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Renewable Energy Sources Within Urban Areas – Results From European Case Studies

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ABSTRACT

Urban energy consumption plays an ever increasing role, as more than half of the world´s population already lives in cities. Many municipalities have decided on ambitious goals to become climate neutral within the next decades, however, very limited experience is available of how demand can be significantly reduced on a city scale and what contributions local renewable energy sources can bring to cities. Many cities are starting to analyse their current CO_2 *emission levels, although continuous monitoring is very rarely available.*

In the current paper, two case studies were carried out in Southern Germany, which cover an entire medium sized city (Ludwigsburg) as well as a city quarter in Ostfildern. Although in both cases solar technologies have the highest potential for decentral renewable supply, the most significant contribution to cover the demand is by central power plants based on biomass. In the low energy building quarter of Ostfildern, a biomass cogeneration plant covers 80% of the heating and 50% of the electricity consumption. The remaining electricity consumption could be provided by photovoltaics on easily available roof tops, however, less than 5% of consumption is currently covered by installed PV systems. The studies show that the main challenge is to reduce emissions caused by individuals in their buildings and transport activities and to implement solar technologies in buildings. The municipalities themselves can be front-runners with highly efficient buildings and central renewable plants constructed by their municipal energy supply companies. However, they are directly responsible for less than 5% of all urban emissions and their energy supply companies only provide a limited fraction of households with heat and electricity.

INTRODUCTION

In Europe 72% of the population lives in urban areas and this fraction will increase to 84% by 2050 (United Nations, 2008). Smart cities with low energy consumption, high renewable energy fraction and efficient energy management are

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crucial to achieve the ambitious goals for climate protection. Usually strategic goals related to energy efficiency or renewables are developed and set on a transnational scale, such as the European Union target of 20% CO_2 reduction until 2020.

One major factor for substantial CO_2 reductions is to shift from fossil fuel power generation to renewable energy supply. Large urban renewable power plants are often based on biomass due to a good economic return of investment in countries with a green feed-in tariff (Madlener and Vögtli, 2008).

Typical renewable energy potentials on a municipal level are about 20-30% of the current heating and electricity consumption. For example in Shanghai, on site power generation by all renewable resources possible was calculated as 24% of the total energy requirements (Ren et al, 2010). Solar technologies clearly dominate the renewable supply potential within urban areas, whereas wind energy, biomass and hydropower can provide high renewable fractions outside the cities. For the province of Ontario in Canada, an average rooftop photovoltaic area of 70 m² per capita was calculated with a potential energy supply of the province of 30% (Wiginton et al, 2010). A case study of the city of Chandler in the Metropolitan area of Phoenix, Arizona, considered 30% of the available roof area as suitable for PV production. The roof area was only evaluated for commercial and governmental buildings, as they provide easiest access and large surface areas. In total, the PV production on these buildings could cover 10% of the total electricity demand of all consumers in the area (Jo and Otanica, 2011).

The solar thermal potential for warm water generation and heating support is equally high, however, most buildings are currently supplied by decentral fossil fuel boilers. A study of all 8005 municipalities in Spain showed that 70% of warm water requirements could be covered with an average 17% of the roof area. Only in 5.5% of the municipalities with low solar irradiance there is not enough roof surface area to cover the warm water demand (Izquierdo et al, 2011).

If district heating systems are extended significantly, the solar thermal integration could advance at competitive costs. In Denmark, a potential of up to 4 million square meter of large-scale solar thermal heating systems for district heating was identified, which can produce heat at around 20 per cent of the cost of individual solar heating panels (Lund et al, 2010).

From the high total energy use for transport in cities, usually less than 10% can be covered by biofuels. These figures clearly show that the consumption has to be significantly decreased for cities to become climate neutral, as the renewable potential on a municipality level is not sufficient (Angelis-Dimakis et al, 2011).

Although most European countries have significantly and measurably increased their renewable energy fraction in the electricity and less so in the heat sector, the urban energy demand has not gone down significantly, as building rehabilitation rates are generally very low at about 1% per year.

On a local level municipal governments often set targets for greenhouse gas reductions, mostly without specifying in detail the measures to achieve these targets (Phdungsilp,2010). When monitoring the effective CO_2 emission, very often the targets are not met in practice. There is clearly a lack of practical implementation strategies to reach the targets (Bennet and Newborough, 2001).

In the UK the councils for climate protection (CCP) involved 24 municipalities as pilots in the year 2000, which set targets to reduce the emissions on their area by more than 20% (for example Leicester with 50% by 2025). However, monitoring of progress was nearly impossible and benchmarks were not available. In one of the case studies in Leicester, annual savings of 312 TJ were achieved, which is negligible compared to the city´s total consumption of 28PJ (Fleming and Webber, 2004).

To obtain significant CO_2 reductions in municipalities, energy auditing should be the first step, followed by a potential analysis for renewables, target setting and implementation with monitoring. This process is shown for the case study city Ludwigsburg/Germany followed by monitoring results from a second case study.

URBAN ENERGY EFFICIENCY AND RENEWABLE POTENTIAL STUDY IN LUDWIGSBURG/GERMANY

A first case study within the International Energy Agency task 51 – energy efficient cities - was carried out in 2010 for the medium size town of Ludwigsburg (87000 inhabitants) in Southern Germany. The goal was to analyse, which renewable supply options are best suited for urban areas, what fraction of energy demand can be covered by renewables and which policy strategies have to be adopted to reach the goals set. Ludwigsburg has created an “Energy Development Plan” on the basis of an integrated urban development concept.

Ludwigsburg is member of the Climate Alliance and committed therefore to reduce CO_2 emissions by 10% every five years and to halve per capita emissions by 2030 at the latest (from 1990 baseline). Ludwigsburg developed a municipal energy and climate protection concept, based on its integrated urban development concept. Its implementation by numerous individual projects is currently in progress. The town has a municipal energy supply company Stadtwerke Ludwigsburg-Kornwestheim GmbH (SWLB), which owns 10 cogeneration plants and 12 heating plants, one wood chip heating plant, a gas fuelling station and a waste gas plant.

In November 2009 SWLB opened the largest wood chip fired organic rankine cycle (ORC) cogeneration plant in Baden-Württemberg. With an electric power of 2.1 MW it produces 10 000 MWh electricity and 48 000 MWh heat. This covers 70% of the currently available district heating energy and supplies 3000 households. By using 42 000 tons of regionally produced wood chips annually, the plant saves 18 000 tons of CO_2. Total costs of the plant were 16 Million Euros, which represents the largest investment of SWLB so far.

Energy Auditing and urban energy efficiency

The demand of heat, electric current and mobility was evaluated in the city itself and the region. The total final energy consumption in Ludwigsburg in the year 2007 was 2244 GWh/a, 45% of which in the residential sector followed by transport with 28%, trade and small commerce with 13% and industry with 12%. The public sector contributes only 2% to the total final energy consumption. Per capita the energy consumption is 25700 kWh per annum, of which 11600 kWh/a are directly used with 2300 kWh/a for electricity. The CO_2 emissions are 6.2 tons per capita and year, which is lower than the Baden Württemberg county average of 6.6 tons.

Electricity and heat consumption. The electricity consumption in 2007 was 430 GWh/a. The main consumers are appliances and lighting with 29%, followed by industry with 26.3%, trade/commerce with 22.5 % and electricity for heating and warm water with 14.9%. The heating pumps alone contribute to 3% of the total electricity consumption. The public sector electricity consumption is 2.9%, street lighting 1.4%.

The total heating energy consumption of Ludwigsburg is 906 GWh/a. 80% of the energy is required for space heating, 13% for warm water production and 7 % for industrial process heat.

Transport. 78% of transport related CO_2 emissions are caused by motorised individual transport, followed by lorry traffic with 13.3%. The total energy use is 628 GWh/a. Currently, 7.4% of the total transport energy of 628 GWh is covered by biofuels. Further potentials have not been calculated so far, but will be limited on a local level.

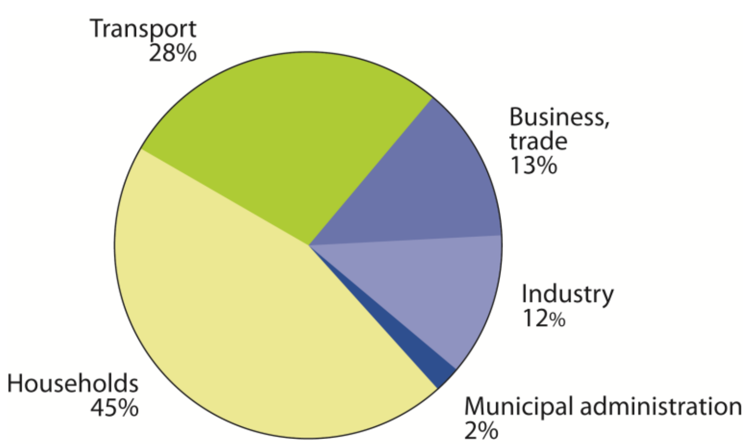

Figure 1: Distribution of CO_2 emissions within the urban area

One of the first conclusions of the urban demand analysis is that consumption directly caused by the public sector is usually very small (less than 5%). The residential sector with its high heating and electricity consumption as well as individual transport causes more than 50% of all emissions (see Figure 1). Although the public sector is supposed to take a leading role in promoting energy efficiency, it can directly influence only a small part of urban emissions. Energy advice services combined with local or central government regulations have to be provided to significantly reduce emissions on an urban level.

Energy potential analysis

The renewable electricity fraction in 2008 was 5.4% or 23.45 GWh/a, the renewable heating supply 0.7% or 6 GWh/a. Since 2009 this renewable energy fraction could be significantly increased by the new biomass ORC power plant. The locally produced renewable electricity fraction is now 7.8% and the renewable heating fraction 6%. This clearly shows that one individual measure of supply side switching can significantly shift the renewable fractions.

In addition imported renewable electricity contributes to another 2.5% of electricity consumption. In the transport sector bioenergy use contributes 7.4% to the total consumption.

The highest renewable electricity potential is provided by photovoltaic energy with 78.8 GWh (of a total consumption of 430 GWh). If regional biomass use is included, biomass could contribute 53.4 GWh and hydro power 27.3 GWh (see Figure 2). Based on today´s consumption, this corresponds to 38% renewable fraction. If regional biomass is excluded, the biomass potential reduces to 5 GWh and the total renewable heat potential to 115 GWh or 27%.

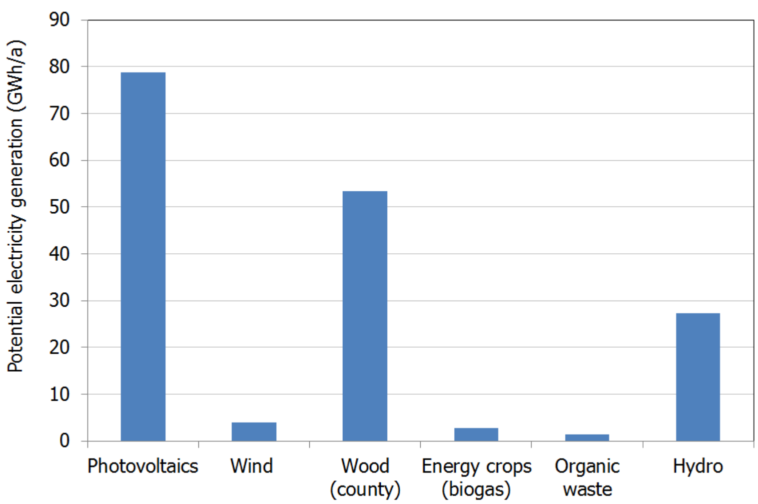

Figure 2: Renewable electricity potential in Ludwigsburg with regional biomass potential.

The current potential of renewable energies for heating is 22.5% of the total consumption of 906 GWh (2007). The highest potential in the urban area is solar thermal energy (about 164 GWh), followed by biomass and geothermal energy (each 16 GWh). If regional biomass is included, the biomass fraction could be increased up to 158 GWh. Also the geothermal potential could be increased to 80 GWh, if 5% of the urban area was usable (instead of 1%). The total renewable heating potential is 410 GWh or 45%. If the consumption is reduced by 20% until 2025 the renewable heating fraction increases to 56.5%.

In conclusion, solar technologies in form of photovoltaics and solar thermal energy prove to have the highest potential for urban integration, however, the contribution to the current total energy consumption even in such a moderately dense city is less than 30%.

An analysis was done, how the end energy consumption will reduce following the increasingly tight energy legislation in Germany (Trend scenario) and including more than 100 individual measures in all sectors (see Figure 3). Following the trend scenario the consumption is calculated to go down by 30% in 2050 with a renewable fraction of 32%, with additional measures by 50% with a renewable fraction of 38%. The remaining CO_2 emissions (30% of today´s values for the best scenario) are mainly used for transport and gas for heating. To become climate neutral, especially the building rehabilitation and transport sector need to be addressed.

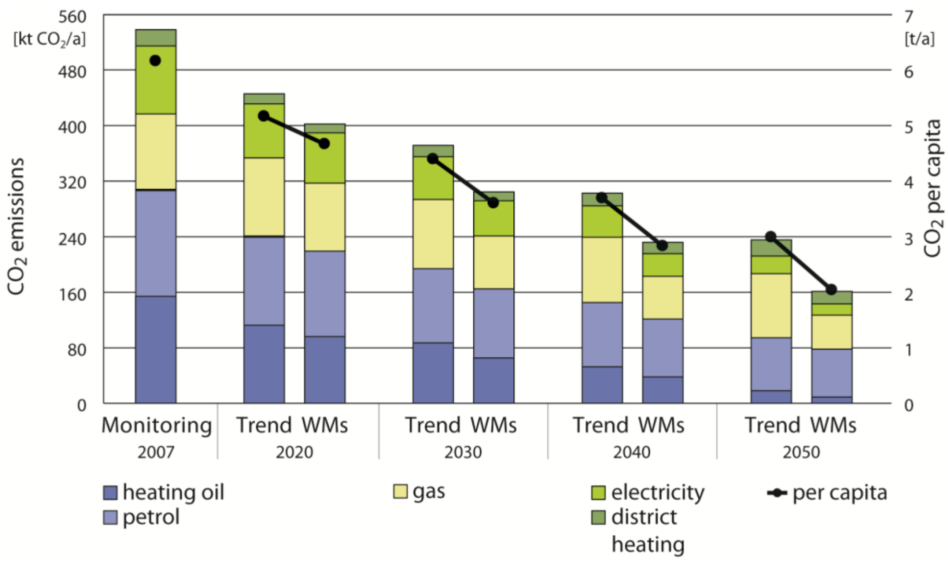

Figure 3: CO_2 reduction following the political trends (Trend) and with special municipal measures (WMs).

BIOMASS ORGANIC RANKING CYCLE POWER PLANTS FOR HIGH RENEWABLE FRACTIONS IN OSTFILDERN/GERMANY

The German case study has been investigated during a European funded demonstration project for six years, so that detailed information about the building energy consumption and the renewable supply systems are available. The case study area analysed is located in the German town of Ostfildern at the southern perimeter of the city of Stuttgart and the neighbourhood investigated is the Scharnhauser Park. The area is a former military ground and has been developed since 1992. The area has 150 hectares and includes public spaces, 90 000 m² of commercial area and several housing types such as multifamily apartment blocks, row houses, public buildings and some single family homes. The project is part of a large European funding initiative named CONCERTO, which supports concepts for city neighbourhoods with high energy efficiency and renewable integration in 58 communities in Europe. The heating and cooling loads as well as the electric energy consumption of these buildings were continuously monitored from 2005 to 2010.

The renewable supply of the city quarter is mainly done by using biomass. Some additional photovoltaic systems were installed, but contribute only small fractions to the total electricity demand. To cover the demand for both heating and electricity, an Organic-Rankine-Cycle (ORC) was chosen, which is the most suitable combined heat and power solution for biomass in the power range of 500 kW to 2000 kW electric output.

RESULTS BUILDING ENERGY EFFICIENCY

The district heating network supplied by the ORC cogeneration plant provides heating for row houses, public buildings and multi-family houses. 16% of all the energy delivered by the cogeneration plant is lost through distribution, 63% of total heating energy is delivered to residential buildings, mainly multi-family buildings and row houses. Other buildings with commercial, educational and administrative functions account for 21% of all the heating energy delivered.

Due to a higher compactness, the measured heating energy consumption of all multi-family houses is in general slightly lower than for the average row houses: between 56 and 68 kWh /(m^2a) for the years 2005 and 2009 for multi-family houses, compared to 62 to 69 kWh /(m^2a) for the row houses. The average electricity consumption per square meter of gross building surface is between 30 and 50 kWh /(m^2a) for most buildings, i.e. higher in terms of primary energy than the heating energy consumption.

RESULTS FROM ENERGY SUPPLY SYSTEMS

PV-generators. At the project site several building integrated PV generators have been implemented. The main building of the biomass power plant has been equipped with a roof system (99 modules /20.8 kW_p) and a facade system containing 70 modules (10 columns 7 rows/ 14.0 kW_p). Table 1 shows the yields of the system at the power plant. The performance ratios as the ratio of measured energy to the energy production at standard test conditions are excellent for both systems.

Table 1: Energy yield and performance ratios of PV systems integrated in power plant building

Year	Facade				Roof				Overall	
	energy yield	specific yield	irradiance	PR	energy yield	specific yield	irradiance	PR	energy yield	PR
[-]	[kWh/a]	[kWh/kWp]	[kWh/m².a]	[%]	[kWh/a]	[kWh/kWp]	[kWh/m².a]	[%]	[kWh/a]	[%]
2006*	8.291	592	854	69%	19.775	951	1.265	75%	28.066	73%
2007	11.435	817	915	89%	23.320	1.122	1.325	85%	34.755	87%
2008	10.205	729	841	87%	21.642	1.041	1.233	84%	31.847	85%
2009	10.969	784	913	86%	21.539	1.036	1.271	82%	32.508	83%
2010	10.099	721	809	89%	20.024	963	1.130	85%	30.123	87%

The yield has also been simulated with the simulation environment language INSEL (Schumacher, 1991). For the roof the simulated average 20 year yield is 1054 kWh/kWp and for the façade system 694 kWh/kWp. The total PV energy production of the two buildings of 35 MWh corresponds to about 0.5% of the quarter's electricity demand.

A photovoltaic potential study was done for the whole district using laser scanning data to determine all suitable roof areas and the simulation tool INSEL for the yield simulations as a function of tilt angle and PV generator orientation. Of the total roof surface area of 98000 m^2 , 54% was considered suitable for PV installation. This area could cover about 45% of the total measured electricity consumption of 10700 MWh (2005 data).

Cogeneration plant. From the total combustion power of 8 MW, the thermal power from biomass into the network is 5.3 MW and electric power delivered to the electric grid is 1 MW. During normal operation, the biomass supplies 80% of the total heating energy demand and about 50% of the total electricity consumption (see Figure 4). Only in 2009 there was a long plant shutdown due to a fire incidence, causing a huge deviation. Since then the plant is running at a reduced maximum power level; the auxiliary natural gas boilers were then started up for meeting the heating network demand.

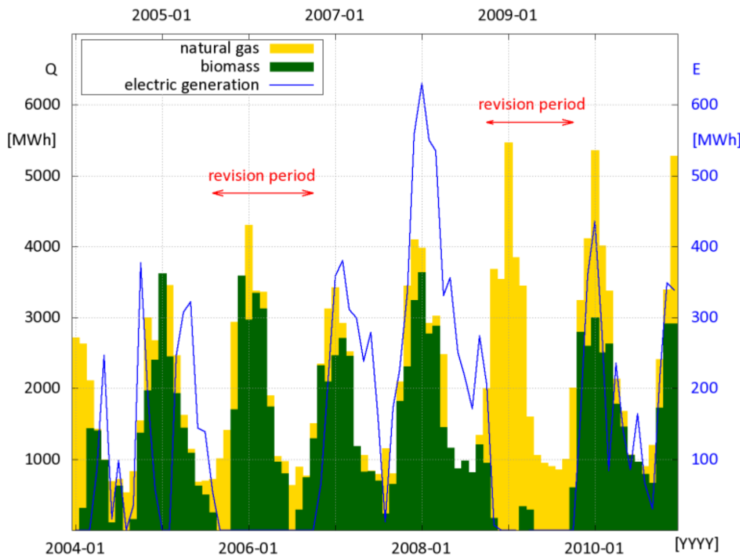

Figure 4: Monthly demand and biomass coverage and electric yield

The electric gross efficiency of the ORC module was expected to be around 16.4%. So far, the mean annual efficiency is 8.9 % (seven years) and maximum values of 15.5% in the upper load range (5.5 MW - 6.3 MW) have been reached. The so far best year was 2008, with an average efficiency of 14.5%. The large number of down-times and the unexpectedly low demand for heating energy forced part-load operation.The overall feed-in tariff according to the German Grid-Access-Act can be up to 0.22 €/kWh, using sustainable fuel and a new technology for conversion. Economic studies assume a project feasibility with a compensation of 0.1 €/kWh to 0.14 €/kWh for a unit size of 1 MW to 1.5 MW (Duvia et al, 2009).

Decentralised absorption cooling. To increase the summer operation time of the biomass cogeneration plant, an absorption chiller has been implemented in one of the office buildings and is fed by the district heating network. The office building with a surface area of 3.280 m² is heated and cooled using the heat from the biomass ORC cogeneration plant. Winter heating energy is supplied to thermally activated ceilings in addition to convectors at the air outlets. Cooling is only provided to the concrete core ceiling. The installed absorption chiller with 105 kW cooling power is directly connected to the district heating network and provides about 2/3 of the total cooling energy demand of the building (180 MWh per year); approximately 50% of the low summer district heating hot water flow is necessary for driving the absorption chiller.

The coefficient of performance of the chiller was between 0.6 and 0.7 during summer months and thus corresponds to expectations. A performance drop during autumn and winter months down to 0.3 and 0.4 can be attributed to frequent switch-on and off under part load conditions and needs to be optimised during the next months. The annual heating energy required for the absorption chiller (371 MWh of heating in 2009) is similar to the winter heating energy demand (320 MWh heat for cooling in 2009) and this helps to increase operation hours of the ORC plant in summer.

CONCLUSIONS

The case study results for a medium size town in Germany (Ludwigsburg) show that solar technologies have the highest potential for local urban energy supply, but are used only marginally today. Individual measures by the municipally owned energy supply companies have a high impact on the overall city CO_2 emissions, for example by the construction of large biomass cogeneration plants.

At current energy consumption levels, all renewables could cover less than 30% of a city´s energy consumption. If regional biomass potentials are included in the energy supply system, about 40% of today´s consumption could be covered. This demonstrates the strong requirement for reducing the energy demand in all sectors. The consumption directly caused by the public sector, however, is usually very small (less than 5%). The residential sector with its high heating and electricity consumption as well as individual transport causes more than 50% of all emissions. Although the public sector will take a leading role in promoting energy efficiency, it can directly influence only a small part of urban emissions.

If the energy analysis is done on a city quarter scale, the renewable fractions can reach higher levels than for an entire city, especially if regional biomass potentials are included and transport energy consumption is not considered. Monitoring results of the city quarter Scharnhauser Park in the German city of Ostfildern showed that low energy building standards can be reached on a city neighbourhood scale. Biomass cogeneration was chosen as the supply technology, which results in a very high renewable energy fraction of 80% of the heat and up to 50% of the electricity consumption. In addition a photovoltaic potential study was carried out for the district. It could be shown that using about half of the available roof surface, another 45% of electricity could be generated locally, which would make the supply of heat and electricity nearly 100% renewable.

ACKNOWLEDGMENTS

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