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OPTIMAL ENERGY TECHNOLOGY NETWORKS IN SPATIAL ENERGY PLANNING IN AUSTRIAN CITY QUARTERS

S. Maier[2]*, H. Dumke[1], M. Eder[2], J. Fischbäck[2], M. Malderle[3], E. Rainer[3]

[1] Department of Spatial Planning, Vienna University of Technology, Karlsplatz 13, A-1040 Vienna / Austria

[2] Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 13/3, A-8010 Graz / Austria

[3] Institute for Urbanism, Graz University of Technology, Rechbauerstraße 12/II, A-8010 Graz / Austria

*Corresponding author; e-mail: stephan.maier@tugraz.at

Abstract

High energy demands of urban areas force energy planning and spatial planning in Europe to foster closer links with each other's discipline. Besides an open ground for common actions fundamental research is needed to extend knowledge and space about what the performance can look like.

The paper discusses fundamental research on energy demand and supply issues of cities and the influences on city development due to the interdependencies between living spaces. Two Austrian city quarters were chosen as reference cases, one of each located in the Austrian cities Graz and Vienna. These reference cases shall afterwards support future smart city developments considering city planning as an interdisciplinary process of integrating spatial and energy planning as a whole.

Process Network Synthesis (PNS) is used to find optimal energy technology networks to supply city quarters. With this method a variety of locally possible technologies can be considered for their application. Different characteristics of cities, as there were (resource) limits, ethical aspects and natural boundaries can be considered as well as financial aspects. The outcome helps to design future pathways of cities to an integrated sustainable development.

Keywords:

Spatial energy planning; process optimisation; urban energy systems; use of renewable energy

1 INTRODUCTION

Development of energy frameworks in urban areas depend on the respective context. Individual settings like geographical location, interests of local inhabitants or settlement densities can form the city in many ways.

Local energy planning is not always managed in an optimum way. Options must be found to rethink and rebuild existing parts of cities and build new city quarters only after identifying and jointly applying typically separated planning approaches. From a steering perspective, both the spatial and the social policy triggers for entire city quarters clearly need more future attention although the coordination of both approaches are a "hard candy" in daily implementation practise. Energy planning and spatial planning need a common ground to converge both disciplines in an integrated spatial energy planning [1]. The existence of many approaches saving resources and making cities more sustainable de Jong et al. recently gave a broad overview [2].

This paper discusses an integral part of such a planning approach, the search for optimal energy systems for cities [3]. This optimisation is part of a project trying to find a contradictable guideline for an integrated spatial energy planning for city quarters. Fig.1 shows the two cities with the highlighted city quarters selected for case study areas. Both are located in the two Austrian cities Vienna and Graz. Both cities are constantly growing and consequentially concentrate energy demands.
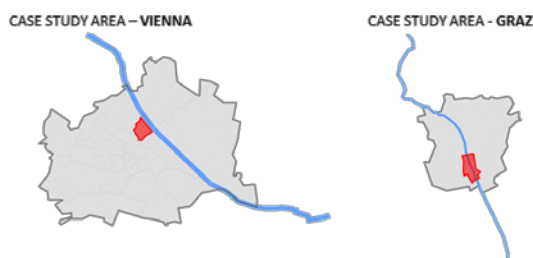

Fig. 1: Case study areas Vienna and Graz.

The settlement structure in the city quarter in Vienna is denser than that of Graz. Vienna has a well-established gas- and district heat grid. In both city quarters, green and brownfield areas are located. Due to the constant population growth these areas are a welcomed potential to expand the cities to handle the increasing demand for housing in the cities [4]. Both test areas were selected carefully in order to cover and respect various mixes of densities, existing settlement types, but also some projects that are yet unbuilt.

2 METHOD

Process Network Synthesis (PNS) is a method to optimise material and energy flows in finding combinatorically feasible structures in and for specific systems. This method is a further development of the p-graph method, a process graph framework based on combinatorial algorithms for process synthesis [5].

Capacities of technologies as well as availability, amount and quality structure of materials are user-defined. The optimisation was carried out with the software tool PNS Studio [6]. For the application of optimal energy technology systems for cities a discussion process about all locally available resources and implementable technologies was required. Moreover, the specific demand of products, all included mass- and energy flows, investment and operating costs of the whole infrastructure, cost of raw materials, transport and selling prices for products were defined.

With this information in PNS Studio a local maximum technology system could be created and all feasible maximal structures can be generated. The tool uses a branch-and-bound algorithm to create an optimum structure out of the maximal structure. For this application the revenue for the whole system was set as target value to find the economically most feasible technology system.

3 STUDY AREAS FRAMEWORK

The following describes the framework of the case study areas. Because the aim of the work is to find an optimal energy system for the year 2030 it includes assumptions made for changes which seem to most likely be influencing the energy demand from 2015 until 2030.

The sizes of the study areas are 513 ha of Graz and 694 ha in Vienna. In the study area in the city of Graz the number of 21,500 inhabitants is predicted to grow to approximately 31,000 inhabitants (9,300 just due to developments in two green and brownfield areas). The area is located South, along the river Mur, in a very inhomogeneous area of grassland, fields, single-family houses, multi-storey houses, garden plots and industry.

The number of inhabitants in the second study area in Vienna is predicted to grow from 105,000 to more than 142,000 inhabitants (32,000 due to developments in two former railway areas). The area is located North of the central city district along the right bank of the river Danube in a very homogenous area of mainly multi-storey houses except the former railway areas.

More energy demand for building developments due to a growing population in the cities and growing electricity demand for electric cars as well seem to be very likely on the one hand but better insulated housing means less energy consumption (-50% for heating demand) on the other hand. Considering this the assumptions shown in Fig. 2 were made for the year 2030.
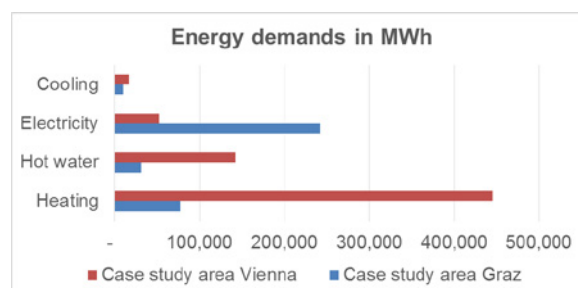

Fig. 2: Energy demands in case study areas.

The pre-calculations also included energy needs for mobility, where electricity need for electric cars was part of the electricity demand in PNS. All 2030 benchmarks also contained moderate "savings paths" in heat consumption, both output of deep thermal retrofit measures, but also from the growing number of entirely new buildings with low or passive house energy standards.

3.1 Maximal energy technology network

Beside energy demand also the respective resource availability for the year 2030 was assumed.

Both cities do have gas and district heat, in Vienna it is available area-wide. In Graz the spatial structure is very inhomogeneous. The northern part of the study area is mainly connected to district heat whereas the southern part is mainly connected to the gas net. In-between a mix of both or no network is accessible. Existing infrastructure and possible expansions were allowed in each quarter.

Geothermal energy could be accessed at a total of building area about 133 ha in Graz and 297 ha in Vienna. For solar thermal and photovoltaic 319,000 m² of roofs is the realistic potential in Graz and 1.6 Mio. m² that of Vienna.

Biomass for energy (grass, short rotation, green cuttings and bio waste) which is still not in use could be just found in Graz.

The maximal energy technology system includes central technologies (to supply parts or the whole quarter centrally) as following:

- Biogas fermentation
- Biogas cleaning
- Biogas supply station
- Combined heat and power
- Gas burner
- Pellet burner

Decentral technologies (to supply sub-quarters directly within sub-quarters):

- Air conditioning
- Combined heat and power
- Gas burner
- Geothermal heat or cooling
- Pellet burner
- Photovoltaic system
- Solar thermal collector for domestic hot water
- Solar thermal collector with Storage for domestic hot water and heat

Tab. 1 gives an overview about the baseline scenario 0-0 for the status quo of the year 2015 and 2030. The scenarios 0-1-0 to 0-1-6 include restrictions and changes of resource cost for the year 2030. Scenario 0-1-0 2015 includes basic energy demands of the city quarters in the year 2015 where population, densification, insulation and electric mobility of the cities are likely to be on a lower level than the predicted fifteen years later.

0-0 2015	**Baseline open – status quo 2015:** no further densification / development, no growing population, no insulation, no electric mobility
0-1-0	**Network restrictions – status quo**
2015	**2015:** based on scenario 0-0 2015, but district heating and gas grid just possible in quarters where it is better extendable for practical reasons; geothermal energy just possible in quarters with one-family houses and new developments where it could be installed without too many hindrances
0-0 2030	**Baseline open:** no further variation
0-1-0 2030	**Network restrictions:** based on scena rio 0-0 but district heating and gas grid just possible in quarters where it is better extendable for practical reasons; geothermal energy just possible in quarters with one-family houses and new developments where it could be installed without too many hindrances
0-1-3 2030	**Purchase price variation natural gas:** based on scenario 0-1-0 but variation natural gas purchase price
0-1-4 2030	**Purchase price variation district heat:** based on scenario 0-1-0 but variation of existing district heat purchase price
0-1-5 2030	**Purchase price variation wood pellets:** based on scenario 0-1-0 but price variation wood pellets purchase price
0-1-6 2030	**Renewable energy goal:** based on scenario 0-1-0 but fixed minimum renewable energy share 2030 (Graz: 60%; Vienna: 30%)

Tab. 1: Scenario description.

4 RESULTS

4.1 Optimal energy system (baseline open scenarios 0-0)

In the test area of Graz, the heat demand in the baseline scenario is mainly covered with pellets (in scenario 0-0 2015: 76%; in 0-0 2030: 47%). The rest is biogas and natural gas used in central combined heat and power plants and gas burners (in both scenarios: 58 % of total gas consumption is biogas). The total share of renewables for the total energy demand is more than 90% in 0-0 2015 and more than 75% in 2030. Photovoltaic installations cover 49% of the electricity demand in 2015. This drops to 41% coverage in 2030.

In the test area in Vienna, the main resource to cover the energy demand is natural gas (in scenario 0-0 2015: 98%; in 2030: 97%) used in central and decentral combined heat and power plants. The rest of the heat (2% to 3%) and the cooling energy (100%) is provided by geothermal energy.

Technologies test area Graz	Scenario	0-0 2015	0-1-0 2015	0-0 2030	0-1-0 2030	0-1-3 2030	0-1-4 2030	0-1-5 2030	0-1-6 2030
Gas burner	central	0%	0%	0%	0%	0%	0%	35%	17%
Gas burner	decentral	4%	5%	14%	14%	0%	14%	23%	14%
Pellet burner	central	76%	64%	47%	41%	62%	33%	0%	19%
Pellet burner	decentral	9%	21%	10%	16%	28%	16%	4%	16%
Combined heat and power	central	10%	10%	18%	18%	0%	18%	25%	23%
Combined heat and power	decentral	1%	1%	11%	11%	10%	11%	2%	11%
Solarthermal for warmwater	decentral	0%	0%	0%	0%	0%	0%	0%	0%
Solarthermal with storage for warmwater and heating	decentral	0%	0%	0%	0%	0%	0%	3%	0%
Geothermal heat	decentral	0%	0%	0%	0%	0%	0%	8%	0%
District heat	existing	0%	0%	0%	0%	0%	9%	0%	0%
Sum		100%	100%	100%	100%	100%	100%	100%	100%
Combined heat and power	central	46%	46%	36%	36%	0%	36%	51%	46%
Combined heat and power	decentral	5%	5%	22%	22%	21%	22%	3%	22%
Photovoltaic	decentral	49%	49%	41%	41%	44%	41%	45%	31%
Elektricity	existing	0%	0%	1%	2%	35%	2%	1%	1%
Sum		100%	100%	100%	100%	100%	100%	100%	100%
Geothermal cooling	decentral	0%	0%	100%	0%	0%	0%	0%	0%
Air conditioner	decentral	0%	0%	0%	100%	100%	100%	100%	100%
Sum		0%	0%	100%	100%	100%	100%	100%	100%

Technologies test area Vienna	Scenario	0-0 2015	0-1-0 2015	0-0 2030	0-1-0 2030	0-1-3 2030	0-1-4 2030	0-1-5 2030	0-1-6 2030
Gas burner	central	80%	0%	55%	57%	0%	7%	0%	81%
Gas burner	decentral	0%	0%	0%	0%	0%	1%	0%	0%
Pellet burner	central	0%	57%	0%	0%	76%	0%	57%	0%
Pellet burner	decentral	0%	0%	0%	0%	24%	0%	0%	0%
Combined heat and power	central	5%	19%	20%	19%	0%	15%	19%	5%
Combined heat and power	decentral	13%	24%	22%	24%	0%	25%	24%	14%
Solarthermal for warmwater	decentral	0%	0%	0%	0%	0%	0%	0%	0%
Solarthermal with storage for warmwater and heating	decentral	0%	0%	0%	0%	0%	0%	0%	0%
Geothermal heat	decentral	2%	1%	3%	1%	1%	0%	1%	0%
District heat	existing	0%	0%	0%	0%	0%	52%	0%	0%
Sum		100%	100%	100%	100%	100%	100%	100%	100%
Combined heat and power	central	28%	44%	48%	44%	0%	35%	44%	25%
Combined heat and power	decentral	72%	56%	52%	56%	0%	59%	56%	75%
Photovoltaic	decentral	0%	0%	0%	0%	53%	6%	0%	0%
Elektricity	existing	0%	0%	0%	0%	47%	0%	0%	0%
Sum		100%	100%	100%	100%	100%	100%	100%	100%
Geothermal cooling	decentral	100%	17%	100%	17%	17%	12%	17%	0%
Air conditioner	decentral	0%	83%	0%	83%	83%	88%	83%	100%
Sum		100%	100%	100%	100%	100%	100%	100%	100%

Tab. 2: Energy technology supply of scenario results in shares of specific technology.

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4.2 Optimal energy system (other scenarios 0-1-0 to 0-1-6)

In scenario 0-1-0 the central supply of heat is limited to more reasonable parts of the city quarter. In the test area in Graz 57% (2015) of the total heat demand could so be provided from wood pellets. Natural gas and biogas burned in gas burners and combined heat and power plants is 15% (2015, with a share of 58% biogas) and 43% (2030, with a share of 29% biogas).

In the test area in Vienna natural gas use drops to 42% of the total heat demand in 2015 and increases to 99% in 2030. In 2015, 57% of the heat demand are covered with wood pellets. In both scenarios, the 2015 and the 2030 scenario, 1% of the heat comes from geothermal heat and 17% of the cooling demand from geothermal energy (including electricity demand from net). 83% of the cooling demand are covered with air conditioners.

When natural gas costs rise (from 53 Euro to 80 Euro/MWh) or no natural gas is available in the test area in Graz, 90% of heat is generated from wood pellets and 10% from biogas. Cooling energy would be provided by 100% from geothermal plants. Photovoltaic potential would increase to 89%, covering 44% of the total demand. The use of the existing electricity net would increase to 35% because there are less combined heat and power plants.

When natural gas costs rise in the test area in Vienna (from 49 Euro to 80 Euro/MWh), most of the heat would be generated from wood pellets (99%) and 1% from geothermal plants. Cooling energy would be provided by 83% air conditioning and 17% from geothermal plants. In the Viennese case, photovoltaic covers 53% of the electricity demand. 47% are covered with electricity from existing net.

A reduction of the costs of the existing district heat (91 to 45 Euro/MWh in Graz and 80 to 50 Euro/MWh in Vienna) would make it feasible in allowed sub-quarters of the test areas (scenario 0-1-4). In the test area in Graz 9% and in Vienna 52% of the heat could so be provided from the existing district heat, and most of the further demands by pellets (48% Graz), natural gas (48% Vienna) and biogas (just Graz, 29% of total gas demand).

Scenario 0-1-5: When pellets costs rise from 47 to 55 Euro/MWh in the test area in Graz the heat demand is mainly covered with 85% gas (containing 19% biogas), 4% wood pellets (some sub-quarters need decentral burning of wood pellets because energy demand density is too low for grid-based alternative). Geothermal energy generates 8% and solar thermal collectors with storages 3% of the heat demand.

When pellets costs drop from 47 to 45 Euro in Vienna 57% of the heat is generated from wood pellets, 42% from natural gas and 1% from geothermal energy.

5 DISCUSSION

5.1 Electricity and heat

In the test area in Graz in most of the scenarios energy demand is mainly covered with biomass because availability of gas and district heat infrastructure is limited and new developments are cost intensive.

The test area in Vienna has a well-developed gas and district heat infrastructure. The availability of local resources is limited and low natural gas prices and electricity can be flexibly provided from central and/or decentral combined heat and power units. Bio-resources become part of the optimal energy system when the natural gas price rises. For Graz this also includes local use of biomass for biogas fermentation.

Geothermal energy is part of the energy system in the test area in Vienna, whereas in the test area in Graz this is just the case when availability of biomass is limited. When geothermal installations can be used longer than the expected minimum lifetime or pellets are not allowed due to particulate matter (PM) limits, installations could also become feasible in Graz. Restrictions in scenarios 0-1-0 to 0-1-6 were made according to local energy suppliers and their scope for development regarding the gas and district heating grid. Together with the restrictions of geothermal heat, this shall test two more practical limitations in the framework.

5.2 Cooling

In many scenarios in the test area in Vienna geothermal energy would be a feasible form of energy supply because it can also provide cooling energy in the summer. The comparable little energy demand for cooling in the summer could easily be covered with geothermal energy but especially in Graz due to the low building density a provision of cooling energy over distances is economically not feasible. Realistic chances for installing geothermal energy is given mainly in new building lots.

5.3 Bio-resources

A trend reversal to the current low natural gas price seems to be a realistic future scenario. So the chance to economically use biogas in the energy network of the case study area in Graz could rise in the future. The case study area in Vienna is already too densely developed to locate adequate biomass resources which are still free for energy use.

6 CONCLUSIONS

Low natural gas prices underline the dictate that as long as the market is spoiled with cheap fossil fuels this acts as a barrier to change to

renewables on a large scale. In their heat supply big Austrian agglomerations are often dependent on gas or coal. Another cost factor is that natural gas can easily be transformed to heat and electricity and existing infrastructure is already there and needs comparably simple fireplaces. Notwithstanding this, local resources (photovoltaic, solar thermal and in Graz biomass) and regional resources (wood pellets) are already financially feasible. Furthermore, the scenarios in the test area in Graz show that a lack of gas and district heat infrastructure development makes decentral and biomass-based solutions more feasible. In the test area in Vienna the lower energy demand of new developments in former railway areas shows high potential to use geothermal energy. Already well-developed gas and district heat infrastructure in Vienna makes fossil fuels financially more attractive there.

7 SUMMARY

This paper discusses optimal energy technology systems in spatial energy planning in two Austrian city quarters. It shows how individual urban developments, economic conditions and possible contextual changes influence the selection of optimal energy networks in cities.

8 ACKNOWLEDGMENTS

scopes: The development alongside railway nodes and the regional potentials of renewable energy production.

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