on project priorities energy and/ or mobility planners. This could be a workshop where the different MQ will be developed together with the decision makers and stakeholders by means of the modular system.

6 REFERENCES

Mair am Tinkhof, O. et al., (2017), Richt- und Zielwerte für Siedlungen, zur integralen Bewertung der Klimaverträglichkeit von Gebäuden und Mobilitätsinfrastruktur in Neubausiedlungen. Bundesministerium für Verkehr, Innovation und Technologie (Berichte aus Energie- und Umweltforschung), Wien, Austria

Fleischhacker, A. (2018), Sektorenkopplung führt zu einer Elektrifizierung des Systems, Blogeintrag https://smartcity-mikroquartiere.at, TU Wien

Please fill in for the chairs:

Name: Leibold
Surname: Jens
Institute, company, organisation: IBO – Österreichisches Institut für Bauen und Ökologie GmbH
Key activities: Renewable energies, buildings and simulation
Miscellaneous:

Portfolio Optimization of Energy Communities to meet Reductions in Costs and Emissions

Andreas Fleischhacker*, Georg Lettner, Daniel Schwabeneder, Hans Auer

TU Wien, Institute of Energy Systems and Electrical Drives, Energy Economic Group (EEG), Gußhausstraße 25-29 / E370-3, 1040 Vienna, Austria

Abstract

Cities are expected to grow further, and energy communities are one promising approach to promote distributed energy resources and implement energy efficiency measures. To understand the motivation of those communities, we improve two existing open source models with a Pareto optimization and two objectives: costs and carbon emissions. Clustering algorithms support us to improve the models' scalability and performance. We apply the models to a case study using data from an Austrian city, Linz. Four scenarios help us to understand aspects of the energy community, such as the lock-in effect of existing infrastructure and future developments. The results show us that it is possible to reduce both objectives, but the solutions for minimum costs and minimum carbon emissions are contrary to each other. We see the highest effect of emission reduction by the system electrification.

Keywords: open source model, energy communities, Pareto optimization, emission accounting, data clustering, machine learning

*Corresponding author

Email address: `fleischhacker@eeg.tuwien.ac.at` (Andreas Fleischhacker)

1. Introduction

Globally, 54 % of the population lives in urban areas today, and this trend is expected to continue – by 2045. The number of people living in cities will increase by 1.5 times to 6 billion, adding 2 billion more urban residents [1]. Cities also play an important role in tackling climate change, as they consume close to 2/3 of the world's energy and account for more than 60 to 80 % of global greenhouse gas emissions [1, 2]. By taking future trends into account, fossil energy consumption of cities has to be reduced dramatically to meet the emission reduction targets (such as the Paris agreements). Only in that way, sustainable development could be ensured.

Though no one-size-fits-all solution exists to ensure urban energy sustainability, compact and dense urban development and new ways of planning, financing and using energy infrastructure projects are structural prerequisites to many of the sector-specific options for carbon emissions reduction[3]. In the past years, the term energy communities (EC) has been established to promote distributed energy resources (DER) and implement energy efficiency measures. The European Commission defines an EC as a " legal entity which is effectively controlled by local shareholders or members, generally value rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at a local level, including across borders" [4].

For this paper, we consider a large-scale EC covering a whole city district. It is assumed that, the EC owns the energy grids (e.g., electricity and district heating grid), DER and storages within the community's area. The assumption is in line with [5], where the ownership of EC projects might be: (i)

100 % community owned or (ii) developed under co-ownership arrangements with the private sector (e.g., community ownership of one turbine in a larger wind farm). For the sake of simplicity, we assume in this paper the first case.

This paper aims to quantify the advantages of optimizing the technical portfolio of ECs regarding cost and carbon emission reduction. We model the EC as multi-energy system with the restriction of satisfying needs for electricity and heat. We combine two verified open source models, couple them by the use of clustering algorithms and expand them with three features: Pareto optimization, economies-of-scale and time dependent efficiency factors. As a result of this, we take existing and future building stock set-ups into account, as well as the implementation of energy efficiency measures (lower heat demand and electric vehicles (EV)).

We organize the paper as follows. Section 2 shows the current state-of-the-art. In Section 3, we introduce the open source models and as well as their improvement. Section 4 presents the project site and different scenarios. We show the results in Section 5, while Section 6 discusses and concludes the paper.

2. Related Work

The present paper is related to at least five strands of the literature.

First, we see the necessity of including an EC as a multi-energy system. Various studies investigate optimum energy designs of cities and small entities of cities (such as districts and blocks). They conclude, that an important design element is an introduction of multi-energy systems (e.g., electricity, heat, cooling, fuels, transport) [6]. Such systems have become highly relevant in the last decade. Investigation of one energy carrier makes sense for detailed technical issues (such as grid or market integration of PV systems). Multi-energy systems, as reviewed in [6], on the other hand, can feature better technical, economic and environmental performance relative to "classical" independent or separate energy systems at both the operational and the planning stage. [6].

Secondly, various optimization models have been developed to optimize urban energy systems. DER-CAM is an optimization model that determines the optimal capacity and dispatch strategy of distributed generation technologies to minimize global annualized cost on the customer level [7]. Other modeling tools basing on the energy hub concept are designed to couple various energy systems and manage energy flows through process conversion, storage, and distribution of energy [8, 9]. Fichera et al. use a framework of encompassing complex networks theory and energy distribution issues [10]. Weber and Shah adapt mixed integer linear optimization techniques to design and optimize district energy systems [11]. Mehleri et al., present on a mathematical model to size decentralized energy generation systems including a district heating network [12]. Consequentially, we use two types of optimization models in our work, one for a high temporal resolution and one for a high spatial resolution.

Thirdly, in recent years, open source models (OSM) became more relevant, and there are many OSMs in use in the energy research [13]. The advantages of such models are the ability to share modeling approaches, the improvement of quality and the decrease of adaption costs [13]. Dorfner presents a suite of OSMs adapted to rural energy systems. We use the models *urbs* and *rivus* of Dorfner [15] and [16] in our work and make further improvements.

Different scales (e.g., buildings, blocks, districts) have different requirements. We were investigating grid operation and investments highly relevant for spatial distributed energy generation and consumption. Based on these considerations, various network flow models have been developed in the past [17, 18, 19]. Most models have to deal with a very long computation time when large networks are taken into account. Therefore, special tools are required for the model to be applicable in larger districts [17].

Finally, optimization models may be solved in respect of different objectives. Sameti and Haghighat show that objective functions at the district level are typically carbon emission, production, revenue, operation costs, investment, fuel costs, and renewable exploitation [17]. However, supply concepts with minimum costs are often incompatible with emission reduction targets. Multi-objective optimization models are frequently used in literature [20, 21, 22, 23, 7] to tackle the problem of including different objectives. These approaches determine the optimal energy system (e.g., for district heating) from both environmental and economic perspectives. Therefore, multi-objective optimization models are preferable to support decision makers, because the effects of (often) conflictive objectives can be quantified and allow them to make reasoned (investment) decisions. In our work, we apply a multi-objective optimization to quantify an EC's trade-off curve of costs and emissions. So, at any point on the curve the objective's value cannot be decreased without increasing the other [23]. This so-called Pareto front shows the most efficient solutions concerning both, costs and emissions. The results and changes in deployed technology along the Pareto front help us, e.g., to quantify the costs of emission reduction targets.

In this paper, we propose a framework for establishing an EC in a city district. The usage of different OSMs and scenarios help us to identify how the most economic EC and, contrary, a low carbon emission EC may look. The main contributions of this paper are:

- We propose a new method to quantify the benefits of EC in city districts.
- We introduce a method to describe city districts based on the building structure of city blocks. Such a method may be of practical relevance for city planners as it reduces the complexity.
- We improve an established OSM with features such as economies-of-scale, input data clustering algorithms and Pareto optimization.
- Finally, as ECs might be interested in reducing the carbon emissions, we discuss the different methods of emissions accounting based on the electricity market's conditions as well as the introduction of carbon taxes.

3. Methodology

The methodology of this work bases on two OSMs: *urbs*[1] and *rivus*[2]. We choose these models, because they are well documented and allow us the

[1] Latin term for city [15].
[2] Latin term for stream [16].

description of an EC in two dimensions, spatial and temporal. Dorfner [14] developed both models and published them on the web-based Git version control repository GitHub under the terms of the GNU General Public License. In our work, we introduce the framework *HERO*[3], as a combination of both models *urbs* and *rivus*. Figure 1 shows the setup and the interconnection of our model's components.

As input data, we use three different types of data sources:

1. time-series data, such as energy consumption (electricity, heat, cooling, etc.), solar radiation and the temperature depending heat pump coefficient-of-performance (COP) as well as the energy system's emissions.

2. geographical data, such as building area or grid length and

3. technical (energy and emission conversion efficiency, technical limits, etc.) and economic parameters (investment, maintenance, and fuel costs).

To improve the calculation performance and allow the interoperability of the models, we develop de/-clustering algorithms to meet the different requirements of the models.

In the following subsections we described (i) the applied clustering algorithms for varying the input data, (ii) improvements to the model *urbs* such as the implementation of economies-of-scale and Pareto Optimization, (iii) the modeling approach of EC and (iv) a methodology to account emissions.

[3] Abbreviation of "Hybrid EneRgy Optimization".

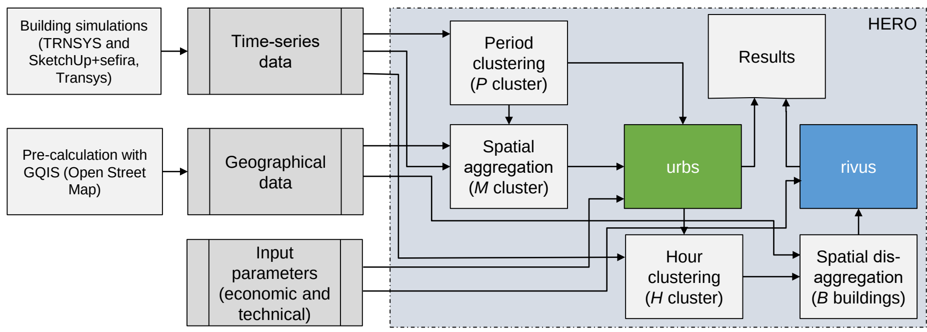


Figure 1: Block diagram of the framework *HERO*, developed in this work.

3.1. Applied data clustering and aggregation methods

As mentioned above, the two models put their focus differently: While *urbs* models process (e.g. energy conversation including the operation of storages) in a high temporal resolution, *rivus* helps to plan the EC grid infrastructure on a disaggregated spatial layer. Consequently, both models have different requirements for the input data. This encourages us to develop different clustering algorithms in order to benefit from each model's strength.

We cluster the input data to reduce the size of both models as well as the computation time of solving the optimization problems. We adopt the K-Means clustering algorithm for the *period clustering* to cluster the time-series data into P representative weeks (3.1.2). Consequentially, we use a *spatial aggregation* based on the method of different city blocks (3.1.1). This allows us to aggregate the reduced time-series data spatially into M clusters.

The model *rivus* requires a higher reduction of the time-series data. The second time-series clustering method *hour clustering* selects the results of *urbs* to characteristic hours (3.1.2). The *spatial disaggregation* method prepares the input data for *rivus* on a building level (3.1.1). The model *rivus* bases on the theory of graphs and consists of edges and vertexes. Each edge of *rivus* (e.g., a grid connection between two houses) is represented by a binary variable.

In the following, we have a more comprehensive look at the applied clustering algorithms.

3.1.1. Aggregation and disaggregation of spatial data

A novel approach of this work is the assignment of urban areas to characteristic city blocks. This approach helps us to reduce the complexity of planning the urban EC. The advantage of this approach is the fact that it requires less information about the area and it may be rather easy to be collected (e.g., by a standard GIS software). We modeled only the characteristic blocks in detail, e.g., in terms of a dynamic heat load.

We define three types of buildings and blocks, significant for the Austrian housing situation within the tested case study[4]:

Single-family housing block (E) is a city block of free-standing residential buildings. This building type is widespread in suburban or rural areas. Even though the buildings share one or more walls with another, it has direct access to a street or thoroughfare. Furthermore, it does not share heating facilities, and hot water equipment with any other dwelling unit.

Apartment building block (B) is a city block of buildings with a high housing density. Apartment buildings are constructed around the bor-

[4]For a further description of the case study see Section 4.

der of the block, resulting in an enclosed area. Open space inside the block is used for collectively. Each building's apartments are self-contained housing units, whereby energy infrastructure could be shared (e.g., by a central heating plant) or not.

Large-panel system building or "Plattenbau" block (Z) is similar to apartment building block but consists of buildings constructed of large, prefabricated concrete slabs. In comparison, "Plattenbauten" are stand-alone buildings, resulting in limitations of energy sharing concepts.

In a first step, we cluster the city area in blocks, by using streets or another kind of obstacles (e.g., parks) as demarcation. In a second step, we assign the blocks to the three predefined block-types. Figure 2 shows the result of this assignment as well as the block types. While E-type blocks consist of small stand-alone buildings, B-type blocks are rather enclosed entities consisting of large buildings covering the block's border. On the opposite, Z-blocks are identifiable as a stand-alone buildings, but the area covered by buildings is much higher than those of single-family buildings.

In a third step, we introduce *characteristic blocks* of each type to describe the remaining blocks. The assessment of the *characteristic blocks* bases on experts interviews (A. Kleboth and I. Granzow, both civil engineers, personal communication, Feb-June, 2016). Figure 2 shows all blocks and the characteristic blocks per type, namely B1, Z1, and E1. We use the energy demand (which consists of electricity, heat and hot water and cooling demand) as well as the supply of renewable generation (solar radiation) of the *characteristic blocks* to describe the corresponding demand and supply characteristics. The description to the other blocks is based on two criteria, the building area A

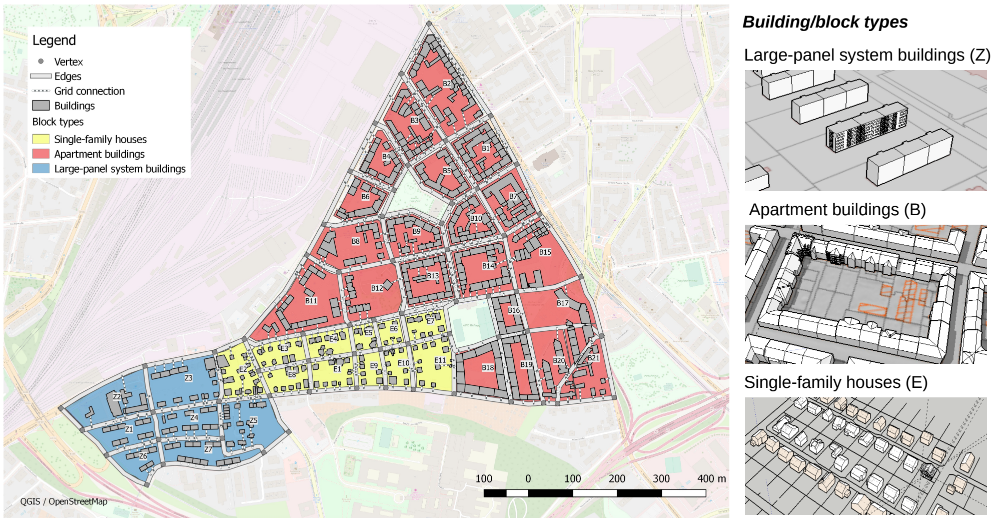


Figure 2: Geographical location of all blocks in the area of Linz an city in Austria (left) and the detailed blocks (E), (B) and (Z) created in SketchUp (right). Source: [24]

and the number of stories S. We describe the energy demand as

$$d^i_{m,j} = d^i_{m,1} \frac{A^i_{m,j}}{A^i_{m,1}} \frac{S^i_{m,j}}{S^i_{m,1}}, \tag{1}$$

$$i \in \{Heat, Elec, Cool\}\,,\ m \in \{E, Z, B\}\,,\ j \in \{2, 3, \ldots, N_m\}$$

with $d^i_{m,j}$ the electricity, heat and cooling demand of block type m and number j. $d^i_{m,1}$ is the demand of the characteristic block modeled by detailed building models (described in [24]).

By applying the *spatial aggregation*, we get a four node model (three for each block types plus one central slack node). We recapture the full spatial information of the area, the *spatial disaggregation* reverse the approach (1) and recalculate the energy demand of each block. Consequentially, we calculate the demand on on a building level by the buildings'.

3.1.2. Clustering temporal data

Period clustering for urbs. We apply the K-Means clustering algorithm to identify P characteristic weeks. One weakness of this approach is that long-term (future) storage technologies such as hydrogen systems might not be integrated with an adequate accuracy because of the lack of consecutive weeks.

As written in [25], the K-Means method minimizes the quantization error function by using the Newton algorithm, i.e., a gradient-based optimization algorithm. We apply the K-Means method to cluster time-dependent inputs:

- Demand vectors of heat (space heating and hot water demand), electricity (residential and commercial demand including the charging demand of electric vehicles) and cooling d_m^{Heat}, d_m^{Elec} and d_m^{Cool}
- Supply vectors of solar photovoltaic (PV) and solar thermal generation q_m^{PV} and q_m^{ST} and
- Conversion efficiency of electricity to heat (COP) of heat pumps $\eta_m^{HP_{liq-water}}$ and $\eta_m^{HP_{water-water}}$.

All vectors have a length of T. Firstly, we standardize the time vectors by applying the ℓ_2 norm. Standardization improves the convergence performance of the K-Means algorithm [26]. Secondly we reshape the time vectors into matrices

$$D_m^{Heat}, D_m^{Elec}, D_m^{Cool}, Q_m^{PV}, Q_m^{ST}, \Gamma_m^{HP_{liq-water}}, \Gamma_m^{HP_{water-water}} \in \mathbb{R}^{T_w \times W} \tag{2}$$

with T_w of timesteps within a week $w \in \{1, \dots, W\}$ and include them in the

K-Means input matrix

$$X = \begin{bmatrix} D_1^{Heat} & & D_M^{Heat} \\ \vdots & \ddots & \vdots \\ \Gamma_1^{HP_{water-water}} & & \Gamma_M^{HP_{water-water}} \end{bmatrix}. \tag{3}$$

This algorithm requires the number of clusters to be specified. In our work we use $P = 4$ periods (therefore four representative weeks per year) $p \in \mathcal{P}$.

We use the python package "scikit-learn" [26, 27][5]. The K-Means algorithm divides a set of W samples X into P disjoint clusters C, each described by the mean of the samples in the cluster. The means of those clusters are commonly called the cluster "centroids"; note that they are not, in general, points from X, although they are in the same space.

Given enough time, K-means will always converge, however, this may be to a local minimum. As a result, the computation is done several times (1000 times in our approach), with different initializations of the centroids, with varying initializations. The random initialization leads to probably better results. [28]

Because these centroids are neither in the dataset nor the right scale (as a result of the standardization), we calculate the Euclidean distance of each centroid to its nearest neighbor and use this as the new cluster center. The corresponding length of the cluster indicates each cluster center's weight ϱ_p. In total, the sum of all weights is equal to 52 weeks per year.

Figure 3 shows exemplary results of the micro-quarter E9 in Linz. For

[5] More in detail, we used the method `kmeans++`.

the sake of simplicity, we showed only results of clustering d_{E1}^{Heat} and q_{E1}^{PV}.

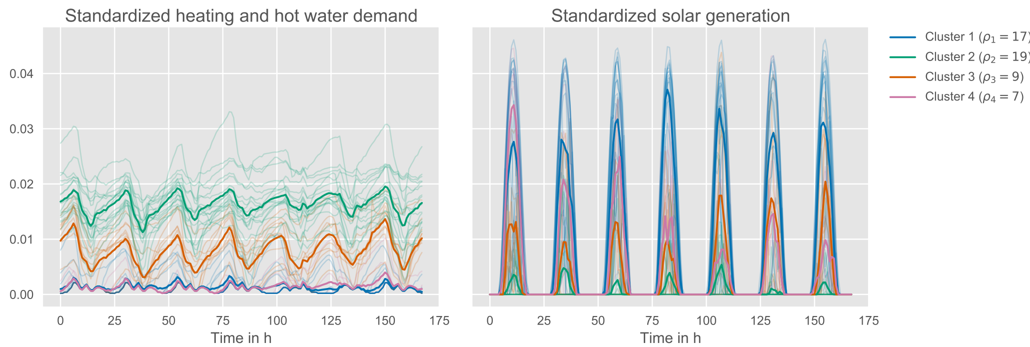


Figure 3: Results for Linz (block E1) for heat and hot water demand and solar generation. While thin lines includes the whole data set, the thick lines indicate the cluster centroids.

Hour clustering for "rivus". Similar to the approach presented before, we use hourly clustering to find representative hours in the dataset. Because of its characteristics, K-Means is not very suitable to cluster peaks or outliers of a dataset [25]. Therefore, we develop an algorithm for both, peak detection and mean-value clustering:

(i) ***Peak detection*** identifies the annual peaks in the time series dataset. These parameters are essential for grid planning. Consequentially, we exclude all detected peaks from the dataset.

(ii) We apply the ***K-Means*** to the reduced dataset (excluding the peaks). In contrast to period clustering (of 3.1.2), the clusters' size is one hour instead of a week.

We apply the algorithm to the results of *urbs*. The model's results give insight into the optimal size and commitment of processes and storages. Consequentially, we used the data to model the required grid infrastructure. The grid infrastructure allows us to describe the distributed generation and sector-coupling[6].

Figure 4 shows the results of *urbs* as violin plot as well as cluster centers of the hourly clustering algorithm. Hours of negative energy flows indicate an excess of distributed generation.

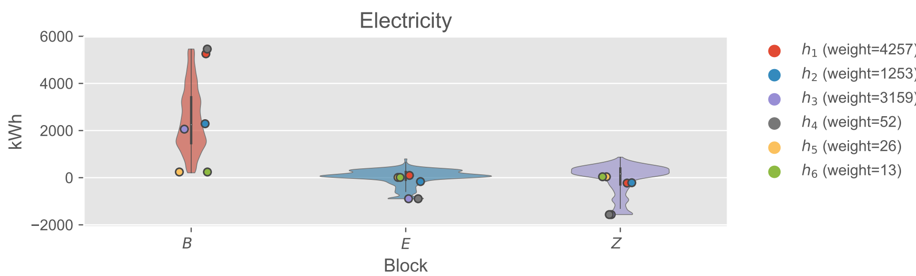


Figure 4: Results of *urbs* (scenario *Status Quo* - minimum cost solution) of the electricity demand as violin plot and the corresponding *rivus* cluster center (including the weight) as points. The points h_4 - h_6 are the peaks of (i), while h_1 - h_3 are the centers of (ii).

3.2. Improvements of the open source model "urbs"

For our requirements, we adapt *urbs* by additional features to handle the needs of modeling EC. Firstly, we include multiple time periods (e.g., weeks) with the corresponding weights. As the first improvement is a standard method, we won't go into detail. Secondly, we include economies-of-scale to capture the investment decision on a building level. Thirdly, we introduce the time dependency of heat and solar generation. In a fourth step, we change the model's objective to a Pareto Optimization with two objectives, costs and emissions.

[6]E.g., a rise of the electrical peak load resulting from the electrification of the system

3.2.1. Economies of Scale

[29] and [30] describe that optimization models have to be able to picture the economies-of-scale (EoS) to describe the economics e.g. of DERs sufficiently. In accordance with the nomenclature introduced in [14] we expand the process rules as follows: Total process capacity κ_{vp} (decision variable) of site $v \in V$ and process $p \in P$ consists of installed capacity K_{vp} (parameter) and new capacity $\hat{\kappa}_{vp}$ (decision variable), as

$$\kappa_{vp} = K_{vp} + \hat{\kappa}_{vp} \tag{4}$$

By the inclusion of binary decision variables s_{vp} we define the lower and upper restriction as

$$s_{vp}\underline{K}_{vp} - K_{vp} \leq \hat{\kappa}_{vp} \leq s_{vp}\bar{K}_{vp} - K_{vp} \tag{5}$$

Both parameters $\underline{K}_{vp}$ and $\bar{K}_{vp}$ are exogenous inputs and defined e.g. by spatial restrictions (such as roof area in the case of PV).

As EoS are significant for investments in the distribution grid as well, we implement those as

$$s_{af}\underline{K}_{af} - K_{af} \leq \hat{\kappa}_{af} \leq s_{af}\bar{K}_{af} - K_{af} \tag{6}$$

with the corresponding index f referring to a transmission process to transfer a commodity along a distribution line a.

Finally, we expand the investment costs of [14] by fixed investments costs

$$\zeta^{inv,fix} = \sum_{\substack{v \in V \\ p \in P}} n_{vp} s_{vp} \hat{\kappa}_{vp}^{inv,fix} + \sum_{\substack{a \in A \\ f \in F}} s_{af} \hat{\kappa}_{af}^{inv,fix} \tag{7}$$

including the binary decision variables. Parameter n_{vp} includes the number of processes to be purchased, e.g. in the case of PV the number of roofs

(n_{vPV}= number of buildings at site v)[7]. We extend *urbs* for storages in the same way, but for the sake of simplicity we do not describe the extension in detail.

3.2.2. Time dependent conversion coefficients

We add the time dependent COP to *urbs* by the expansion of the output ratio r^{out}_{pct} by the dimension of time $t \in T$. To include generation time series of solar photovolatic (PV) and thermal (ST), we multiply the efficiency with the plants nominal capacity κ_{vp}.

COP of heat pumps (air source and ground source). We use the supply temperature to calculate the hourly COP. As introduced in [31] we describe the COP of process p[8] by a polynomial function

$$COP^{i}_{pt} = k_0 - k_1(T^{supply}pt - T^{source}pt) + k_2(T^{supply}pt - T^{source}pt)^2 \qquad (8)$$

for both, domestic hot water (DHW) and space heating (SH) ($i \in \{\mathrm{DHW}, \mathrm{SH}\}$) separately. T^{source} describes the water or air temperature, while T^{supply} is different for DHW or SH. We use a DHW of 55 °C and for SH 50 °C/35 °C[9]. As we do not differentiate between DHW and SH in our model, we calculate a mean COP

$$COP_{pt} = (1 - share^{SH}_{p})COP^{DHW}_{t} + (1 - share^{SH}_{p})COP^{SH}_{t} \qquad (9)$$

with the $share^{SH}_{p} = 84\,\%$, a typical value for Austrian heat demand [32].

[7] For the following study, we assumed all distributed technologies are build on a building level.

[8] $p \in \{HP\ (air\text{-}water), HP\ (water\text{-}water)\}$

[9] As presented in [32] for radiator heating in an old building stock (block type B) and floor heating for the case of a new building stock (E and Z).

Solar energy (ST and PV). Lindberg et al. [31] describe the efficiency of the solar thermal collector (ST) by a polynomial function. The framework requires the following inputs: the solar irradiation on the tilted surface, the temperature within the solar thermal collector and the ambient temperature. Additionally, we describe the solar PV collectors' efficiency by a function introduced in [33]. The authors describe the collectors' efficiency as a function of the solar irradiation (the same as for ST), the modules temperature (calculated from the outdoor temperature) and a static power inverter's efficiency[10].

3.2.3. Pareto optimization

We expand *urbs* by a Pareto optimization to combine two opposing objectives: *costs* and *emissions*. In the following, we name the model's continuous and binary variables $\mathbf{x}$ and $\mathbf{y}$, respectively. As introduced in [34], Pareto optimization dealing with two objectives may be formulated as

$$\begin{aligned} \min_{\mathbf{x},\mathbf{y}} \quad & f(\mathbf{x},\mathbf{y}) = (\mathit{costs}(\mathbf{x},\mathbf{y}), \mathit{emissions}(\mathbf{x},\mathbf{y})) \\ \text{subject to} \quad & \mathbf{x} \in \mathcal{X}, \mathbf{y} \in \mathcal{Y} \end{aligned}$$

with the feasible solution spaces $\mathcal{X}$ and $\mathcal{Y}$.

Both should be minimized by iterative use of the optimization model *urbs*. With this, we implement a three-step approach basing on the ϵ-constraint method for bi-level combinatorial optimization problems[11]:

(I) In a first step, we calculate the minimum cost solution without any

[10] We assume a power inverter's efficiency of 0.95.

[11] See [34] for detailed information of the characteristics of the ϵ-constraint method.

restrictions concerning the emissions.

(II) Secondly, we change the objective from costs to emissions. The results show us the solution in respect of minimal emissions.

(III) Finally, we change the model's setup back to (I), but introduce an upper limit of the emissions. The upper limit is a linear space between the emissions of (I) and (II) and is separated in 10 % steps.

Figure 5 shows the approach graphically. The vectors of the two different objective functions are $\mathbf{c}_{costs}^T$ and $\mathbf{c}_{emissions}^T$, respectively. Starting from point (I) (causing emissions $\overline{e}$), the Pareto front is moving along (III) to (II) (causing emissions $\underline{e}$). The movement along (III) is a result of the ϵ-constraint in the form

$$emissions = \mathbf{c}_{emissions}^T \begin{bmatrix}\mathbf{x}, \mathbf{y}\end{bmatrix}^T \leq \underline{e} + (\overline{e} - \underline{e})(1 - \alpha) \tag{11}$$

by the variation of the parameter α. In our work, we chose the variation of α in 10 % steps.

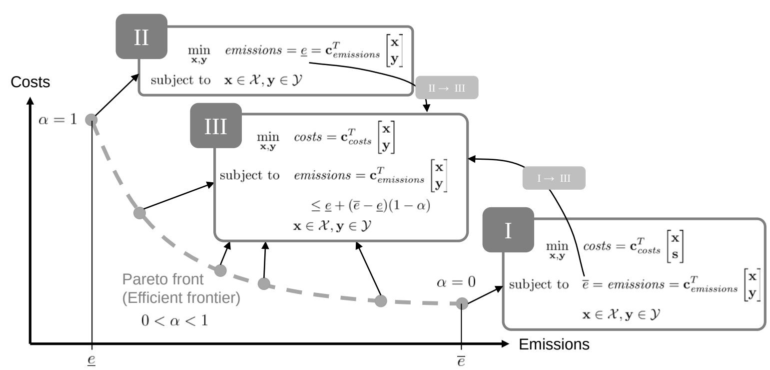


Figure 5: The three-step approach of the Pareto optimization applied in this work.

3.3. Modeling of Energy Communities

The big advantage of an EC is the fact that ECs can make joint investments. To capture this effect, we allowed the EC to make investments of processes and storages on a building level (for all block types). Contrary, if there isn't an EC, the investments of processes and storages are on a flat (B or Z blocks) or building (E blocks) level. So, the EC can exploit the EoS of processes and storages (modeled by binary decision variables in 3.2.1). The investment costs in the distribution grid are unchanged between those two cases.

3.4. Merit order based accounting of emissions

One of the objectives of EC addresses emission reduction. So, the EC may consider two types of emissions: (i) mean or (ii) marginal emissions. Both types of emissions reflect the current market conditions, but marginal emissions give us information of one additional unit of energy fed into or consumed from the grid. The idea behind the comparison is that the ECs might be interested in substituting certain power plants (e.g., coal), as implied by the consideration of marginal emissions.

We calculate mean emissions by using the total carbon emissions and the total amount of electricity generated for each time-step (hour). For the introduction of marginal emissions, we have to define the marginal generator: The marginal generator is the unit selling the last bid and setting the price.

Figure 6 shows the result of the two types for two exemplary hours. While the upper part of the Figure shows the Central European merit order, the lower part shows the corresponding emissions of each power plant[12]. So, the marginal generators are gas power plants (hour 1) and lignite power plants (hour 2). The merit order does reflect costs (and prices) but not the emissions: while the demand and electricity price for time step 1 is high, marginal and mean emissions are low and vice versa for time step 2. So, the marginal emissions at time step 1 are high compared to the mean emissions, as the lignite power plant sets the price.

In the following analysis, we use the Austrian merit order because of two aspects. Firstly, the Austrian electricity market[13] has a high share of RES, therefore gives an outlook how future merit orders may look like. So, the difference of mean and marginal emissions are significant. Secondly, Austrian consumers (and therefore ECs as well) have a high affinity to buy Austrian products. We showed the effects of considering either mean or marginal emissions by the planning of local energy infrastructure of an EC. If not stated otherwise, we use mean emissions.

4. Definition of the case study and scenarios

In the following, we describe an EC in a site in the city of Linz, Austria and the corresponding scenarios regarding the available energy infrastructure, energy demand, and generation. We choose this site because data is accessible and all three building types, typically for Austrian building stock, are present. We list our assumptions in regard of the economic (such as in-

[12]Emissions according to the German Bundestag [35]

[13]Installed capacity according to the Austrian TSO *Austrian Power Grid*: Hydro 55.16 %, Wind 13.03 %, PV 4.73 %, Gas 20.48 %, Coal 2.74 % and Misc 3.86 %.

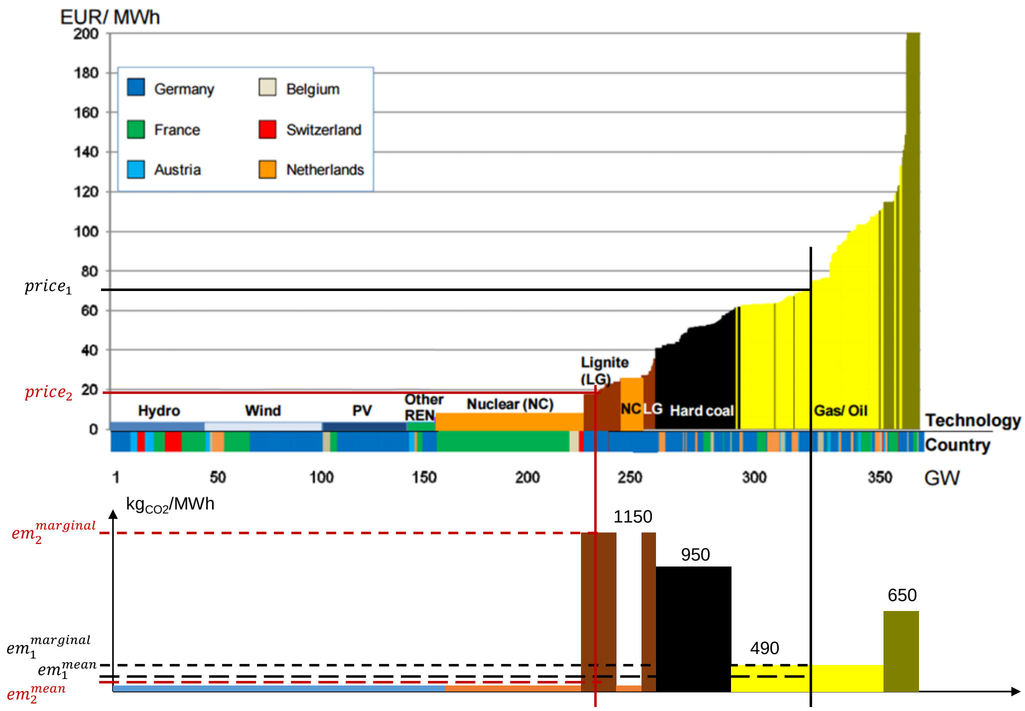


Figure 6: Central European merit order (top) and the corresponding emissions (bottom). Own representation basing on [36] and [35].

vestment, maintenance and operational costs of processes, storages, and the grid) and technical (e.g., efficiency factors) parameters in the Appendix A.

4.1. Project site and energy infrastructure

We apply the model, to a project site in Linz, more precisely the "Andreas-Hofer-Viertel"[14]. The existing buildings (Figure 2) are currently connected to the electricity and district heating grid [37]. Consequentially, we assume in one scenario that a utility company provides electricity and heat demand (via the electricity and district heating grid). We name this scenario *"Ex-*

[14]Geographical location: N 48°17′12.2", E 14°17′49.8"

isting Infrastructure". Also, we included the possibility that no generation and distribution system is available and call this scenario *"Green Field"*. In this case, the EC has to invest into the grid. The comparison of those scenarios helps us to understand the "lock-in effect" given by existing energy infrastructure.

4.2. Energy demand and generation

We describe demand, generation, and efficiency data by measured and synthetic data from the year 2016[15]. To understand the effects of load development, we introduced two scenarios: The scenario "*Status Quo*" describe the current situation at the project site, while the second scenario, "*Future*", include a higher population density but also a higher energy efficiency standards[16] according to the current standard of legislation[17]. Also, we address the future availability of electric vehicles (EV), by introducing one EV per two inhabitants[18]. We assume that the electric vehicles are charged at home[19]

[15]Electricity profiles: [38], heat profiles: [39], PV and solar thermal and heat pump generation [33, 31, 40, 41]. Further information regarding the building specific modeling may be found in [24].

[16]The implementation of energy efficiency measures allow a significant reduction of SH and DHW demand, especially for the B block type. Electricity demand (w/o any demand for heat pumps) depends on the number of inhabitants, whereas it is independent of building specific energy efficiency measures.

[17]Provincial Law of 5 May 1994, which enacts a building code for Upper Austria (Oö. Bauordnung 1994 - Oö. BauO 1994)

[18]Current status in Linz [42].

[19]The charging profiles originated from an Austrian EV Study *E-Mobilitätsmodellregion VLOTTE* [43]. As the case study in this paper addresses an urban area, we assume a daily demand of 4 kWh for this paper.

(without discussing the issue of parking), the electricity demand increases more in blocks with a higher number of inhabitants (B and Z).

5. Results and discussion

In this section, we first show the minimum costs solution of the EC of the case study. Secondly, we compare the minimum costs to the minimum carbon emissions solution. Consequentially, we calculate the entire Pareto Front and analyze it in respect to different methods of emissions accounting. The final results address the sensitivity of the minimum cost solution in the case of carbon taxes and compare it to the Pareto Front.

5.1. The economic value of EC

In a first step, we discuss the economic value of an EC. Therefore, we calculate the cost minimal solution, also labeled solution (I) in Figure 5. Figure 7 shows the composition of annual total costs, for the cases without and with EC. Furthermore, it distinguishes between all the previously introduced scenarios.

The results show that the introduction of EC reduces the total costs by up to 32 %. We see the highest gains in the *Green Field* scenarios, therefore showing us the lock-in effect of existing investments. In this scenario, the EC avoided investments in the heating grid. The EC exploits the EoS by investing in one grid only, the electricity grid. So, the EC is not affected by investment costs in district heating networks and heat procurement costs. In all cases, the revenues are minor because the distributed generation was almost entirely consumed locally.

For the following results, we discuss the results for the EC, only.

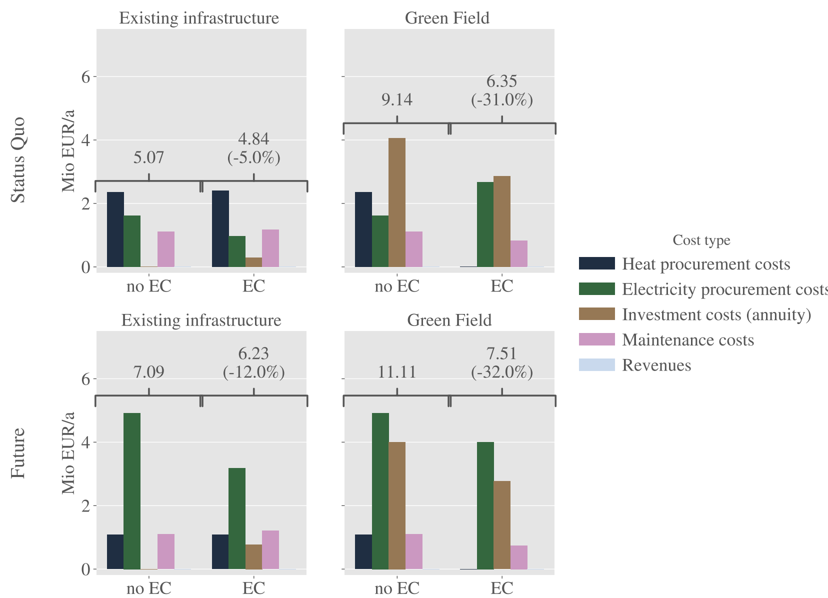


Figure 7: Composition of the costs for the minimum costs solution.

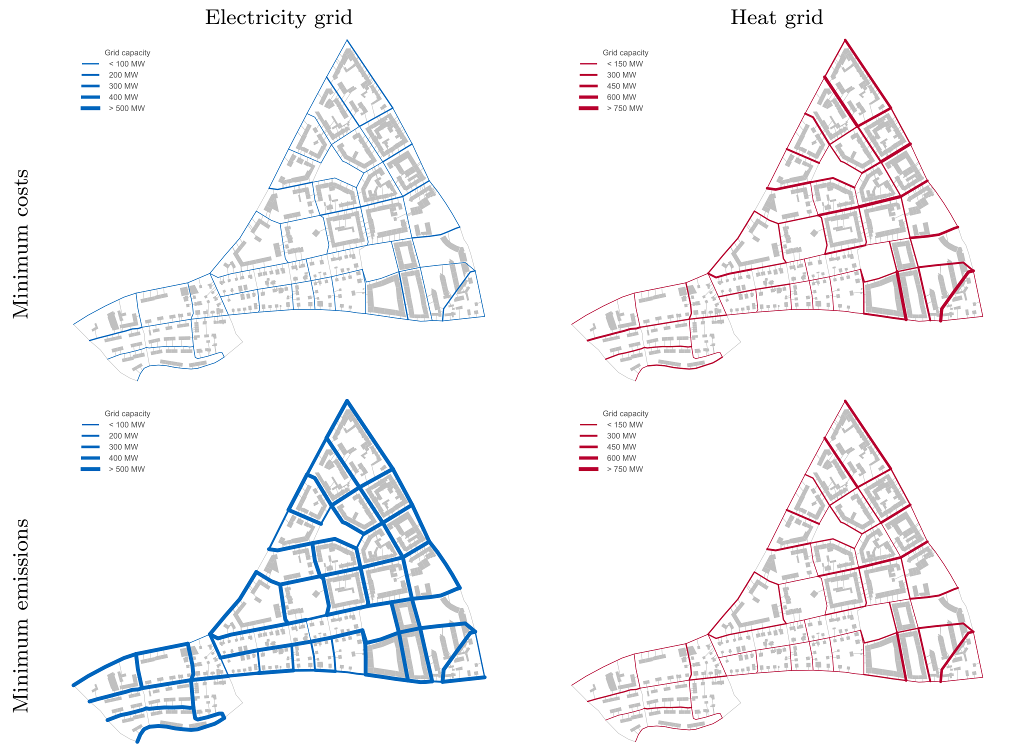
5.2. Minimum costs vs minimum emissions

If we switch the objective to minimum emissions, shown as transition from (I) to (II) in Figure 5), the solutions change drastically. Table 1 shows the results for the grid deployment. It shows the results for the scenario *Status Quo/Existing Infrastructure* and the electricity grid changes strongly.

Figure 8 shows the composition of the commodities used for electricity and heat provision (show in the first two sub-figures) and total emissions. The results indicate that the emission reduction of 85 % is the result of PV installations and heat pumps. Such investments requires investments in electricity grid infrastructure (see Table 1 bottom/left) and processes (especially solar PV and heat pumps). As a result, the total costs increases by 598 %. For real-world installations, such an increase in costs would be hardly manageable.

Therefore, the following results will give more information about the transition towards a renewable energy community and quantify the trade-off between costs and emissions.

Table 1: Grid deployment for minimum costs and minimum emissions *Status Quo/Existing infrastructure*.



5.3. Pareto Front and methods of emissions accounting

In the next step, we extend the minimum costs and minimum emissions optimization by the Pareto Optimization. Additionally, we include different methods of emission accounting, as introduced in 3.4

Figure 9 shows the Pareto Fronts, as well as two methods of emission accounting. The results vary highly between mean and marginal emissions

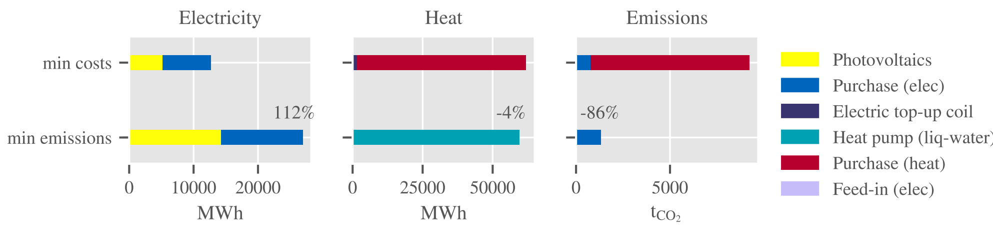


Figure 8: Commodities created for minimum costs and minimum emissions solution.

(up to 389 %), although the technology portfolio is very in both emission scenarios. As shown in the previous results, the highest gains of emission reduction are achieved by electrifying the EC. By accounting emissions by the method of marginal emissions, the total annual emissions increases, although there are only minor changes in the optimal technology portfolio.

As stated in 5.1 and 5.2 the minimum costs solution in the case of *Existing Infrastructure* is the heat procurement via the heat grid. Contrary, the heat procurement in the *Green Field* scenario, is based on heat pumps. The results show that newly designed energy infrastructure under the aspect of cost reduction benefits in terms of emission reduction, named ΔE. ΔE might be interpreted as the emissions savings potential of green-field infrastructure.

The results also show that the Pareto Front of *Existing Infrastructure* converges to the Pareto Front of *Green Field*, but differs in costs by ΔC (the result of an existing electricity grid). ΔC may be interpreted as the monetary value of existing infrastructure regarding the minimum emissions solution.

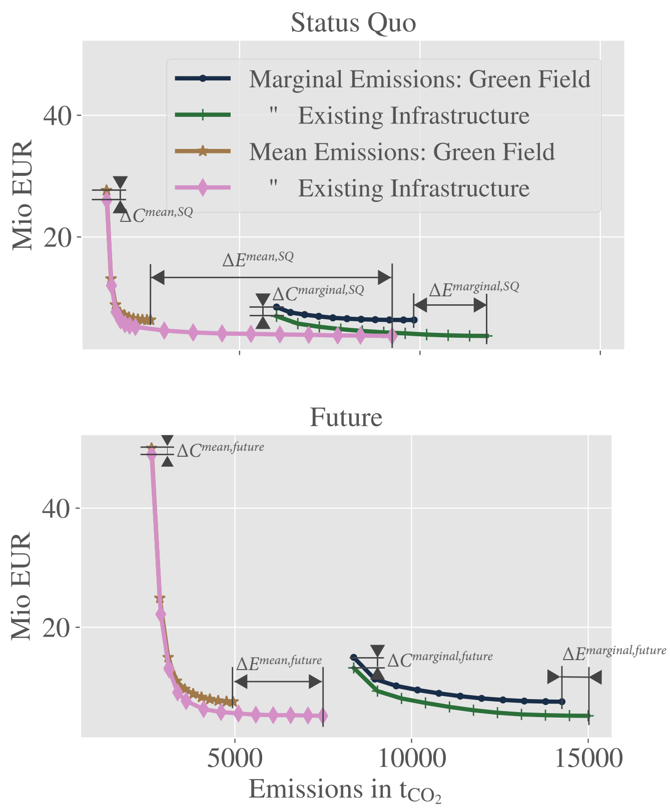


Figure 9: Pareto Fronts with two methods of emissions accounting: mean and marginal emissions. Besides comparing the demand scenarios *Status Quo* and *Future*, we also distinguishes between *Green Field* and *Existing Infrastructure*.

5.4. Introduction of Carbon Taxes

For the final results, we investigate the impacts of carbon taxes on the minimum costs solution. In comparison to the Pareto Optimization, we do not restrict the emissions up to the minimum emissions solution (quantity based reduction of emissions); instead, carbon taxes emissions increase the total costs (price based reduction of emissions).

The results in Figure 10 shows the results for carbon taxes starting from

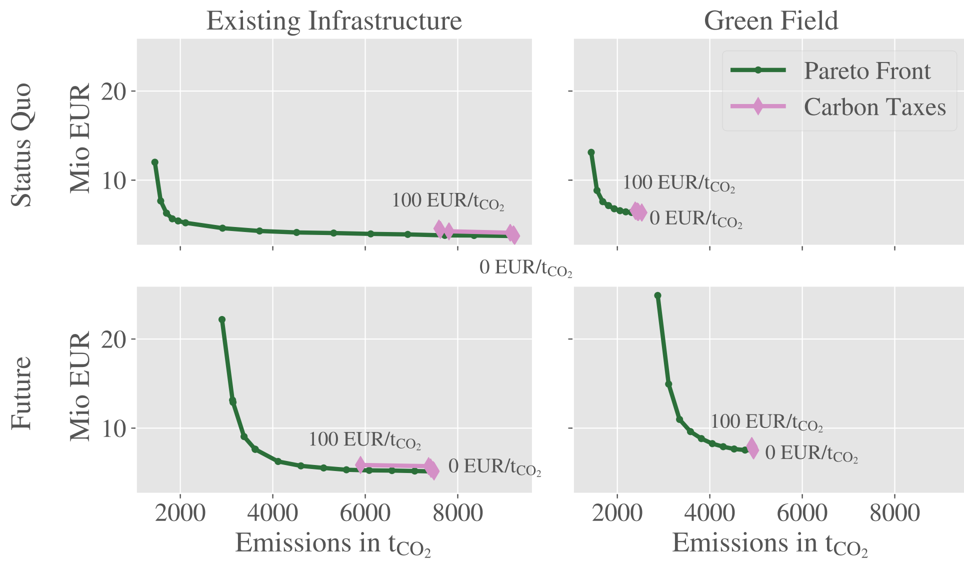


Figure 10: Comparison of the Pareto Font with multiple minimum cost solutions with carbon taxes from 0 to 100 EUR/t_{CO_2}, ascending in 20 EUR/t_{CO_2} steps.

from 0 to 100 EUR/t_{CO_2}[20] in 20 EUR/t_{CO_2} steps. Comparing *Existing Infrastructure* with the *Green Field*, we see that *Existing Infrastructure* is more sensitive to carbon taxes. On the other hand, carbon taxes up to 100 EUR/t_{CO_2} do not provide monetary incentives to change the technology portfolio for the *Green Field* significantly.

As shown in Figure 8 most of the emissions are the result of heat procurement. Lower heat load characterizes the *Future* scenario, but a higher electricity load. So, the sensitivity to carbon taxes is even reduced compared to *Status Quo*.

[20]There is an ongoing discussion about the introduction and an appropriate level of carbon taxes. So, France plans to increase the carbon tax rate to 56EUR/tCO2 in 2020 and 100 EUR/tCO2 in 2030. [44]

6. Conclusions

To address the value of EC in terms of two objectives: costs and emissions, we develop an energy system model basing on two open-source optimization models. While the focus of the first sub-model is the optimal investment decisions on a high temporal level, the second sub-model address the optimal deployment of energy grids on a building level. Also, we develop spatial and temporal clustering algorithms to increase the models' performance.

The results show that ECs could reduce the costs as well as emissions. Not surprisingly, the solutions for minimum costs and minimum carbon emissions are contrary to each other. Therefore, the calculation of the Pareto Front helps us to quantify the optimal technical portfolio as a function of both objectives. We see that a higher degree of emission reduction is mostly the result of electrification, although the use of one single energy carrier increases the risk of the EC (e.g., concerning security-of-supply or price shocks).

Furthermore, we analyze the lock-in effect of existing infrastructure. It is very significant, as carbon emissions are much higher for existing infrastructure than green-field investments. Also, any sunk costs, e.g., in the form of an existing heat grid, make the EC more vulnerable to carbon taxes.

As this paper assumes that all consumers at the project site join the EC, the situation, in reality, may depend on the willingness of the consumers to join such an EC. For the practical implementation to establish an EC, the *Green Field* scenario may be more suitable: In an urban development project, an appropriate framework may provide the incentives to inhabitants to join the EC.

We see multiple directions for future research, including an improved modeling approach for the implementation of long-term storages and the effects of uncertainty (e.g., in terms of future energy demand).

Acknowledgements

This work was developed in part within the framework of the project "SC_Mikroquartiere" funded by the Austrian Ministry for Transport, Innovation and Technology.

Appendix A. Data

Table A.2: Technical and economic parameters of processes

Process	inv-cost in EUR/building	inv-cost-p in EUR/kW	fix-cost in % of inv	wacc in %	area-per-cap in m^2/kW	depreciation in a	source
Photovoltaics	3,494	1,038	1	2	6.5789	25	[45]
Solarthermal	4,000	2,461	1	2	1.25	25	[45]
Hybrid collector	6,000	3,000	1	2	6.5789	25	[46]
Electrolyser	5,235	4,278	1	2	-	20	[47]
Fuel cell	4,635	3,753	1	2	-	20	[47]
Electric top-up coil	100	60	2	2	-	25	[31]
Gas boiler	1,200	600	1	2	-	20	[45, 31]
Heat pump (liq-water)	17,000	770	2	2	-	20	[31]
Heat pump (air-water)	3,000	1,150	2	2	-	18	[31]
Mikro CHP	1,200	3,400	3	2	-	20	[31]

Table A.3: Technical and economic parameters of grids

Grid	inv-cost in EUR/m	inv-cost-p in EUR/kW	fix-cost in % of inv	wacc in %	depreciation in a	source
Elec. grid	400	390	1	0.02	40	[48]
Heat grid	500	742	1	0.02	40	[48]
Gas grid	400	594	1	0.02	40	[48]

Table A.4: Technical and economic parameters of storages

Storage	eta in %	inv-cost in EUR/builing	inv-cost-p in EUR/kW	inv-cost-c in EUR/kWh	fix-cost-p in EUR/kW/a	fix-cost-c in EUR/kWh/a	depre-ciation in a	wacc in %	source
Battery	96	1000	10	1200	0.5	0.5	15	2	[49]
Hot Water Storage	90	0	1	90	1	1	15	2	[31]
H2 Storage	98	0	0.1	25	0	0	25	2	[47]

References

[1] The World Bank, . The World Bank In Urban Development. ???? URL \url{http://www.worldbank.org/en/topic/urbandevelopment/overview}.

[2] European Commission, . Cities. ???? URL \url{https://ec.europa.eu/clima/policies/international/paris_protocol/cities_en}.

[3] IEA, . Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems. ???? URL \url{https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2016_ExecutiveSummary_EnglishVersion.pdf}.

[4] European Commission, . Proposal For a Directive of the European Parliament and of the Council on Common Rules for the Internal Market in Electricity: IEM Directive. 2016.

[5] Walker, G.. What are the barriers and incentives for community-owned means of energy production and use? Energy Policy 2008;36(12):4401–4405. doi:\bibinfo{doi}{\url{10.1016/j.enpol.2008.09.032}}.

[6] Mancarella, P.. MES (multi-energy systems): An overview of concepts and evaluation models. Energy 2014;65:1–17. doi:\bibinfo{doi}{\url{10.1016/j.energy.2013.10.041}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0360544213008931}.

[7] Stadler, M., Groissböck, M., Cardoso, G., Marnay, C.. Optimizing Distributed Energy Resources and building retrofits with the strategic

DER-CAModel. Applied Energy 2014;132:557–567. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2014.07.041}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0306261914007235}.

[8] Geidl, M.. Integrated Modeling and Optimization of Multi-Carrier Energy Systems. Dissertation; ETH Zurich; 2007.

[9] Nazar, M.S., Haghifam, M.R.. Multiobjective electric distribution system expansion planning using hybrid energy hub concept. Electric Power Systems Research 2009;79(6):899–911. doi:\bibinfo{doi}{\url{10.1016/j.epsr.2008.12.002}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0378779608003180}.

[10] Fichera, A., Frasca, M., Volpe, R.. Complex networks for the integration of distributed energy systems in urban areas. Applied Energy 2017;193:336–345. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2017.02.065}}.

[11] Weber, C., Shah, N.. Optimisation based design of a district energy system for an eco-town in the United Kingdom. Energy 2011;36(2):1292–1308. doi:\bibinfo{doi}{\url{10.1016/j.energy.2010.11.014}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0360544210006407}.

[12] Mehleri, E.D., Sarimveis, H., Markatos, N.C., Papageorgiou, L.G.. A mathematical programming approach for optimal design of distributed energy systems at the neighbourhood level. Integration and Energy System Engineering, European Symposium on Computer-Aided Process

Engineering 2011 2012;44(1):96–104. doi:\bibinfo{doi}{\url{10.1016/j.energy.2012.02.009}}. URL \url{http://www.sciencedirect.com/science/article/pii/S036054421200103X}.

[13] Bazilian, M., Rice, A., Rotich, J., Howells, M., DeCarolis, J., Macmillan, S., et al. Open source software and crowdsourcing for energy analysis. Energy Policy 2012;49:149–153. doi:\bibinfo{doi}{\url{10.1016/j.enpol.2012.06.032}}.

[14] Dorfner, J.. Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale. Dissertation, München, Technische Universität München, 2016; 2016.

[15] Dorfner, J.. urbs: A linear optimisation model for distributed energy systems. 06.2017. URL \url{https://github.com/ojdo/urbs}.

[16] Dorfner, J.. rivus: A mixed integer linear optimisation model for energy infrastructure networks. 06.2017. URL \url{https://github.com/tum-ens/rivus}.

[17] Sameti, M., Haghighat, F.. Optimization approaches in district heating and cooling thermal network. Energy and Buildings 2017;140:121–130. doi:\bibinfo{doi}{\url{10.1016/j.enbuild.2017.01.062}}.

[18] Orehounig, K., Evins, R., Dorer, V.. Integration of decentralized energy systems in neighbourhoods using the energy hub approach. Applied Energy 2015;154:277–289. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2015.04.114}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0306261915005772}.

[19] Eicker, U., Monien, D., Duminil, É., Nouvel, R.. Energy performance assessment in urban planning competitions. Applied Energy 2015;155:323–333. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2015.05.094}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0306261915007278}.

[20] Morvaj, B., Evins, R., Carmeliet, J.. Optimization framework for distributed energy systems with integrated electrical grid constraints. Applied Energy 2016;171:296–313. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2016.03.090}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0306261916304159}.

[21] Falke, T., Krengel, S., Meinerzhagen, A.K., Schnettler, A.. Multi-objective optimization and simulation model for the design of distributed energy systems. Applied Energy 2016;184:1508–1516. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2016.03.044}}.

[22] Voll, P.. Automated optimization-based synthesis of distributed energy supply systems; vol. 1 of *Aachener Beiträge zur Technischen Thermodynamik*. Aachen: Mainz; 1. aufl ed.; 2014. ISBN 978-3-86130-474-6.

[23] Molyneaux, A., Leyland, G., Favrat, D.. Environomic multi-objective optimisation of a district heating network considering centralized and decentralized heat pumps. ECOS 2008 2010;35(2):751–758. doi:\bibinfo{doi}{\url{10.1016/j.energy.2009.09.028}}. URL \url{http://www.sciencedirect.com/science/article/pii/S0360544209004216}.

[24] Zelger, T., Leibold, J., Lettner, G., Fleischhacker, A., Huemer-Kals, V., Kleboth, A., et al. SMART CITY - MIKROQUARTIERE Energie- und lebensqualitätsoptimierte Planung und Modernisierung von Smart City-Quartieren (Working Document): Endbericht; 2018.

[25] Bottou, L., Bengio Yoshua, . Convergence Properties of the K-Means Algorithms. Advances in Neural Information Processing Systems 1995;(7):585–592.

[26] Garreta, R.. Learning scikit-learn: Machine learning in Python : experience the benefits of machine learning techniques by applying them to real-world problems using Python and the open source scikit-learn library. Community experience distilled; Birmingham, UK: Packt Pub; 2013, 2013. ISBN 978-1783281930.

[27] Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., et al. Scikit-learn: Machine Learning in Python. Journal of Machine Learning Research 2011;12:2825–2830.

[28] Arthur, D., Vassilvitskii, S.. K-means++: The Advantages of Careful Seeding. In: Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms. SODA '07; Philadelphia, PA, USA: Society for Industrial and Applied Mathematics. ISBN 978-0-898716-24-5; 2007, p. 1027–1035. URL \url{http://dl.acm.org/citation.cfm?id=1283383.1283494}.

[29] Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D'haeseleer, W.. Distributed generation: Definition, benefits and is-

sues. Energy Policy 2005;33(6):787–798. doi:\bibinfo{doi}{\url{10.1016/j.enpol.2003.10.004}}.

[30] Manfren, M., Caputo, P., Costa, G.. Paradigm shift in urban energy systems through distributed generation: Methods and models. Applied Energy 2011;88(4):1032–1048. doi:\bibinfo{doi}{\url{10.1016/j.apenergy.2010.10.018}}.

[31] Lindberg, K.B., Doorman, G., Fischer, D., Korpås, M., Ånestad, A., Sartori, I.. Methodology for optimal energy system design of Zero Energy Buildings using mixed-integer linear programming. Energy and Buildings 2016;127:194–205. doi:\bibinfo{doi}{\url{10.1016/j.enbuild.2016.05.039}}.

[32] Fischer, D., Madani, H.. On heat pumps in smart grids: A review. Renewable and Sustainable Energy Reviews 2017;70:342–357. doi:\bibinfo{doi}{\url{10.1016/j.rser.2016.11.182}}.

[33] Huld, T., Gottschalg, R., Beyer, H.G., Topič, M.. Mapping the performance of PV modules, effects of module type and data averaging. Solar Energy 2010;84(2):324–338. doi:\bibinfo{doi}{\url{10.1016/j.solener.2009.12.002}}.

[34] Bérubé, J.F., Gendreau, M., Potvin, J.Y.. An exact -constraint method for bi-objective combinatorial optimization problems: Application to the Traveling Salesman Problem with Profits. European Journal of Operational Research 2009;194(1):39–50. doi:\bibinfo{doi}{\url{10.1016/j.ejor.2007.12.014}}.

[35] Deutscher Bundestag, . CO2-Bilanzen verschiedener Energieträger im Vergleich; 2007.

[36] IEA Coal Industry Advisory Board, . The Impact of Global Coal Supply on Worldwide Electricity Prices; 2015.

[37] Linz AG, . Kennzahlen 2016: Auf einen Blick. 2016. URL \url{https://www.linzag.at/media/dokumente/infomaterial_2/linzag-kennzahlen.2016.pdf}.

[38] Beausoleil-Morrison, I., Arndt, U.. An experimental and simulation-based investigation of the performance of small-scale fuel cell and combustion-based cogeneration devices serving residential buildings: Final report of Annex 42 of the International Energy Agency's Energy Conservation in Buildings and Community Systems Programme. [Ottawa: Natural Resources Canada]; 2008. ISBN 978-0-662-47924-6.

[39] BGW, . Praxisinformation P 2007/13 Gastransport / Betriebswirtschaft: Abwicklung von Standardlastprofilen. 2007.

[40] MINES ParisTech / Transvalor, . Irradiation values from HelioClim-3 and meteorological data (MERRA-2 and GFS): Generated using Copernicus Atmosphere Monitoring Service Information 2016. 2018.

[41] ZAMG, . Meteorologische Messdaten der ZAMG. 2012-2018. URL \url{https://creativecommons.org/licenses/by/3.0/at/deed.de}.

[42] Statistics Austria, . Motor vehicles: Vehicle stock in 2017. 21.08.2018. URL \url{https://www.statistik.at/web_de/statistiken/

energie_umwelt_innovation_mobilitaet/verkehr/strasse/kraftfahrzeuge_-_bestand/index.html}.

[43] Schuster, A., Leitinger, C., Brauner, G.. Begleitforschung der TU Wien in VLOTTE; 19.04.2010.

[44] Zimmermannová, J., Hájek, M., Rozenský, L.. Carbon taxation in the European countries 2018;URL \url{https://www.researchgate.net/publication/322315012_Carbon_taxation_in_the_European_countries}.

[45] Loschan, C.. Marktanalyse von Skaleneffekten dezentraler Erzeugungstechnologien mit Regressionsanalyse. Bachelor Thesis; TU Wien; 2017.

[46] Adam, M., Wirth, P., Radosavljevic, R.. Verbundprojekt: Standardisierung und Normung von multifunktionalen PVT Solarkollektoren (PVT–Norm): Teilvorhaben: PVT–Systemanwendungen und Simulationen. ????

[47] Kotzur, L., Markewitz, P., Robinius, M., Stolten, D.. Kostenoptimale Versorgungssysteme für ein vollautarkes Einfamilienhaus. In: Auer, H., Haas, R., Hiesl, A., editors. Klimaziele 2050: Chance für einen Paradigmenwechsel? 2017,URL \url{eeg.tuwien.ac.at/iewt2017/}.

[48] Mühlecker, D.. Betriebswirtschaftlich optimale Wärme- und Stromversorgung eines Stadtentwicklungsgebietes. Master Thesis; TU Wien; 2016. URL \url{https://repositum.tuwien.ac.at/obvutwhs/content/titleinfo/1375199}.

[49] Hiesl, A.. Kostenentwicklung dezentraler Batteriespeicher - Evolution oder Revolution? In: Bachhiesl, U., Stiegler, H., editors. Neue Energie für unser bewegtes Europa. 2018,URL \url{https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2018/files/allg/EnInnov2018_Programm_180211.pdf}.

MULTI-OBJECTIVE OPTIMIZATION OF URBAN ENERGY SYSTEMS CONSIDERING HIGH SHARES OF RENEWABLE ENERGY GENERATION

Andreas Fleischhacker, Energy Economics Group, Vienna University of Technology
Gusshausstrasse 25-29/E370-3, 1040 Vienna, Austria
Phone: +43-(0)1-58801-370361
Email: fleischhacker@eeg.tuwien.ac.at
Georg Lettner, lettner@eeg.tuwien.ac.at

Overview

The major challenges in the development of cities and municipalities in terms of sustainability and a low-carbon society addresses the sensible integration of existing buildings and infrastructures. The Austrian government founded project "SC_Mikroquartiere"[1] shows the possibilities of the city planning on a district level towards a low carbon city with a high quality of living and good resilience taking into account existing and planned buildings, infrastructure and utilization. The central element of this project is the modeling of urban structures on micro-district level.

This approach allows us to

- formulate and present of viable district/neighborhood models on a high-resolution spatial scale,
- developing practical district-specific assessment criteria / indicators for post-compression and high-quality energetic solutions, which refer to buildings and indicators
- the examination of the practicability of high-quality planning solutions on the basis of real micro-district.

The overall objective is the identification of neighborhood solutions and the adaptation of these proposals to 2 city districts, as well as the identification of synergies.

Methods

Within this project an optimization model "*urbs_HERO*"[1] consisting of multiple energy-hubs was developed. Energy hubs are a simplification of an urban (i.e. it is an abstraction of a spatial area). An energy hub is characterized by a production capacity, energy consumption and storage capacity. Different energy hubs are connected by grids. Mathematically, energy hubs are formulated by a multidimensional linear system. These predefined energy sources are grid conducted energy sources (e.g. electrical, natural gas and heat grid) as well as stationary energy sources (e.g. coal or biomass). This concept allows us to investige multiple levels of aggregation, starting from analyzing optimum energy distribution systems on building level up to district level. Figure 1 shows the various levels of aggregation.

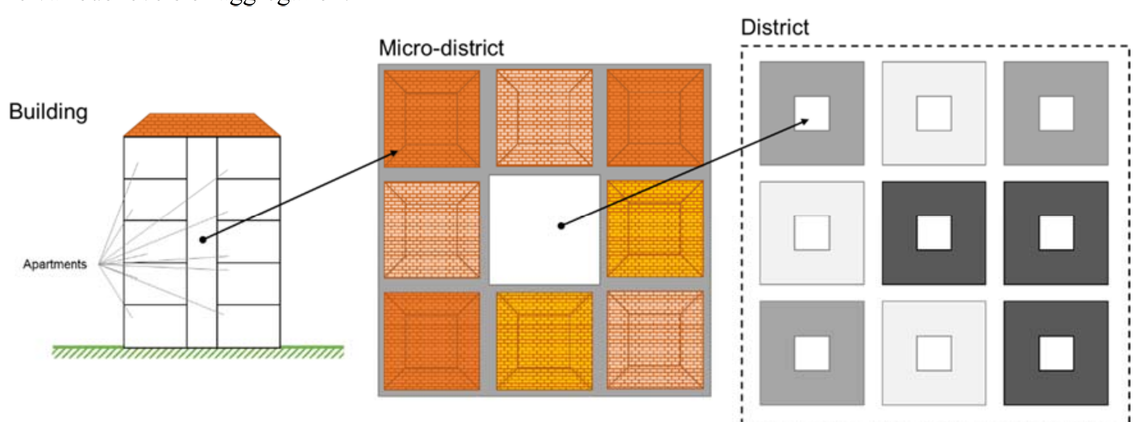


Figure 1: Visualization aggregating three levels of aggregation (from and building to micro-district to district level)

The objective of this optimization model does not only addresses minimal costs rather multi-objectives allows an combined analysis of multiple objectives. The following objectives were considered in this work:

1. ***Minimum total costs***: minimizing total costs, i.e. investment, maintenance and operating costs. This objective function is used to illustrate the maximum cost-effectiveness.
2. ***Minimum emissions***: minimization of emissions, emissions incurred in the production of technologies are not considered.

[1] Based on an open-source python/pyomo[2] optimization model "*urbs*"[3]

3. ***Minimal grid supply / Maximum energy autarky***: This target function increases the level of local self-generation. With this objective, investments in local energy generation technologies are to be strengthened.

Results and Conclusions

The expected results of the investigated cases shall indicate optimal investment strategies differentiated by technology, energy carrier, supply/demand pattern, and others. It also determines the optimal technology portfolio and optimal investment trajectory as well as the optimal dispatch of existing and new plants and storage technologies over the predefined planning horizon. Energy prices are used, among others, as sensitivity parameters.

References

[1] https://nachhaltigwirtschaften.at/de/sdz/projekte/sc-mikroquartiere.php, visited April 1st 2017.

[2] Hart, William E., Jean-Paul Watson, and David L. Woodruff. "Pyomo: modeling and solving mathematical programs in Python." Mathematical Programming Computation 3, no. 3 (2011): 219-260.

[3] https://github.com/tum-ens/urbs/blob/master/doc/overview.rst, visited April 1st 2017.

TECHNISCHE UNIVERSITÄT WIEN

Energy Economics Group

Multi-objective Optimization of Urban Energy Systems Considering High Shares of Renewable Energy Generation

Andreas Fleischhacker

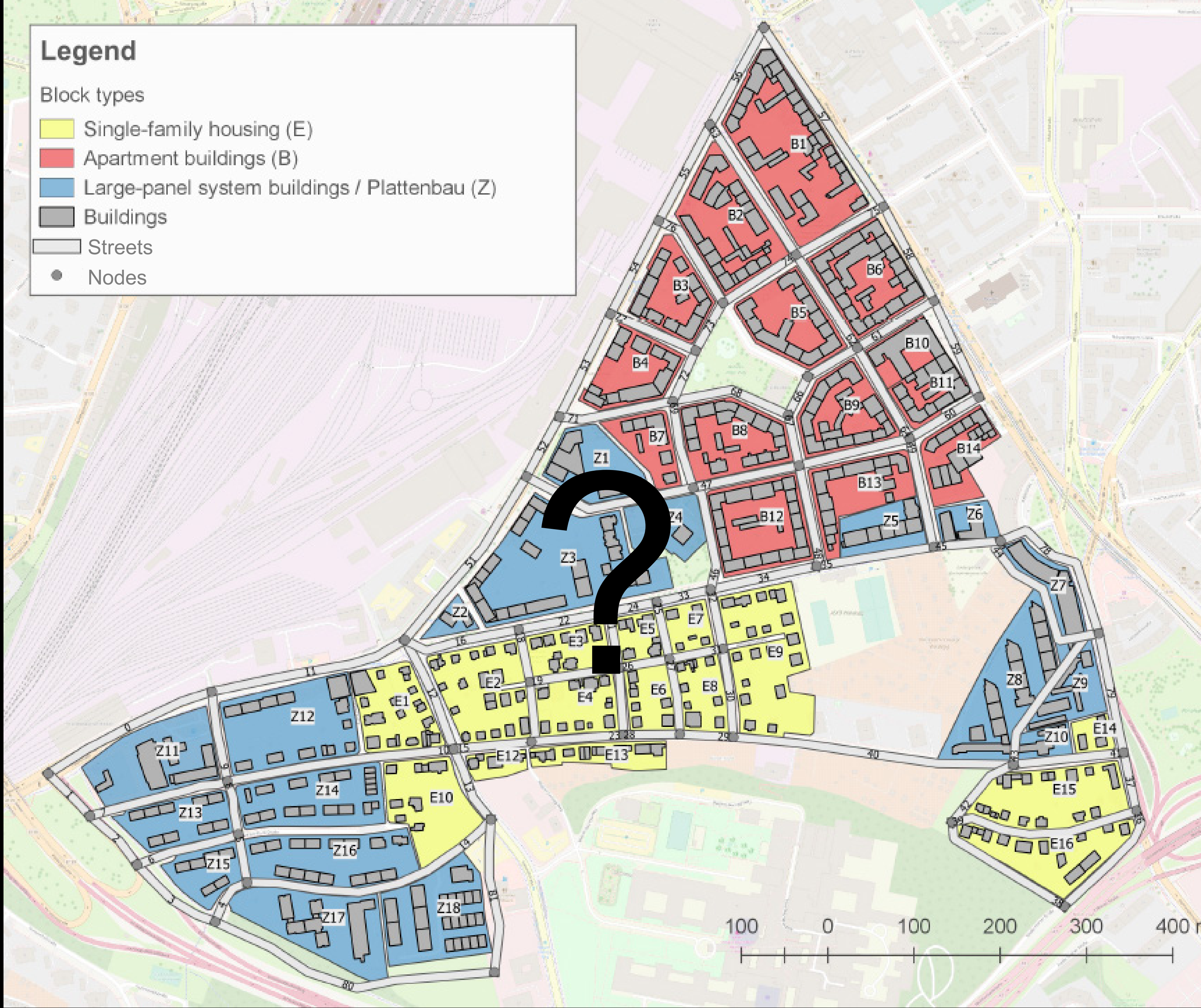
Georg Lettner

Hans Auer

15th IAEE European Conference 2017

Session 2F: Sector Coupling I

04.09.2017


Legend
Block types
Single-family housing (E)
Apartment buildings (B)
Large-panel system buildings / Plattenbau (Z)
Buildings
Streets
Nodes
?
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
Z1
Z2
Z3
Z4
Z5
Z6
Z7
Z8
Z9
Z10
Z11
Z12
Z13
Z14
Z15
Z16
Z17
Z18
E1
E2
E3
E4
E5
E6
E7
E8
E9
E10
E12
E13
E14
E15
E16
100
0
100
200
300
400 m

Motivation

- Today 54% of the global population live in cities. Source: IEA 2016
  - Consume more than 2/3 of the world's energy.
  - Account for 60 – 80% of global emissions.
  - Most of the renewable generation is still deployed off from cities.
- Which kind of **energy generation, storages and grid infrastructure** is necessary to meet **emission targets**?
- To tackle this problem, the Austrian Ministry for Transport, Innovation and Technology founded the project "*Smart City Microquartiere*".

STADT der Zukunft

bmvit Bundesministerium für Verkehr, Innovation und Technologie

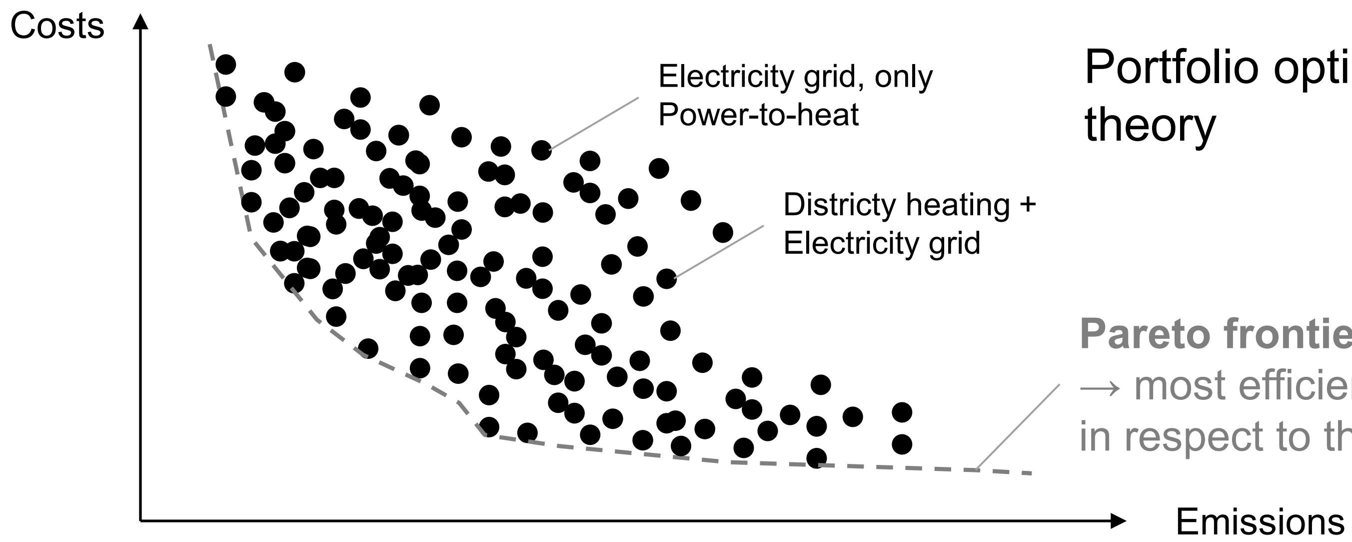
Methodoloy

- Energy consumption is the demand of electricity, heat, cooling and mobility.
- Multiple technologies (power-to-x, etc.) are nowadays available.
- Society aims for two targets:
  - Emission reduction
  - Cost reduction

  Conflictive

→ Require a comprehensive modelling approach!

Example:



Portfolio optimization theory

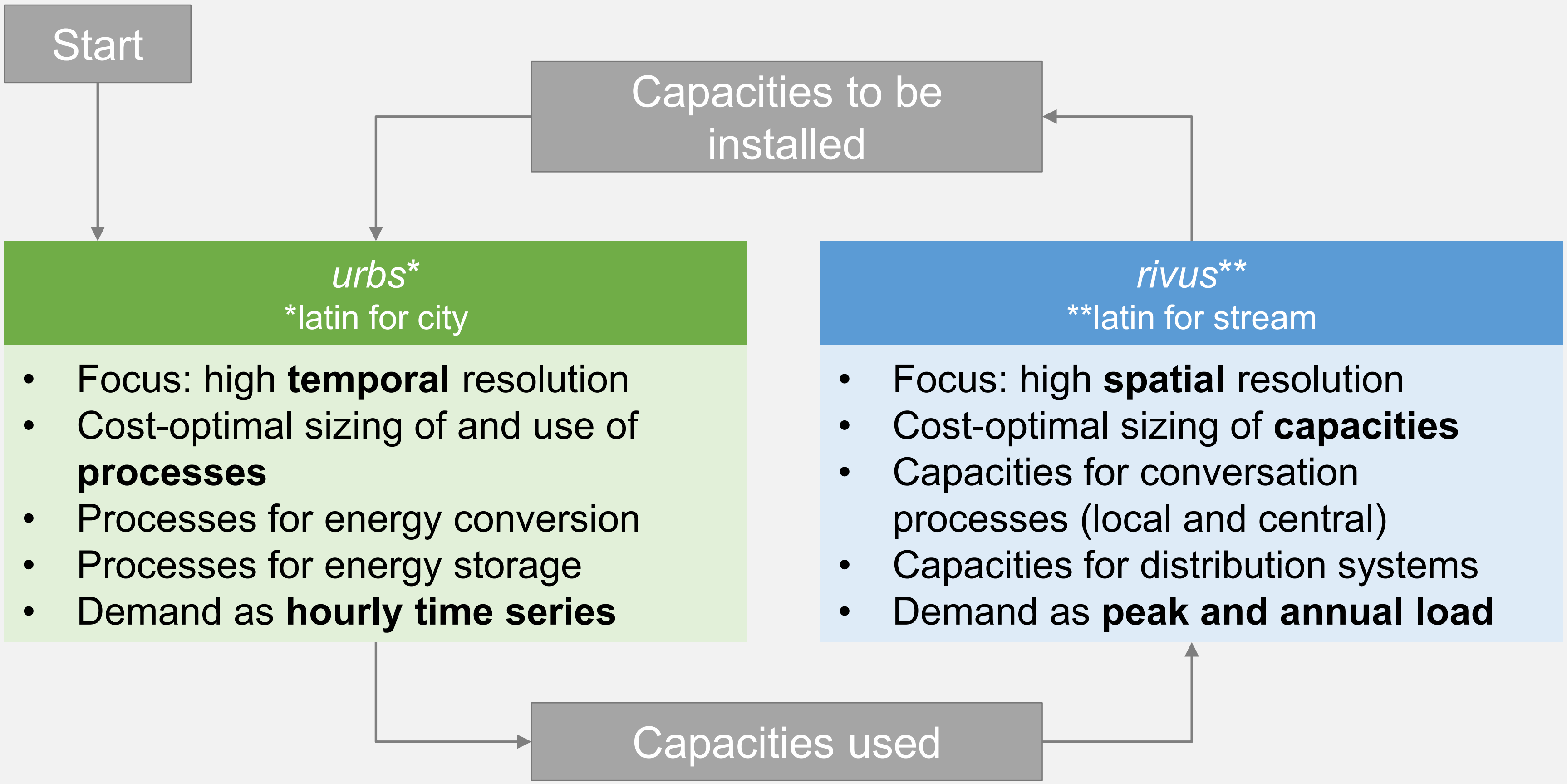
Pareto frontier
→ most efficient solutions
in respect to the two objectives

Novelty of this work

- Comprehensive inclusion of the end-consumer’s energy demand.
- Further development of two open source model of Dorfner (2016) (e.g. by including economies of scale).
- Multi-objective optimization by the ε-constraint method for a large-scale infrastructure problem.
- High variety of technologies:
  - 10 processes (solar generation, gas boiler, etc.)
  - 3 storages (battery, hot water and hydrogen storage)
  - electricity, heat and gas distribution grid (requires a GIS-based model)
- Development of time clustering methods to reduce complexity.
- Multiple scenarios regarding future demand will be taken into account
  → The presented work includes results for “*green-field-deployment*”, only.

Methodology – Combination of two open source models

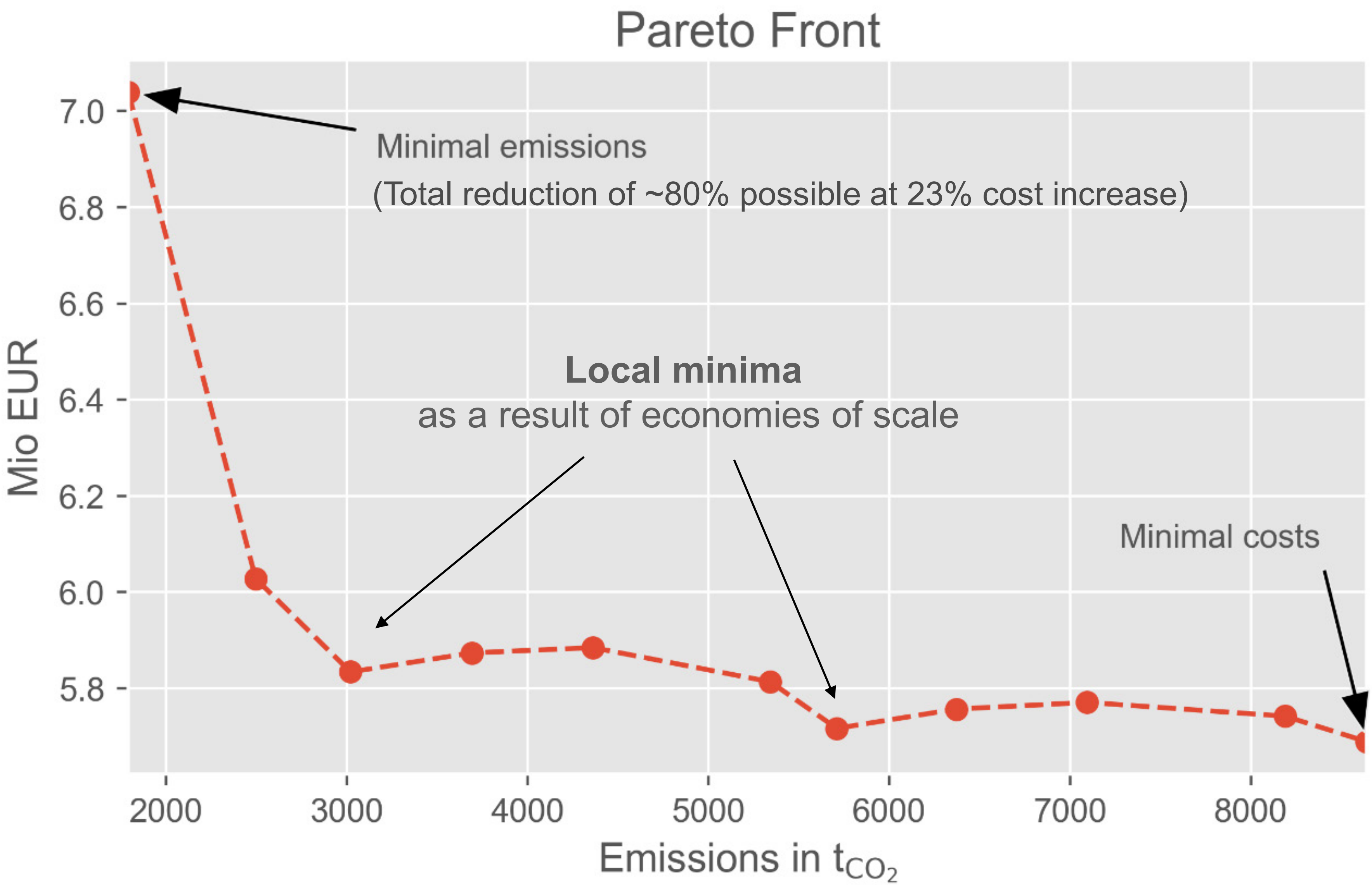
HERO – Hybrid EneRgy Optimization



Source: Johannes Dorfner, "*Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale*", Munich, 2016.
Open source projects: https://github.com/ojdo/urbs/ and https://github.com/tum-ens/rivus

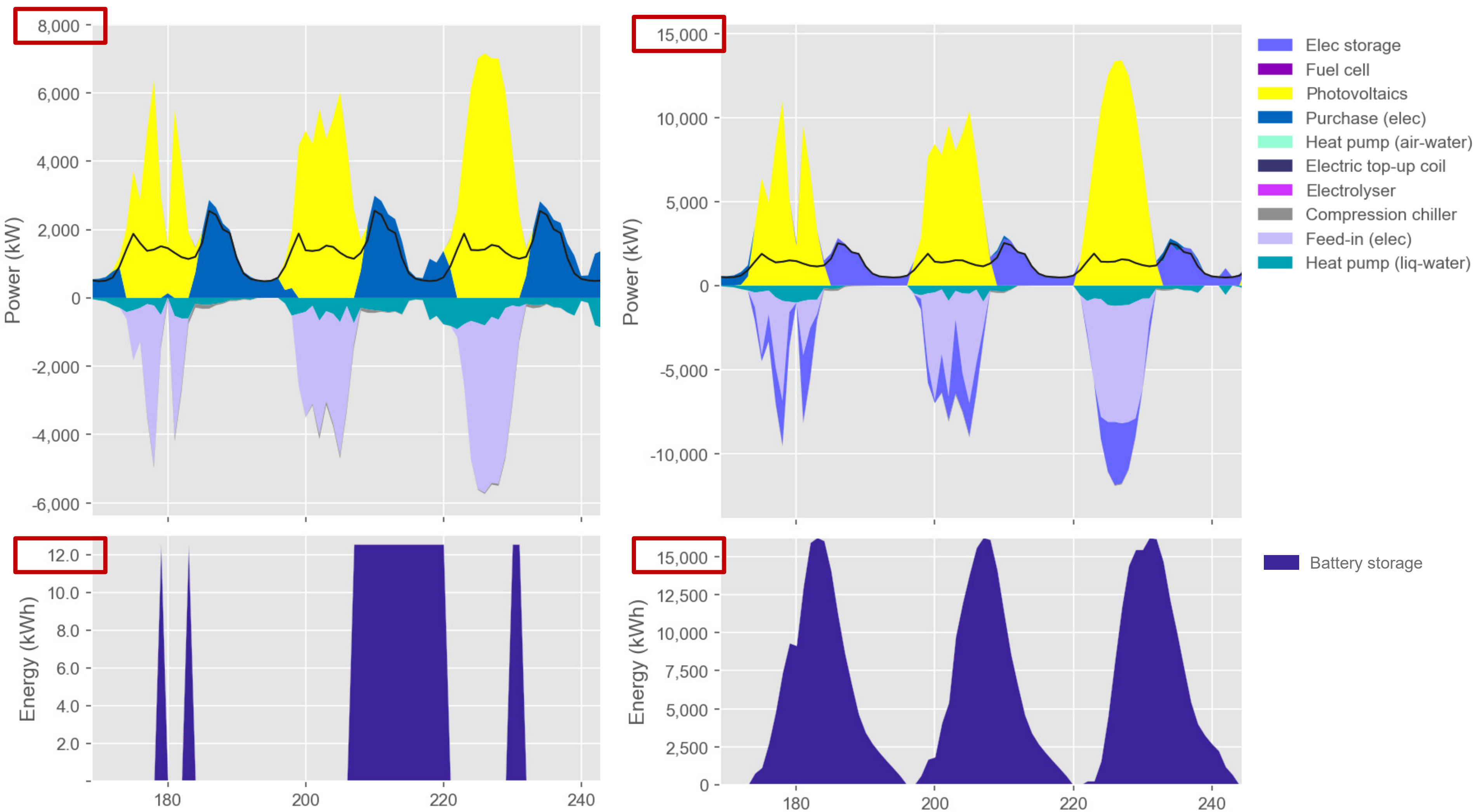
Results

Non-linear Pareto frontier

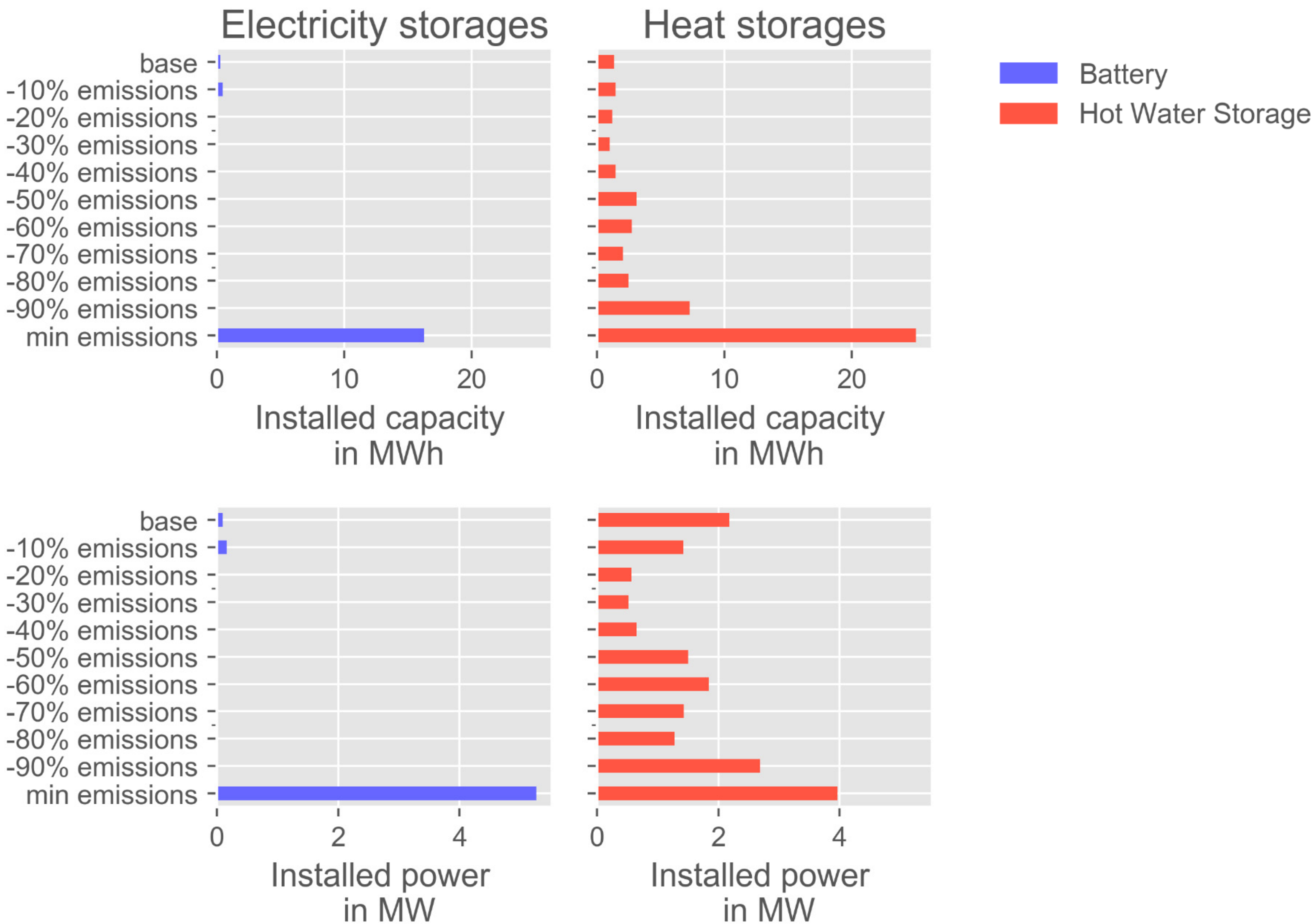


Electricity generation and consumption (summer):

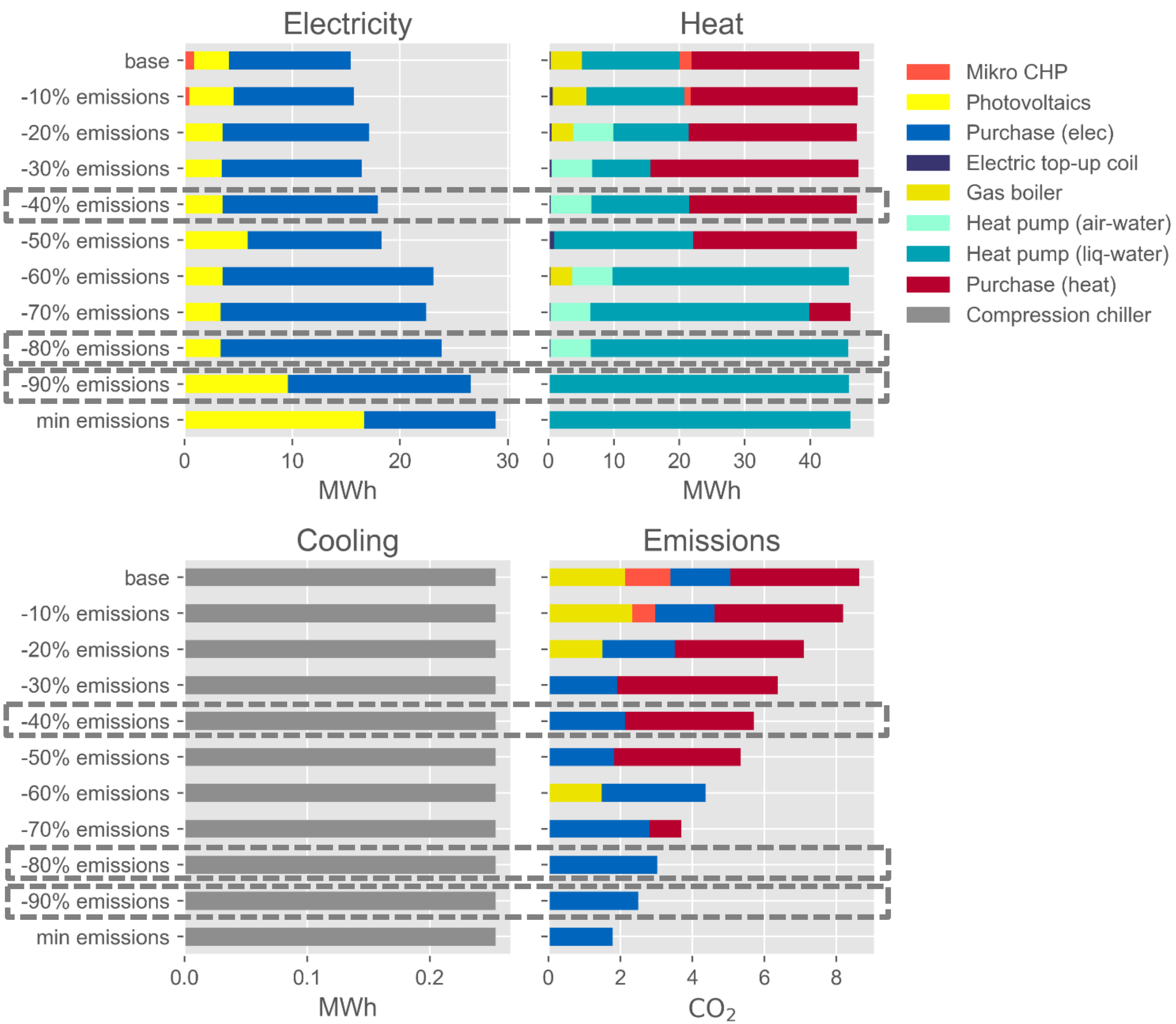
-90% emissions to minimal emissions



Installed storage capacity



Installed process capacity



Distribution grid deployment

Electricity distribution grid

Heat distribution grid

Discussion and conclusions

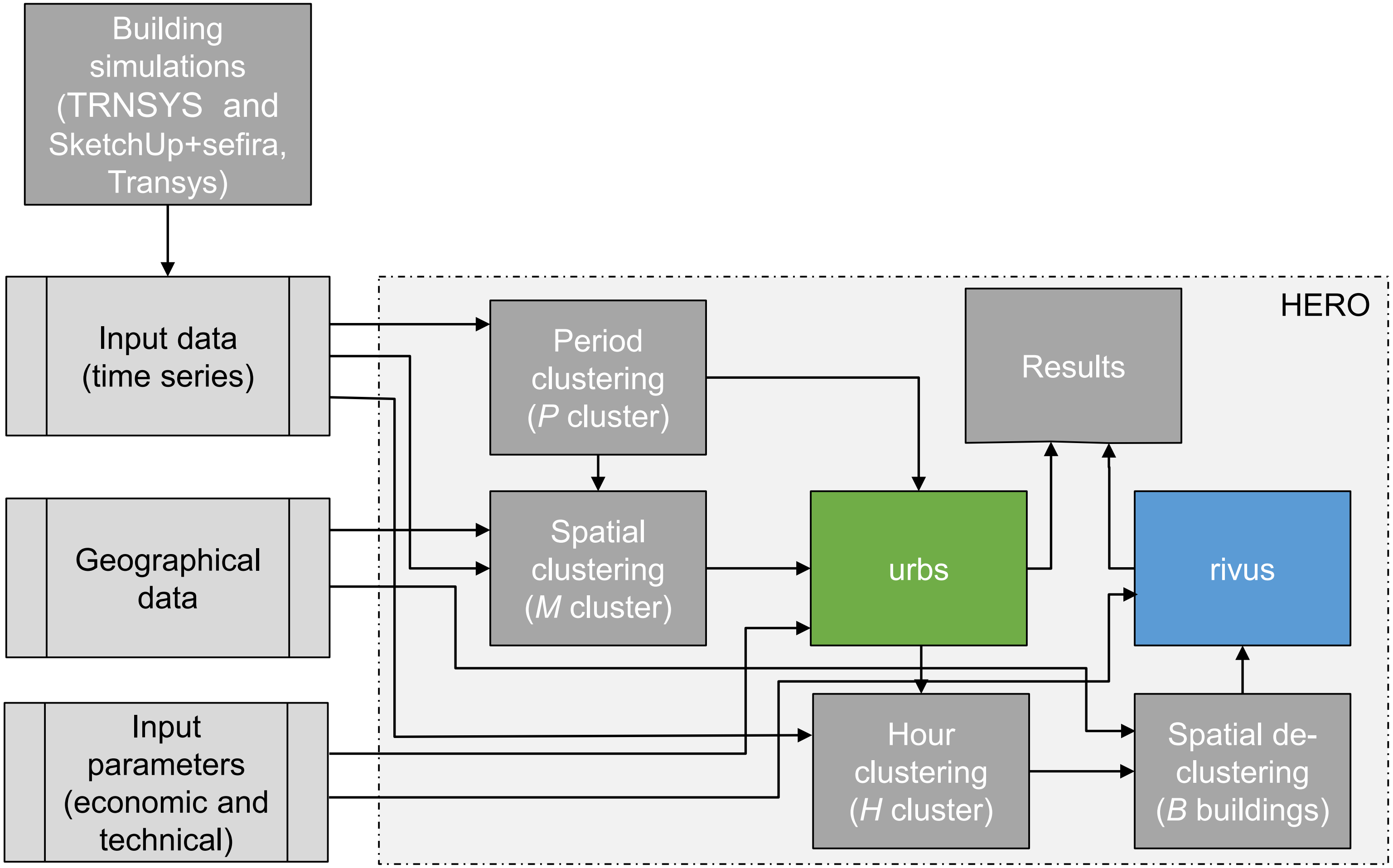
- We learnt a lot from the multiobjective optimization:
  - Results unveil a complex relationship between efficient emission and cost reduction.
    → Trend: more solar, heat pumps and electricity storages.
  - Very high (local) emission reduction results in very high costs
    → 2^{nd} best solution more feasible?
  - Emission reduction mostly by "electrify" the system
    → Large-scale impact on electricity system?
    → Other energy grids will struggle in future.
    → Large scale heat pump deployment realistic?
  - Despite storage deployment, a reliable distribution system is of high importance.
- Future investigation will address:
  - Integration of electric vehicles (EV).
  - Integration of hydrogen long term storages (increase the complexity a lot).

Hans Auer

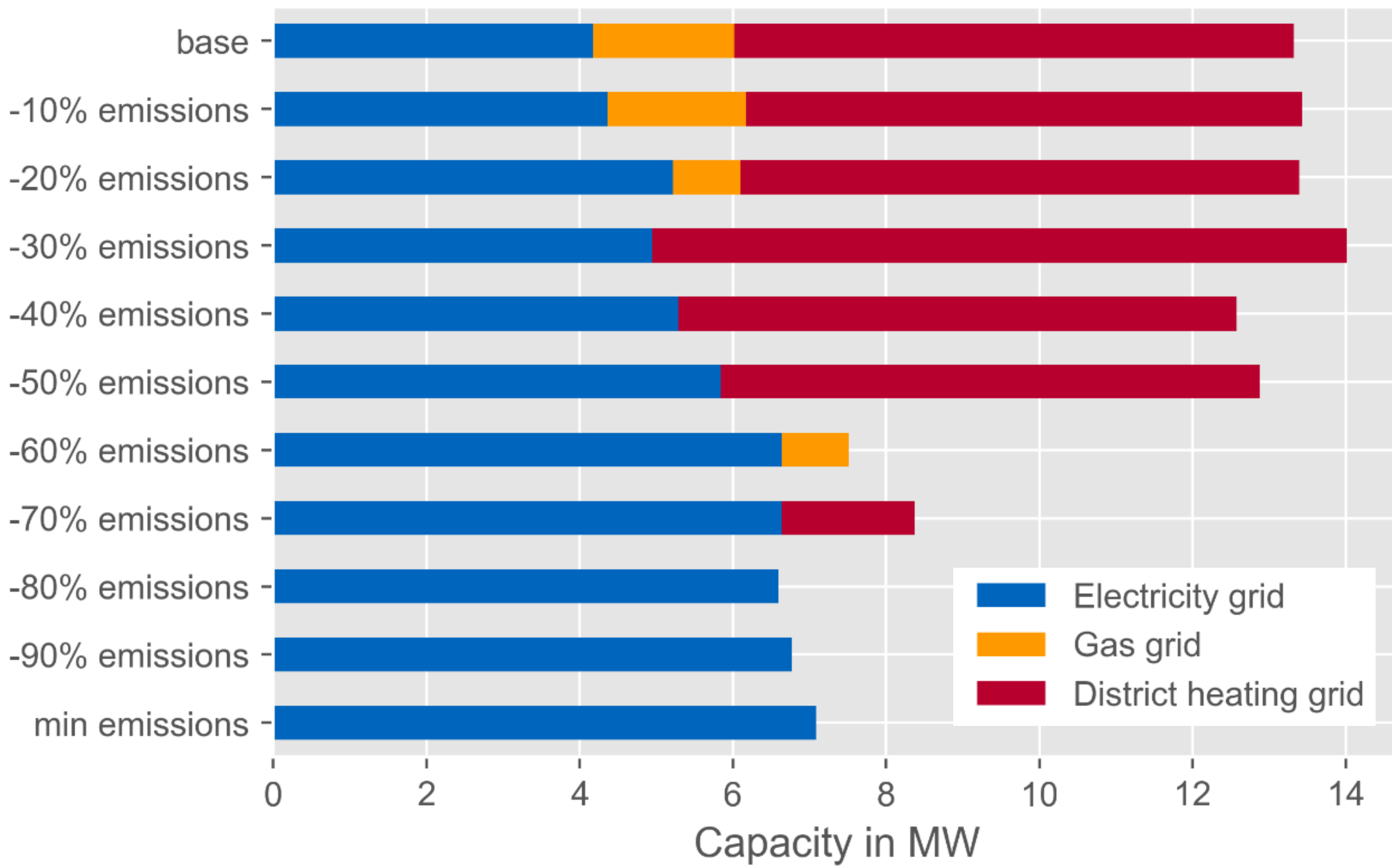
TU Wien
Energy Economic Group, EEG
Gußhausstraße 25-29 / E370-3
1040 Vienna, Austria

[T] +43 1 58801 370 357
[F] +43 1 58801 370 397
[E] auer@eeg.tuwien.ac.at
[W] http://www.eeg.tuwien.ac.at

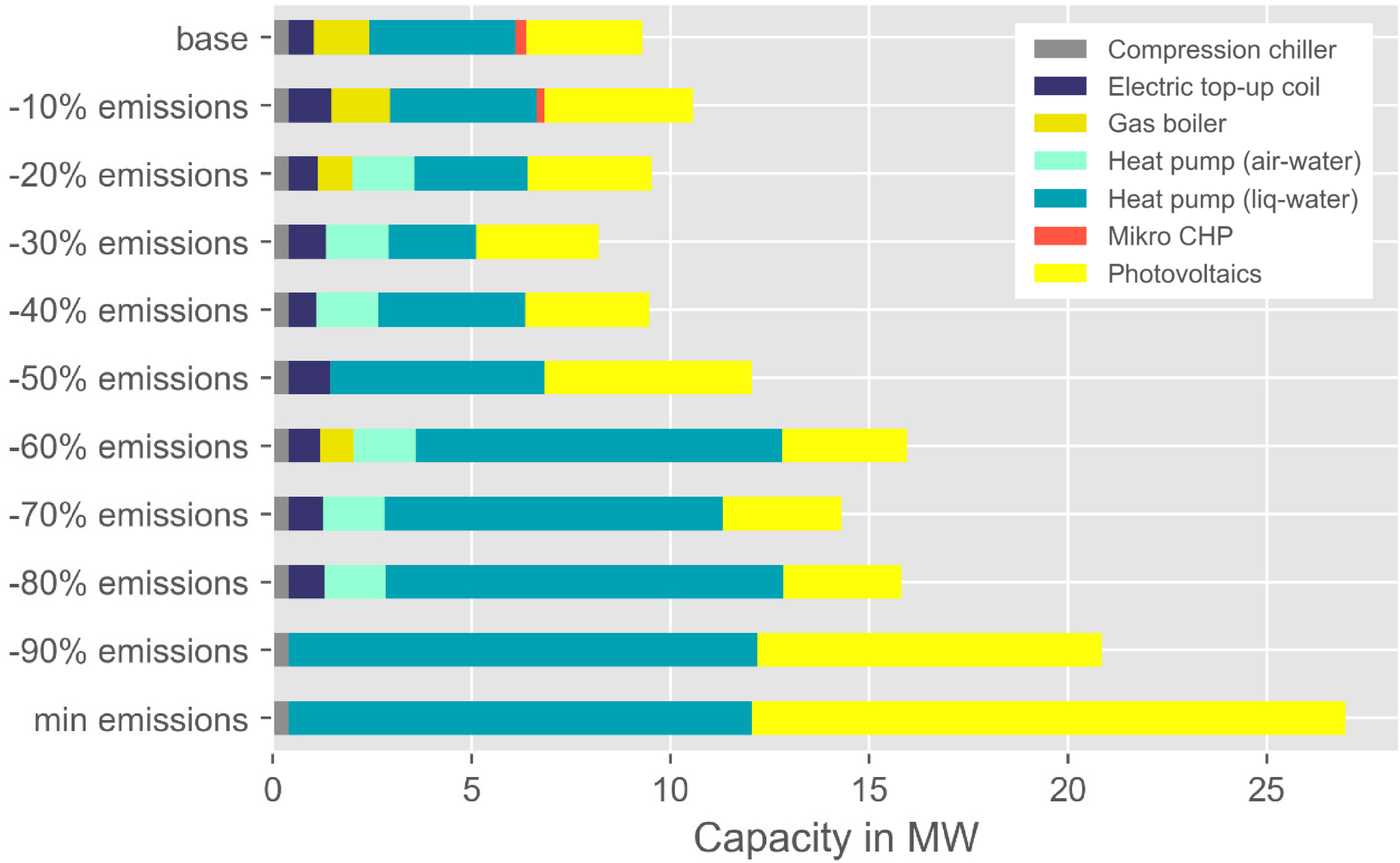
Detailed model



Grid capacity



Process capacity



PARETO OPTIMIZATION OF A LOCAL URBAN ENERGY SYSTEM CONSIDERING COSTS AND EMISSIONS

Andreas FLEISCHHACKER[1], Georg LETTNER[2]

The significant challenges in the development of cities and municipalities regarding sustainability and a low-carbon society address the sensible integration of existing buildings and infrastructures. The Austrian government founded project “SC_Mikroquartiere”[1] shows the possibilities of the city planning on a district level towards a low carbon city with a high quality of living and excellent resilience taking into account existing and planned buildings, infrastructure and utilization. The central element of this project is the modeling of urban areas on a city block level. This approach allows us to formulate and present of viable district/neighborhood models on a high-resolution spatial scale. (Figure 1 shows one city area).

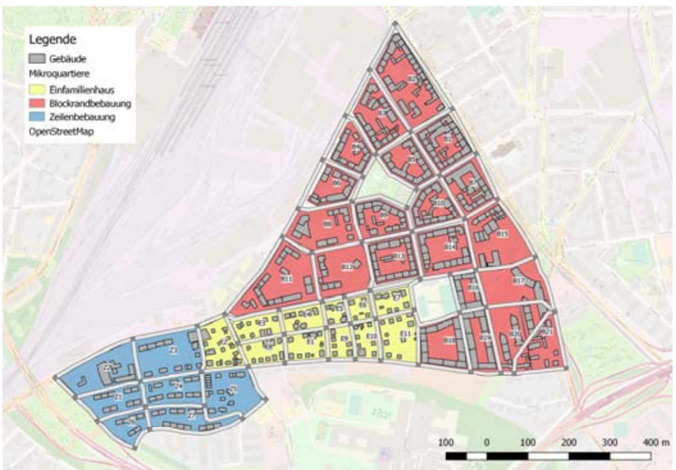


Figure 1: Investigated city area, including the block assignment (three types) in Linz/Austria.

Methods

Within this project, we developed an optimization model “*urbs_HERO*”[3] consisting of multiple energy-hubs. Energy hubs are a simplification of an urban (i.e., it is an abstraction of a spatial area). We characterize an energy hub with a production capacity, energy consumption, and storage capacity. Energy grids, such as electrical, district heating and gas grids connect the energy hubs. Mathematically, energy hubs are formulated by a multidimensional linear system. These predefined energy sources are grid conducted energy sources (e.g., electrical, natural gas and heat grid) as well as stationary energy sources (e.g., coal or biomass). This concept allows us to investigate multiple levels of aggregation, starting from analyzing optimum energy distribution systems on building level up to district level.

The objective of this optimization model does not only addresses minimal costs rather ϵ-constrainted multi-objective optimization allows allows us to conduct a combined analysis of multiple objectives:

1. ***Minimum total costs***: minimizing total costs, i.e., investment, maintenance and operating costs. This objective function is used to illustrate the maximum cost-effectiveness.
2. ***Minimum emissions***: minimization of operation related emission. We are not considering underlying emissions, as incurred by the production of technology.

Results and Conclusions

Figure 2 shows both, the Pareto Front and the corresponding quantities of electricity, heat, cooling, and emissions necessary to cover the load. The results show that a very high share of photovoltaic is

[1] Andreas Fleischhacker, TU Wien, Institute of Energy Systems and Electrical Drives, EEG
Gußhausstraße 25-29 / E370-3, 1040 Vienna, Austria, fleischhacker@eeg.tuwien.ac.at, www.eeg.tuwien.ac.at.
[2] Georg Lettner, -“-, lettner@eeg.tuwien.ac.at.
[3] Based on two open-source python open source optimization model “*urbs*”[3] and “*rivus*”[4]

essential to reduce emissions. Heat pumps may be an essential technology for the integration of renewable generation. On the other hand, grid enforcement measures are necessary, as shown in Figure 3. We will discuss advantages and disadvantages of the electrification in our work.

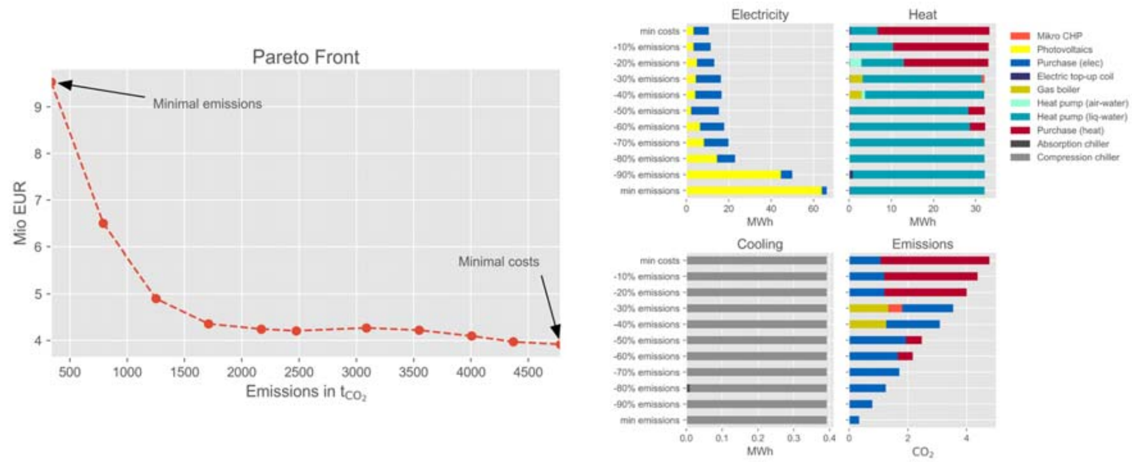


Figure 2: Pareto Front (left) and the corresponding quantities of electricity, heat, cooling, and emissions (right). The composition (e.g. photovoltaic or heat pumps) is shown as well.

Figure 3: Electricity distribution grid capacity in the "minimum cost" scenario (left) and "minimum emissions" scenario (right).

Acknowledgements:

This project has received funding from the Austrian Federal Ministry of Transport, Innovation, and Technology (BMVIT) research and technology program “Stadt der Zukunft.” On behalf of BMVIT, it is handled by the Austrian Research Promotion Agency together with Austria Wirtschaftsservice GmbH and the Austrian Society for Environment and Technology ÖGUT.

STADT der Zukunft

bmvit

References

[1] https://nachhaltigwirtschaften.at/de/sdz/projekte/sc-mikroquartiere.php, visited April 1st, 2017.

[2] Hart, William E., Jean-Paul Watson, and David L. Woodruff. "Pyomo: modeling and solving mathematical programs in Python." Mathematical Programming Computation 3, no. 3 (2011): 219-260.

[3] Johannes Dorfner, “*Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale*”, Munich, 2016.

[4] Johannes Dorfner, https://github.com/ojdo/urbs/, visited Dez. 1st 2017.

[5] Johannes Dorfner, https://github.com/tum-ens/rivus/, visited Dez. 1st 2017.

Pareto Optimization of a Local Urban Energy System considering Costs and Emissions

Andreas Fleischhacker

Kolloquium Urbane Energiesystemsimulation / AIT
09.04.2018

Motivation

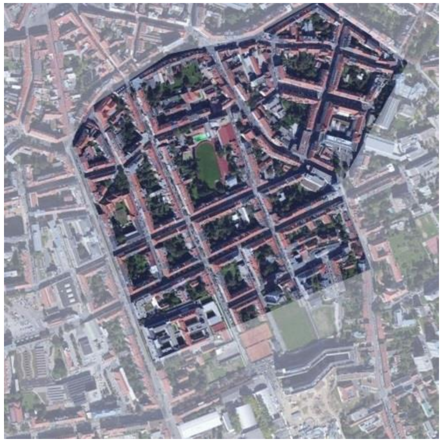
- Today 54% of the global population live in cities. Source: IEA 2016
  - Consume more than 2/3 of the world's energy.
  - Account for 60 – 80% of global emissions.
  - Most of the renewable generation is still deployed off from cities.
- Which kind of **energy generation, storages and grid infrastructure** is necessary to meet **emission targets**?
- To tackle this problem, the Austrian Ministry for Transport, Innovation and Technology founded the project "*Smart City Microquartiere*".

STADT der Zukunft

bmvit Bundesministerium für Verkehr, Innovation und Technologie

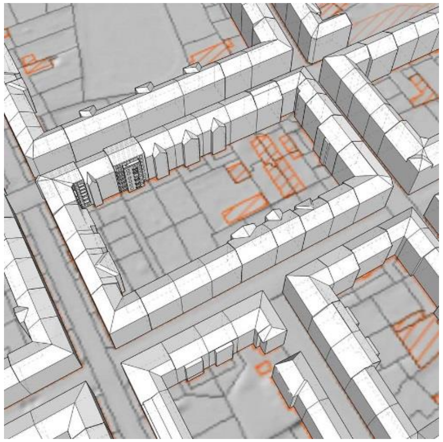
Methodology

Methodology

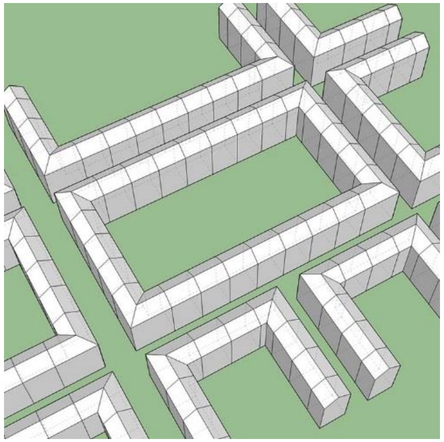


1 Choose the district

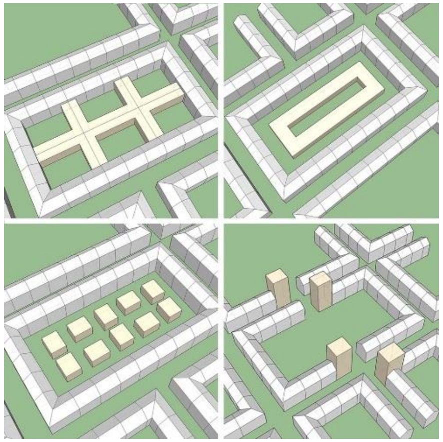
2 Choose the block (Prototypic Block)



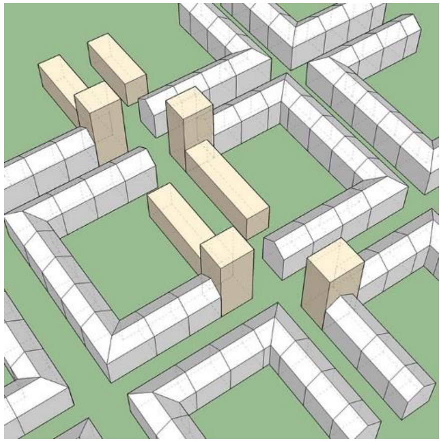
3 Describe the block



4 Abstraction of the block

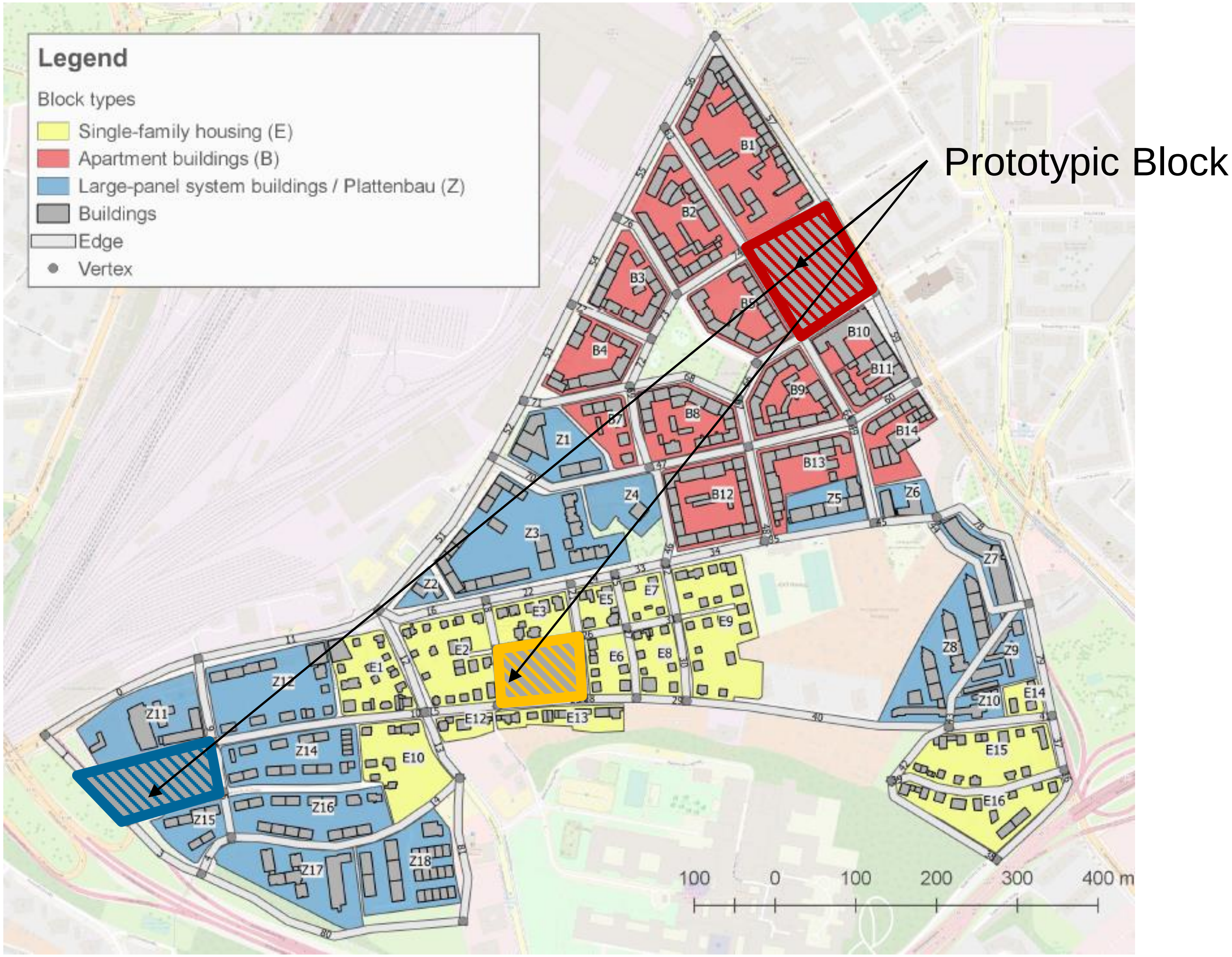


5 Optimize different options



6 Choose the optimized block

Blocks in Linz (Andreas Hofer District)



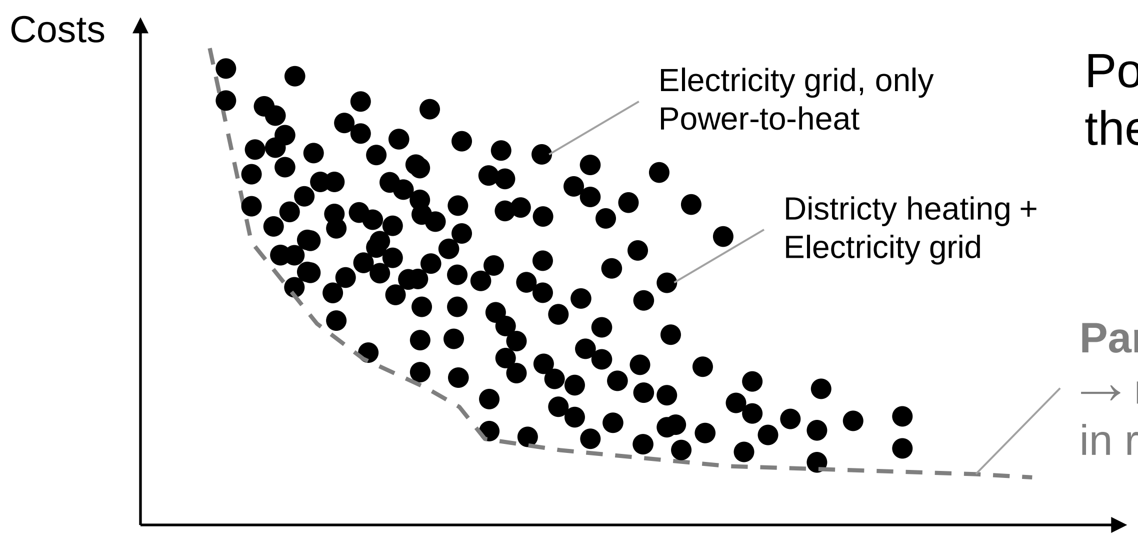
Methodoloy

- Energy consumption is the demand of electricity, heat, cooling and mobility.
- Multiple technologies (power-to-x, etc.) are nowadays available.
- Society aims for two targets:
  - Emission reduction
  - Cost reduction

Conflictive

→ Require a comprehensive modelling approach!

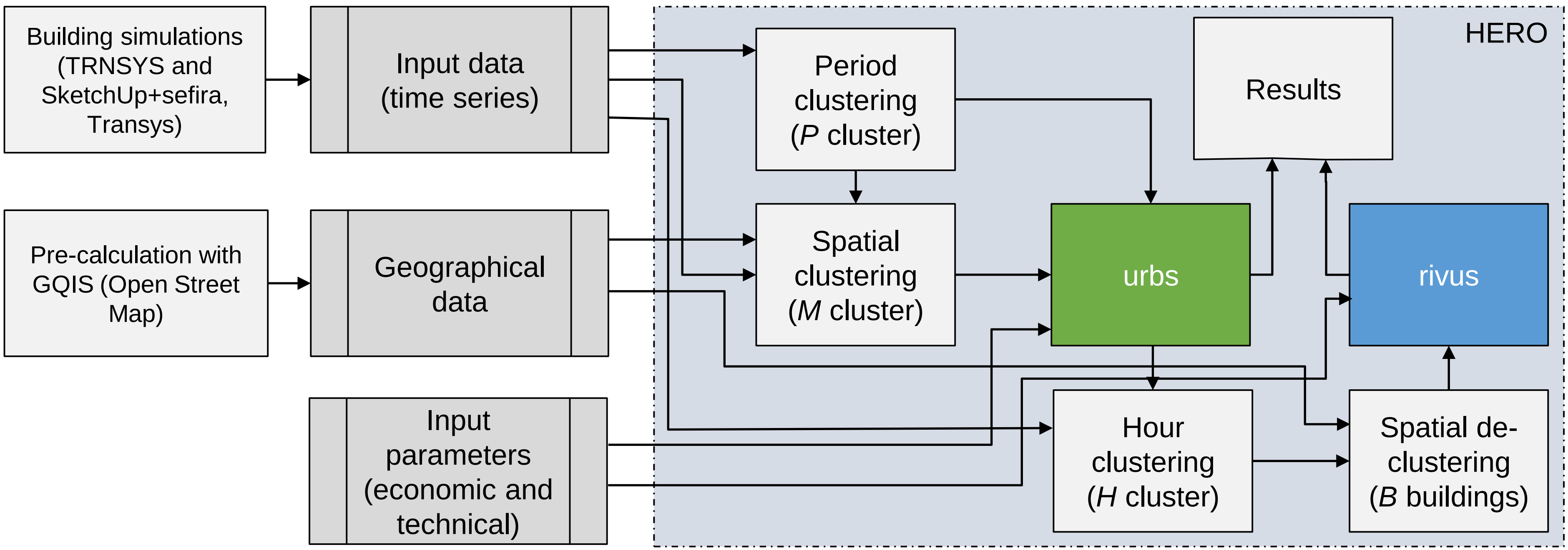
Example:



Portfolio optimization theory

Pareto frontier
→ most efficient solutions in respect to the two objectives

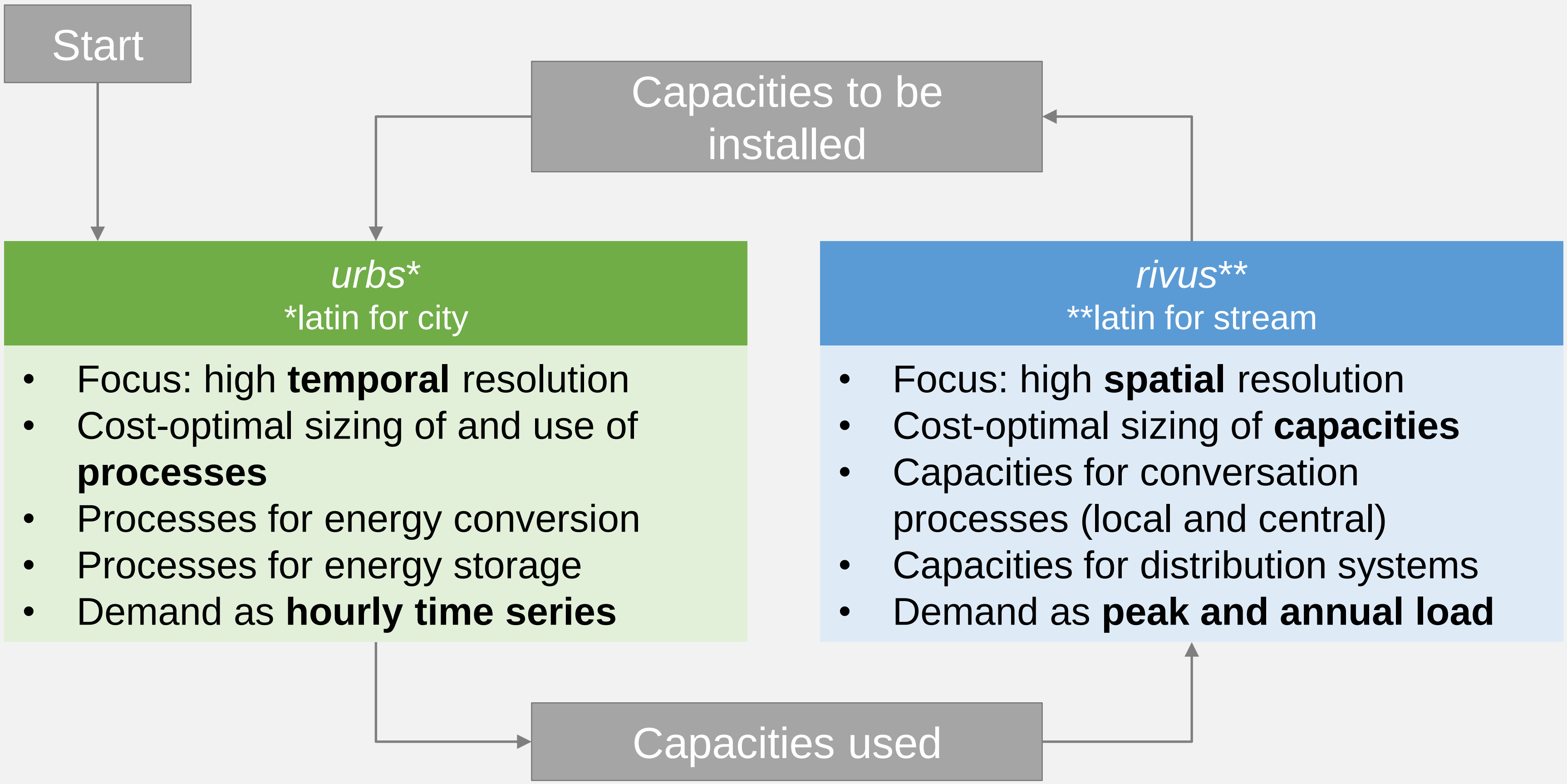
HERO – Hybrid EneRgy Optimization



Source: Johannes Dorfner, "*Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale*", Munich, 2016.
Open source projects: https://github.com/ojdo/urbs/ and https://github.com/tum-ens/rivus

Methodology – Combination of two open source models

HERO – Hybrid EneRgy Optimization



Source: Johannes Dorfner, "*Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale*", Munich, 2016.
Open source projects: https://github.com/ojdo/urbs/ and https://github.com/tum-ens/rivus

Pareto Optimization

We used the **ε-constraint Method** as introduce in Bérubé et al. (2009):

1) Minimum cost problem

$$\min_{\mathbf{e},\mathbf{p}} \quad costs = \mathbf{c}_{costs}^{T} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix}$$
$$\text{subject to} \quad \mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b}$$
$$\mathbf{e}, \mathbf{p} \geq 0$$

2) Minimum emission problem

$$\min_{\mathbf{e},\mathbf{p}} \quad emissions = \mathbf{c}_{emissions}^{T} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix}$$
$$\text{subject to} \quad \mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b}$$
$$\mathbf{e}, \mathbf{p} \geq 0$$

$emissions_{min}$

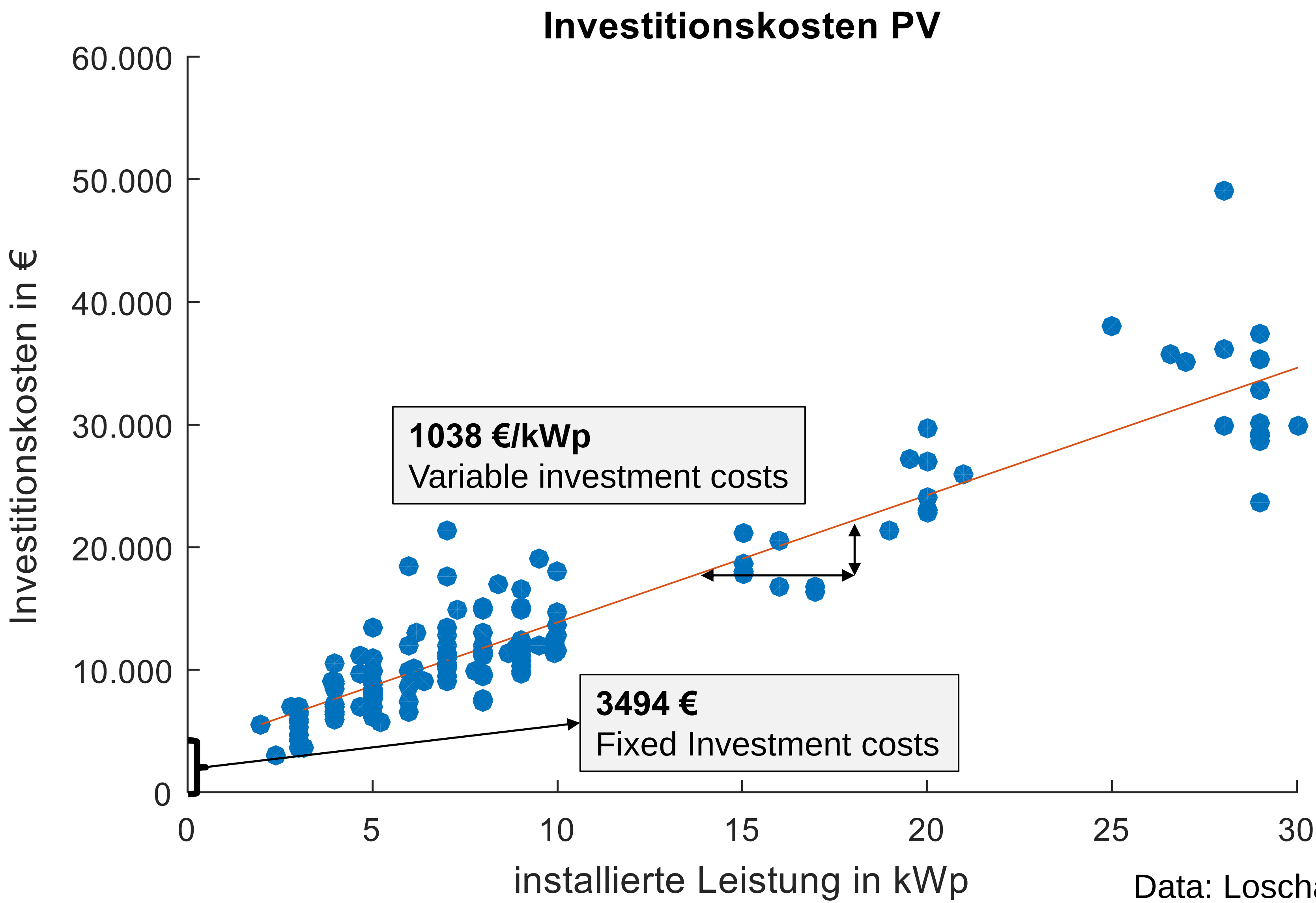
3) Pareto Optimization

$$\min_{\mathbf{e},\mathbf{p}} \quad costs = \mathbf{c}_{costs}^{T} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix}$$
$$\text{subject to} \quad emissions \leq f * emissions_{min}$$
$$\mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b}$$
$$\mathbf{e}, \mathbf{p} \geq 0$$

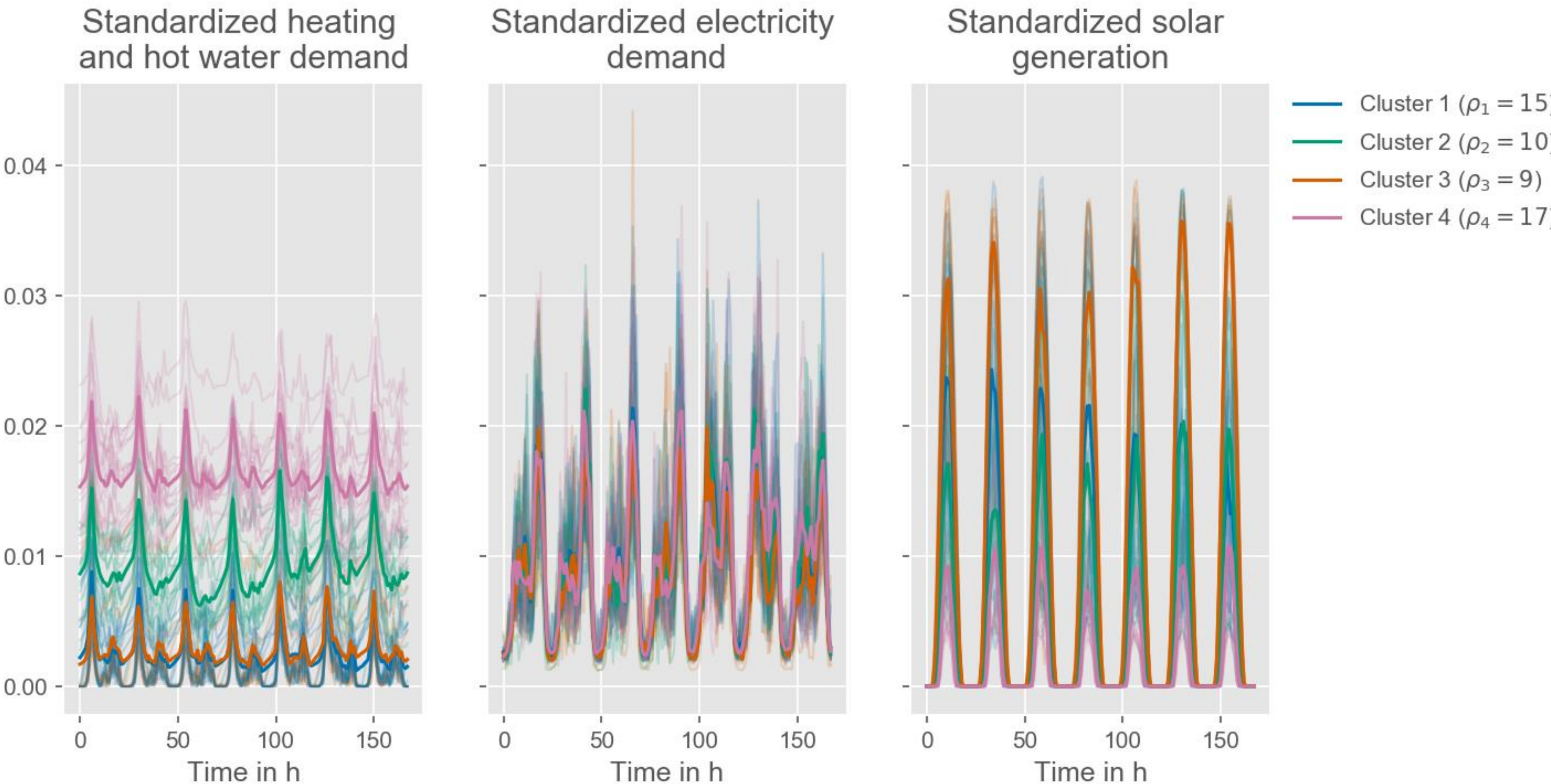
Bérubé, J. et al., „*An exact -constraint method for bi-objective combinatorial optimization problems*“, European Journal of Operational Research, 2009

Economies of Scale

Example: Photovoltaik

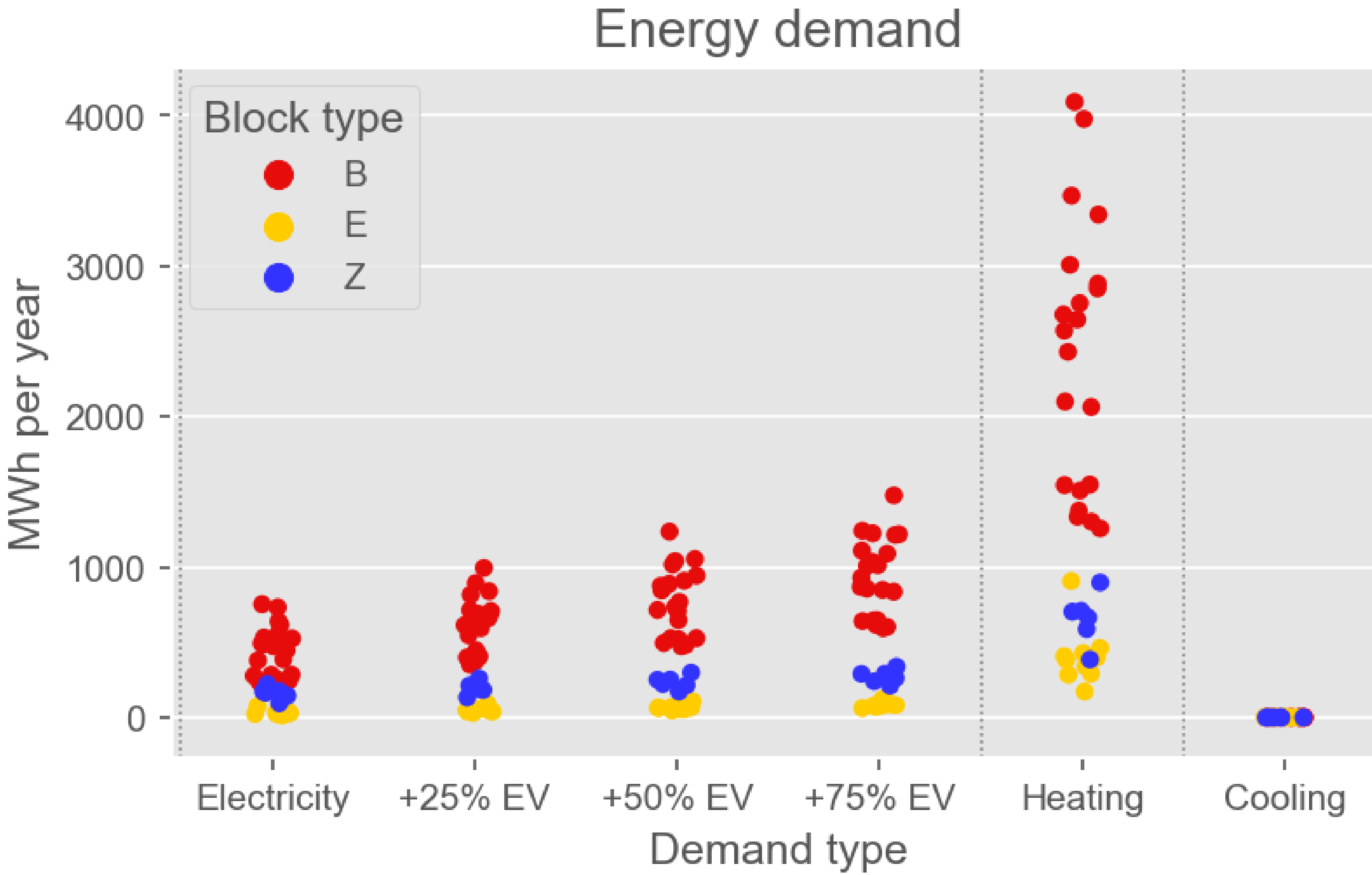


Data: Loschan (2017)



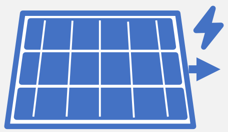
Standardized heating and hot water demand
Standardized electricity demand
Standardized solar generation
0.04
0.03
0.02
0.01
0.00
0
50
100
150
Time in h
Cluster 1 ($\rho_1 = 15$)
Cluster 2 ($\rho_2 = 10$)
Cluster 3 ($\rho_3 = 9$)
Cluster 4 ($\rho_4 = 17$)

Spatial clustering

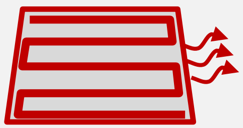


Technologies (1/2)

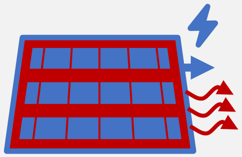
Processes



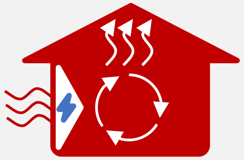
Photovoltaik



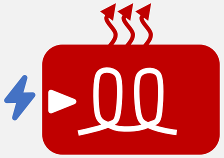
Solarthermal



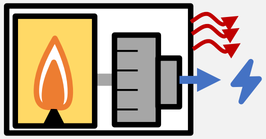
Hybrid collector



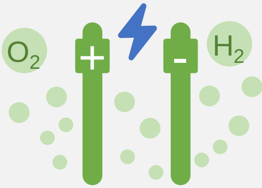
Heat Pump
(Air-water)
(Water-water)



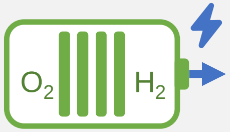
Electric top-up coil



Micro Combined-Heat-Power (µCHP)



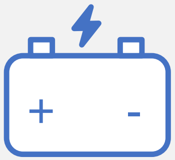
Electrolyzer



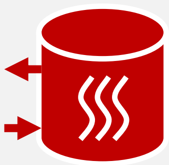
Fuel cell

Technologies (2/2)

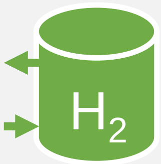
Storages



Battery

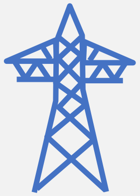


Hot water storage

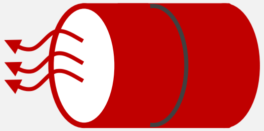


Hydrogen storage

Grids



Electric grid

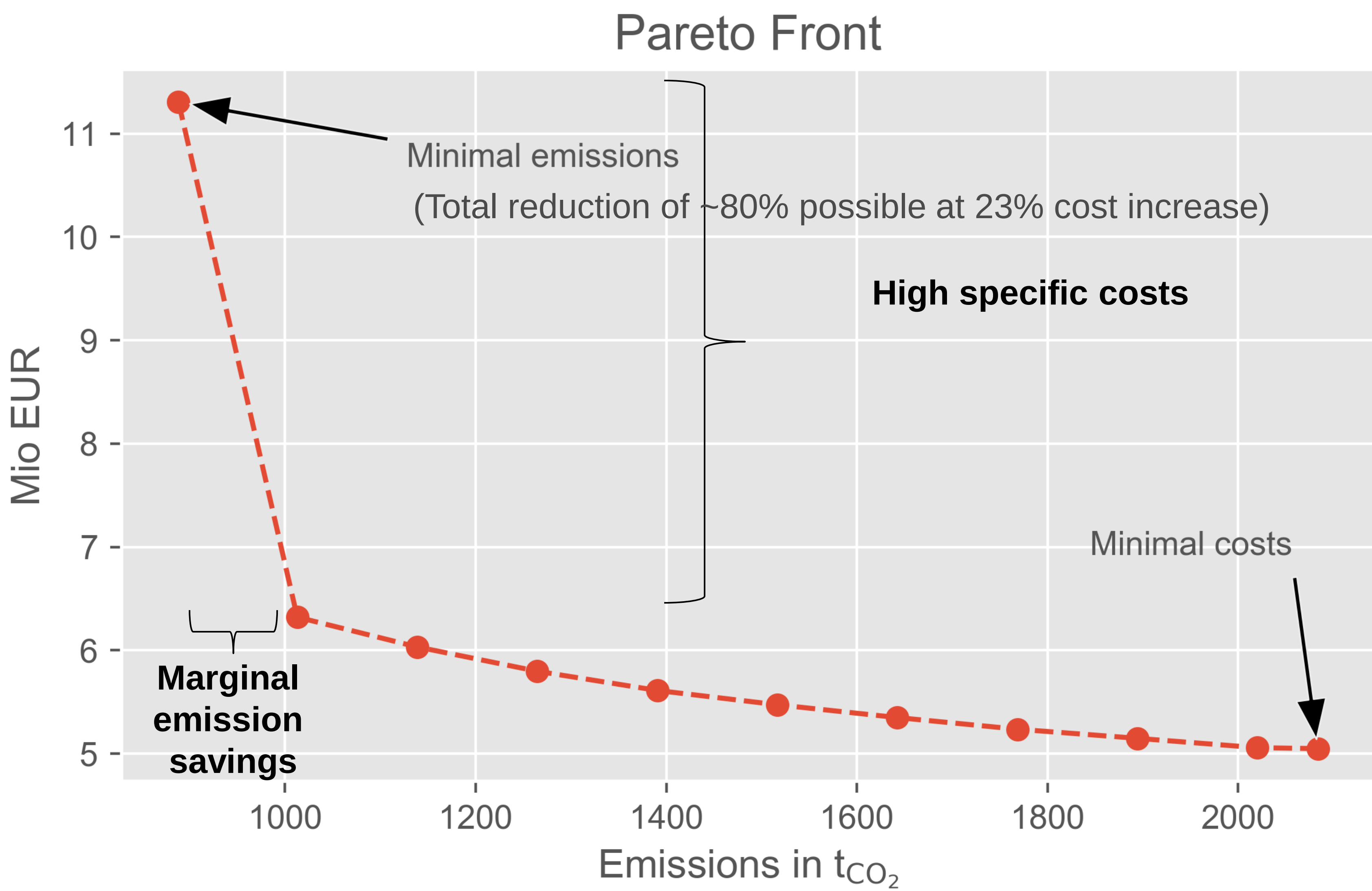


Heat grid

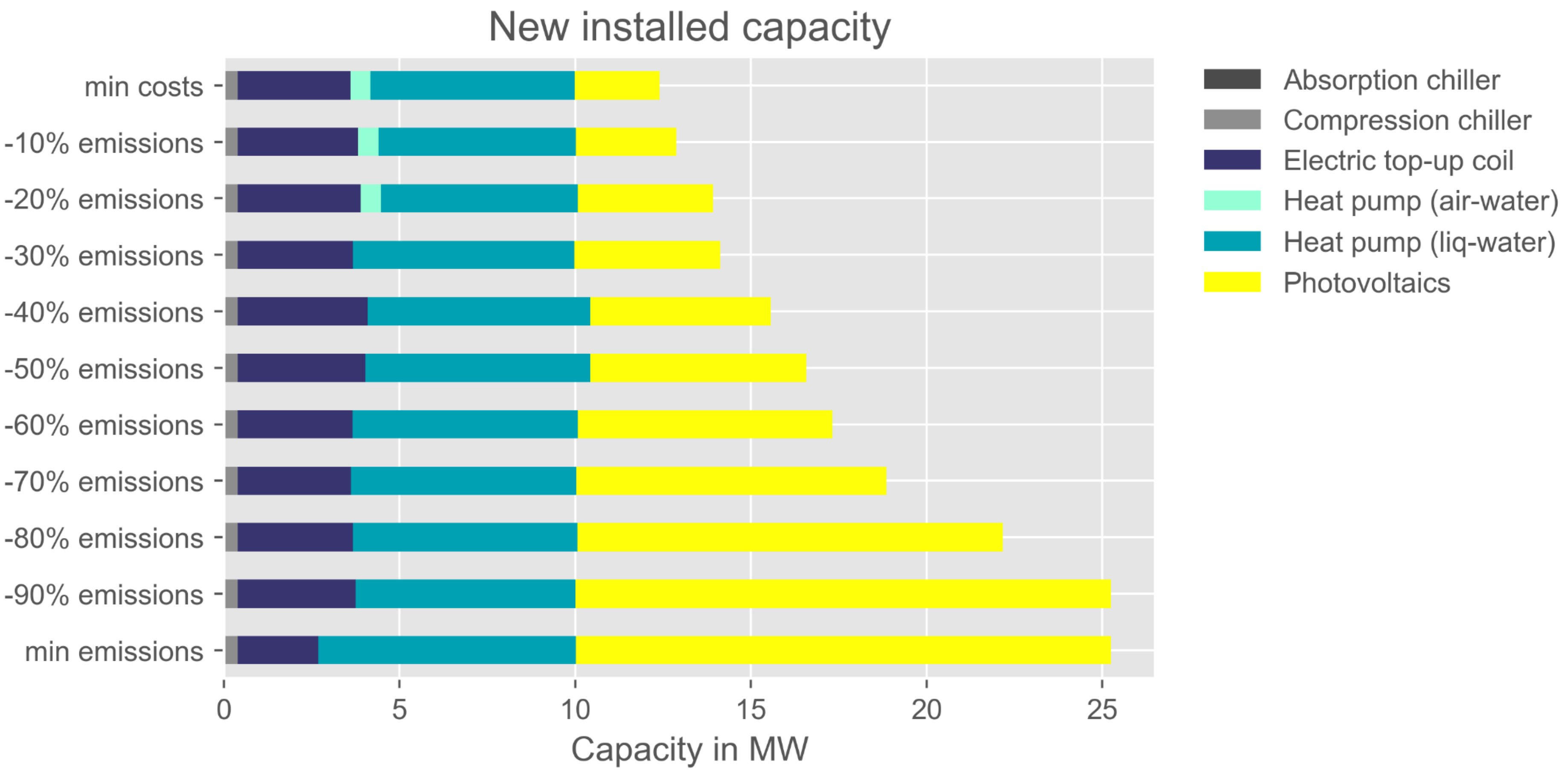
(Natural) gas grid

Status Quo Results

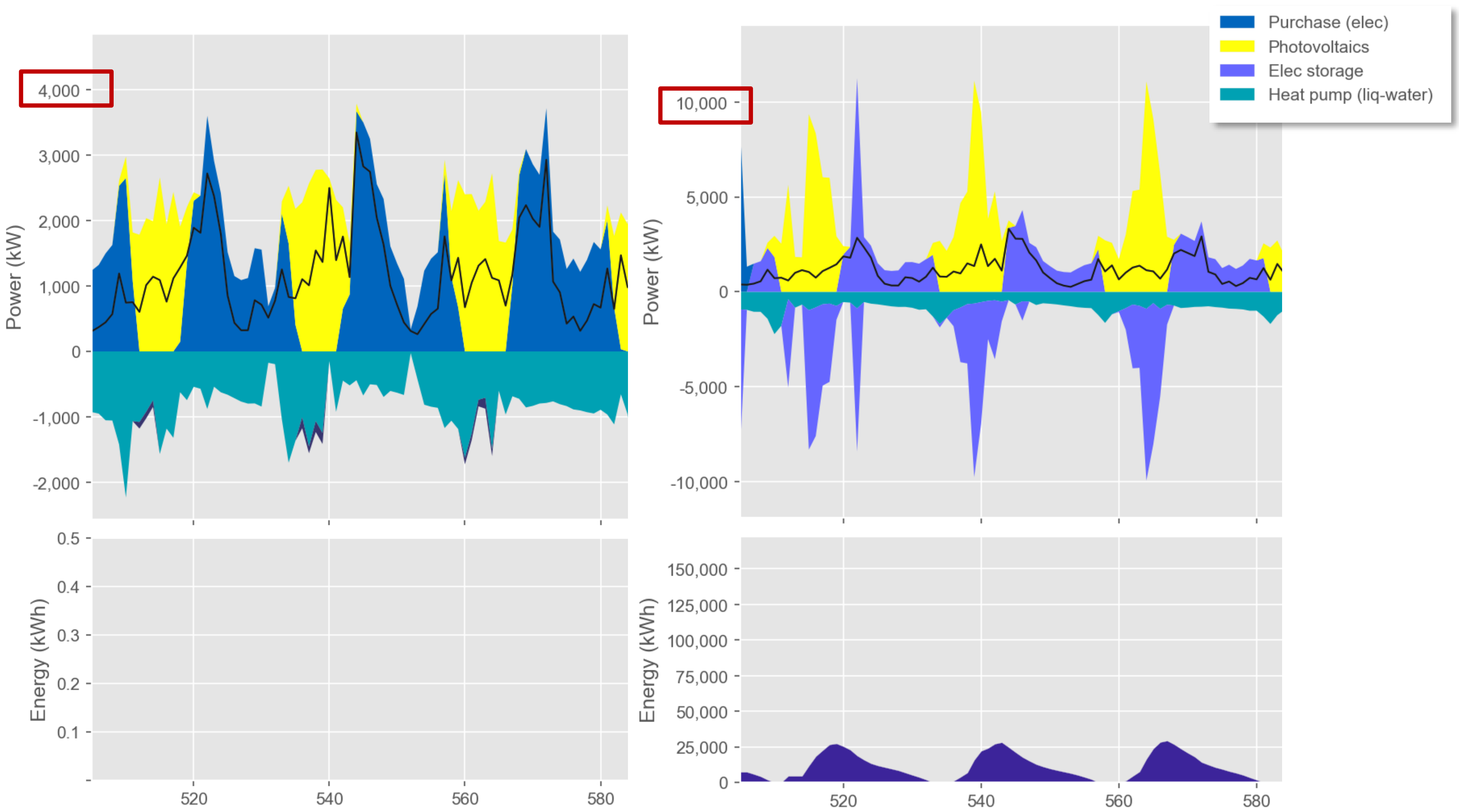
Status Quo Result



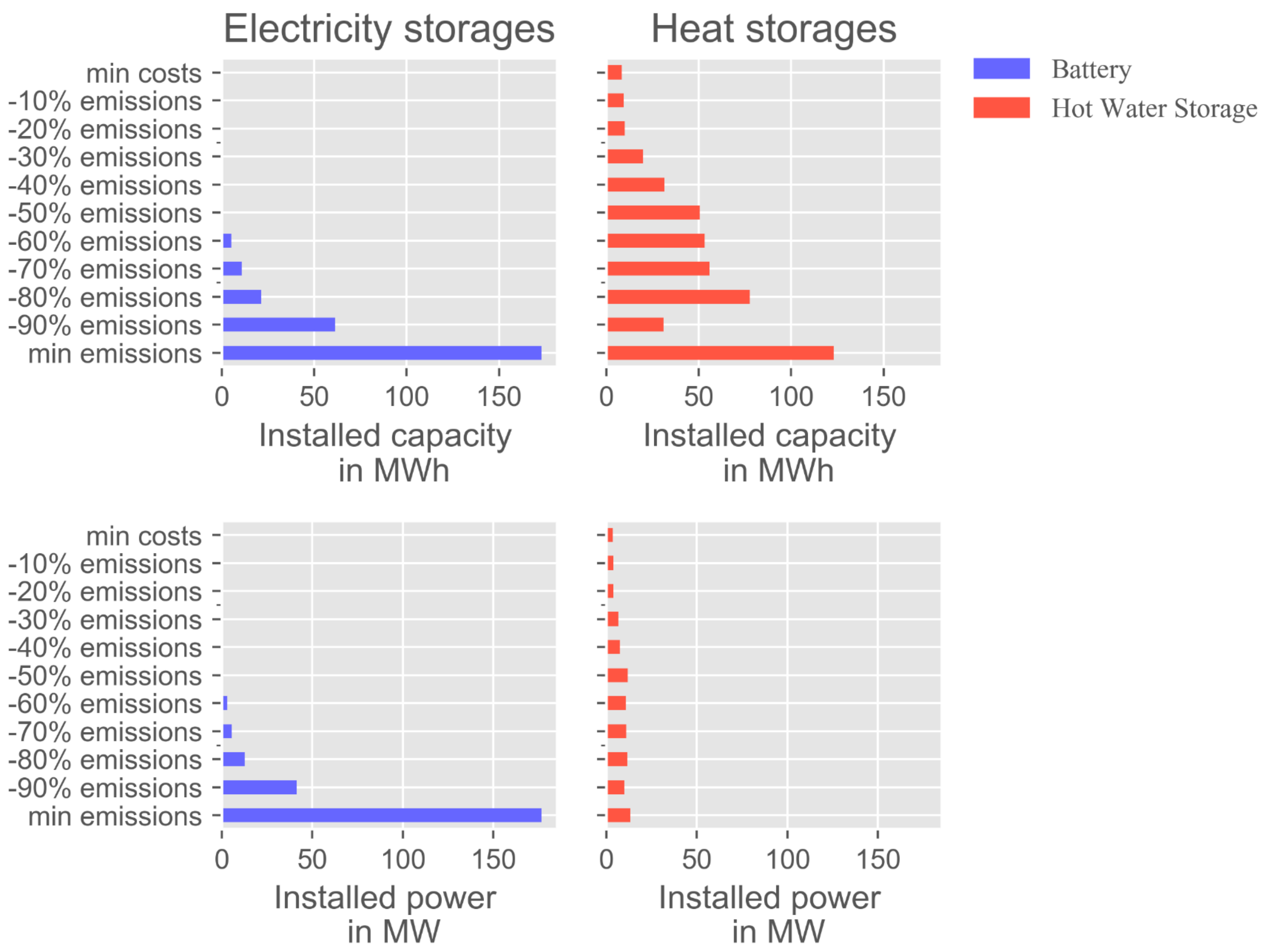
Installed process capacity



Difference between $\min(costs)$ and $\min(emissions)$



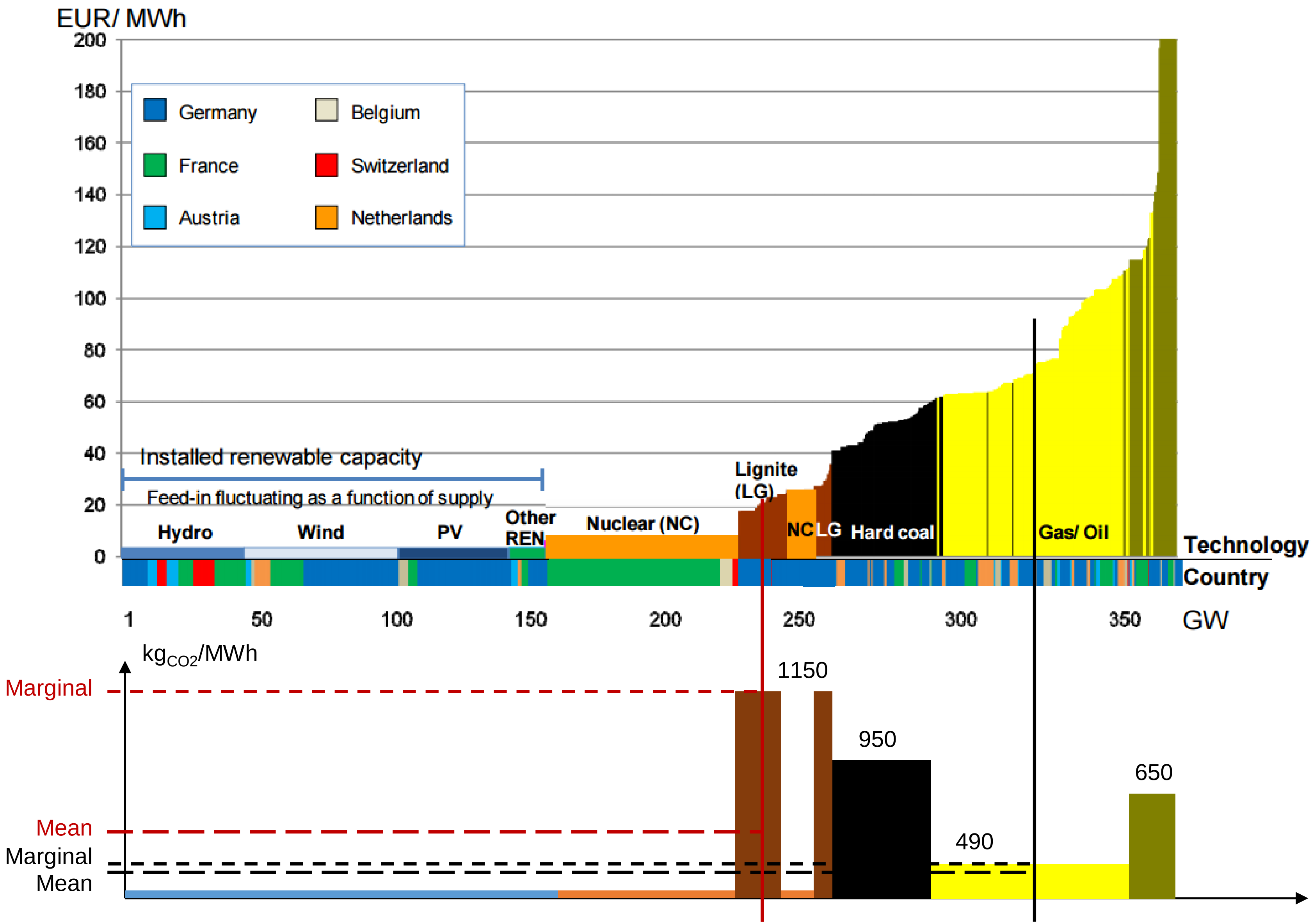
Storage deployment



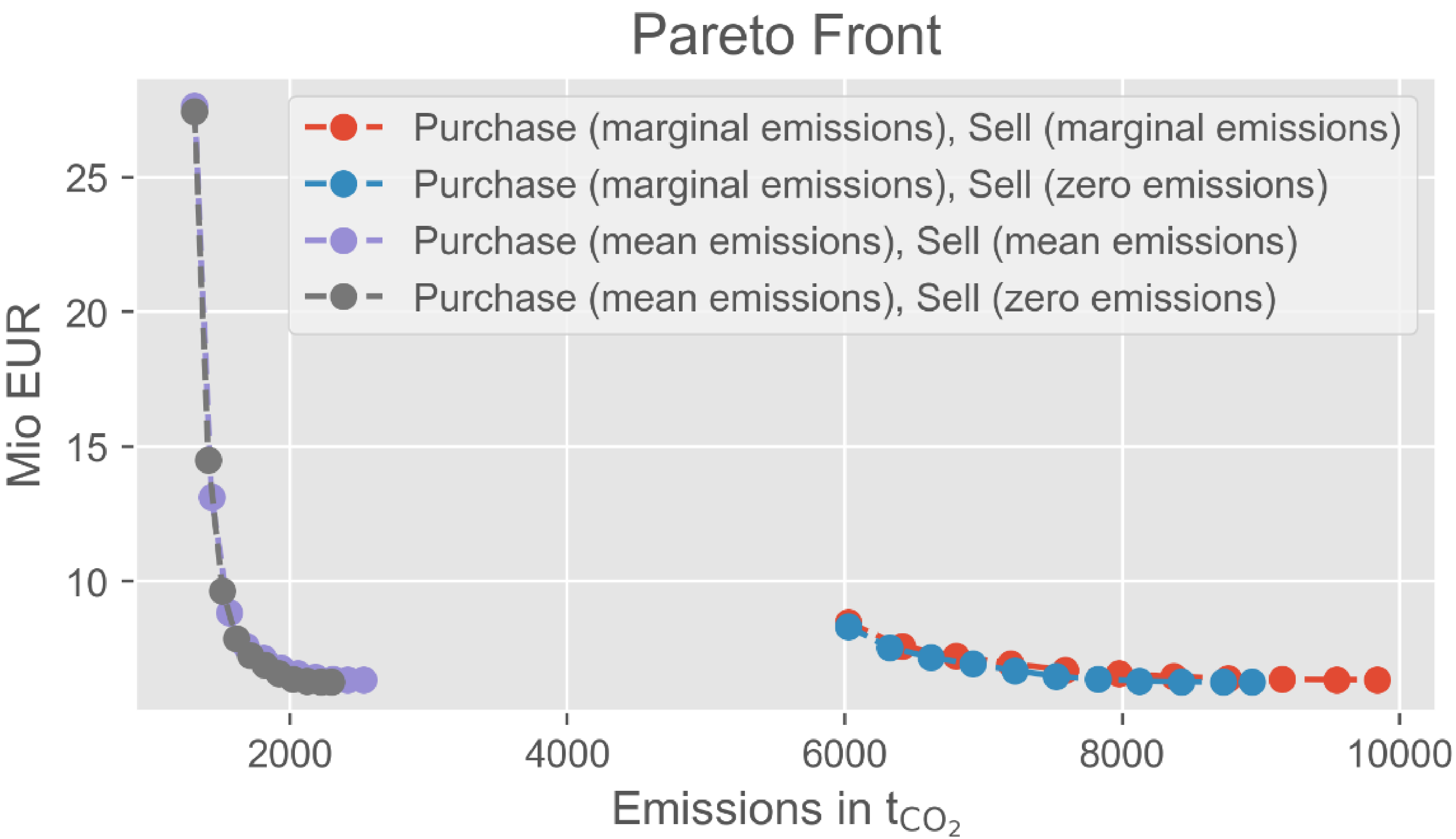
Grid investment

Comparing the value of **marginal** and **mean emissions**

Comparing the value of marginal vs mean emissions

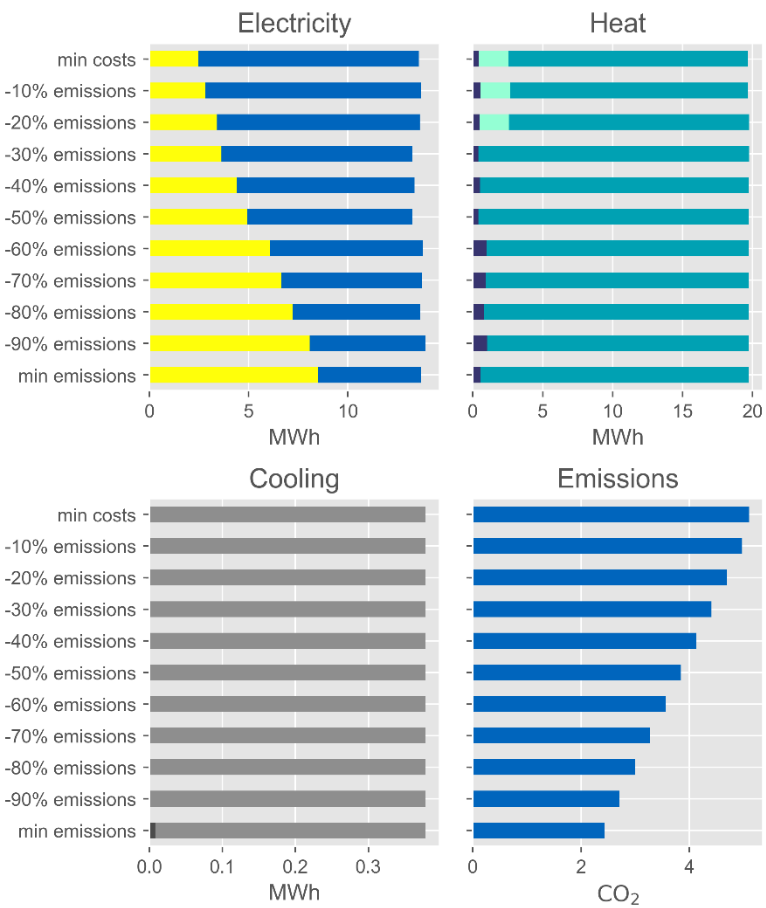


Different value of the Parteto Fronts …

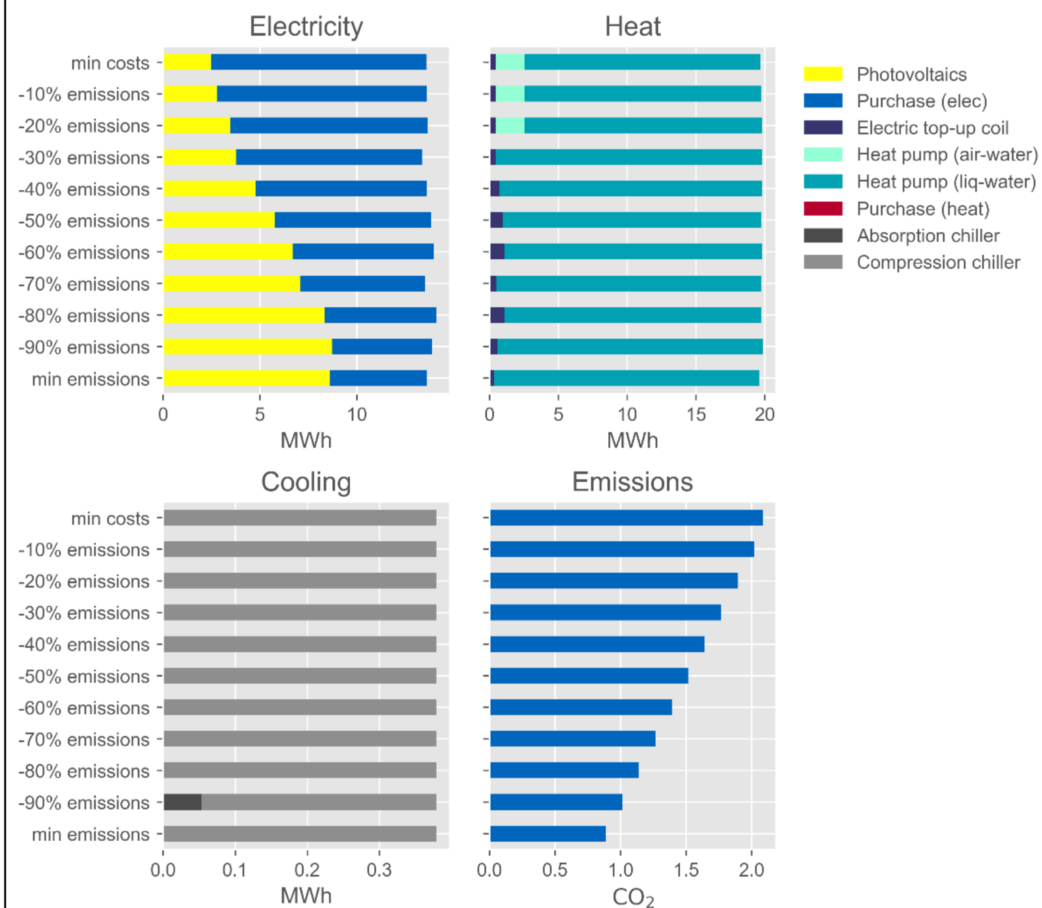


… although the solutions do not differ highly.

Grenzemissionen

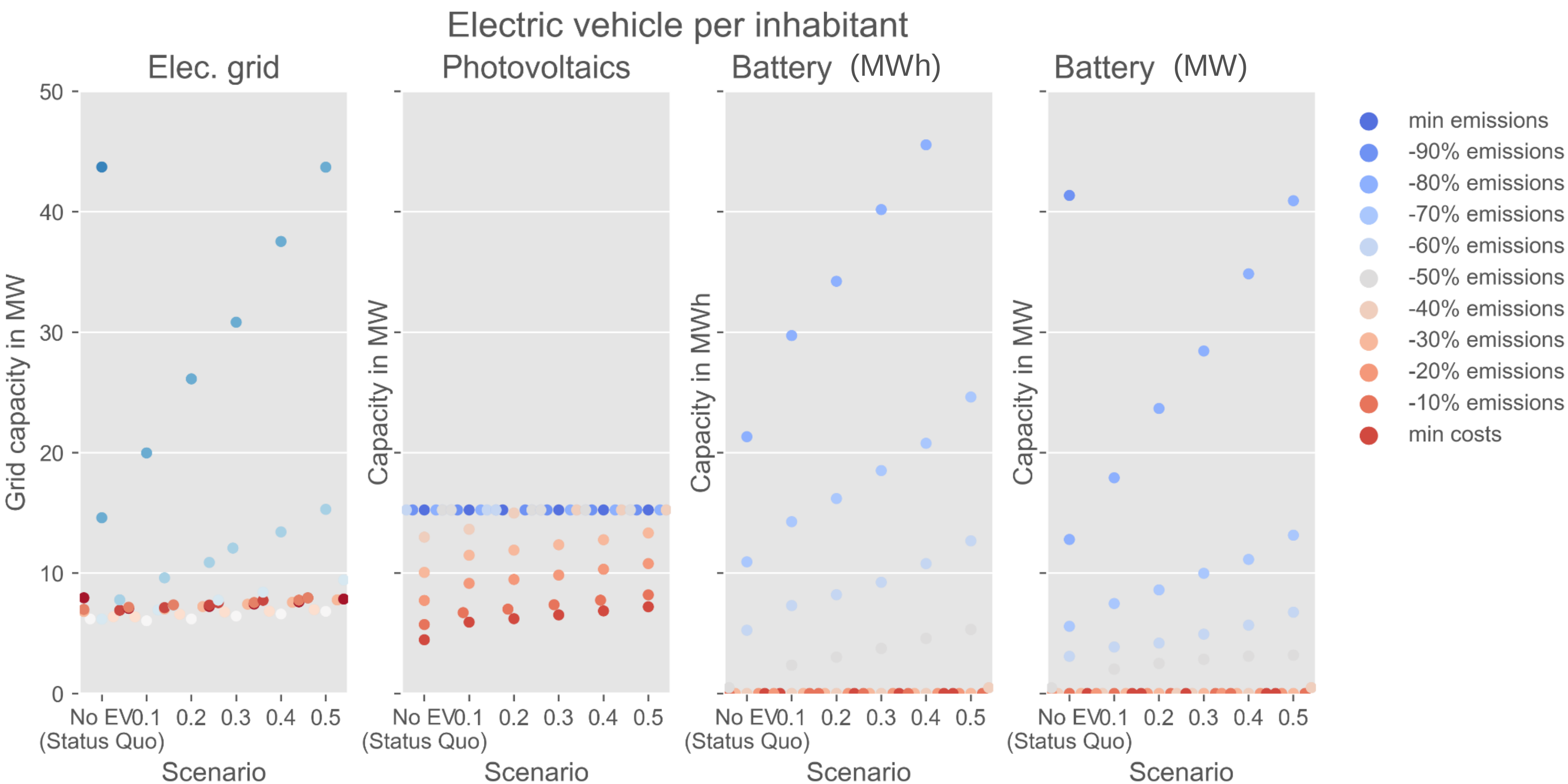


Mittlere Emissionen

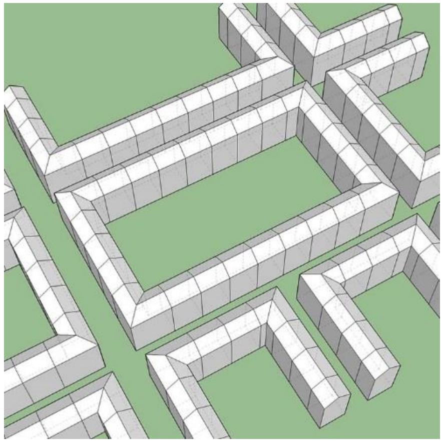


Electric vehicles

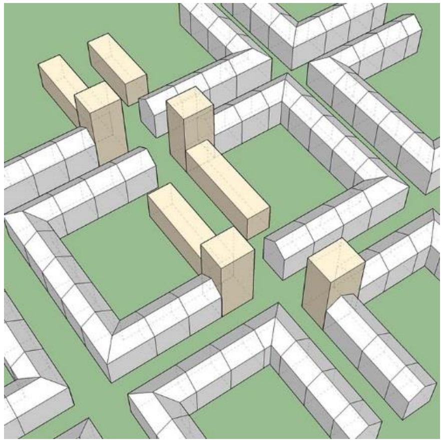
The influence of electric vehicles



Energy Efficiency and High Density

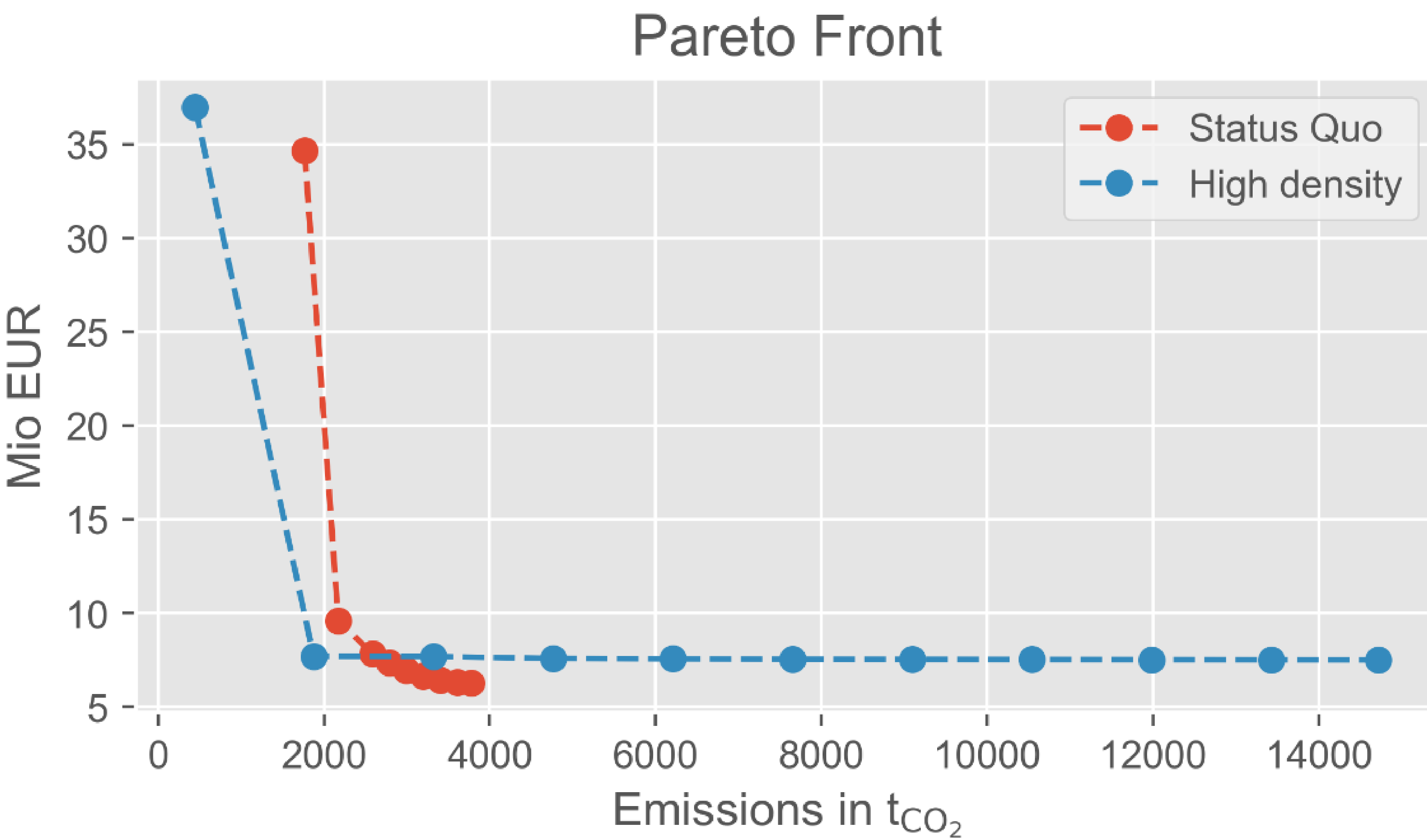


before



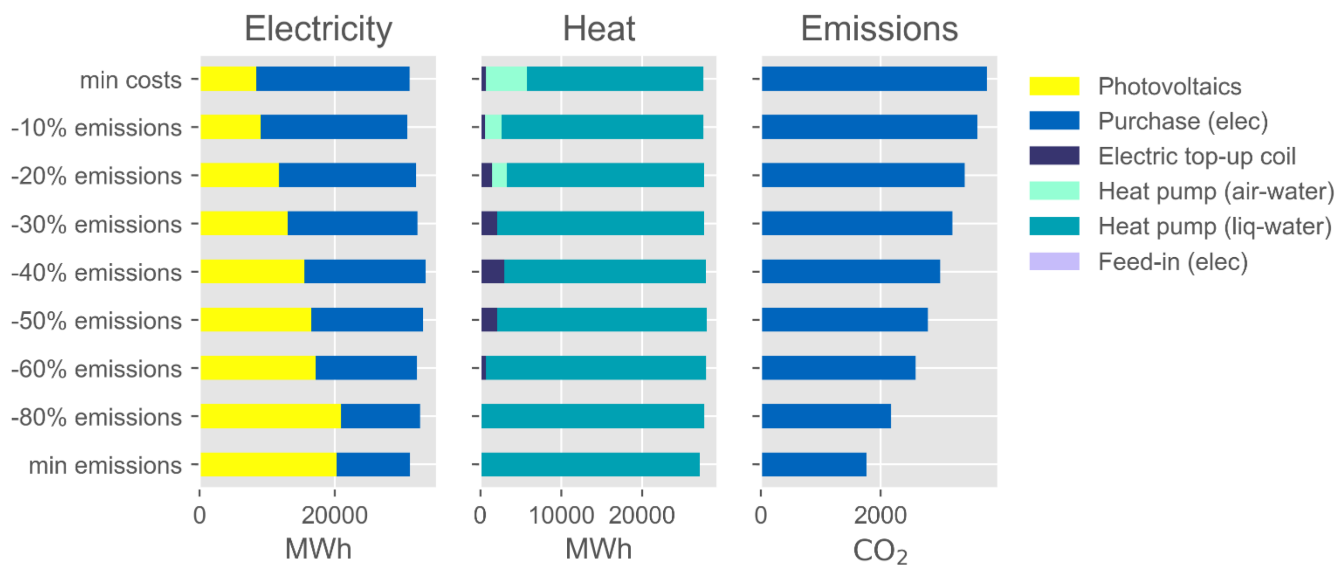
after

Difference in the pareto front

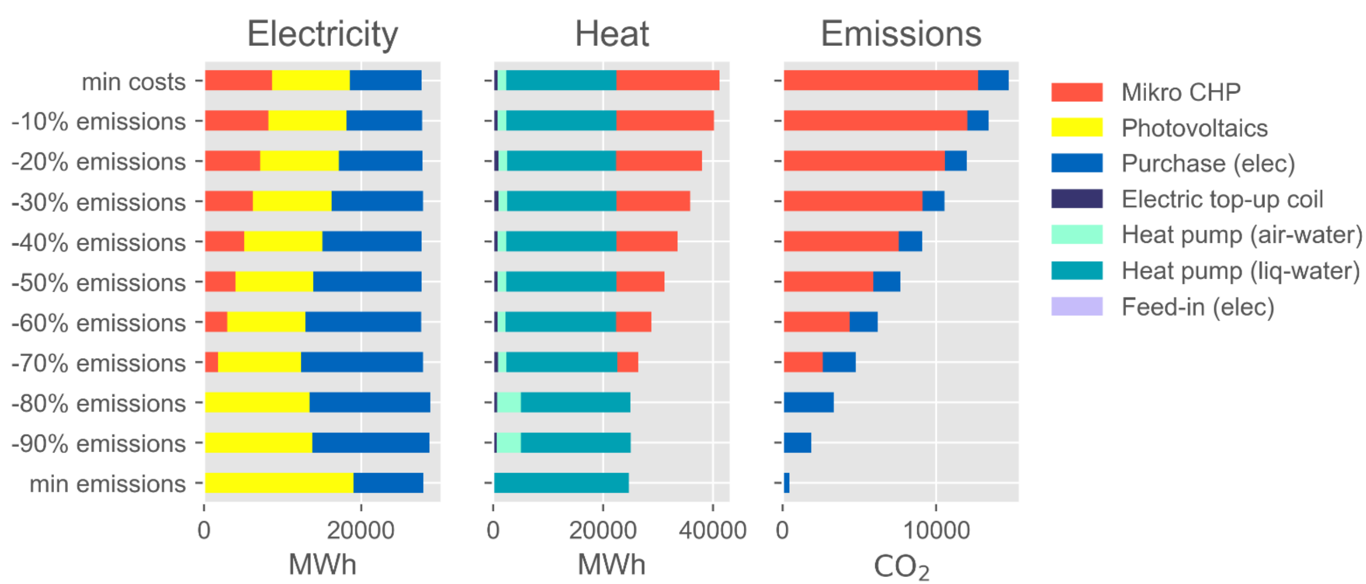


… and the installed capacity

Status Quo



High Density



Discussion and conclusions

Discussion and conclusions

- We learnt a lot from the multiobjective optimization:
  - Results unveil a complex relationship between efficient emission and cost reduction.
    - Trend: more solar, heat pumps and electricity storages.
    - High density shows a potential for gas powered µCHPs.
  - Very high (local) emission reduction results in very high costs
    → 2^{nd} best solution more feasible?
  - Emission reduction mostly by “electrify” the system
    - Large-scale impact on electricity system?
    - Other energy grids will struggle in future.
    - Large scale heat pump deployment realistic?
  - Despite storage deployment, a reliable distribution system is of high importance.
- Future investigation will address:

  Integration of hydrogen long term storages (increase the complexity a lot).

Andreas Fleischhacker

TU Wien
Energy Economic Group, EEG
Gußhausstraße 25-29 / E370-3
1040 Vienna, Austria

[T] +43 1 58801 370 361
[F] +43 1 58801 370 397
[E] fleischhacker@eeg.tuwien.ac.at
[W] http://www.eeg.tuwien.ac.at

Investment costs

Storage	eff-in	eff-out	inv-cost	inv-cost-p	inv-cost-c	fix-cost-p	fix-cost-c	depreciation	wacc	source
Battery	0.98	0.98	1000	10	1200	0.5	0.5	15	0.02	Truong 2016, Tesla 2016, Hiesl 2017
Hot Water Storage	0.95	0.95	0	1	90	1	1	15	0.02	Lindberg et al 2016
H2 Storage	0.999	0.999	0	0.1	25	0	0	25	0.02	Kotzur 2017

Process	inv-cost	inv-cost-p	fix-cost	var-cost	startup-cost	wacc	area-per-cap	depreciation	source
Photovoltaics	3,494	1,038	0.01	0.000	0.000	0.02	6.5789	25	EEffG 2016, Loschan 2017
Solarthermal	4,000	2,461	0.01	0.000	0.000	0.02	1.25	25	EEffG 2016, Loschan 2017
Hybrid collector	6,000	3,000	0.01	0.000	0.000	0.02	6.5789	25	FHD 2014
Electrolyser	5,235	4,278	0.01	0.000	0.000	0.02	#N/A	20	Kotzur 2017, Teichmann 2012
Fuel cell	4,635	3,753	0.01	0.000	0.000	0.02	#N/A	20	Kotzur 2017, Teichmann 2012
Electric top-up coil	100	60	0.02	0.000	0.000	0.02	#N/A	25	Lindberg 2016
Gas boiler	1,200	600	0.01	0.000	0.000	0.02	#N/A	20	EEffG 2016, Loschan 2017, Linc
Heat pump (liq-water)	17,000	770	0.02	0.000	0.000	0.02	#N/A	20	EEffG 2016, Lindberg 2016
Heat pump (air-water)	3,000	1,150	0.02	0.000	0.000	0.02	#N/A	18	EEffG 2016, Lindberg 2016
Mikro CHP	1,200	3,400	0.03	0.000	0.000	0.02	#N/A	20	ASUE 2015, Lindberg 2016

Pareto Optimization of a Local Urban Energy System considering Costs and Emissions

Andreas Fleischhacker
Georg Lettner
Hans Auer

15. Symposium Energieinnovation/Session A2
15.02.2018

Motivation

- Derzeit leben 54% der globalen Bevölkerung in Städten: Source: IEA 2016
  - In den Städten wird 2/3 des globalen Energiebedarfs konsumiert
  - Resultiert in 60 – 80% der weltweiten Emissionen.
  - Dennoch findet der größte Zuwachs von erneuerbarer Erzeugung außerhalb der Städte statt.
- Daraus formulierten wir die Forschungsfrage, welche **Energieinfrastruktur (d.h. Erzeugungskapazitäten, Speicher und Netze)** nötig sind, um emissionsmindernde Effekte zu erzielen.
- Diese und auch andere Fragestellungen warden im Rahmen des Stadt-der-Zukunft Projekts “*Smart City Microquartiere*” beantwortet.

STADT der Zukunft

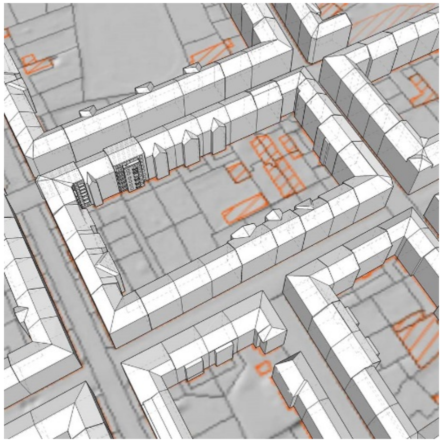
bmvit

Bundesministerium für Verkehr, Innovation und Technologie

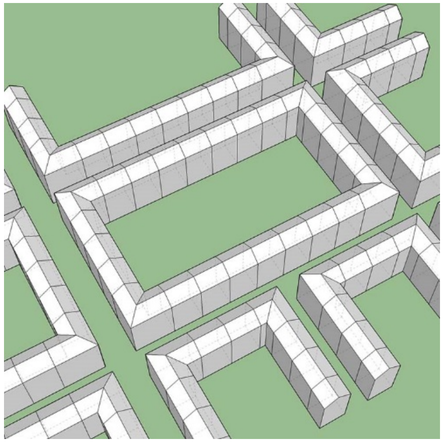
Mikroquartier Methode

1 Auswahl des Areals

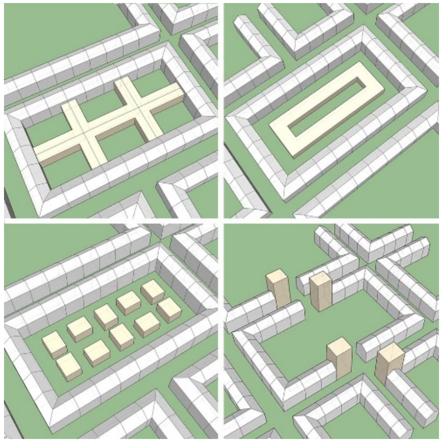
2 Auswahl des Mikroquartiers



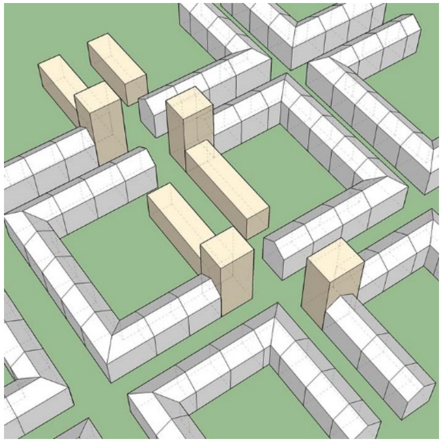
3 Erfassung des Mikroquartiers



4 Abstraktion des MQ

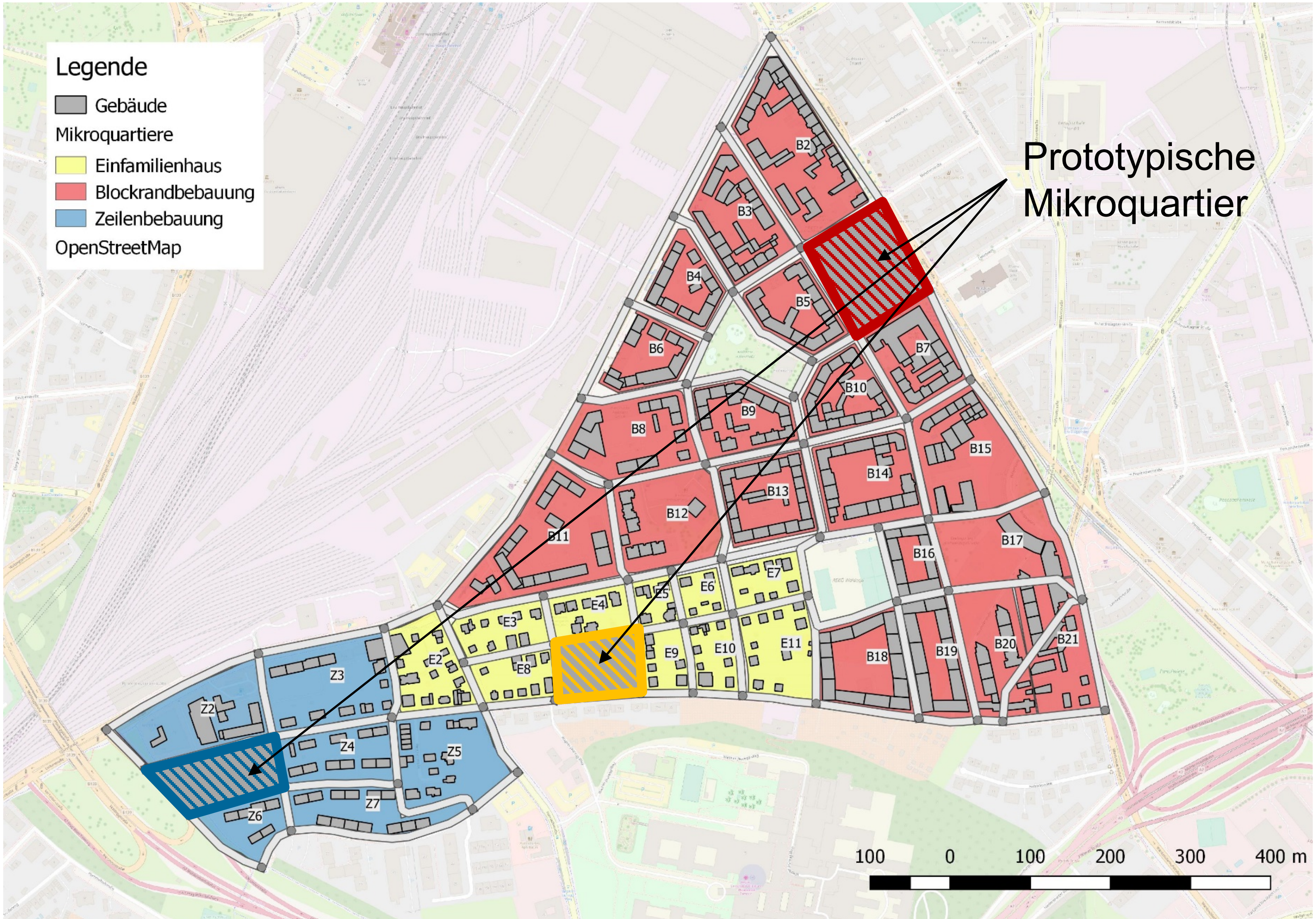


5 Optimieren des MQ in Varianten



6 Auswahl von MQs

Betrachtete Mikroquartiere im Areal Linz



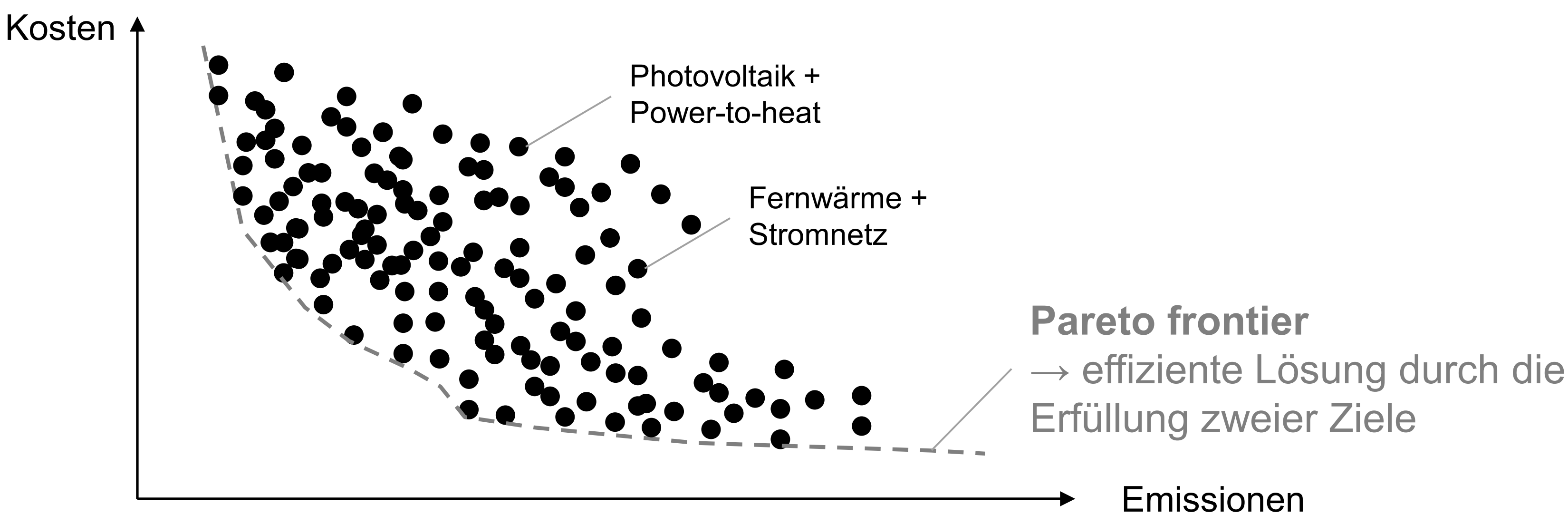
Energetische Optimierung

- Wir betrachten folgenden Energiebedarf: Strom-, Wärme-, Kühl- und Mobilitätsbedarf.
- Zur Deckung des Energiebedarf sind viele (dezentrale) Technologien verfügbar.
- Die Gesellschaft möchte zusätzlich zwei Ziele erreichen:
  - Emissionen reduzieren
  - Kosten reduzieren

  Konflikt!

→ Betrachtung durch eine "*Pareto Optimierung*" !

Bsp.:



Pareto Optimierung

Wir verwendeten die **ε-constraint Methode**:

1) Berechnung der minimalen Kosten

$$\begin{aligned} \min_{\mathbf{e},\mathbf{p}} \quad & costs = \mathbf{c}_{costs}^T \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \\ \text{subject to} \quad & \mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b} \\ & \mathbf{e}, \mathbf{p} \geq 0 \end{aligned}$$

2) Berechnung der minimalen Emissionen

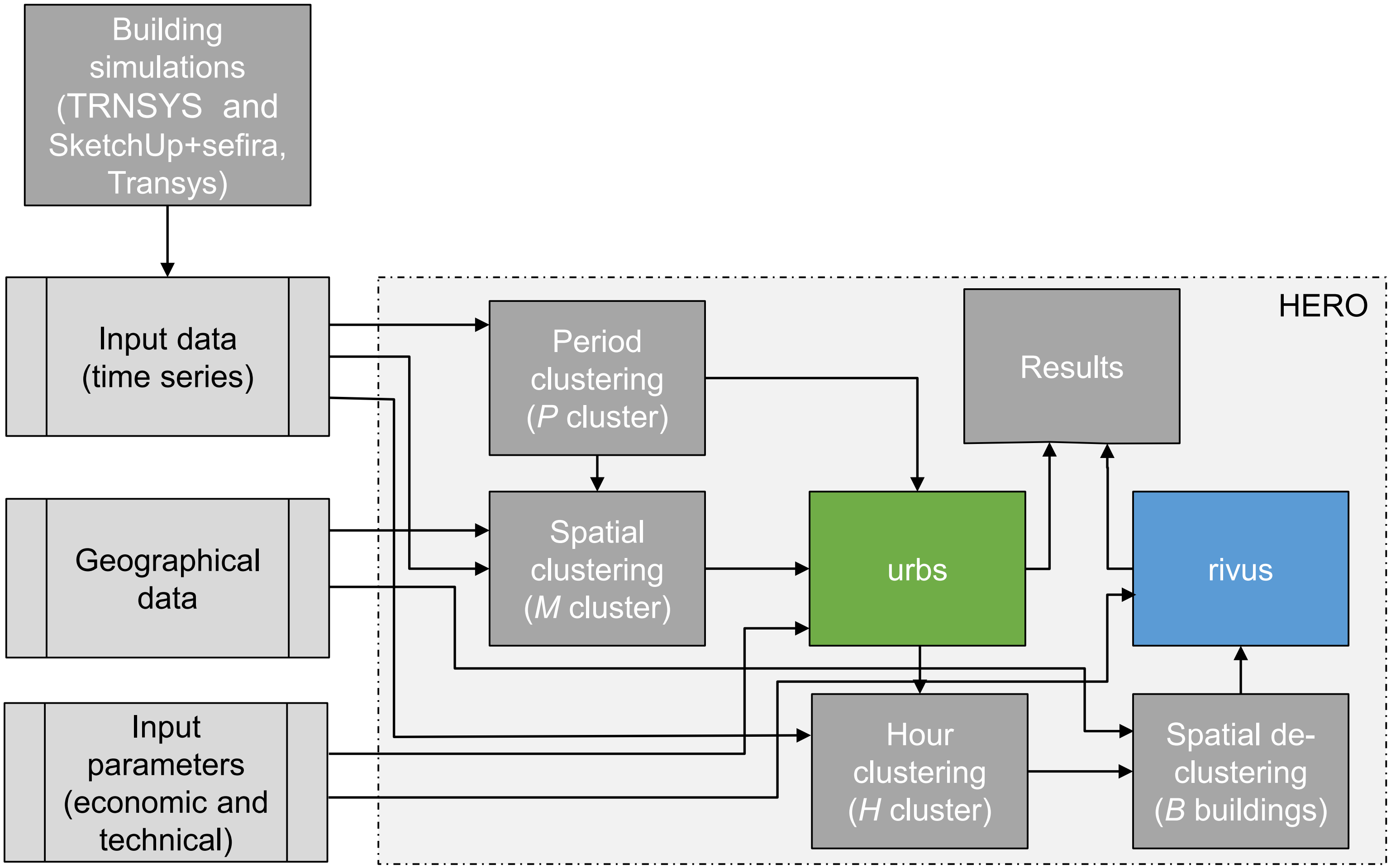
$$\begin{aligned} \min_{\mathbf{e},\mathbf{p}} \quad & emissions = \mathbf{c}_{emissions}^T \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \\ \text{subject to} \quad & \mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b} \\ & \mathbf{e}, \mathbf{p} \geq 0 \end{aligned}$$

$emissions_{min}$

3) Pareto Optimierung

$$\begin{aligned} \min_{\mathbf{e},\mathbf{p}} \quad & costs = \mathbf{c}_{costs}^T \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \\ \text{subject to} \quad & emissions \leq f * emissions_{min} \\ & \mathbf{A} \begin{bmatrix} \mathbf{e} \\ \mathbf{p} \end{bmatrix} \leq \mathbf{b} \\ & \mathbf{e}, \mathbf{p} \geq 0 \end{aligned}$$

HERO – Hybrid EneRgy Optimization



Modelltechnische Umsetzung in der Kombination von zwei Open-Source Modellen

HERO – Hybrid EneRgy Optimization

Start

Capacities to be installed

*urbs**
*latin for city

- Focus: high **temporal** resolution
- Cost-optimal sizing of and use of **processes**
- Processes for energy conversion
- Processes for energy storage
- Demand as **hourly time series**

*rivus***
**latin for stream

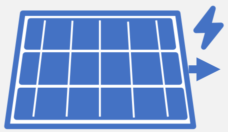
- Focus: high **spatial** resolution
- Cost-optimal sizing of **capacities**
- Capacities for conversation processes (local and central)
- Capacities for distribution systems
- Demand as **peak and annual load**

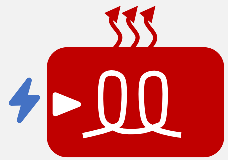
Capacities used

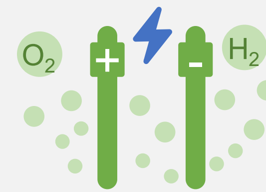
Source: Johannes Dorfner, "*Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale*", Munich, 2016.
Open source projects: https://github.com/ojdo/urbs/ and https://github.com/tum-ens/rivus

Betrachtete Technologien

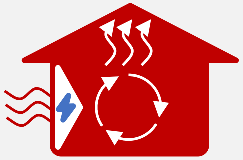
Erzeugungs- bzw. Umwandlungstechnologien

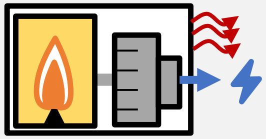

Photovoltaik

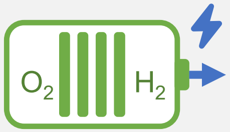

Stromheizer



Elektrolyseur

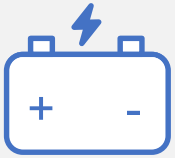

Wärmepumpe


µKWK

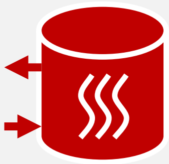


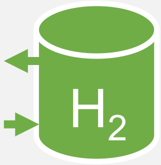
Brennstoffzelle

Speichertechnologien



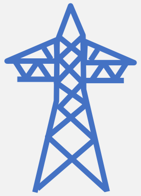
Batterie

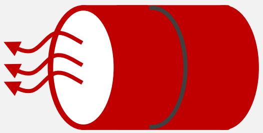

Wärmespeicher



Wasserstoff-
speicher

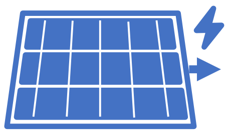
Netze

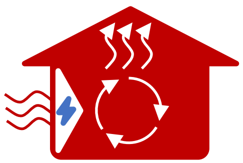

Stromnetz

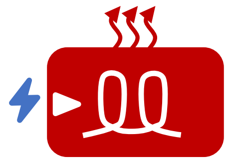

Wärmenetz

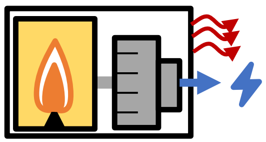

Gasnetz

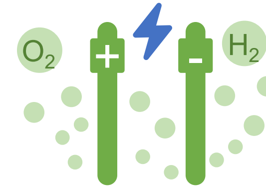
Betrachtete Technologien


Photovoltaik

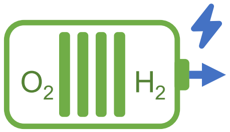

Wärmepumpe


Stromheizer


µKWK

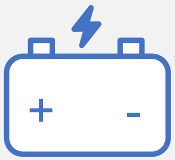


Elektrolyseur

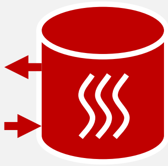


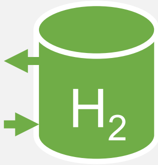
Brennstoffzelle

Speichertechnologien



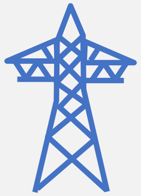
Batterie

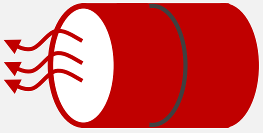

Wärmespeicher



Wasserstoff-
speicher

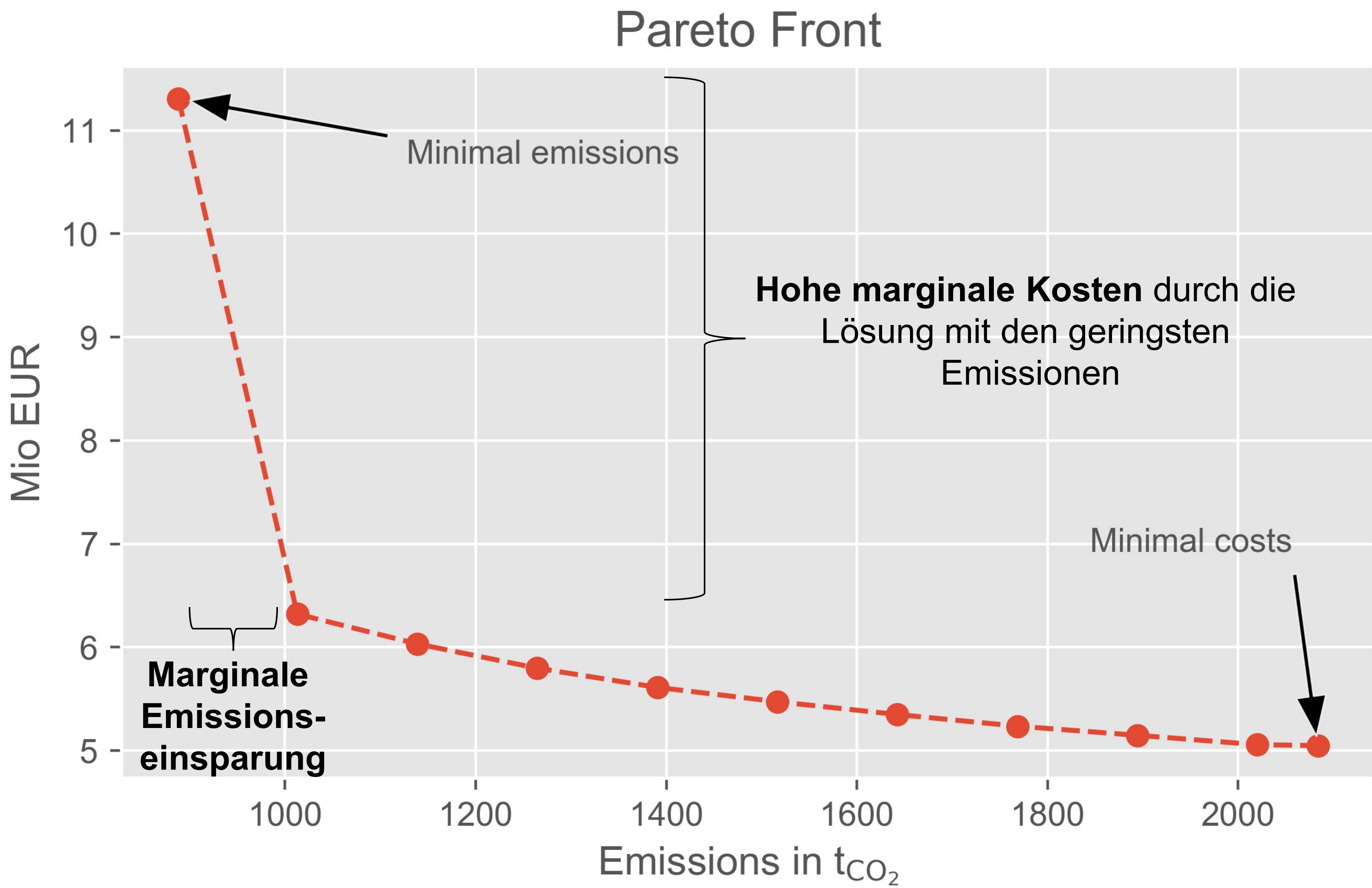
Netze


Stromnetz

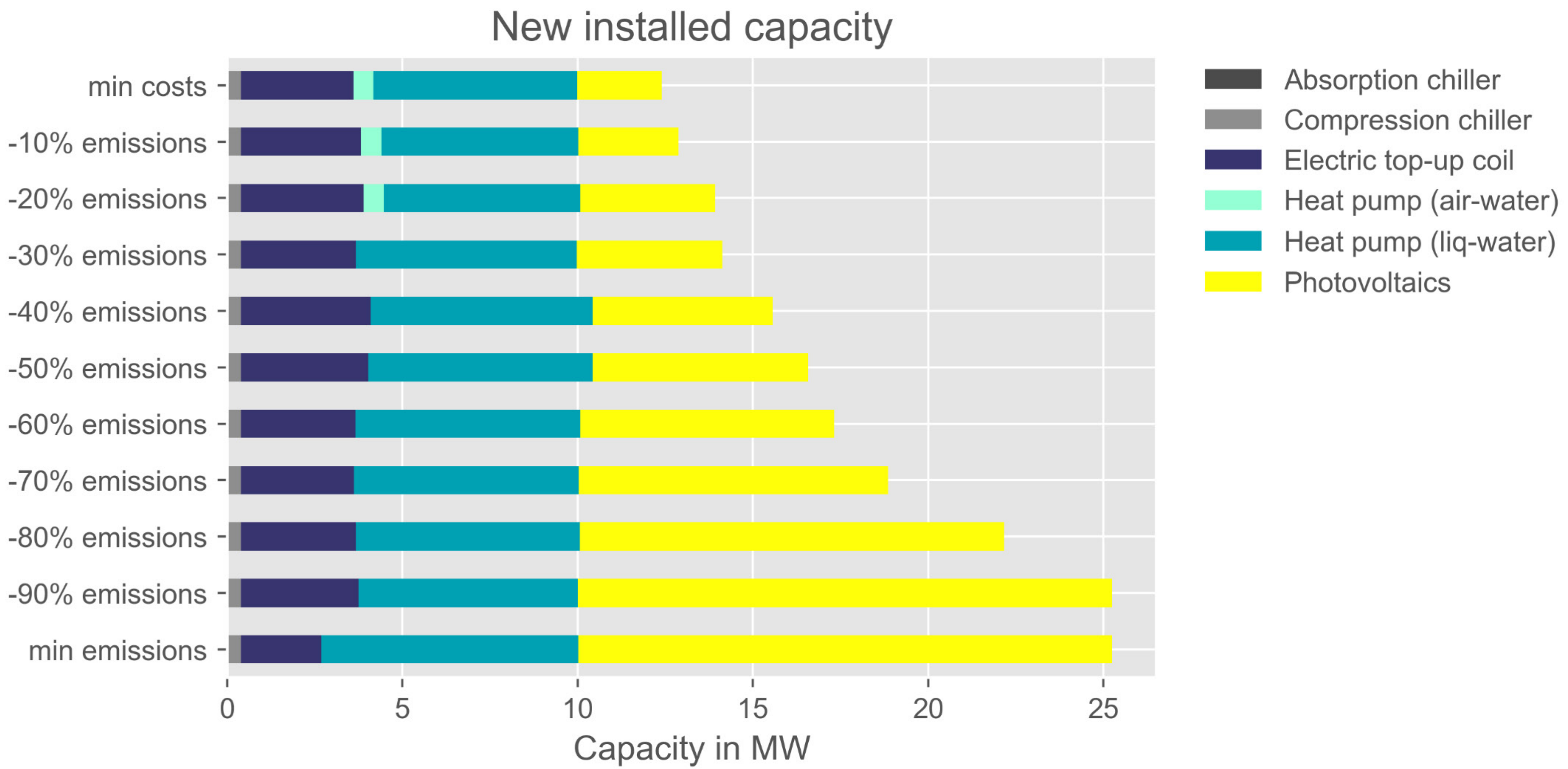

Wärmenetz


Gasnetz

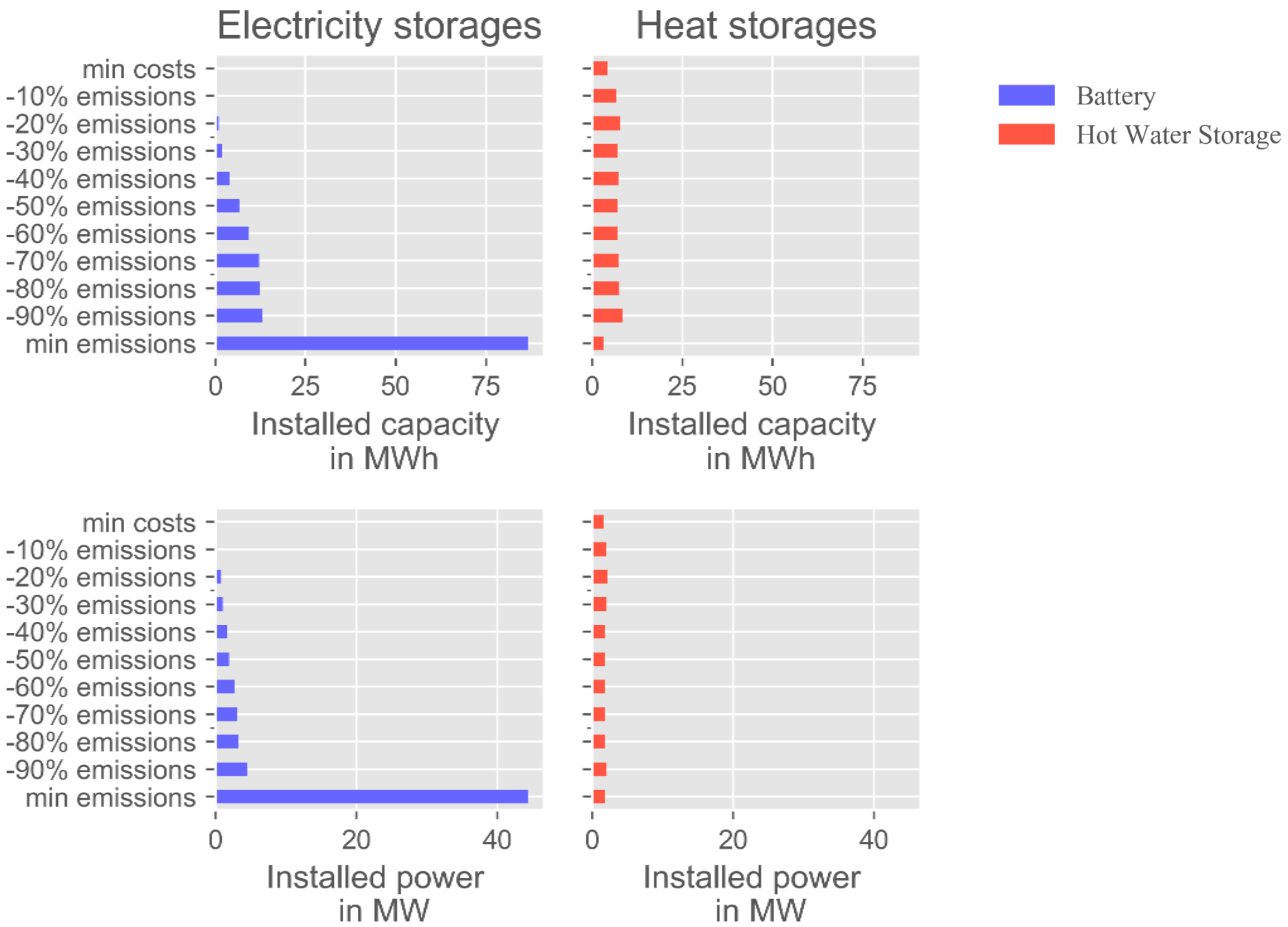
Ergebnis für den Status Quo



Erzeugungskapazitäten



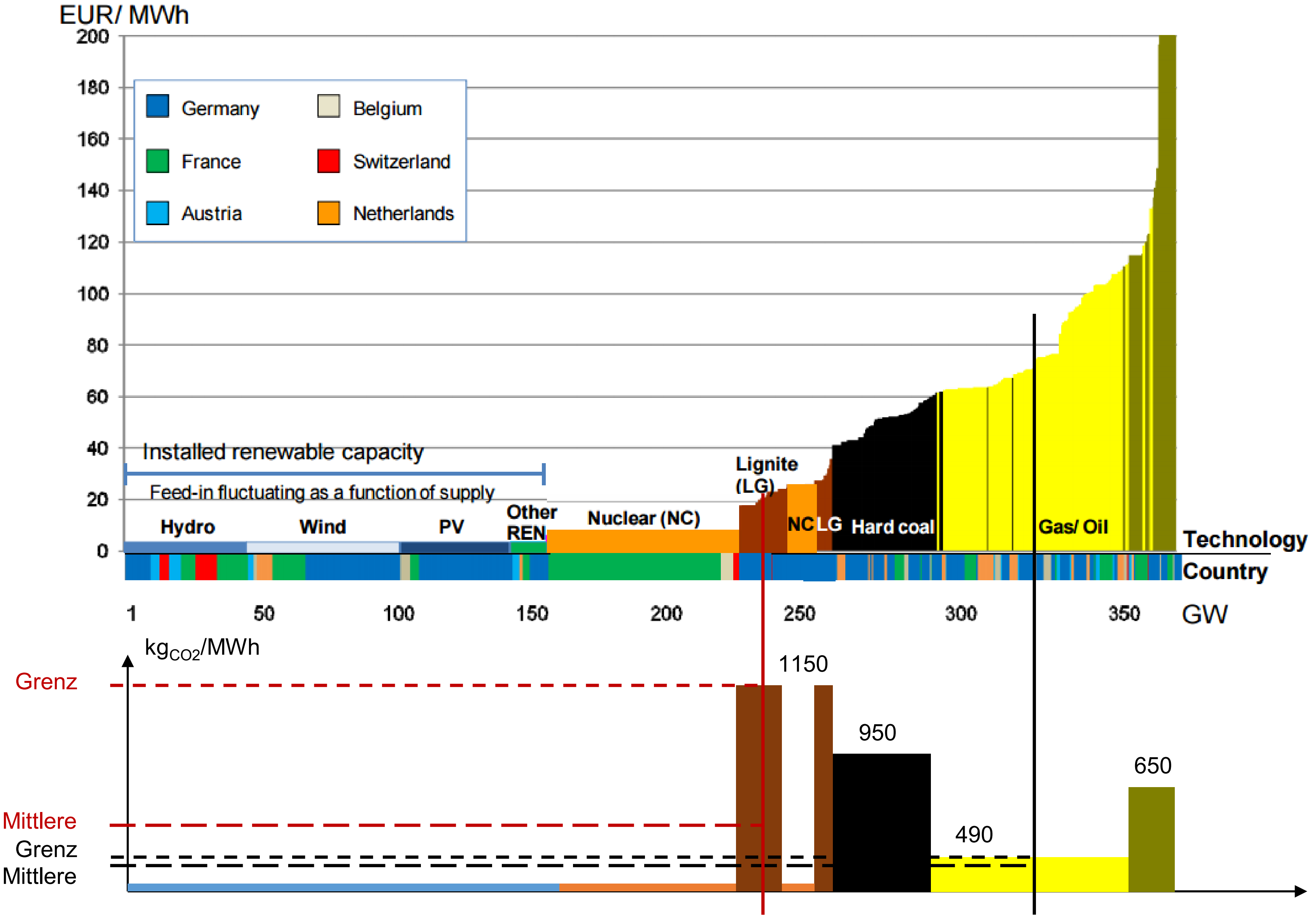
Speicher



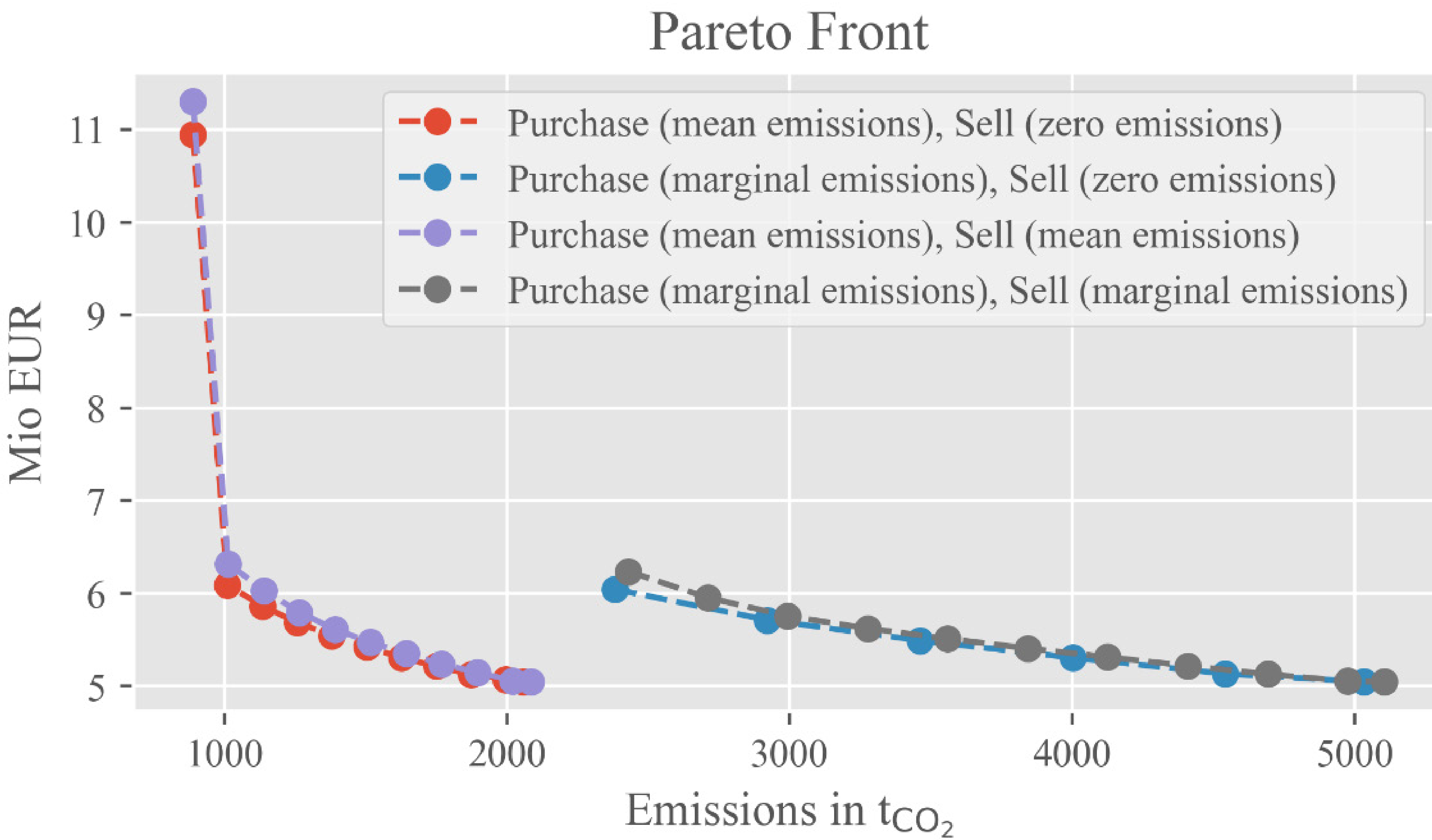
Electricity storages
Heat storages
min costs
-10% emissions
-20% emissions
-30% emissions
-40% emissions
-50% emissions
-60% emissions
-70% emissions
-80% emissions
-90% emissions
min emissions
0
25
50
75
Installed capacity in MWh
0
20
40
Installed power in MW
Battery
Hot Water Storage

Entwicklung des Stromnetzausbaus

Sensitivität von „mittleren“ und „Grenzemissionen“



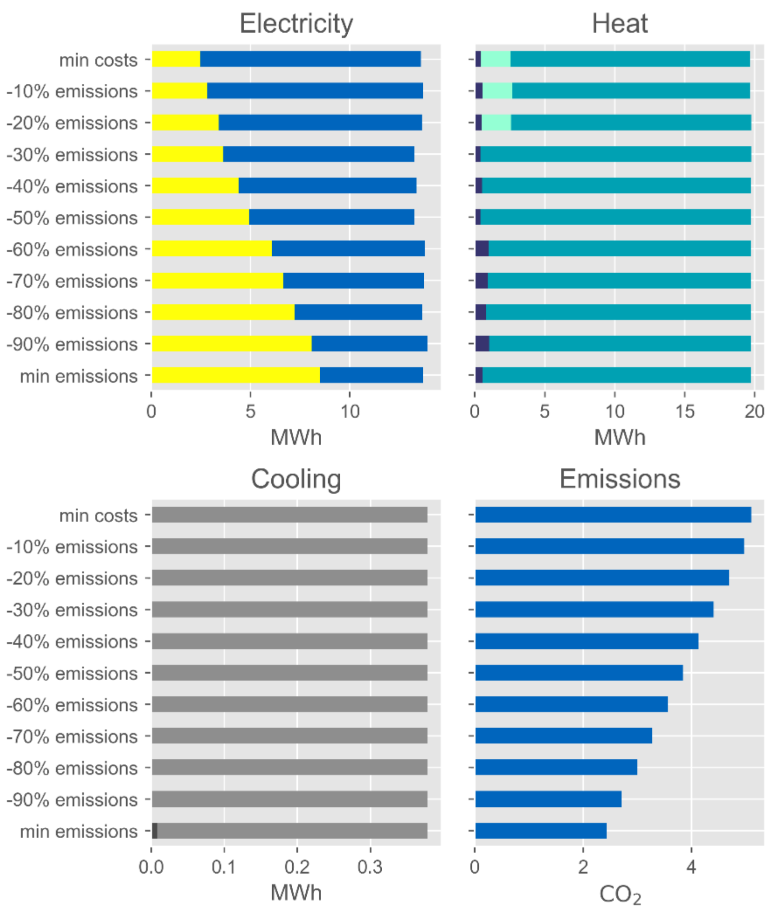
Ergebnisse der Emissionsbewertung



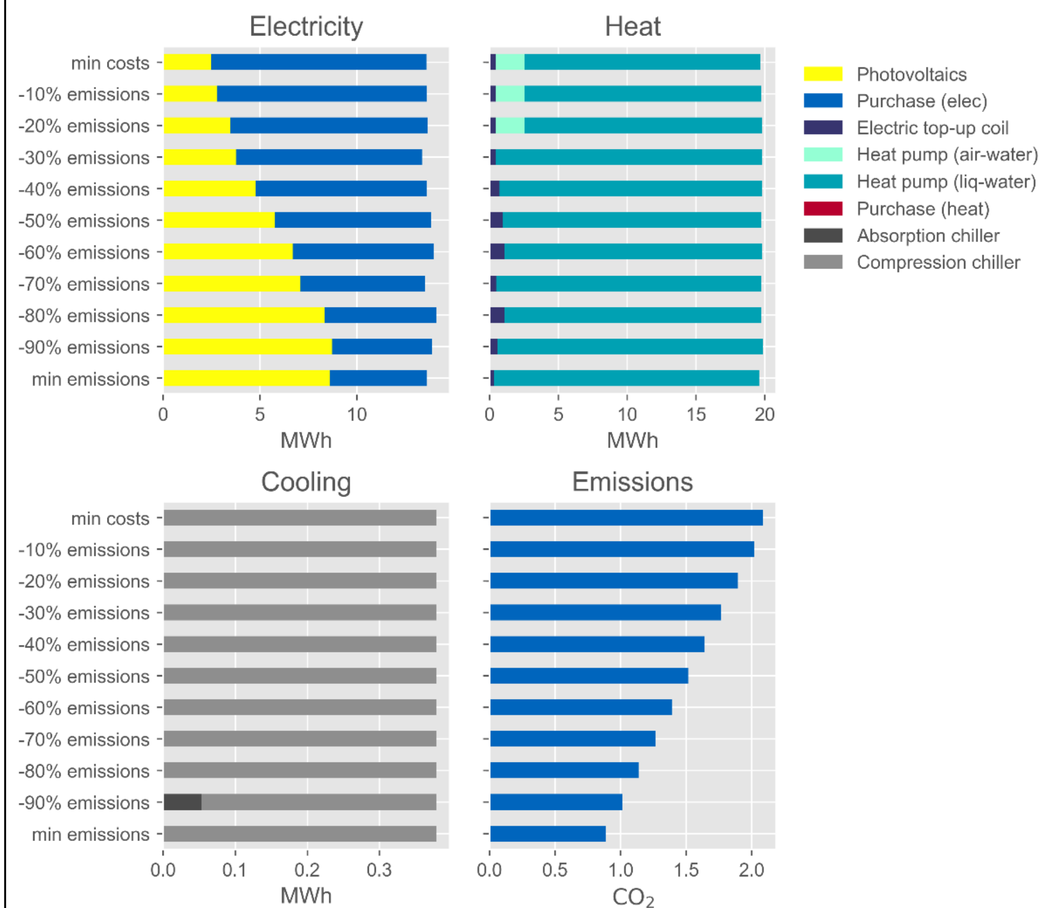
Unterschiedliche Pareto Fronten …

… obwohl die Lösungen nicht sehr abweichend sind.

Grenzemissionen



Mittlere Emissionen



Discussion and conclusions

- Erkenntnisse aus der Pareto Optimierung:
  - Die Ergebnisse zeigen eine komplexe Beziehung zwischen effizienter Emission und Kostenreduzierung. ?
    → Trend: mehr Solar, Wärmepumpen und Stromspeicher?
  - Sehr hohe (lokale) Emissionsreduktion führt zu sehr hohen Kosten?
    → 2. oder x. beste Lösung machbarer?
  - Emissionsminderung meist durch "Elektrifizierung" des Systems?
    → Auswirkungen auf das Stromsystem?
    → Andere Energieversorgungsnetze sind hier wesentlich eingeschränkter
    → Großflächige Bereitstellung von Wärmepumpen realistisch?
  - Trotz Speicherbereitstellung ist ein zuverlässiges Verteilungssystem von großer Bedeutung.
- Zukünftige Untersuchung befasst sich mit:
  - Integration von Elektrofahrzeugen (EV).
  - Integration von Wasserstoff-Langzeitspeichern (erhöhen Sie die Komplexität erheblich).

Andreas Fleischhacker

TU Wien
Energy Economic Group, EEG
Gußhausstraße 25-29 / E370-3
1040 Vienna, Austria

[T] +43 1 58801 370 361
[F] +43 1 58801 370 397
[E] fleischhacker@eeg.tuwien.ac.at
[W] http://www.eeg.tuwien.ac.at

Sensitivität Last und Elektromobilität