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# Optimizing positive energy districts

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**Abstract**. A planning tool was developed which is able to integrate renovation strategies on district level as a combination of energy efficiency upgrades for buildings and the use of renewable energy deliver positive energy districts. It combines elements of energy master planning, district development and optimization in a Modelica environment by combining energy demand, circularity and stakeholder engagement on the demand side and life cycle costs in multi-objective optimisation on the supply side. Thus, the tool consists of six dedicated modules for optimizing positive energy districts (PED).

## 1. Introduction

To achieve the projected building stock decarbonization, large efforts are needed. To achieve these goals, a combination of energy efficiency upgrades and renewable energy use is necessary on a district or city scale. Building retrofitting can reduce demand, while renewable energy aims to decarbonize the energy supply. However, the technical solutions alone are insufficient to achieve the targeted renovation rate in Europe, as barriers such as renovation cost, access to finance, complexity, awareness, stakeholder management, and supply chain fragmentation still exist [1].

District renovation has the potential to significantly reduce greenhouse gas emissions, but it requires a thorough Energy Master Planning process and support for decision-making. To reduce emissions, energy use must be reduced by implementing efficiency measures in the renovation of buildings, and decarbonization of the energy supply through on-site renewable energy measures must be explored. Simulation and optimization tools can help identify the best options for both reducing energy use and decarbonizing the energy supply.

Stakeholders, including homeowners, must be engaged in long-term investment strategies to achieve decarbonization goals. Applying Building Performance Simulation (BPS) and optimization tools can help simulate different options and identify the best strategies for achieving decarbonization goals [2;3]. Several attempts have been made and provide increasing knowledge about urban energy modelling and simulation and optimization of its energy systems [4].

Positive Energy districts are districts that support the transformation of districts to decarbonization. Some of the main barriers to renovation have to do with the renovation cost and access to finance, as well as complexity, awareness, stakeholders' management, and fragmentation of the supply chain [1]. In energy planning of positive energy districts, it is often unclear what energy supply options are available and what influence different technology options have, including demand reduction through energy renovation.

## 2. Aim of research
The aim was to develop a tool for building and district scenarios with optimized energy supply solutions. The tool should be able to integrate renovation strategies on district level as a combination of energy efficiency upgrades for buildings and the use of renewable energy to decarbonize the energy supply, on district or city scale. By combining energy efficiency and renewable energy sources, both energy supply and demand in the district is addressed. Investment costs as well as operational costs were incorporated to provide multi-objective solutions for district renovation options.

## 3. Scientific method
Based on demand profiles for electricity and heat for different building types, demand profiles of positive energy districts were developed [5]. Energy demand, renewable energy resources and imported energy was specified as well as related costs were collected, and circularity potential was estimated. A common approach to calibration of the district models to existing energy use data including grid interaction and load mismatch was developed based on functional and organizational sub-divisions of energy use to be able to include different stakeholder views, goals and ambition levels. Workshops were organized to ensure engagement of stakeholders. Possible conversion, storage and distribution technologies. Optimization algorithms were applied which optimize costs and GHG emissions through thousands of different supply systems [6]. In addition, a reverse value engineering was chosen to develop optimized positive energy districts.

### *3.1. Energy planning*
The optimization process in energy master planning involves identifying and implementing the most effective and cost-efficient energy efficiency measures and renewable energy systems to achieve the desired energy management goals. It typically involves several steps:

- Data collection: Gathering and analyzing data on energy usage, building systems, and operations.
- Energy audits: Conducting a detailed analysis of energy consumption patterns, identifying areas of high energy usage, and evaluating the efficiency of building systems.
- Energy modeling: Using software tools to model energy usage and identify potential energy savings opportunities.
- Options analysis: Evaluating different energy efficiency measures and renewable energy options to determine the most effective and cost-efficient solutions.
- Prioritization: Prioritizing energy efficiency and renewable energy measures based on their potential impact, cost, and feasibility.
- Implementation: Implementing energy efficiency and renewable energy measures, including equipment upgrades, retrofits, and installation of renewable energy systems.
- Monitoring and verification: Tracking and verifying energy savings to ensure that the implemented measures are achieving the desired results.

### *3.2. Optimization*
Several attempts to develop ooptimization-based planning of local energy systems have been documented. This has led to a range of methodologies, which may be combined or adapted depending on nature of the problem. Most commonly, the problem is formulated as one of cost minimization [7]. The problem to be solved in the optimization is formulated as a linear program [6]. The optimization process in energy master planning is an iterative process, and it may involve revisiting earlier steps as new data and information become available or as goals and priorities change. By optimizing energy usage and reducing energy consumption, organizations can lower their energy costs, reduce their carbon footprint, and achieve long-term sustainability goals [8].

Variables in optimization commonly include the input and output energies of conversion and storage technologies per timestep and the capacities of these complex technologies [9; 10].

### *3.3. District development in simulation*

The development of districts requires a distinct understanding of the situation now as well as a vision of the future district to be able develop suitable pathways for this transition. In order to be able to do that a district needs to be modelled that consists of several buildings, sufficiently described so that the future district can actively manage their energy consumption and the energy flow between them and the wider energy system. An accurate determination of energy savings is a key condition for long term success of energy management projects. Energy savings are determined by comparing measured energy use before and after implementation of an energy saving measurements. To perform these kinds of analysis, it was necessary to:

- Identify the market segments and the segmentation of the current energy performance requirements;
- define and select a sufficient number of reference buildings that are characterised by their functionality, characteristics and regional conditions;
- specify packages of energy saving- energy efficiency- and energy supply measures to be assessed;
- assess the corresponding energy-related investment costs, energy costs and other running costs of relevant packages applied to the selected reference buildings;
- use the established reference buildings and relevant packages to identify cost-optimal energy performance requirements for building elements and technical building systems.

## 4. Results

### *4.1. Platform development*

Modelica was used for detailed simulations of the performance of buildings with coupled energy systems [11]. The results from these detailed simulations are then used to train a library of models, which aim to predict a performance profile faster, and without a significant loss of accuracy, compared to the detailed simulation model. The stages of the approach are as follows:

1. Creation of the envelope component using archetype data (DS-PM1: Retrofit)
2. Integration of Circular Economy module based on 3r (reuse, replace, recycle) DS-PM2: CE
3. Testing with co-creation process to engage stakeholders (DS-PM3: Engage)
4. Connection of buildings and district systems inside the Modelica model using a Python wrapper (SS-PM2: building scale)
5. Simulation of Modelica model in JModelica to generate energy profiles (SS-PM2: district scale)
6. Training of an SVR model using the simulation results (SS-PM3: grid scale)
7. Prediction of net zero carbon goals using the trained model

The objective was to extend the approach by devising energy supply solutions for buildings and districts that are optimized for efficiency. To create a scenario, the energy demand at the selected location, as well as imported energy and resources, must be specified, along with potential conversion, storage, and distribution technologies. An optimization algorithm then evaluates thousands of potential supply systems, resulting in two to four solution variants for each scenario.

The analysis of the solutions is based on two variables: the annual life cycle costs (LCC), which includes all technical measures proposed, and the CO2 emissions. Structural optimization measures, such as enhancing the building envelope's energy efficiency, were considered as improved values resulting from structural renovation measures on the building. This heat demand reflects the heat demand of a building that has been renovated according to a specific building standard.

The simultaneous optimization with respect to multiple objectives is enabled through the exploration of a pareto front of optimal solutions with respect to costs and CO2 emissions [12]. Sympheny platform was used and applied this method and can be used to input data and the software then calculates the most suitable energy supply solutions for the selected site and the defined scenario [11]. Figure 1 illustrates the approach.

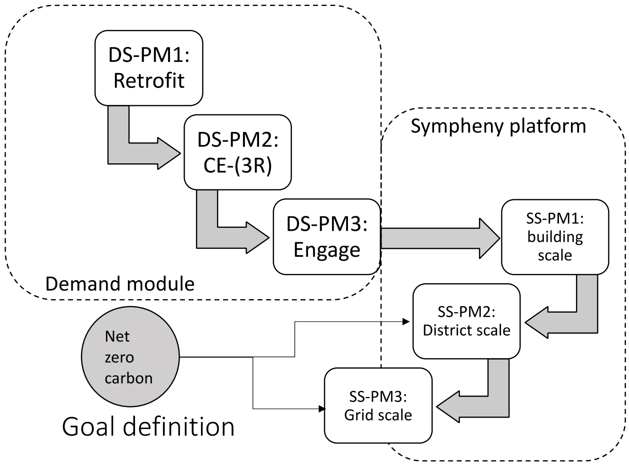

**Figure 1**. Tool structure

DS-PM1: A retrofit plan is produced based on efficiency studies, benchmarking of key performance indicators, and cost estimates.

DS-PM2: A first evaluation of circularity potential is produced for the retrofitting options. These are evaluated according to circularity principles (reduce, reuse, recycle).

DS-PM3: An engagement module was developed that consists of three parts integrated into a workshop concept: 1. Building envelope options, 2. Energy supply options, 3. Financing options. Preliminary results from efficiency studies (GEAK) are presented to participants and evaluated.

SS-PM1 + SS-PM2: The calculated energy system of the first option is thus always designed for a minimum life cycle cost, while the energy system of option 4 has the lowest possible $CO_2$ emissions. The two intermediate optimization options 2 and 3 are targeting both variables [6]. This approach allows to set up several scenarios and determine the pareto curve for each scenario. Klaiber and Haase (2022) reported on this process for a case study in Switzerland [13].

SS-PM3: The grid scale module is still under development. Here, the implications of the district on the grid are evaluated.

*4.2. Application to a case study site*

A case study was conducted based on a settlement located near the city of Winterthur in the North of Switzerland. It consists of 8 buildings containing between 6 and 9 residential row houses each, built in 1972 and 1974. Three different scenarios were analyzed and results given in Figure 2:

- Scenario 1 that determines the energy efficiency of the building energy demand (according to DS-PM1 to DS-PM3).
- Scenario 2 which determines the decarbonization potential of the energy supply options by exploiting SS-PM1 and SS-PM2.
- Scenario 3 as a combination of both scenarios mentioned above (scenario 1+2).

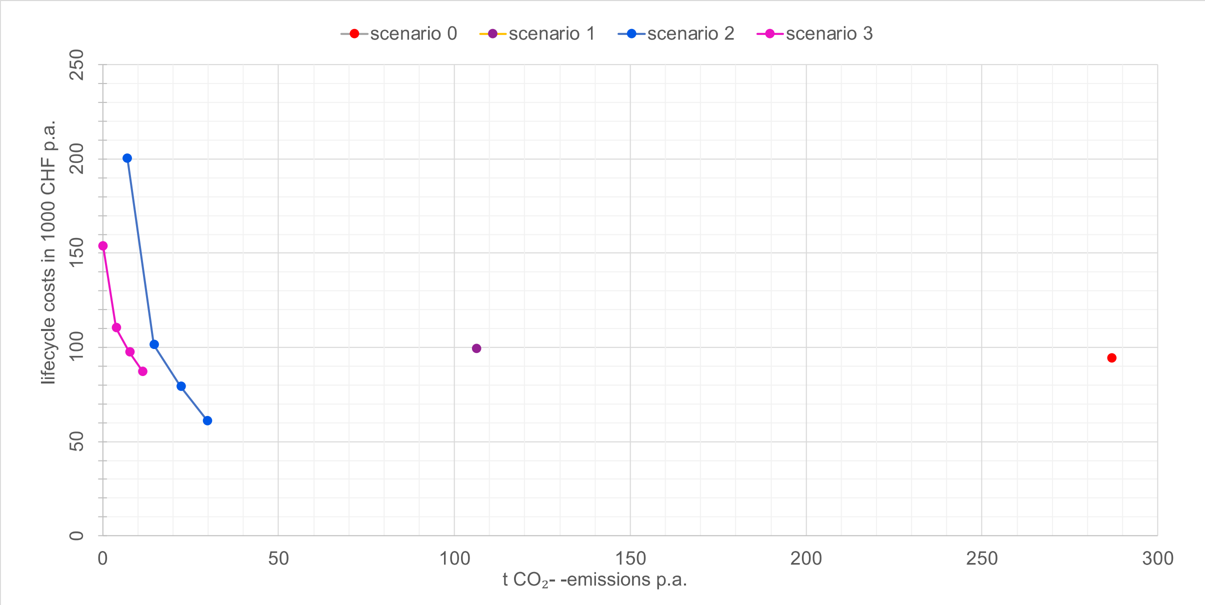


**Figure 2**. Lifecycle costs of optimized district energy system

Figure 2 shows that annual $CO_2$ emissions could be reduced by more than 60% in scenario 1 (violet) by energy efficiency measures of the building envelope with a slight increase of LCC. The pareto results of scenario 2 (blue) are ranging between 60kCHF and 200kCHF and provide two solutions with lower LCC and two solutions with higher LCC than scenario 0. An additional improvement can be achieved in scenario 3, thus offering the highest improvement potential with over 95% $CO_2$ emission savings compared to the current state of the settlement. The final module (SS-PM3) has not been applied in this study yet.

## 5. Discussion

To evaluate which energy supply solution turns out to be the most suitable for the settlement, a compilation of the four scenarios was carried out. The various results of the respective scenarios are categorized and compared according to $CO_2$ emissions and life cycle costs (LCC). The annual $CO_2$ emissions can typically be reduced by more than 60% by renovating the building envelope in terms of energy efficiency. In addition, the LCC, which include the investment costs for the refurbishments, would be about the same as before. The reason for this is the strong savings in fossil fuels. However, by implementing purely technical measures, overall $CO_2$ emissions could be reduced even more than by refurbishing the building envelope alone in scenario. LCC which annualizes investment costs as well as (annual) operational expenses shows that these results are useful for energy planners. However, investments needs are often seen as hindrance to renovation as well as to grid services. More work is needed to incorporate solid investment mechanisms into the decision-making process.

## 6. Conclusions

Energy Master planning can optimize a district's energy system by incorporating renewable energies and efficient solutions to address oversizing problems in the electrical infrastructure and transmission losses during peak energy demand. Optimization can help distribute energy production within the district, but when incorporating renewable systems, interactions between buildings and the grid must be considered. Current computer-based energy performance models for general use buildings are inadequate and require customization to function as archetypes for predicting energy use in districts, accounting for climate conditions and energy use requirements. To be useful for community planning, optimization models must be fully parametrized with common modelling inputs to incorporate energy efficiency measures. The next step will be to collect data from several case studies and calibrating building models with existing energy use data from metering and sub-metering. When communicating the results and its implications we need to consider different stakeholder views, plans, and goals, taking sub-divisions into account.

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