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PERSPECTIVES FOR INCREASING PHOTOVOLTAIC ELECTRICITY GENERATION IN PIROT, SERBIA

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Abstract

Serbia is gradually aligning its energy policies with EU regulations, particularly in promoting renewable energy (RE). Serbia's National Renewable Energy Action Plan targets further expansion of RE, including photovoltaics (PV). The use of RE sources, especially photovoltaics as the most suitable for the urban conditions of cities, has significant potential, but also numerous challenges. In smaller urban areas, such as Pirot which also has significant solar potential, there are various opportunities for the use of PV installations on the buildings or individual households. The main challenges for small, individual PV projects include financial barriers, regulatory hurdles, and infrastructure limitations. The Serbian government and local administrations are introducing various incentive measures, including feed-in tariffs and subsidies for small-scale PV installations. These available measures may not be sufficient to make small PV installations economically viable without additional support, such as tax credits or low-interest loans. In addition, complex and time-consuming subsidy application processes may discourage smaller investors from participating. Informing citizens with reliable data about the selection and cost-effectiveness of PV installations and the necessary procedures for acquiring prosumer status can be one of the key initiatives for the further expansion of PV installations in Pirot.

Keywords: photovoltaic (PV) installations; electricity generation; urban areas; Pirot.

INTRODUCTION

The expansion of conventional electricity production has led to significant environmental degradation, including high greenhouse gas (GHG) emissions, widespread pollution, and extensive land disruption. In response, countries worldwide are adopting smart grid technologies to reduce emissions, enhance overall consumption efficiency, and increase the integration of renewable energy sources (RESs), while empowering consumers to better manage their energy use. The EU's climate and energy framework sets an ambitious target of reducing GHG emissions by at least 55% compared to 1990 levels and achieving a 32% share of RES in final electricity consumption by 2030 [1]. Over the past 15–20 years, EU scientific institutions, research centers, and industry have collaborated intensively to advance the technologies needed to meet these targets.

Pollution levels per capita in the Western Balkans (WB) are among the highest in Europe [2], posing a significant challenge to Europe's green and sustainable future. Serbia's electricity production and consumption urgently require transformative changes toward decarbonization. Currently, only 34% of Serbia's electricity production is low carbon, with renewable energy sources contributing 29%, primarily from hydropower [3]. This ratio has remained largely stagnant for over a decade, underscoring the need for accelerated action to shift towards cleaner energy sources.

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The pronounced trend of population concentration in cities is leading to a significant increase in electricity demand in urban environments, necessitating the development of local distribution networks as well as transmission networks to ensure sufficient electricity supply. Combined with pollution challenges, this situation makes local energy production within cities one of the most promising solutions. Energy generation from photovoltaic (PV) sources is particularly suitable, as it has zero GHG emissions during operation, produces no noise pollution, and can integrate well into both existing and new buildings.

Comprehensive multi-criteria assessment framework [4] for evaluating urban surfaces, such as rooftops and facades, for solar energy integration, considering a wide range of factors including social, legal, and psychological aspects can contribute to a significant expansion of RESs in urban conditions. It can be valuable insights for urban planners and policymakers to optimize solar energy deployment in cities, promoting sustainable urban development and climate resilience [4].

Microgrids and energy communities' formation in urban areas are particularly important for managing energy demand, reducing grid disruptions and improving energy efficiency [5], [6]. They can power critical infrastructure, improve the use of renewable energy and reduce emissions by optimizing local energy production and consumption.

This paper uses the example of a smaller urban area (the city of Pirot, Serbia) to explore possibilities for utilizing photovoltaic energy sources. It also highlights potential challenges for the broader adoption of renewable energy sources, considering legal regulations, economic constraints, public awareness, and the additional challenge posed by significant air pollution in the city.

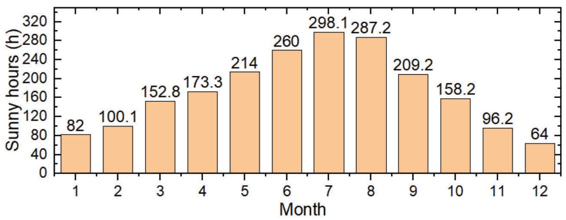
The paper is organized as follows. After the Introduction, the second chapter provides an overview of the solar potential of the Pirot district, Serbia, with a special focus on the urban agglomeration and the challenges for broader PV generation adoption in urban settings. The third chapter describes the existing procedures for attaining prosumer status for individual consumers, as well as the current incentives provided by the local government. The fourth chapter presents an integrated software solution aimed at better informing individual users about the benefits of using solar energy, simplifying the process of selecting a solar installation for individual consumers, and promoting the sustainability of widespread solar installations in urban areas. Finally, there is a conclusion of the paper.

SOLAR POTENTIAL AND CHALLENGES OF WIDE APPLICATION OF PV PANELS

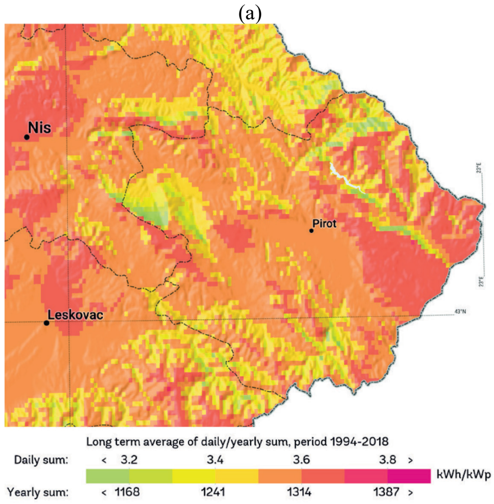
The city of Pirot and the surrounding municipal settlements are located in the southeastern part of Serbia, covering an area of 1,235 km^2. The whole municipality has about 50,000 inhabitants, with about 35,000 inhabitants located in the city [7]. In recent years, the city of Pirot has recognized the need for an energy transition, and considering its geographical location and climate, the use of solar energy has become one of the favored actions toward this goal. Significant efforts are being made to expand photovoltaic installations in local public enterprises and, subsequently, to encourage adoption among individual households through subsidies.

Accurate estimation of solar PV potential is essential for optimizing PV system use, and Geographic Information System (GIS) based methods offer a promising approach. For assessing the PV potential in the municipality of Pirot, PVGIS and SOLARGIS databases were utilized [8]. PVGIS (Photovoltaic Geographical Information System) plays a crucial role in PV implementation by modeling the complex relationships between solar irradiation, climate, atmospheric conditions, the earth's surface, and the specific PV technology employed.

The local climate is moderately continental, with approximately 2,100 hours of sunshine per year. The number of sunshine hours is highest in summer, while it is significantly lower during the winter months. Fig. 1 shows the distribution of sunshine hours by month, based on the multi-year average from measurements conducted between 1991 and 2020, using data from the Republic Hydrometeorological Service of Serbia measuring station located in Dimitrovgrad [8].



(a)



(b)

Fig. 1. *Distribution of sunshine hours by month for Pirot and its surroundings (a); Photovoltaic power potential for the municipality of Pirot (b)*

In the municipality of Pirot global horizontal irradiation has values in the range 3.38 – 3.83 kWh/m^2 (per day) and global tilted irradiation has values in the range 3.69 – 4.43 kWh/m^2 [9]. For the municipality of Pirot optimal PV module tilt angle is in the range 33^o - 35^o, while in the urban area this angle is estimated at 35^o. The applicable PV potential in Pirot city is illustrated in Fig. 1(b) by the estimated power output per month (Photovoltaic Power Output Potential - PVOUT) produced by unit installed capacity (1 kWp) of PV system. This variable, measured in kWh/kWp, quantifies the efficiency of selected PV technology and the influence of the air temperature because the PV conversion efficiency decreases at higher temperatures.

The practical PV power potential is also limited by various operational conditions (MPP tracking, shading, PV panel soiling, grid status, local consumption, etc.) and regulatory land-use constraints. Results in Fig. 2(a) also show the influence of PV panel tilt angle on PVOUT distribution per month. Note that optimally tilted panels (35^o) will have the highest PVOUT over a year, with the maximum amount of energy during the summer months. An installation of 1 kWp of optimally positioned PV panels has an annual production of 1263 kWh, while for PV panels with tilt angles of 65° and 90°, these values are 1138 kWh and 842 kWh, respectively. This data also supports the viable option of installing PV panels on balconies and facades, especially considering the potential shift from a net-metering system to a zero-export system.

Different tilt angles of PV panels will disperse PVOUT in a more suitable way regarding the typical consumption profile per month (Fig. 2b). Based on publicly available data for 2023 from [10], it is known that the total electricity consumption of households delivered by the national DNO in the Republic of Serbia amounted to 13,008 GWh, with the number of delivery points totaling 3,367,109. This effectively gives us an average annual consumption of 3863 kWh per household. Consequently, the average monthly consumption per household in the Republic of Serbia was 322 kWh. Consumption profile by month for a typical household is generated using the data available in references [10] and [11].

Profiling the monthly production of PV systems can be particularly beneficial for consumers who use air conditioning for heating and/or cooling. It's worth noting that Serbia currently uses a net-metering system for prosumer energy consumption and production, with an accounting period ending on April 1. Therefore, increasing the tilt angle beyond the optimum can enhance the specific power output (PVOUT) during the winter months and transitional periods, making it advantageous for consumers who use electricity for heating during these periods of time.

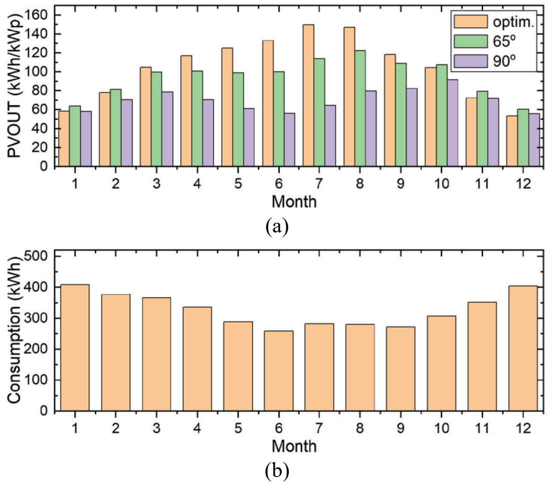


Fig. 2. *PVOUT distribution per month for different tilt angles (a); Typical monthly load profiles (b)*

A significant issue that can greatly reduce electricity production from PV panels is air pollution, which leads to panel soiling [12]. The municipal government recognized this problem and initiated the process of mapping individual combustion plants as dominant sources of air pollution. In Pirot, it is known that individual households not connected to the district heating system predominantly use wood as a heating source (73%), while 8% use pellets, and 17.6% of households use electricity for heating.

Based on data from the IQAir website [13], air pollution in Pirot is significant and ranks it 926th in terms of pollution level in the World. Dominant indicators of air pollution are concentrations of PM2.5, PM5 and PM10, which exceed the World Health Organization's (WHO) and nationally set limits, mostly during the winter months.

REGULATORY FRAMEWORK AND INCENTIVES FOR PROSUMERS

In March 2021, Serbia adopted the Law on the Use of Renewable Energy Sources and the Law on Energy Efficiency and Rational Use of Energy [14]. Through these acts, the Government of the Republic of Serbia aims to encourage new investments in clean energy. For the first time, citizens were offered the opportunity to be both consumers and producers of electricity, known as prosumers. With the introduction of these laws, citizens are now able to:

- generate RES electricity for their own consumption;
- store electricity for their personal needs;
- supply excess generated electricity to the distribution system, or a closed distribution system;
- enjoy additional rights and obligations in accordance with this law and the law governing the energy sector.

According to the Law on the Use of Renewable Energy Sources and Article 58, to obtain prosumer status, the installed capacity of the producer's facility cannot exceed the approved capacity of the end customer's connection and additionally not exceed:

- the equivalent capacity corresponding to a current of 10 A if the connection to the system is not three-phase;
- 10.8 kW if the prosumer falls under the household category;
- 150 kW if the prosumer is not under the household category.

The law simplifies licensing and installation procedures for small-scale renewable energy systems (up to 10.8 kW for households and 50 kW for businesses), encouraging adoption. To obtain prosumer status, the end customer goes through four key steps:

- Step 1 – Construction of a PV production facility in compliance with the project and the regulations of the Distribution System Operator (DSO);
- Step 2 – Adjustment of the metering point in accordance with DSO requirements and installation of a bidirectional electricity meter;
- Step 3 – Conclusion of a Full Supply Agreement with net metering;

▪ Step 4 – Registration in the National Prosumer Register.

The local government of the city of Pirot, recognizing the low energy efficiency of households, has decided to allocate non-refundable funds within the Scaling-Up Residential Clean Energy (SURCE) project [15] to implement energy retrofit measures for households within the local government's jurisdiction. The 2024 public call invites homeowners in the municipality of Pirot to apply for subsidies aimed at improving household energy efficiency. Grants are offered for energy efficiency measures, such as window and door replacement, wall and roof insulation, installation of heating systems that use renewable energy (e.g., biomass boilers, heat pumps), and the addition of PV panels for hot water or electricity. Specifically, for photovoltaic panels, the incentive covers up to 50% of the investment, with a maximum amount of approximately 3,600 EUR. If combined with other energy efficiency measures, this incentive reaches up to 65%, with a maximum amount of approximately 4,700 EUR [16].

AN INTEGRATED SOLUTION FOR ENCOURAGING THE INSTALLATION OF PV PANELS

In Serbia, the lack of reliable information on the cost-effectiveness of investments in photovoltaic panel installations is one of the main obstacles to further expansion of small solar power plants. Additionally, citizens are not systematically and clearly informed about the procedures for installation and obtaining prosumer status. The calculation methods and lack of transparency in connection procedures also discourage existing or new prosumers. These conclusions were confirmed through a survey conducted by the National Alliance for Local Economic Development (NALED) in 2023 among both current and potential prosumers [17]. It was found that about ¾ of existing or prospective prosumers emphasize the issue of insufficient information regarding prosumer rights and obligations.

Within the GovTech program, which aims to encourage the public sector to use innovative technological solutions in service delivery and operations to accelerate digital transformation, the Innovation Fund of the Republic of Serbia is funding a tailored solution for the needs of the municipality of Pirot [18]. The proposed solution aims to address the above-mentioned issues related to informing prosumers, as well as to offer some additional functionalities.

ReEne SoSmart is a Web application designed with a main goal to support the local community in successful transition to alternative energy sources, specifically transition to solar energy. This platform will provide guidance for the citizens who are planning to become prosumers (producer-consumers) of electric energy by installing small-scale capacity photovoltaic systems on their properties.

The ReEne SoSmart Web application is designed as a web mashup portal that will aggregate data from several different sources. The core components of the portal are:

- PV Infrastructure Optimizer - The component helps users to plan optimal layout of PV panels infrastructure. The component will collect basic input form the users (e.g. property location, roof type, roof orientation, planned capacity, PV panels type). Using property location, the component will obtain orto-photo or satellite images of the area from the WebGIS portal. Based on a provided input, obtained images and complex computer vision and AI algorithms, optimizer suggests the PV panels layout, that users can further customize;
- Prosumer Calculator - component that is responsible for running simulation to establish prosumer potential for a specific user, using PV layout generated by optimizer, annual energy consumption, and solar irradiation data (historical and current);

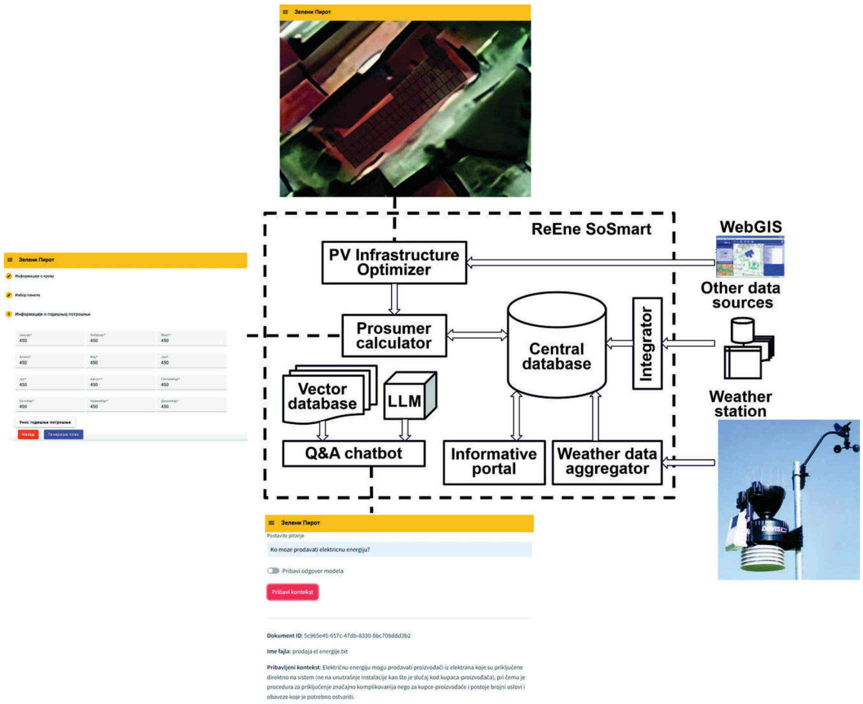


Fig. 3. Architecture of ReEne SoSmart Web application

- Q&A chatbot - designed as a Retrieval-Augmented Generation (RAG) system based on pre-trained large language models (LLM), this component answers common questions regarding prosumer concepts, legislative, PV panel technology, etc.;
- Informative portal - standard Web portal providing informative and educational articles regarding prosumer concepts, legislative, PV panel technology, etc.;
- Weather data aggregator - component responsible for collecting weather data from different sensors to provide real-time solar irradiation data.

Figure 3 shows the high-level architecture of the ReEne SoSmart platform, which aims to become a solution for use in local communities throughout Serbia and the region as part of the information system of smart cities.

The main goal of the proposed platform provides users with easy access to relevant information related to the prosumer concept. This information is available in a traditional way through a portal offering articles related to solar energy, prosumer concepts and related legislation. Additionally, the key element of the system is the Q&A chatbot component, designed to assist users with limited or no professional knowledge by answering their questions in natural language. To train AI models used by Q&A chatbot, great attention was paid to communication with local government experts and collecting examples of the most common questions from potential users.

Another key component is the Prosumer Calculator, which guides potential users with limited or no professional knowledge through estimating the profitability of investing in PV panels infrastructure. This component, with a simple, interactive interface, collects necessary information and provides recommendations for optimal capacity of the infrastructure and the layout of the PV panels. This tool allows potential users to easily evaluate investment feasibility and to identify potential problems caused by limited knowledge and lack of information.

CONCLUSION

The solar potential of the city of Pirot is significant, with an expected annual specific production (PVOUT) of 1263 kWh/kWp for optimally positioned PV panels. Air pollution is the most significant environmental factor affecting the reduction of electricity production from PV sources. The interest of the local city administration in expanding PV installations requires addressing several challenges, the most notable of which relate to insufficient information and the effective use of incentives. As a solution to support broader PV panel installations, a web application has been developed to assist citizens in all stages, from the initial assessment of benefits, through the selection of PV system components, to guidance through administrative procedures and evaluation of overall benefits for the local community.

The Web application ReEne SoSmart utilizes computer vision techniques and AI algorithms, enabling the identification of suitable roof surfaces for PV panel installation. A Q&A chatbot, designed as a Retrieval-Augmented Generation (RAG) system based on a pre-trained LLM, allows for two-way interaction with citizens, providing users with reliable information. The authors of this web application aim to integrate it into a comprehensive smart city information system solution, contributing to widespread PV panel installations, optimizing costs for users and the local municipal government, and benefiting the electricity distribution network.

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