Waste-heat re-use from commercial sources in urban environments – identification of potentials and assessment of supply-demand matches, a Vienna case study

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Abstract: The mitigation of Global Warming triggered by accelerated greenhouse gas (GHG) emissions requires changes in the energy supply towards renewables. Thus in this paper possibilities are identified to improve the energy supply system using waste heat as an additional energy source in the City of Vienna as case study.
As no observation data for waste heat and heating demand is available this data has to be derived from proxy data for estimating waste heat potential and heating demand patterns. Commercial heat consumption as a waste heat source is mapped based on the distribution of industries and services within the urban area, estimated via employees and turnover as proxy numbers. Waste heat share and temperature ranges are reviewed from literature. Heating demand is mapped based on floor space distribution related to building age, class, type and heating demand factors per m2. The difference of both maps shows the local heat supply deficit or surplus pattern to be eventually covered through local waste heat sources. The distribution of new housing developments and the retrofitting potential of existing housing has been identified to examine the possibilities of local waste heat re-use.

Key-Words: Smart Cities, renewable energy sources, waste heat potential, waste heat distribution, heating demand distribution, heat supply – demand mapping

1 Introduction

Climate Change and Global Warming is triggered through accelerated greenhouse gas (GHG) emission. Reducing GHG in the atmosphere requires to change the way of energy consumption by reducing energy demand and the change of energy supply towards alternative energy carriers making a shift from fossil fuel supply to renewable energy sources.

To achieve the ambitious climate protection targets, cities need to develop innovative instruments and measures within the energy and building sector. One option to avoid additional greenhouse gas emissions is to re-use waste heat, heat generated in processes by way of fuel combustion or chemical reactions, which is then emitted to the environment. The appropriate waste heat recovery technology must be selected and evaluated from an economic perspective.

Basically, we distinguish four types of waste heat utilization [1]:

- process-internal heat recovery: waste heat used in the various process [2],
- in-house use: waste heat can be used in other processes, for heating etc.
- in-house conversion: waste heat converted into cold or electricity.
- external use: waste heat fed into neighbouring companies, households' heating systems or district heating networks.

Here we concentrate on the external use of remaining waste heat fed into local micro heating networks or into large district heating systems of entire cities. High-grade thermal energy is typically recovered within processes, which are usually not located within urban settlements. However, lower grade-heat emission can be frequently found in production processes as well as in cooling processes in urban areas, which are often emitted to the environment ([3] see Ammar et al., 2011). Such low temperature waste heat sources may serve as heat supply for heating purposes in urban environments by feeding it into municipal district heating networks or to utilize waste heat locally by installing micro grids linked to adjacent building blocks.

1.1 Test Case Vienna

The City of Vienna serves here as a case study area to identify the waste heat recovery potential. Vienna has about 1.8 M inhabitants living in 182.000 buildings, occupying around 1 M flats. In Vienna around 630.000 employees are working in 92.000 companies [4]. According to various urban planning documents another 60.000 flats can be expected to be built within 5 years.

To roughly estimate the heating demand, information about the building specific heating demand – estimated from floor space, building size (amount of 1-2 family houses, and multi-story buildings) and the age structure of the buildings is required. Vienna can supply around 13% of the energy demand from local sources, 87% is based on imports. More than 35 % of the flats are heated through district heating network, around 50% have gas boilers, the rest is heated by oil, a few percent by renewables – heat pumps, solar-thermal heating, wood and pellets combustion and similar [5].

Heat distributed through the Vienna district heating network is provided by several heating plants, the two largest ones are fueled by waste incineration supported by gas, further ones by gas and one by wood-chips – all are using CHP technology for producing power as well as heat - which is a disadvantage in the summer season, were only little heat is used. For several years a district cooling network has been established in Vienna, but until now only a few street blocks (occupied by hospitals and office towers) could be connected. A few micro networks supplying some neighbourhoods have been established

1. Applied data and methods

The study compares the heat supply potential from waste heat with heating demand from housing to be covered by waste heat. As no observation data for waste heat and heating demand is available this data has to be derived from available and spatially explicit proxy data related to heat consumption and heating demand and factors that allows to quantify the relation for estimating waste heat potential and heating demand patterns out of the proxies. Figure 1 gives an overview of the approach.

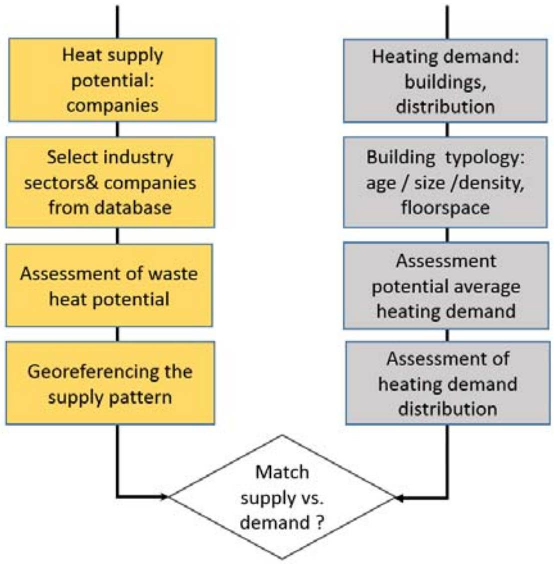

Figure 1: Concept to identify and allocate waste heat potentials, heating demand and related matches

2.1 Approach to estimate the heat consumption

Waste heat has been for several years recognized as a significant source, but not documented and mapped regularly due to missing guidelines for monitoring. Only large combustion-based production sites and power- or heat generation plants are obliged to monitor and report greenhouse gas emission volumes. So usually estimations are required based on proxy data. There are different ways to estimate the waste heat potential. McKenna and Norman (2010) [6] are using emission data as proxy for deriving waste heat potentials. This helps only for large sources with emissions based on combustion.

In urban areas we deal more with smaller industries and to a lesser extent with (smaller) combustion sites, which require other statistical data sources as proxy for waste heat load estimation.

Based on a comprehensive literature review on employee-specific energy characteristics for different industries (energy consumption heat consumption or electricity consumption) the per capita energy / heat consumption for relevant industry sectors was extracted and quantified by identifying the location of industries and services based on a company database with company address, commercial activity codes (NACE-codes, *Nomenclature statistique des activités économiques dans la Communauté européen*ne) and employee and turnover numbers.

NACE Code	Description
	C - Manufacturing
10	Manufacture of food products
11	Manufacture of beverages
16	Manufacture of wood and of products of wood and cork, except furniture
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment
29	Manufacture of motor vehicles
30	Manufacture of other transport equipment
32	Other manufacturing

NACE Code	Description
	G - Wholesale and Retail Trade
45	Wholesale and retail trade and repair of motor vehicles and motorcycles
46	Wholesale trade, except of motor vehicles and motorcycles
47	Retail trade, except of motor vehicles and motorcycles
	H - Transportation and Storage
52	Warehousing and support activities for transportation
	J - Information and Communication
58	Publishing activities
62	Computer programming, consultancy and related activities
63	Information service activities
	Q - Human Health and Social Work Activities
86	Human health activities
87	Residential care activities
	S - Other Service Activities
96	Other personal service activities

Table 1: Selection of industries and services by NACE-Code relevant as potential waste heat sources

Based on a literature review the industries listed in table 1 were selected as intensive energy consumers and thus potential waste heat sources.
The required heat volume and temperature ranges are derived for different productions and services from literature. Table 2 provides the temperature ranges for the most important industrial processes.

Business	Process	Temperature [°C]	Business	Process	Temperature [°C]
Food Industry	Drying	30-90	Chemical Industry	Cooking	95-105
	Washing	40-80		Distill	110-300
	Pasteurizing	80-110		various chemical processes	120-180
	Cooking	95-105	Wood Industry	Drying	50-100
	Sterilizing	140-150		Pressing	125-175
	Heat Treatment	40-60		Steaming	120
	Baking	150-250	Pulp and Paper Industry	Cooking	100
Brewery	Cooking	100		Thickening	130
	Sterilizing	120		Drying	100
Textile Industry	Washing	40-80	Manufacture of motor vehicles	Drying of paint	200
	Bleeching	60-100	Manufacture of machinery	Drying of paint	120
	Coloring	100-160	Foundry	Melting	1000-1600
	Drying	100	Plastics Processing	Processing of various plastics	100-300

Table 2: Industries as potential waste heat source by process and temperature range in Germany (compilation based on [7],[8])

	low-temp. process heat <100°C MWh$_{th}$/(EMP*a)	medium-temp. process heat 100-500°C MWh$_{th}$/(EMP*a)	high-temp. process heat >500°C MWh$_{th}$/(EMP*a)
Bakery			
up to 10 EMP	0,31	5	0
up to 100 EMP	0,48	8,33	0
up to 200 EMP*	0,76	13,24	0
up to 300 EMP*	1,05	18,16	0
up to 400 EMP*	1,33	23,07	0
more than 500 EMP	1,9	32,9	0
Brewery			
up to 10 EMP	51	12	0
up to 100 EMP	79,1	19,4	0
up to 200 EMP*	91,95	22,5	0
more than 500 EMP	104,8	25,6	0
Chemical Factory			
up to 50 EMP	31	48	0
up to 1.000 EMP	48	127	0
more than 1.000 EMP	31	48	127
Printing House			
up to 10 EMP	0	0	0
up to 100 EMP	0	34,5	0
up to 200 EMP*	0	38,6	0
up to 300 EMP*	0	39	0
more than 500 EMP	0	55,2	0

* own calculation, interpolated

	low-temp. process heat <100°C MWh$_{th}$/(EMP*a)	medium-temp. process heat 100-500°C MWh$_{th}$/(EMP*a)	high-temp. process heat >500°C MWh$_{th}$/(EMP*a)
Manufacture of motor vehicles			
up to 1.000 EMP	3	3	5
up to 10.000 EMP	3	3	5
more than 10.000 EMP	3	3	5
Foundry			
up to 25 EMP	0	0	40
up to 100 EMP	0	0	48
more than 500 EMP	0	0	55
Plastics processing			
up to 10 EMP	0	660	0
up to 100 EMP	0	907	0
more than 100 EMP	0	1081	0
Malthouse			
up to 10 EMP	1.030	0	0
up to 100 EMP	1.133	0	0
up to 200 EMP*	1.184,50	0	0
more than 500 EMP	1.236	0	0
Dairy			
up to 10 EMP	41	0	0
up to 100 EMP	50	5	0
up to 200 EMP*	54,7	5,45	0
more than 500 EMP	59,4	5,9	0

Table 3: Heat demand for relevant industries in Vienna by employee for working site size classes (N of employees (=EMP)), (compiled from [8])

The average heat consumption total by employee is the basis to estimate the overall energy and heat demand and thus the waste heat potential. Table 3 provides the heat demand volume in MWh by employee for relevant industries in Vienna distinguished into low, medium and high temperature.

The temperature ranges for industry-related process temperatures are important for estimating waste heat potentials and have been therefore divided into the following temperature level classes:

- Low temperature - NT (35-100°C): is directly usable in low temperature systems (e.g., underfloor heating) or by means of a heat pumps raised to a higher temperature level to enable the feeding into a heat network.
- Medium temperature - MT (100-500°C): can be directly fed into a heating system or used for conversion into electrical energy.
- High temperature - HT (> 500°C) can be directly used for conversion into electrical energy or cooled for feeding into a heat network.

Waste heat below 35°C was not considered as this is no output from main production processes

2.1 Estimation of the waste heat potential

As no empirical data on waste heat volume or share are available, a literature review has been carried out which shows a wide range of waste heat shares.

When defining the temperature level of the available amount of waste heat one must consider that the literature often mentioned heat demand by temperature level and industries does not correspond to the waste heat temperature. A further barrier for estimating waste heat availability is the operating hours of the production process, where no clear assessment could be made about the times of waste heat availability.

Table 4 gives an overview of the waste heat shares by industry sector based on different literature. The applied value is marked with bold letters.

Business	Subcategories	Share Source 1	Share Source 2	Share Used Value	Reference Unit	Source 1	Source 2
Chemistry	-	2-5%	-	3,5%	of total energy consumption	Blesl et al (2011): 29	-
Printing	-	15%	-	15,0%	of total energy consumption	KPC (21012): 34	-
Kitchen	-	6%	25%	15,5%	of total energy consumption	Waldhoff et al (2014): 68	KPC (2012): 34
Plastics Processing	-	3%	-	3%	of total energy consumption	Waldhoff et al (2014): 68	-
Paint Shop	-	25%	30%	27,5%	of total energy consumption	KPC (2012): 34	berechnet aus Emikat und Litzellachner (2009)
Food - Retail	-	-	-	no appraisal possible	-	-	-
Food - Bakery	-	44%	-	44%	of process heat consumption	Gewerbegas (online)	-
Food - Production	Brewery	6%	25%	15,5%	of total energy consumption	Waldhoff et al (2014): 68	KPC (2012): 34
	Butcher	15-20%	-	17,5%	of process heat consumption	Brandstätter (2008): 87f	-
	Malthouse	-	-	value known	-	-	-
	Dairy	6%	25%	15,5%	of total energy consumption	Waldhoff et al (2014): 68	KPC (2012): 34
Other - Metal	Foundry	25% (iron and steel production)	30% (metal production)	27,5%	of total energy consumption	KPC (21012): 34	Waldhoff et al (2014): 68
	Manufacture of fabricated metal products	3%	-	3%	of total energy consumption	Waldhoff et al (2014): 68	-
	Surface Technology	3%	-	3%	of total energy consumption	Waldhoff et al (2014): 68	-
Other - Production	Manufacture of machinery	3%	10%	6,5%	of total energy consumption	Waldhoff et al (2014): 68	KPC (2012): 34
	Manufacture of vehicles	10%	-	10%	of total energy consumption	KPC (21012): 34	-
Laundry	-	5%	-	5,0%	of process heat consumption	Litzellachner (2009): 140	-

Table 4: Indicative waste heat shares by industry sectors [9], [10], [11], [12], [13], [14]

3.2 Approach to estimate the heating demand

Residential heating demand depends mostly on the quality of the construction, which in turn is influenced by various factors: The building shape and compactness define the volume to surface ratio, a higher surface area generally relates to higher heat losses. Detached houses are in this context less energy efficient as row houses or block of flats with the otherwise same properties. Choices of material, structural build-up as well as air-tightness of the building also significantly affect the heating, ventilation and infiltration heat losses. According to available statistical data on building stock characteristics, building type, size and age are the most important attributes to provide rough estimates for the heating demand. The building age indicates the building standards in terms of economics, style and legislation during the time of construction and is thus a crucial indicator for a rough estimation.

Heating demand is calculated from statistical data on housing stock considering floor space, building age and building type. Adjusted to Vienna framework settings, heating demand per m^2 for those building types are taken from the Austrian subset of the TABULA study [15]. The numbers are averages derived from empirical assessments of sample buildings of these age classes.

Heating demand/m^2 floor space distinguished from building age classes and building size classes allow an estimate for the heating demand pattern in the entire city for 250x250m raster cells.

Figure 2 shows the typical heating demand ranges by age class and building type for Austrian and thus Vienna buildings. The annual energy demand is highest for single-family houses built during the 1960ies and before World War II ranging from 160 to 380 kWh/m^2 per year. Low energy buildings erected after World War II show annual heating demands between 35 and 100 kWh/m^2 per year.

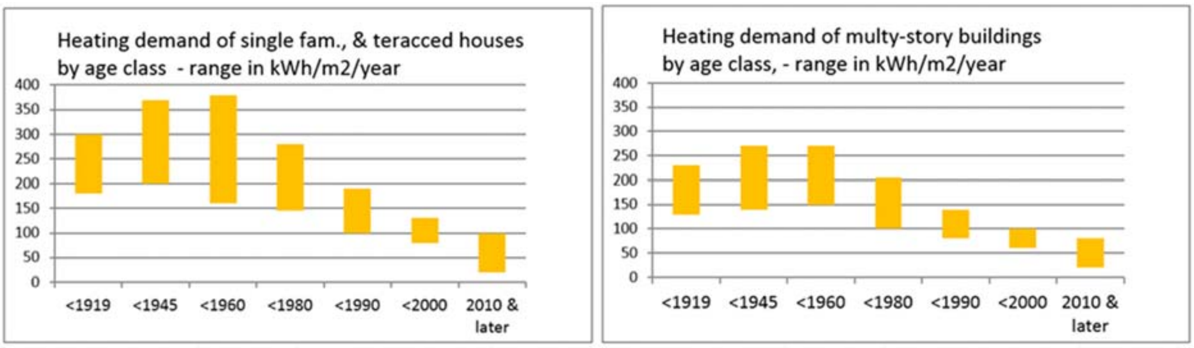

Figure 2: Annual heating demand ranges by age class and building type: single family / terraced houses (left), and multi-story buildings (right) [16]

3 Results

3.1 Waste heat supply potential allocation

The gross domestic energy consumption in Vienna amounted to 40,650 GWh. The final energy consumption is according to the Energy Balance 36,800 GWh, which accounts for more than one-third oil, followed by electric energy with 22% and district heating with 16%. Renewable energy sources are used with 5.5% for energy supply. The conversion to usable end energy in power plants or through the non-energy consumption (for industrial processes) results in 9.5% losses. The greatest loss of 38.5%, however, is to be charged at the end consumers or end users. In 2014, about 53% of energy inputs (gross domestic consumption) have been used as useable energy. Here, the final energy consumption is divided between sectors as follows:
The majority of 38% is recorded in the transport sector, households need 29%, the public and private service providers 24% and the manufacturing sector 8%. The industry sectors with the largest final energy consumption in Vienna are the food and beverage industry, the mechanical engineering industry and chemical and petrochemical industries. In the sector "rest of industries" the construction sector is included with the highest overall consumption of 900 GWh.

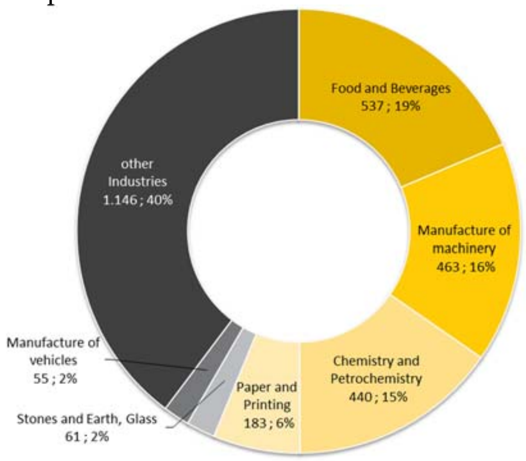

Figure 3: Final energy consumption of Vienna industries in 2014 [GWh, %], based on [17]

To allocate heat consumption to locations the entire heat consumption by industry sector has been divided by employee numbers to get average heat consumption by employee which allows using workplaces by company data and address to distribute the sectoral heat demand total to the various industry sites of the particular sector in Vienna, as basis for waste heat potential estimation. The following diagram depicts energy consumption by employee numbers for the (relevant) industry sectors as well as the energy consumption total of these sectors.

This diagram made clear that “Food Industry” shows the highest absolute final energy consumption, the “per employee” rate is with 64 MWh among the most energy-intensive sectors. The “Chemical and Petrochemical Industry” lies with 70 MWh final energy consumption per employee in the first place of the most energy-intensive industries (with a total of 440 GWh on the 2nd place). “Manufacture of Machinery” and “Paper and Printing” are further production sectors with high absolute energy consumption and rather high energy demand per employee-rates. The other production industries, are less important potential waste heat sources in Vienna.

Besides production industries, services are relevant too – in data centers not the heat consumption is an issue but the required cooling loads which lead to waste heat. (Those numbers have not been extracted by energy consumption by employee ratios but from single company investigations to identify the server floor space as indicator for cooling demand.

About 108.000 work sites have been screened for Vienna and out of those 180 work sites of the relevant sectors have been selected as potential waste heat sources. Figure 4 depicts the share of selected work sites in the different business classes.

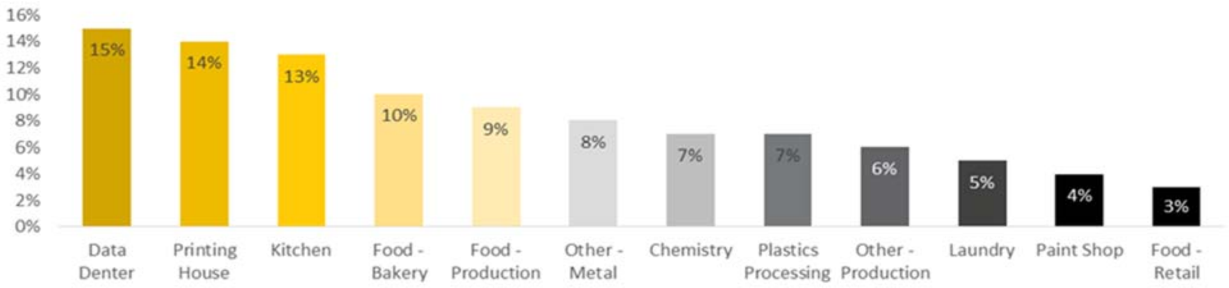

Figure 4: Share of selected work sites in different business classes [in %]

The following table 5 provides the final results for the estimated usable waste heat potential in Vienna:

Business	Subcategory	low temperature (35-100°C) [GWh]	medium temperature (100-500°C) [GWh]	high temperature (>500°C) [GWh]
Chemistry		-	3,7	-
Printing		-	8,2	-
Kitchen		-	57,0	-
Plastics Processing		-	29,0	-
Paint Shop		-	6,7	-
Food - Bakery		0,3	26,5	-
Food - Retail		-	-	-
Food - Production		5,0	6,8	-
	Butcher	-	6,2	-
Data Center		383,3	-	-
Other - Metal		-	1,5	2,8
	Manufacture of fabricated metal products	-	1,3	-
	Surface Technology	-	0,2	-
	Foundry	-	-	2,8
Other - Production		10,8	24,8	-
	Manufacture of machinery	-	4,7	-
	Manufacture of vehicles	4,5	0,1	-
Laundry		3,1	-	-
Result		**402,4**	**164,3**	**2,8**

Table 5: Usable waste heat potential from Vienna industries by sectors

Figure 6 depicts the waste heat potential pattern in Vienna by Temperature range. This map is the basis to relate waste heat supply to residential heating demand.

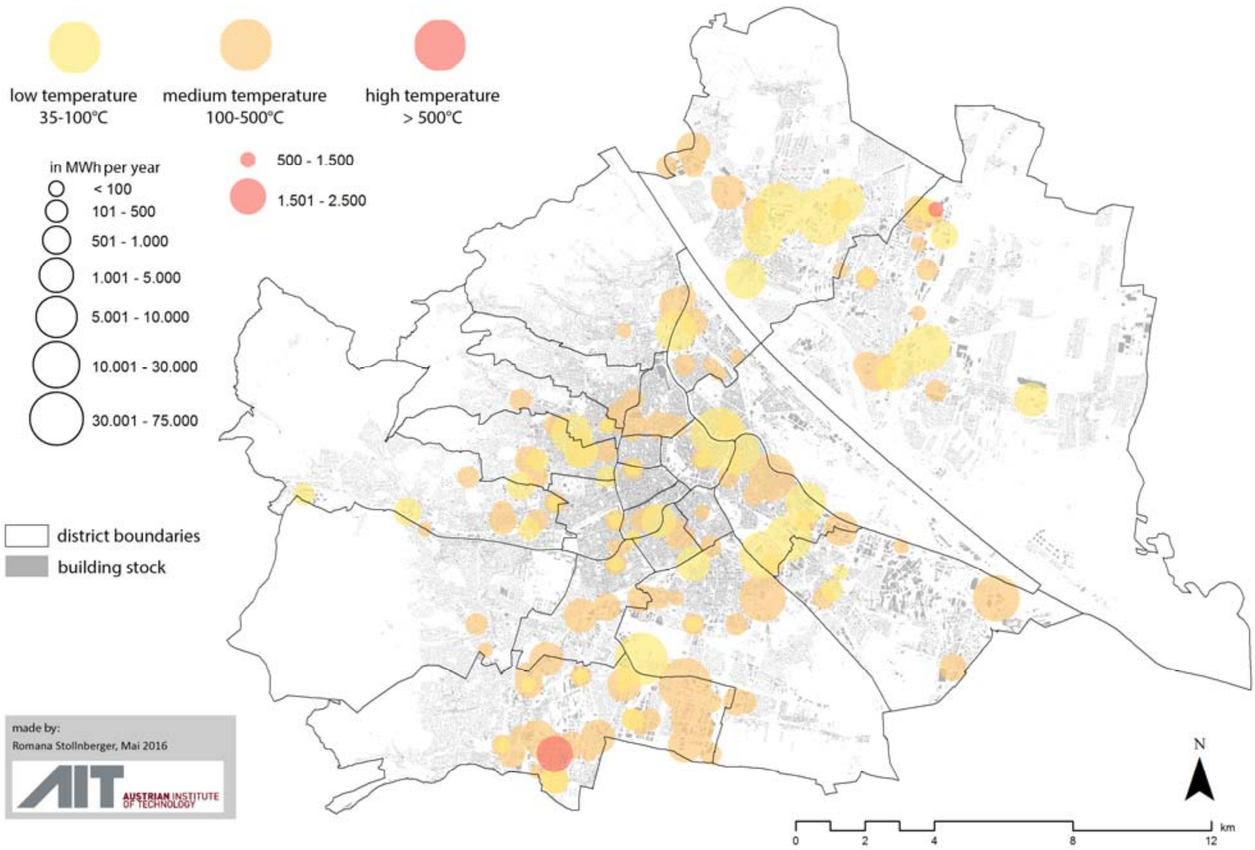

Figure 6: Annual waste heat potential distribution in Vienna from the most relevant industry sectors

3.2 Residential heating demand distribution

The age class distribution of the buildings in Vienna, results in different heating demands patterns According to recent data from the building register Vienna had in 2015 182.620 Buildings (including non-residential buildings.) Figure 7 shows the age class distribution of the building stock in Vienna. The following figure 8 provides a deeper insight with respect to building sizes

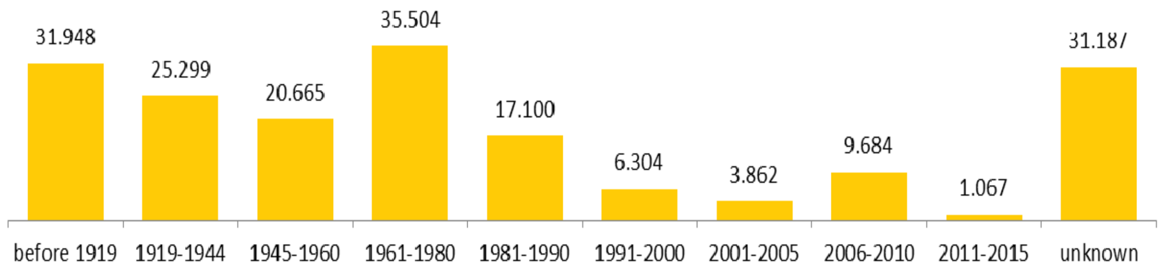

Figure 7: Number of buildings by age class (compiled from Statistik Austria, building register 2013)

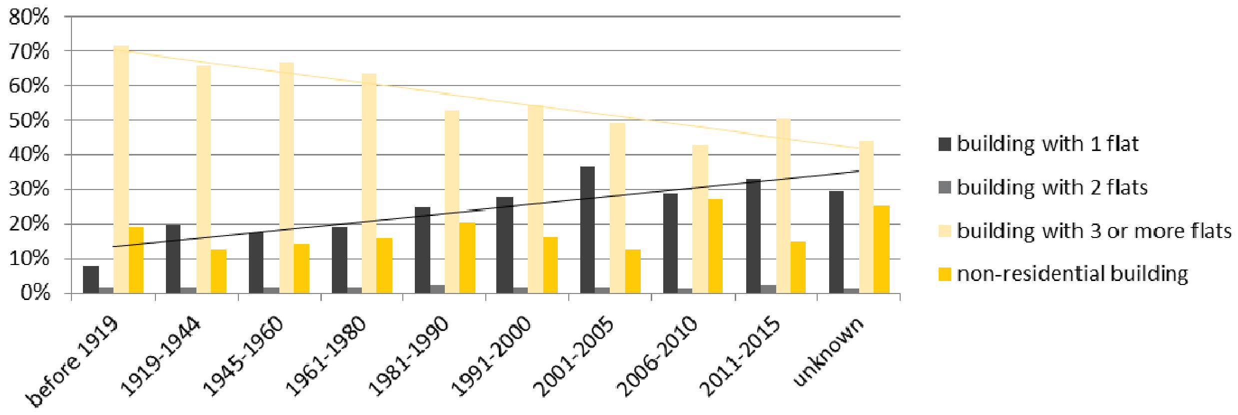

Figure 8: Buildings and apartments by age class (compiled from Statistik Austria, building register 2013)

In figure 8 two contradictory trends are visible. On the one hand, the proportion of buildings is steadily increasing in buildings with one or two apartments until 2006, thereafter it falls or stagnates again. On the other hand, the proportion of buildings with three or more apartments falls constantly until 2011. The increase in single-family houses may be justified in the aforementioned desire for "Green Living". The opposite trend of a decrease in the proportion of multi-family houses can be justified by population growth. From the period 2011-2015, the proportion of multi-story building homes rising due to high demand for housing, which is due to population increase, again. Single family houses are less efficient for connection to a district heating network under certain conditions. The economics of a connection increases with the attainment of high heat density. Therefore the connection of multi-family houses has a higher economic feasibility.

Figure 9 depicts the distribution of residential buildings with one or two versus three or more apartments. Single- or two family buildings are mostly located in the outskirt districts of Vienna, while the larger share of multistory buildings are concentrated in the inner, densely populated areas. The latter location pattern arises from the historically grown structure of the city where in the late 19th to the early 20th century large building developments took place to accommodate the increasing population moving into the growing city.

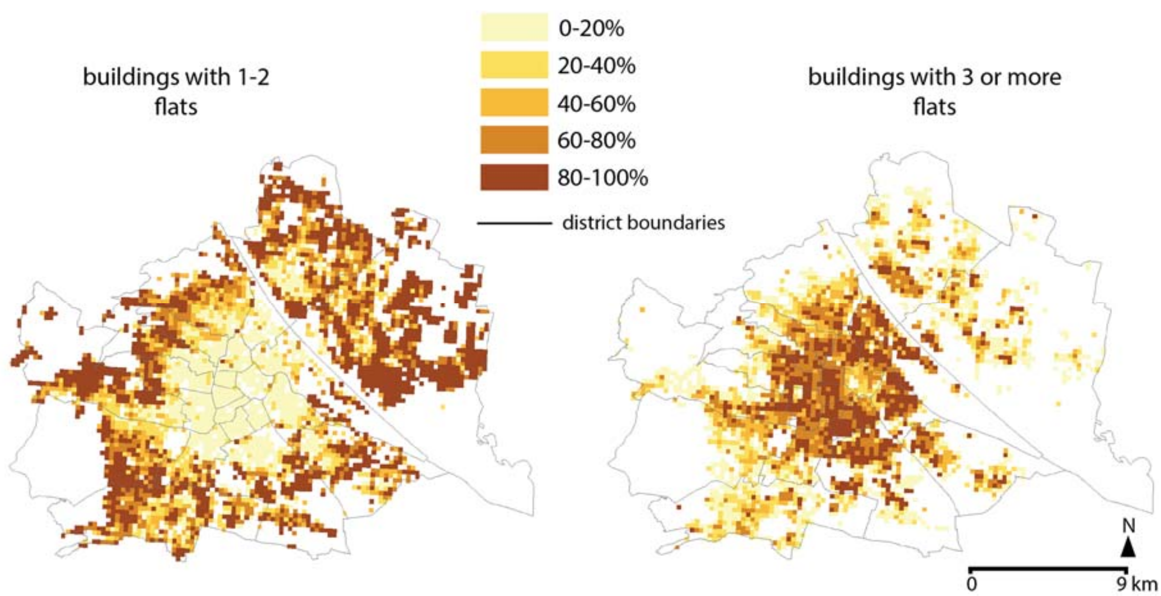

Figure 9: Share of residential buildings with 1-2 apartments (left) and multi-story apartment buildings (right) (Statistik Austria, Buildings Register, 2015)

Figure 10 presents the residential heating demand pattern of Vienna as respondent area for waste heat use reflecting the housing density pattern indicated in figure 9.

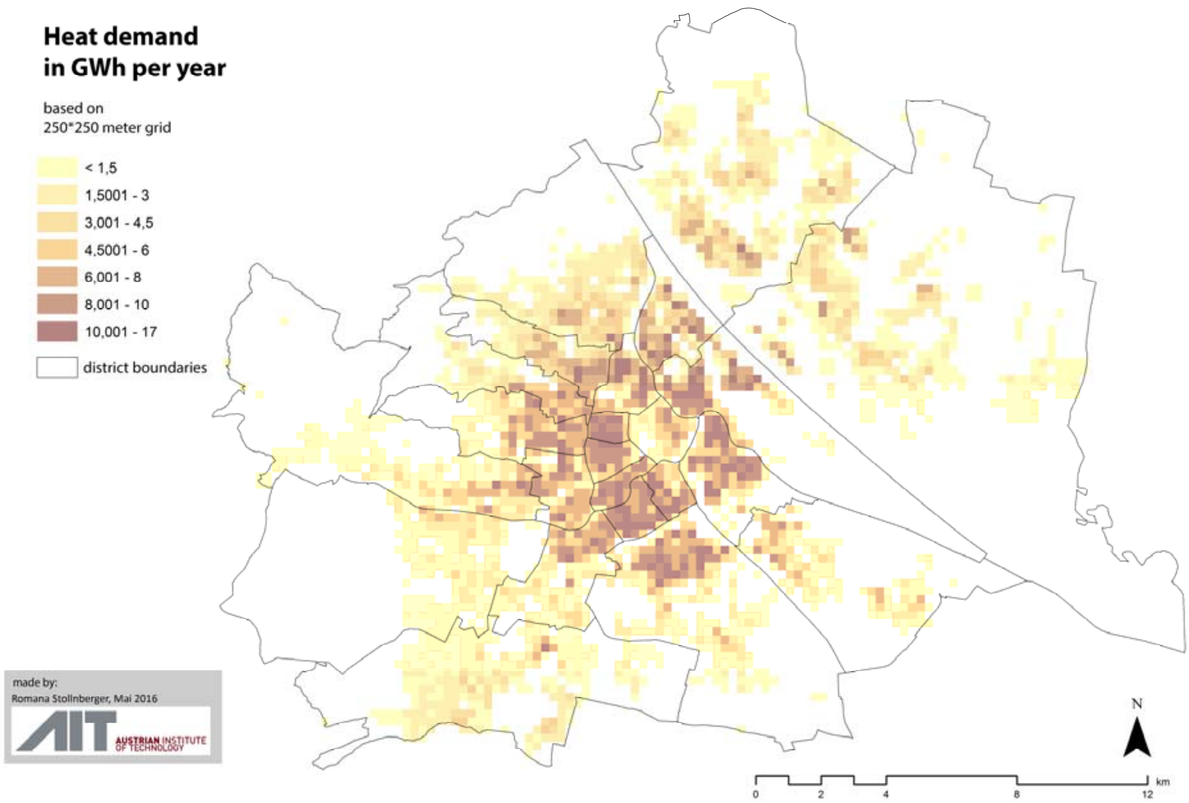

Figure 10: Residential heating demand in Vienna based on building age, type and floor-space

In densely built-up urban areas the residential heating demand is expected to be highest. The following chart shows the distribution of buildings by age class to identify the retrofitting potential. Un-refurbished buildings built between 1919 and 1980 would require most improvement or renewal of the heating systems before being connected to the district heating grid, as the old heating systems usually do not match the specific system requirements. Social housing complexes in the Vienna (outskirt) districts 10, 11, 21, 22 as well as some large social housing blocks in the inner districts show a high potential for future waste heat use.

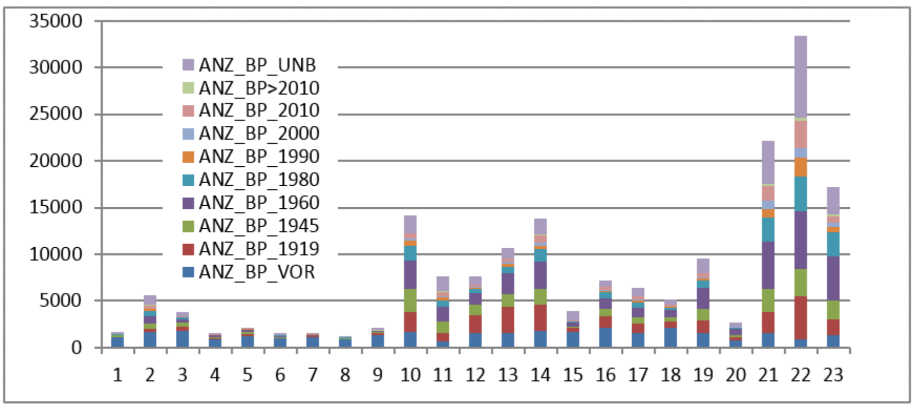

Figure 11: Number of buildings by age class and Vienna district. ([10] based on Statistik Austria, register counts 2014, data from 250x250m statistical raster cells aggregated to the Vienna districts)

New Development areas are further target areas for potential waste heat use – the following map shows those areas with the number of apartments indicating an increasing heating demand in specific locations.

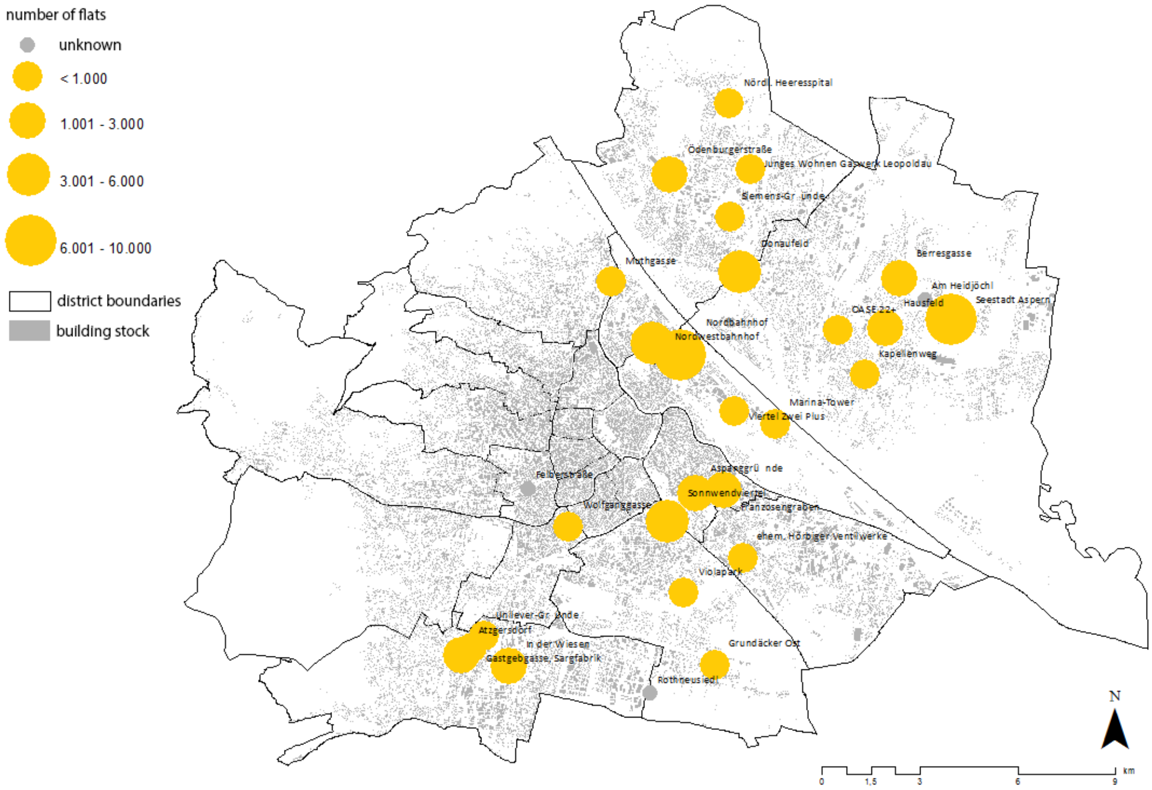

Figure 12: Future urban development sites (own compilation, source: various Vienna Urban Development Strategy documents and press releases on housing development)

The figure 13 presents the final result – matching waste heat potential pattern with residential heating demand.

All areas, which are expected to have additional heating demand, especially those, in which an additional need from 0 to 10 GWh has been identified, have been classified as a priority location. The supply area of local waste heat sources was defined by a buffer of 500m around source.

In the densely built-up inner districts the waste heat supply rate would be comparatively low (marked in red and orange). In areas in the outskirt districts near commerical/industrial sites there is sufficient waste heat available to supply new residential areas which are currently planned or under construction.

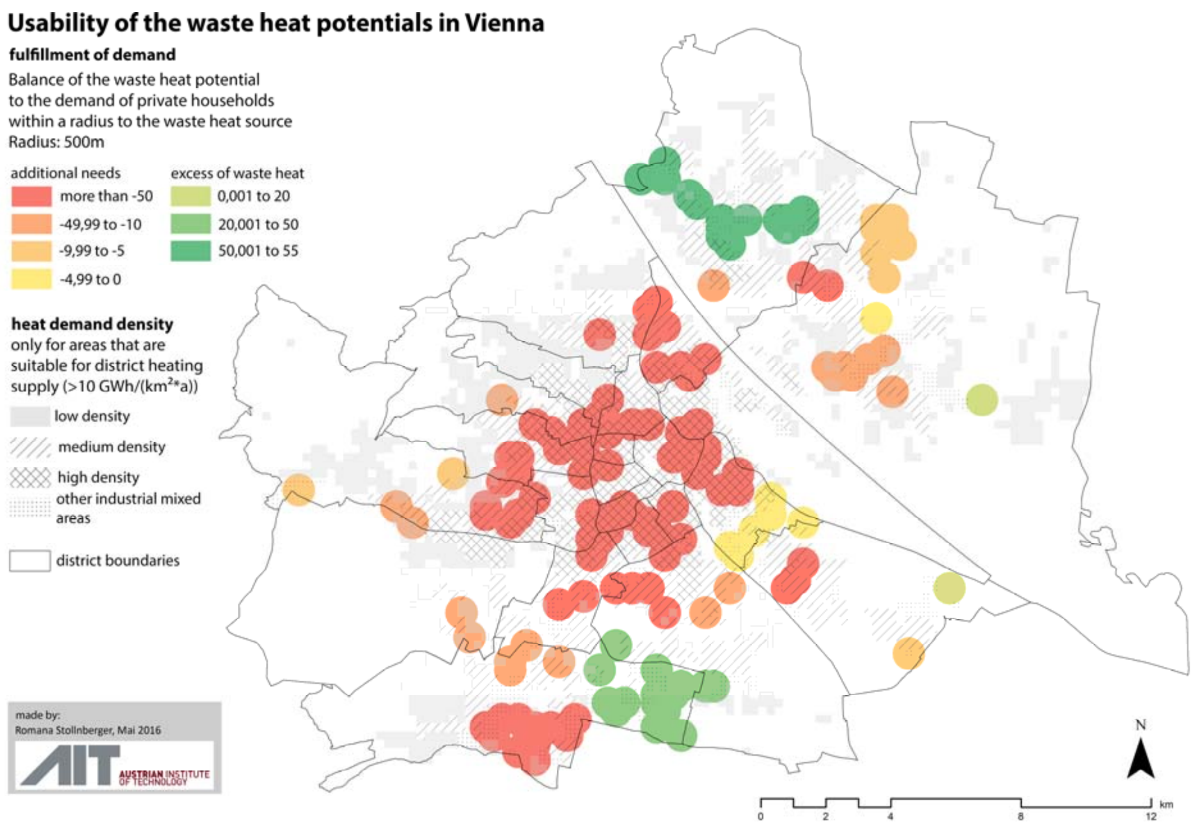

Figure 13: Residential heating demand in Vienna, to be covered by waste heat from commercial sources

4. Discussion

Focusing on cities as a whole has increased in the last years due to the advance of the topics of *smart cities*. By connecting the various sectors in the cities – buildings, energy infrastructure, mobility, and industry – efficiency can increase more substantially rather than focusing on single sectors individually. Since cities play a crucial role in the reduction of greenhouse gas emissions, optimisation processes, which consider the entire city, must be further exploited. The connection of buildings with electrical and thermal grids has for a long period of time been largely one-directional as energy was delivered from the power stations to the consumers. With the increase of decentralized renewable energy production, consumers can also become ‘producers’ and supply surplus energy back to the grid.

The topic of *Smart Grids* is heavily researched, as electricity networks are increasingly reaching their load limits and must further deal with the rise in volatile feed-in of decentralized renewable energy.

On the thermal side however *smart thermal grids* are only slowly on the rise. Small scale feed-in of heat into thermal networks is still relatively rare and district heating utilities are usually providers of energy only. This paper shows on the example of Vienna, the theoretical potential of using waste heat on a larger scale. On the one hand, the heating energy demand is on the rise as the city is growing in population. Thus, even though the building standards in terms of energy efficiency have significantly increased over the last thirty years, the total heating energy demand is still increasing. On the other hand there are a number of industries located in the city, which could offer decentralized heat supply, as waste heat through cascading use of their average energy consumption.

As the paper describes, in theory a matching between industrial waste heat and residential heating demand can be beneficial as there is a significant overlap in terms of location of demand and supply. In practice there are a however still some challenges, which would need to be resolved:

- *Smart thermal grids:* Load shifting of thermal energy requires a smart thermal network including storage solutions, as capacity, pressure and temperature would need to be managed for the network to be able to deal with these variable loads. Cascading use of thermal energy could be exploited if the network is able to balance feed-in and supply.
- *Smart expansion of district-heating networks*: Currently district heating expansion is to some extent blocked, as new buildings require less (thermal) energy due to stricter building regulations. Small passive houses with a heating demand of below 15kWh/m^{2}yr cannot be economically feasible connected to the network, as the yearly heating demand is too low to justify the connection costs. New connections must be planned in cooperation with new large housing developments by including local supply sources to increase efficiency.

Business models: Business models and legal framework conditions would require improvement to allow individuals serving as heat suppliers enabling marketable models where small scale industries can easily sell their energy from waste heat to residential customers.

4. Conclusions and outlook

To implement a "Smart City" requires a combination of factors such as retrofitting of old buildings and the construction of new ones towards an energy efficient housing stock, the use of renewable energies or the development of a multi-modal transport system. In terms of strategic planning, it is necessary to harmonize the goals of energy efficiency and increasing renewable supply among other urban development objectives (inter alia social mix, urban quality).

Waste heat detection and re-use is one key topic with respect to energy planning in line with spatial planning. Waste heat from small scale urban industries still provides a yet unmapped potential to meet the heating energy demands of residential quarters. As cities should be optimised as a whole by exploiting synergies between various urban sectors, the overall energy efficiency could be substantially increased and energy demand from non-renewables sources decreased if connections between the described sectors are undertaken. However, this is a theoretical example which needs to be further reviewed for a practical market application.

Given that there is a substantial rise in the share of renewables from electrical systems such as wind power or photovoltaic and a decline in renewables from thermal systems, waste heat could also be converted into power thus load shifting between buildings can be more easily undertaken with the use of the electrical rather than thermal grids. Further research is required, to investigate the feasibility of small-scale waste heat to be converted and connected to electrical systems with the incurred conversion losses.

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