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A hierarchical methodology for the mesoscale assessment of building integrated roof solar energy systems

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ABSTRACT

Buildings and other engineered structures that form cities are responsible for a significant portion of the global and local impacts of climate change. Consequently, the installation of building integrated renewable energy sources such as photovoltaic or solar thermal systems on building rooftops is being widely investigated. Although the advantages for individual buildings have been studied, as yet there is little understanding of the potential benefits of urban scale implementation of such systems. Here we report the development of a new methodology for assessing the potential capacity and benefits of installing rooftop photovoltaic systems in an urbanized area. Object oriented image analysis and geographical information systems are combined with remote sensing image data to quantify the rooftop area available for solar energy applications and a renewable energy computer simulation is included to predict the potential benefits of urban scale photovoltaic system implementation. The new methodology predicts energy generation potential that can be utilized to meet Arizona's Renewable Portfolio Standard 2025 renewable energy generation requirements.

1. Introduction

The world is now predominantly urban. More than half of the planet's population live in cities and by the year 2030 this will have climbed to 60% [1]. The expansion of cities resulting from population and economic growth will have a major impact on global and local climates and environmental degradation due to the increased energy consumption and emissions associated with urban growth [2]. The buildings and other engineered structures that form cities are responsible for a significant portion of these negative impacts. The location, material selection and spacing of buildings directly affect micro climates at the neighborhood and street level, while the emissions associated with energy consumed in building operations contribute to global warming [3]. Building integrated renewable energy systems that address issues from meeting the building energy demand by replacing conventional fossil fuel based energy generation have the potential to achieve a significant reduction in the building's overall environmental impact [4,5]. The installation of a building integrated photovoltaic (BIPV) system on a rooftop is widely recommended as a design feature and a sustainable solution that can address both the energy use and environmental impacts of that building. The benefits of BIPV applications for individual buildings are well documented; examples include a 260 m^2 mono-crystalline silicon PV wall on a 30-story building in China [6] and the BIPV system at the University of Nottingham in the UK [7].

Determining the potential application and aggregated benefits of implementing and promoting building integrated renewable energy systems is a growing concern for both power utilities and urban planners. There is a need for improved analysis methods that will provide fast, reliable and accurate results for BIPV applications at the city scale. Here we report the development and validation of a new methodology for assessing the potential capacity and benefits of installing rooftop photovoltaic systems in an urbanized area and provide a real-world case study demonstrating its use.

1.1. Renewable energy and buildings

Buildings are responsible for 72% of the electrical energy used in the US every year [8], most of which is generated from conventional fossil fuel sources. Renewable energy sources such as biofuels, biomass, geothermal, hydroelectric, solar, and wind power provided only 10.51% of domestic U.S. energy production and 10.21% of net U.S. electrical generation for the first nine months of 2009, the latest time-frame for which data has been published [9]. New renewable energy sources such as solar and wind account for

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less than 10% of the total renewable energy produced. A new methodology to assess the potential contribution of new energy sources to diversify and complement the current energy mix focused on fossil-fired energy sources would be a useful tool to encourage the development of this sector of the power generation industry.

As part of the national effort to support the use of renewable energy sources, a renewable portfolio standard (RPS) has been introduced in many states. An RPS is a policy that requires electricity retailers to provide a minimum percentage or quantity of their electricity supplies from renewable energy sources [10]; by the end of 2007, 25 states and the District of Columbia had enacted RPS policies, ranging from 2% of the electricity supply in Iowa to 40% in Maine. Arizona requires 4.5% of the distributed energy generation and an overall 15% of the total electricity sold to come from renewable energy sources by 2025 [11]. Building integrated renewable energy generation is one option that could help meet this distributed generation requirement. Many state governmental entities and energy utilities actively support renewable energy use by offering voluntary incentives and/or by imposing mandatory requirements, for example Arizona Public Service's Renewable Incentive Program and the Green Power Purchasing programs in California [12].

Most US urban regions have significant opportunities to utilize building integrated renewable energy systems due to their intensive built environment density and thus gain substantial benefits from the resulting reduction in conventional energy generation from fossil fuel sources and subsequent indirect benefits such as reduced GHG emissions and energy security. Roofs account for 20–25% of all urban land cover [13], so rooftop photovoltaic systems show great promise for building integrated renewable energy systems. This strategy is supported by many state and federal government organizations. In a recent Executive Order, President Obama cited the example of "reducing energy intensity in governmental buildings and implementing renewable energy generation projects on governmental buildings" as a progressive strategy that could be utilized to reduce fossil fuel use in federal buildings [14].

1.2. Research objective

Although a series of research studies have examined the benefits of rooftop photovoltaic systems for individual buildings, few have examined the potential of urban scale implementations. Izquierdo et al. [15] developed a method for estimating the geographical distribution of the available roof surface area for country-wide application of photovoltaics that integrated building and population density information into a geographical information system, taking into account the effect of shade and facility coefficients, by human inspection of satellite digital imagery for average building typologies to quantify the rooftop area available for PV installation. This approach does not, however, capture the actual

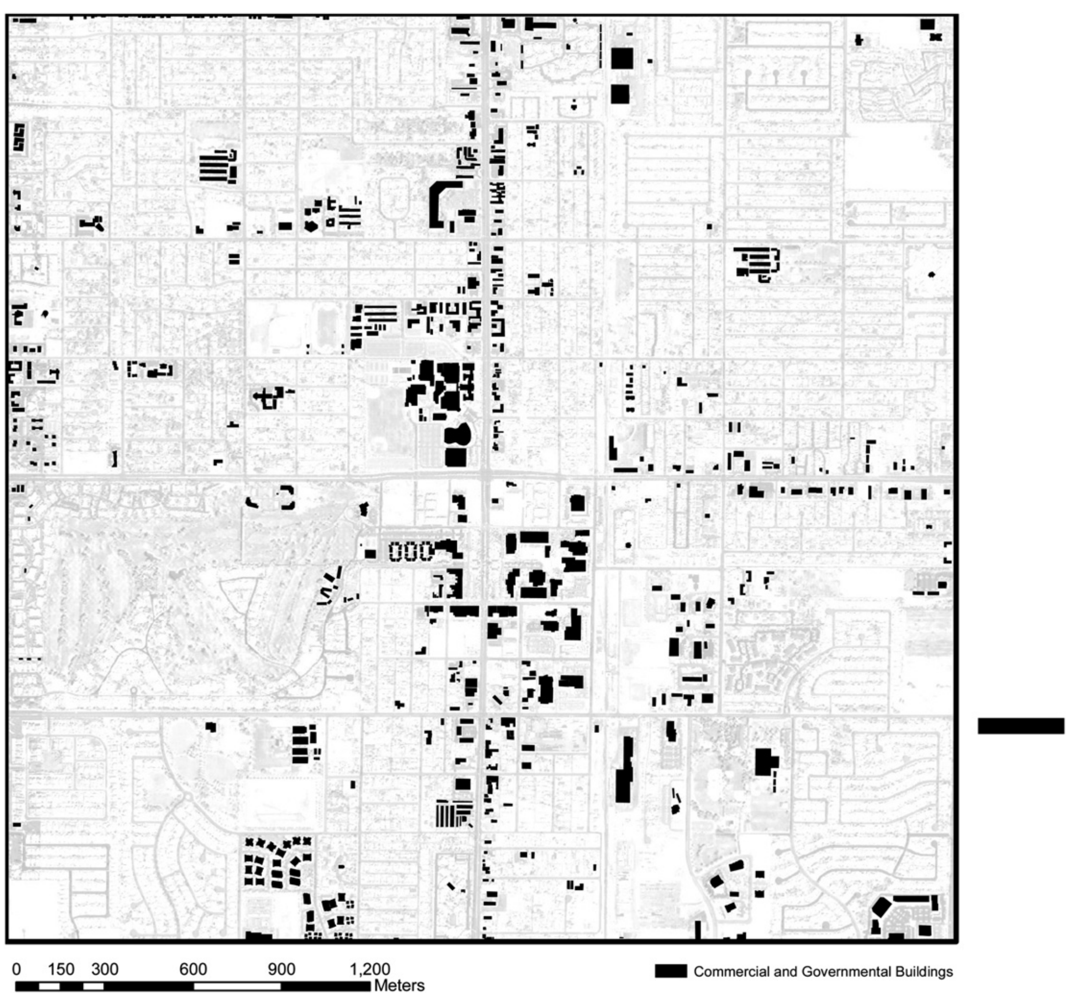

Fig. 1. Commercial and government buildings in the case study area in Chandler, Arizona.