

# ENERGY SAVING POTENTIAL AND ECONOMICAL ANALYSIS OF SOLAR SYSTEMS IN THE URBAN QUARTER SCHARNHAUSER PARK

A. Tereci<sup>1</sup>, D. Schneider<sup>2</sup>, D. Kesten<sup>3</sup>, A. Strzalka<sup>4</sup> and U. Eicker<sup>5</sup>

Stuttgart University of Applied Sciences, Centre of Applied Research - Sustainable Energy Technology (zafh.net),  
Stuttgart, Germany,

<sup>1</sup> ayseguel.tereci@hft-stuttgart.de

<sup>2</sup> dietrich.schneider@hft-stuttgart.de

<sup>3</sup> dilay.keiten@hft-stuttgart.de

<sup>4</sup> aneta.strzalka@hft-stuttgart.de

<sup>5</sup> ursula.eicker@hft-stuttgart.de

## Abstract

Energy efficiency and application of renewable energy systems have become crucial issues due to the increasing consumption of fossil fuels and their negative environmental impact. Energy efficiency and renewable energy potential studies, which started on the building scale, were extended to the urban scale in last decades in order to have more significant ecological and economical impact. The objective of this paper is to determine the feasibility of implementing solar energy systems at the city quarter "Scharnhauser Park" with 7000 inhabitants, located in Stuttgart-Germany. In this study, the specific site factors and potentials for solar energy applications are determined. Requirements, possible efficiency strategies and aesthetic values are evaluated in this context. The possible applications are evaluated in two phases. In the first part, PV and thermal solar collector installation potential evaluated by using a GIS application with automatic extraction of useful roof areas. In the second part cost reduction potential, energy payback times for different solar applications focusing on innovative solar thermal energy use such as combined thermal cooling and heating are evaluated. According to these studies up to 30% of the primary energy demand of the "Scharnhauser Park" can be covered by saving strategies and the application of solar systems.

## 1. INTRODUCTION

World energy consumption has increased due to the rapid raise of the world population especially in the developing countries. Growing energy demand has resulted in increment in supply and non efficient use could cause serious economical, environmental and social problems. Mankind's total primary energy consumption was 472,274 (Quadrillion (10<sup>15</sup>) Btu) in 2006. At present most of the world's energy supply comes from fossil and nuclear sources but the humanity have restrictions in respect to resource limitation. Energy-related emissions of carbon dioxide and other greenhouse gases cause irreversible global climate change. The average global temperature is expected to rise as much as 6°C in the long term. Decarbonisation of the world energy resources can be a solution partner of the climate change and global warming (EIA2009),(IEO 2008).

Local and regional authorities have a key role to play in the fight against climate change so one of the important subjects is the regional energy autonomy. Energy efficiency and renewable energy potential studies are getting the first place as economically and environmentally at the cities and municipalities level. The development of local clean energy sources will help to balance of payments problems for nations and transmission inefficiencies for regions. The city scale energy management decision and the energy efficient renovation of old buildings improve the security of energy supplies. On this point, sustainable energy sources have become an alternative environmental solution as a result of dependence on fossil fuels and facing with life-threatening problems from these fuels (Scheer, 2007).

Between March 1998 and March 1999, 84 countries including Germany signed the Kyoto Protocol. Since the signing and ratification of the protocol, Germany has committed to reducing its emissions 21% below 1990 levels between 2008 and 2012. In November 2008, a study found that Germany had already reduced its greenhouse gas emissions by 22.4%, which means it already reached its Kyoto Emissions

Commitments. Germany played a key role in installing 64% of the Solar Energy generation capacity in 2003 and plans to generate 20% of its energy with renewable energy sources by 2010 (EC,2007).

Solar power solutions are currently being developed to be cost efficient and widely available. In the four years from end-2004 to end-2008, solar photovoltaic (PV) capacity increased six fold to more than 16 gigawatts (GW) and grid-connected solar PV continued to be the fastest growing power generation technology, with a 70 percent increase in existing capacity to reach 13 GW. During the same period, solar heating capacity doubled to 145 gigawatts-thermal (GWth) and Solar hot water in Germany set record growth in 2008, with over 200,000 systems installed (The REN21,2009). In Germany approximately 872 million tons of the greenhouse gas carbon dioxide was generated in 2005. 77 million tons of generated carbon dioxide was originating from the state of Baden-Württemberg: 31% from households (particularly from heating), 30% from traffic, and 25% from power plants and 14% from industry.

In this study, the potential of solar thermal and the PV application will be calculated for one urban quarter. This quarter, Scharnhäuser Park, is a demonstration site of the EU Concerto Project, Polycity and EU Marie-Curie Project, Citynet. The possible applications are evaluated according to local parameters. The solar potential of the area is calculated for an integrated approach of the solar technology systems. In this context, PV and thermal collector installation are considered.

## 2. FEASIBILITY OF IMPLEMENTING SOLAR ENERGY SYSTEM

The Sun, free-unlimited resource, has always been the main supply of energy to the earth and it is also the most obvious alternative energy source. Solar radiation, the primary source of all energy types, is used as a source of heat for thermal engines, domestic hot water production, and drying process; moreover source of the photoelectric which is used in PV systems for creating the electricity. Besides this artificial usage, the Sun is the main actor of passive design strategies, which maximize the benefits from daylight and thermal effects, and contribute to the energy efficiency of buildings and improve the comfort conditions for the occupants. The solar potential is based on the irradiation intensity and clear sky percentage of the area.

Although the photovoltaic power has been known for more than one hundred fifty years, the efficiency of this technology has begun to improve with studies on generating electricity onboard space vehicles (Kazmerski 1997). Mono-silicon, polycrystalline, thin film, sensitized dye, organic polymer, quantum dot, very high performance PV cells and concentrator PV technologies are using standalone, grid connected or hybrid. According to monthly electricity bill, desire for backup power, visual properties or environmental benefits, the PV systems can be sized or installed to different orientations with special technologies. The almost limitless dimensions and the designs of photovoltaic modules, the selectable module color design and the possibility of partial transparency offer special architectural possibilities. While the PV systems have high cost and require large areas for installations, the use of PV for remote applications is getting importance for independence from grid connections. Besides those off-grid applications, PV grid-connected systems help to reduce ever-increasing utility power costs with sustainable solution (Eicker, 2003). PV modules come in a wide array of configurations and can be installed onto the roofs or facades of buildings. The simplest option for integrated approach is to locate a modular panel to a flat roof, inclined at the optimum angle. The south orientation and the maximum elevation according to the latitude and declination angle give the ideal PV's places in the northern hemisphere. While shading reduces the output of the shaded cells and shaded cells reduces the flow of electric current, other buildings, trees, chimneys, and TV aerials in the vicinity have a big effect on performance of PV. The facade application has generally been done for taller buildings with small roof areas. Feed-in tariffs, net metering, green tags, capital subsidies, grants or rebates for PV financing have been put into effect in the last decades in EU. The legal framework for RESs support in Germany is the German Renewable Energy Sources Act . FITs in 2007 for electricity generated from PV in Germany are between 0.421-0.545FIT (€/kW h) (Campocciaa and Dusoncheta and Telaretia and Zizzo, 2009).

Heating accounts for a significant proportion of the world's total energy demand. Besides buildings, there is considerable heat consumption for industrial processes. Replace the remaining heating and cooling demand by renewable energy sources together with higher energy efficiency strategies must play a major role in reaching the environmental and energetic politics goals (The European Solar Thermal Technology Platform, 2009). Solar thermal systems are based on a simple principle that the sun heats up water in a

dark container and it is commonly used for domestic hot water requirement. Solar systems work very successfully in diffuse light conditions so small scale, low temperature solar thermal systems can supply heat for domestic hot water and space heating. The system consists of collectors, solar circuits, hydraulics, and decentralized or centralized storage tanks. The main thermal collector technologies include swimming pool absorbers, flat plate, vacuum tube and parabolic concentrating collectors. The estimated annual solar thermal energy production from the collector areas in operation depends on the solar radiation available, the outside temperature and the solar thermal technology used.

About the potential of an application of these technologies at urban level, theoretical background and methodologies are described in different papers (Kosuke Kurokawa, 2001), (Wei Tian and Yiping Wang and Jianbo Ren and Li Zhu, 2007), ( Pillai and Banerjee, 2007), (Hernández and Medina and Jurado, 2008). In the last years the geoinformation system is begin to use for the assessment of photovoltaic potential in urban areas using and they includes the calculations based on the 3-D city model and integrated solar radiation tools (S.úri and Hofierka, 2004) (S.úriM and HuldTA, DunlopED, 2005),(Rylatt and Gadsden and Lomas, 2001,2003),(Hofierka and Kaňuk 2009).

These studies cover a depth analysis of local solar radiation and urban geometry. Before the detailed shading analysis of the real solar integrations this study was carried out in order to calculate the roof potential for applications in order to investigate feasibility, economical and environmental effect for two different solar energy applications.

### Case Study Area: Scharnhäuser Park

Scharnhäuser Park is located at the southern border of Stuttgart, Germany. It has been developed after United States army forces left the municipality of Ostfildern on the possession of the field in 1992. The area is 150 hectares and the site offers the opportunities of public spaces, 40,000 m<sup>2</sup> of industrial area and 90,000 m<sup>2</sup> of commercial area and a wide range of housing types; apartments, residential tower blocks, row houses. Scharnhäuser Park is separated to east and west districts by main community highway and railway traffic artery within the green belt. The south area was designed for industrial usage; the commercial buildings like cityhall, school, shops and restaurants have been settled in the north part of the site.



Figure 1. Designed schema and building types of Scharnhäuser Park

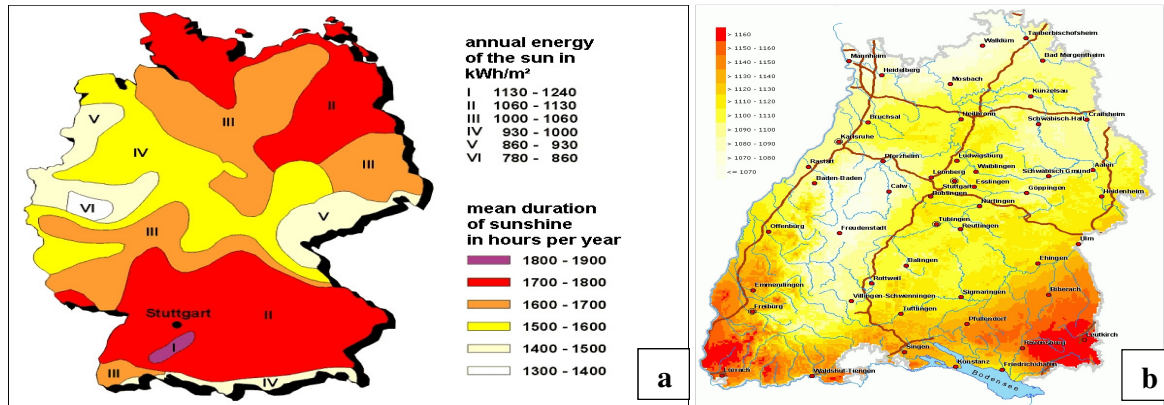


Figure 2a. Average annual duration of sunshine and global radiation in the Federal Republic of Germany, [Source: Renewable Energies in Bavaria, Bayerisches Staatsministerium für Wirtschaft und Verkehr]  
 Figure 2b. Middle annual solar irradiation (kWh / m<sup>2</sup>) in Baden-Württemberg, [Source: Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW)]

The Scharnhäuser Park has 7000 inhabitants and at present 80% of the energy demand is supplied from renewable sources. The supply system is fed by a 6.3 MW<sub>th</sub> wood fired co-generation plant which provides electricity and heating energy to the site. It delivers the hot water to all buildings in Scharnhäuser Park with 13 km long district heating network. Decentralized, district heating connected thermal cooling is realized in the commercial building “Elektor”, where a 130 kW<sub>cool</sub> LiCl-H<sub>2</sub>O absorption cooler is installed.

The general development scheme for Scharnhäuser Park allows the construction of 4-storey buildings and the buildings have to be constructed regarding to German low energy standards or better. In average they have 30% less consumption than the national standard (EnEV 2007). A communal energy management system was set up to optimize supply and demand of the area. Communal buildings like the city hall, youth center, school and sports hall are equipped with a building management system, which monitors the building performance and controls of the heat distribution and the installed ventilation systems.

The main input data used in the planning process for solar energy installations is solar radiation. Figure 2a. represents the distribution of average durations of sunshine and the annual energy supply of the sun on 1 m<sup>2</sup> surfaces in the Germany. The duration of sunshine here varies between 1,300 and 2,000 annual hours, while the global radiation varies between 780 and 1,240 kWh/m<sup>2</sup>. Furthermore, average annual solar irradiation (kWh / m<sup>2</sup>) in Baden-Württemberg is shown in Figure 2b.

According to local regulations, the thermal energy supply contracting should be subscribed between the municipal energy supplier and the inhabitants of Scharnhäuser Park. The municipality does not approve the construction permit without thermal energy supply contract. The inhabitants tied down by this contract to use district heating network for domestic hot water and heating requirements so they have to connect their house to the infrastructure of district heating network. They are not allowed to use solar thermal energy utilization even in the summer period when the great amount of solar energy is available. Although the inhabitants are mandated to use this network, this research aims to evaluate the solar thermal application potentials besides implementation potential of PV for estimating the total solar implementation potential.

### 3. IMPLEMENTATION POTENTIAL OF PV AND SOLAR COLLECTOR WITH GEO-INFORMATION TECHNOLOGIES

Airborne LIDAR (Light Detection and Ranging) data recording is a technique for determination of digital surface models. This system measures the running time of an emitted laser beam to an object on the earth’s surface and back as shown in the Figure 1a. The coordinates of the point on earth, which is hit by the laser beam, is calculated. With this technique a high sampling frequency can be achieved and therefore a high information density. The filtering approaches enable to separate the bare ground from

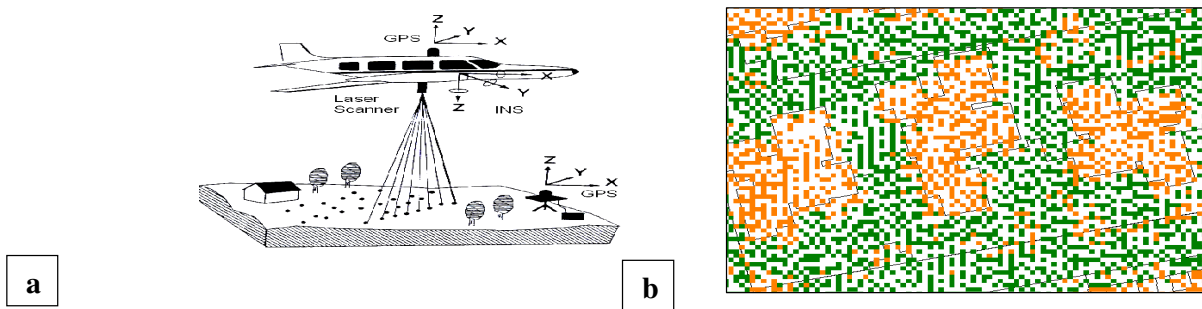


Figure 3a. Principle of airborne laser scanning [Modified from illustration in Flood, 1997]  
 Figure 3b. Laser scanner data of first-pulse (Buildings + Vegetation) and last-pulse (Ground points) measurement.

natural objects, which cover the topographic surface. Large objects like buildings, serve as a special challenge for filtering approaches (Hahn, 2007). In this research an effort has been made to segment and classify the 3D laser points to buildings.

The buildings contours from the ALK map and the vegetation points from laser scanning served as a basis for the analysis of solar roof potential. The first classification of the type of the roofs within the Program GeoMedia Grid gave a result, that the most roofs of Scharnhäuser Park are flat roofs. The Figure 4 shows the whole workflow of the analysis for the flat roofs of the analyzed residential area. The remaining inclined roofs occurred to be not suitable for the PV installation, because of constructional systems like windows, chimneys, etc.. Therefore only the flat roofs have been considered into the calculation of the solar roof potential.

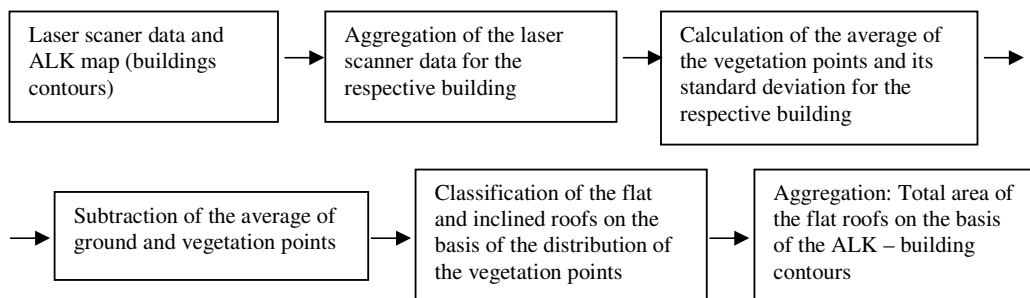


Figure 4. Workflow of the analysis of the flat roofs ASCII format of the laser scanner data

### Calculation of the Photovoltaic Energy Potential

For the reason that flat roofs have been analyzed, the calculation of the size of the roof has been required. This parameter could be evaluated by using the program GeoMedia Professional. The solar energy potential was calculated within the following formula:

$$Y = \eta * F * H * f \quad (1)$$

Where:

- $\eta$ : efficiency factor of the PV-system [-]
- F: suitable roof area [m<sup>2</sup>]
- H: average annual global radiation on the installation location [kWh/m<sup>2</sup>a]
- f: correction factor for the PV-system inclination and exposition [-]

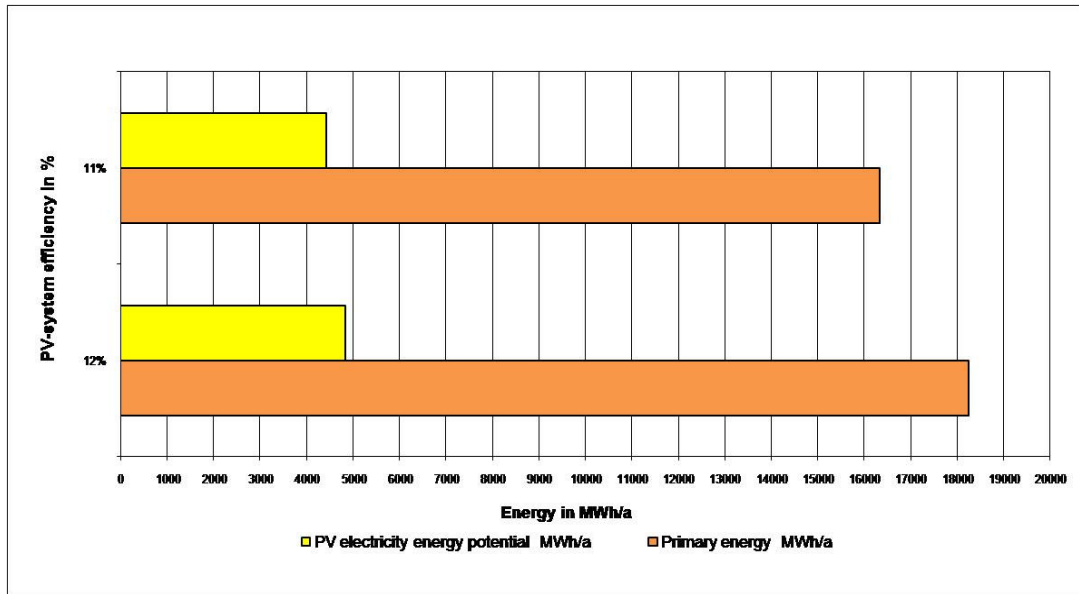


Figure 5. PV potential of Scharnhäuser Park for two different PV-system efficiencies and corresponding primary energy equivalents.

This calculation takes into consideration the following assumptions:

- Efficiency factor of the PV-System: 0,11 and 0,12
- Global radiation: 1299 kWh/m<sup>2</sup>a (for Scharnhäuser Park, with 40° slope of the PV-systems)
- Size of the suitable roof area: 52.000 m<sup>2</sup> (for the year 2005), where only 60% of it could be used by PV-systems, which gives a new suitable roof area of 31.000 m<sup>2</sup>
- Correction factor: 0,9 to 1,15

Corresponding to PV-system efficiencies of 11% and 12% respectively between 4400 MWh/a and 4800 MWh/a of electricity can be delivered to the grid of the Scharnhäuser Park area. The saving potential of primary energy related to the energy conversion factor of 0,38 (present energy mix of Europe) amounts to 16340 MWh/a respectively 18240 MWh/a as shown in Figure 5.

### Calculation of the Solar thermal Energy Potential

The above described solar energy potential calculation method can be applied for thermal solar systems as well. Nevertheless some factors and assumptions have to be adjusted to the specific characteristics of thermal systems.

$$Y = \eta * F * H * f$$

Where:

- $\eta$ : efficiency factor of the solar thermal-system [-]
- F: suitable roof area [m<sup>2</sup>]
- H: average annual global radiation on the installation location [kWh/m<sup>2</sup>a]
- f: correction factor for the thermal-system inclination and exposition [-]

This calculation takes into consideration the following assumptions:

- Efficiency factor of the solar thermal-System: 0,45 and 0,55
- Global radiation: 1299 kWh/m<sup>2</sup>a
- Size of the suitable roof area: 31.000 m<sup>2</sup>
- Correction factor: 0,9 to 1,15

Corresponding to solar thermal-system efficiencies of 45 % and 55 % 17590 MWh/a and 22000 MWh/a respectively of thermal energy can be delivered to the Scharnhäuser Park area.

## System comparison and cost calculations

Neglecting exergetic considerations, from this analysis can be deduced, that in means of primary energy saving and correlated CO<sub>2</sub> and economical saving potential high efficiency solar thermal systems should be preferred for the energy supply of the settlement, in case of an appropriate thermal energy demand. Taking further into consideration that the investment, maintenance and operational costs even for high efficiency solar thermal systems are lower than the costs of PV-systems, the advantages are even better for high efficiency thermal systems. If exergetic considerations play a role in the decision making process, high temperature thermal solar – electricity conversion systems with lower efficiency (18 %) than low temperature systems (45-55%) have to be compared to high efficiency PV-systems (12%). Also in this case, from the primary energetic point of view, the solar thermal-electricity conversion system would be ranked before the high efficiency PV-system. Nevertheless in urban areas, especially in central and northern Europe with low direct solar radiation, usually there is no opportunity for the installation of high temperature solar power plants with collectors on roof tops, meaning that this solar application might not be an alternative for an urban energy planner and therefore is not considered in this work for further energetic and economical analysis.

Comparison between the primary energy saving of PV- systems and solar thermal systems show, that for low efficiency systems (PV 11%) 16340 MWh/a and (thermal 45%) 17590 MWh/a can be saved. This gives a slight advantage to the solar thermal system of 1250 MWh/a.

With an assumed energy price of 0,06 €/kWh<sub>primary</sub> ( Germany, 2009) the difference in financial savings of low efficiency systems (11%<sub>PV</sub>-45%<sub>thermal</sub>) adds up to 75000 €/a.

$$60\text{€/MWh}_{\text{primary}} * 1250 \text{ MWh/a} = 75000 \text{ €/a.}$$

Comparison between the primary energy saving of pv systems and solar thermal systems show, that for high efficiency systems (PV 12%) 18240 MWh/a and (thermal 55%) 22000 MWh/a can be saved, which results in a significant preference for the solar thermal system of 3760 MWh/a. The difference of savings of high efficiency systems (12%<sub>PV</sub>-55%<sub>thermal</sub>) amounts to 225600 €/a.

$$60\text{€/MWh}_{\text{primary}} * 3760 \text{ MWh/a} = 225600 \text{ €/a}$$

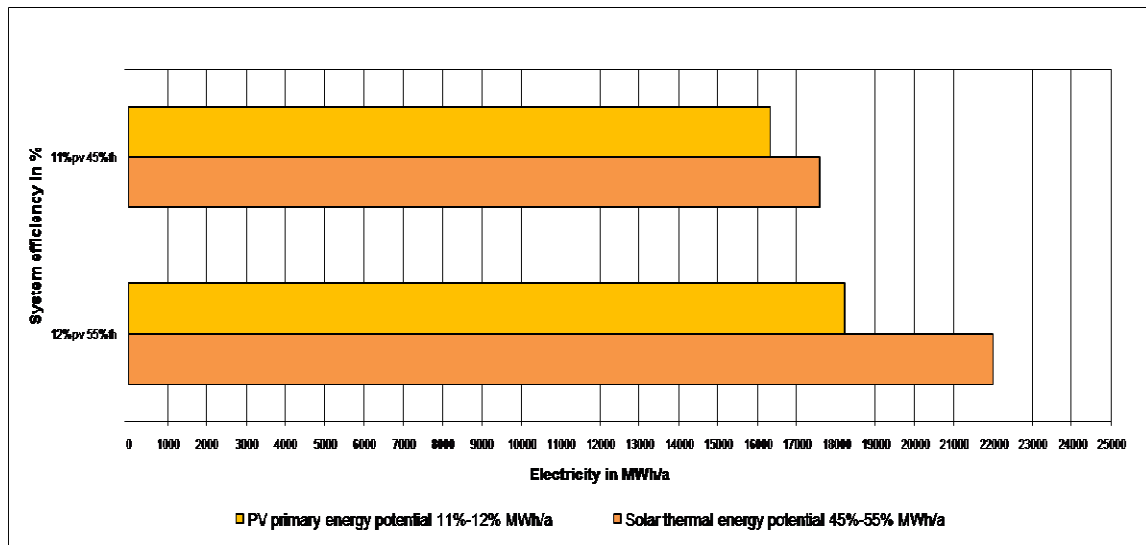


Figure 6. PV-primary energy potential compared to solar thermal energy potential of the roof area of the Scharnhäuser Park settlement.

#### 4. RESULTS

The first general calculation gave, that almost 40 % of the electricity consumption of the analyzed area could be covered by the solar energy from PV-systems as shown in the Figure 7. The results are based on the dataset of the year 2005, because for this year the annual electricity consumption data for all buildings in Scharnhäuser Park are available. Using the data from the analysis of the solar roof potential and the annual electricity consumption data it was possible to calculate the solar fraction by considering the relation between the PV energy production and the measured electricity consumption.

The analysis of the solar roof potential showed a significant photovoltaic potential due to the fact, that 80% of the roofs of the analyzed area are flat roofs. Inclined roofs have not been considered, because of constructional restrictions, such as chimneys, windows, dormer windows. Despite this fact almost half of the total roof area of Scharnhäuser Park (98.000 m<sup>2</sup> for 2005) could be used as PV suitable roof area.

Airborne LIDAR data recording proved to be a helpful tool for the analysis of the solar potential of an urban site. In combination with ALK map data and GIS software a fast and easy overview about the solar potential can be gained. The analysis enables communal energy managers and planners to provide a basis of solar suitable roof surfaces. These surface areas can be supplied with different solar technologies and according to geological position, radiance values, shading situation and solar system efficiencies yearly solar yields from the roof surfaces can be calculated. Broken down to primary energy values solar thermal and PV systems can be compared and according to the demand structure of the site decisions can be made by the energy manager of the quarter. The gained information on yields in relation to investment, operational and maintenance costs can be further processed for economical investigations and comparison.

In this paper the solar potential of the “Scharnhäuser Park”, an example urban site of the EU funded Concerto project POLYCITY and the EU Marie Curie funded project CITYNET, was investigated as a case study. Solar thermal systems with different system efficiencies were compared with PV systems for their solar yield, primary energy equivalents and cost effectiveness. High efficiency solar thermal systems proved to be the best alternative from the energetic and economical point of view. Nevertheless, in the Scharnhäuser Park, where 80% of the thermal demand can be supplied by a Biomass-CHP combined with a district heating network, the remaining thermal demand is low and the solar suitable roof areas will be supplied with grid connected PV-systems.

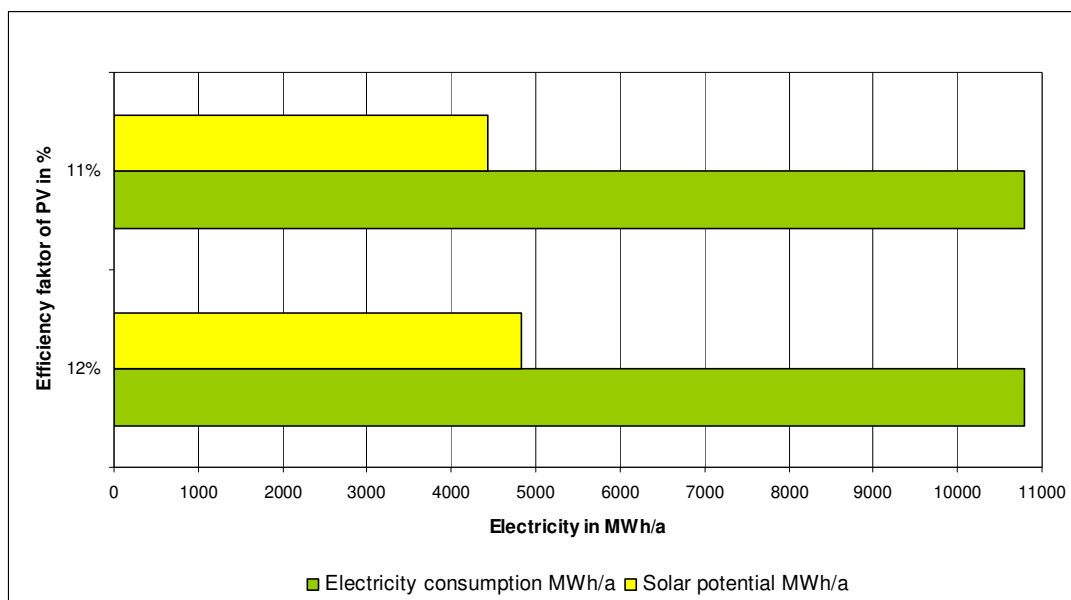


Figure 7. Solar roof potential of Scharnhäuser Park for two different PV-system efficiencies together with the electricity consumption data from 2005.

## 5. ACKNOWLEDGEMENTS

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