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Boosting solar accessibility and potential of urban districts in the Nordic climate: A case study in Trondheim

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ABSTRACT

The harvesting of solar energy still encounters many barriers in Scandinavia. This paper proposes a set of solar urban planning recommendations to enhance the solar accessibility and potential and thereby increase the energy production from integrated solar active systems installed in a Nordic urban environment. In this work, solar analyses using *DIVA-for-Rhino* were conducted on two typical Norwegian residential housing types, row houses and high-rise apartment blocks, to maximize their solar potential in an isolated scenario and to evaluate the contributions of indirect mutual solar reflections created by the urban surroundings. The effect of the buildings' orientation, the finishing materials of the buildings' façades, and the ground soil on solar potential have been estimated in geometrically simplified urban districts. The numerical outcomes observed were transferred into solar urban planning recommendations that were applied to the task of developing the masterplan of the *Øvre Rotvoll* district, located in Trondheim, Norway. Simulations were run (i) to apply and evaluate the solar urban planning recommendations, (ii) to optimize the district morphology, and (iii) to localize the most suitable surfaces for installing integrated solar active systems. The results demonstrated that by optimizing the urban morphology (e.g., orientation, building height and distance between buildings) and choosing the finishing materials (e.g., colors and materials of the façades and the ground soil) from the early design phases, the solar potential can be increased by up to 25% and the energy yield from the integrated solar active systems can provide up to 55% of the total primary energy demand of an entire urban district, even in a Nordic climate.

1. Introduction

Since 2011, when the European Climate Foundation published the Energy Roadmap 2050 (European Climate Foundation, n.d.), five decarbonization scenarios have been proposed, and the use of renewable energy sources (RES) such as solar energy, is growing rapidly worldwide (Mohajeri et al., 2016). In the last decade, cumulative installed capacity has grown yearly by about 49% for photovoltaic (PV) (International Energy Agency, 2014a) and 12% for solar thermal (International Energy Agency, 2014b, 2014c). However, despite these figures, the exploitation of solar energy is facing barriers, especially in the Scandinavian region where the adoption of solar technologies has been discouraged for a long time due to adverse weather conditions and false beliefs related to the exploitable solar potential at high latitudes as well as logistical impediments and economic feasibility (Skaugen and Romundstad, 2016). The most significant beliefs are related to the low temperature, long hours of darkness and low inclination of solar rays. A research project conducted by the Nordic Energy Research (Boström, 2013) revealed that it is incorrect to presume that a cold climate has a negative effect on solar systems. Moreover, the efficiency of energy systems has been extensively studied in relation to their operating temperature (Dubey et al., 2013), and a low ambient temperature has been shown to help maintain optimum efficiency of solar systems (Jones and Underwood, 2001). Furthermore, this study has demonstrated that two identical sun tracking systems installed in Sweden and in Germany receive almost the same global solar radiation, with a higher total of sun hours in Piteå, Sweden (with about 2000 annual sun hours) than in Freiburg, Germany (with about 1700 annual sun hours) (Boström, 2013; Klitkou and Godoe, 2013). Additionally, the low inclination

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of solar rays at high latitudes can present an opportunity for exploiting solar energy by using vertical harvesting surfaces (Fig. 1). Nevertheless, this creates a significant challenge due to the overshadowing effect caused by the urban surroundings, not only in high-density urban built environments, but also in low- and medium-density ones, typical of the Scandinavian latitudes (Good et al., 2014).

In Norway, the distribution of solar radiation over the year is another relevant challenge to the exploitation of solar energy. The larger proportion of total solar radiation is available during the summer months, while in the winter it is limited, even though the average hourly direct normal radiation on the horizontal plane can, in some winter months such as February (251 W h/m^2), reach almost the same value as in June (253 W h/m^2) (Fig. 2).

Moreover, the sun path changes significantly during the year. For example, the sun height at noon in Trondheim varies from around 50° in the summer to below 4° in the winter. Furthermore, the topography of the Norwegian territory, characterized by deep valleys and an indented shoreline, represents another relevant issue for urban planning. In that regard, an unconventional and ingenious solution was adopted in Rjukan, a town in southern Norway, where an installation of three giant mirrors on the top of a mountain steadily track the movement of the sun across the sky, reflecting the sun's rays and bringing winter sunshine to the market square of the town that before this installation resulted completely affected by the overshadowing effect created by the natural landscape around for the most part of year (Henley, 2013).

2. Background

According to different stakeholders operating in the Norwegian building sector (Åm, 2015), the main legal barriers to the deployment of solar systems are: (i) the lack of regulations and policies; (ii) the lack of education and practical expertise of practitioners and designers; and (iii) the lack of a domestic market. Recent Norwegian energy policies (Olje- og Energiedepartment, 2016) identify wind and hydropower as the most suitable RES for the country and relegate solar energy to a marginal role. With a share of 95.9% of the entire domestic energy demand covered by renewable energy from hydropower (Statistics Norway, 2015), the Norwegian government has not defined any national goals for the exploitation of solar technologies (International Energy Agency, 2015a). The absence of a legislation that regulates the use of solar energy represents the main obstacle to the development of a market for solar technologies in Norway (Multiconsult, 2014).

2.1. Exploitation of solar energy in Norway

Until today, the Norwegian legislation has not addressed any specific provisions related to solar energy nor developed any recommendation for solar accessibility and right to light. However, some exceptions are present from a few municipalities that have regulated the installation of solar systems and the related duties (Trondheim Kommune, 2013). For example, Bergen City Council is considering the possibility of installing solar systems on its own buildings (Bergen Kommune, 2016), and Oslo is the first Norwegian city to promote the rollout of solar energy with a specific municipal funding program, *Oslosola* (Oslo Kommune, 2015b). Furthermore, Oslo municipality promotes the use of solar energy through its Climate and Energy Strategy (Oslo Kommune, 2015a). This strategy sets a minimum goal for solar power installed capacity of 150 MW by 2030 and promotes the development of an action plan for solar energy and solar mapping of the city (Oslo Kommune, 2015a). In addition, there is more data relating to solar installations in Norway that supports the increasing focus on solar energy in the country. Despite the fact that in Norway, the sun provides an amount of energy 1500 times higher than that currently used (Andresen, 2008; Halvorsen et al., 2011; Nord et al., 2016), the energy production from solar systems is still low compared to neighboring countries (Merlet and Thorud, 2015). However, the number of installations has been growing in recent years: the installed capacity of PV has tripled from 2013 to 2014 (Holm, 2014), with total installed capacity reaching 12.8 MW (International Energy Agency, 2015b). During the last decade, a significant interest in solar technology investment has been registered in the country. The number of large-scale solar energy projects has increased, both for private and public buildings (Fig. 3) (Table 1).

The housing market is seeing a significant increase in the deployment of solar systems: in 2015 installations of solar cells increased four-fold compared to 2014 (Holm, 2016). The funding scheme of Enova SF, a public agency owned by the Ministry of

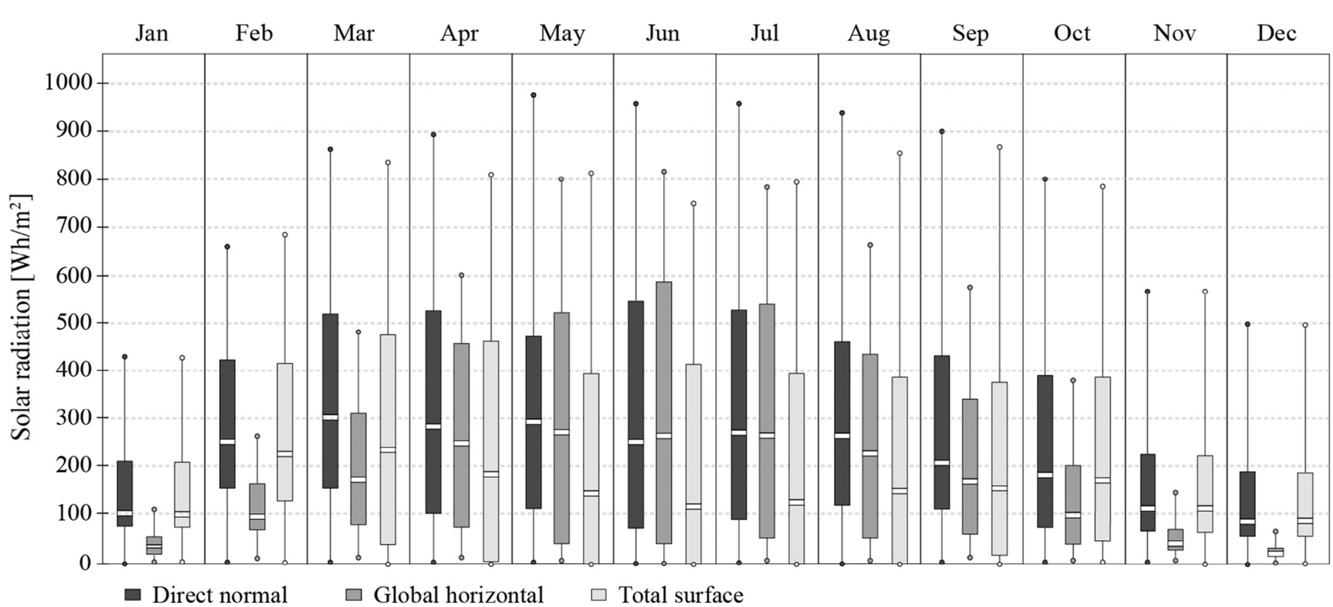

Fig. 1. Monthly distributions of solar radiation incident on a vertical surface considering a ground reflectance of 20% (typical value for the most common ground materials such as grass, asphalt) according to a typical weather dataset for Trondheim.