The reduction of greenhouse gas emissions and the development of Renewable Energy Sources (RES) are critical for addressing the challenges posed by climate change. The integration of Distributed Generation (DG) resources and the rising of Energy Communities offer innovative models to optimize energy flows and empower consumers in the transition towards a more sustainable energy system.

This doctoral thesis introduces a novel distributed infrastructure that combines Geographic Information Systems (GIS) procedures with models and simulation techniques to assess the potential of photovoltaic (PV) systems and estimate energy generation and consumption profiles at a high spatio-temporal resolution. The proposed geospatial tool employs an open-source GIS framework to generate synthetic representations of Urban Energy Systems (UES) and simulate energy flows within them. By considering surrounding conditions, real availability of Renewable Energy Sources (RES), and environmental constraints, the infrastructure identifies suitable areas for PV exploitation. The infrastructure evaluates the electricity production from distributed PV systems integrated into building rooftops and the electricity demand of buildings within a specific area. Additionally, it includes a methodology to generate the electricity grid network and simulate energy flows within it.

The flexible nature of the platform enables its application to different areas with varying boundaries, ranging from conventional political boundaries to infrastructure-related boundaries such as electricity substations and distribution grids. The simulation environment facilitates the exploration of a wide range of scenarios, enabling users to define the desired spatial and temporal resolution, thereby providing the necessary flexibility to tailor the analysis to specific needs. This allows for conducting simulations with different resolutions, each serving a distinct purpose and producing different outcomes. For example, a higher spatial resolution enables a detailed assessment of energy profiles and environmental indicators at the level of individual buildings or specific areas within the city. Conversely, a lower spatial resolution offers a holistic view of the entire urban energy system. The platform supports the use of simulated synthetic structures or the integration of actual infrastructure if available.

The proposed methodology is tested and validated in the Municipality of Turin, Italy. For the entire municipality, it realistically estimates the electricity consumption from both the residential sector (simulating a realistic synthetic population) and the tertiary sector (integrating normalized commercial profiles with PAES integral data). Additionally, it simulates the electrical energy that can be generated by installing PV systems on building rooftops. Three different scenarios are analyzed: i) considering only residential demand and rooftops of residential buildings; ii) considering only residential demand and all the available rooftops, including both residential and tertiary buildings; iii) considering the electrical consumption of residential and tertiary sectors and all available rooftops.

The proposed methodology not only provides detailed energy and power profiles at a high spatio-temporal resolution but also enables the determination of various energy indicators. These indicators include the Self Consumption Ratio (SCR) and Self Sufficiency Ratio (SSR), which assess the proportion of generated energy consumed on-site and the system’s ability to meet its energy needs from generated energy, respectively. Additionally, the platform allows for estimating the avoided CO_2 emissions resulting from the deployment of the distributed PV system. These results provide valuable insights into the potential impacts of distributed PV systems on a specific area. Moreover, the platform facilitates the evaluation of potential impacts on the grid infrastructure, identifying critical points that require further analysis and prospective future studies. By simulating power flows in the synthetic grid network, the platform enables the identification of potential bottlenecks and areas susceptible to overvoltage or line congestion. This information supports decision-making regarding infrastructure upgrades, load management strategies, and the implementation of electricity storage systems to enhance the resilience and efficiency of the energy system. The high spatio-temporal resolution allows for accurate estimation of energy profiles and environmental indicators, providing concrete recommendations for the integration of RES and flexibilization technologies in Energy Communities and future smart cities.