Site Evaluation and Data Modeling for Renewable Energy Integration: A Case Study in Seville, Spain

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Abstract: With a focus to automation and optimization, this paper offers a methodical approach to site inspection and data modeling in renewable energy projects. Using solar photovoltaic (PV) panels, an air-source heat pump (ASHP), and battery storage, our team applied this approach to a case study of a residential building in Seville, Spain, obtaining a zero-emission energy system. The approach consists of a thorough investigation of renewable energy sources, including solar, wind, biomass, geothermal energy, and heat pumps, and then a thorough evaluation procedure to find the most appropriate energy solutions for buildings. Our results show how well photovoltaic panels combined with heat pumps reduce energy demand while nevertheless guaranteeing sustainability by means of a battery storage system for ongoing operation.

Key-Words: Renewable energy; solar PV; heat pumps; site evaluation; energy modeling; automation; Seville case study; zero-emission buildings

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1 Introduction

The transition to renewable energy sources is critical to addressing climate change and reducing the dependence on fossil fuels. Renewable energy systems, such as solar, wind, geothermal, and biomass, play a pivotal role in sustainable energy strategies. This paper outlines the decision-making process for "Site Evaluation and Data Modelling Preparation" with a focus on automation. The publication includes a step-by-step guide for evaluating areas of potential renewable energy, considering factors such as shading from nearby buildings and availability of space and regional regulations. The method was applied to the specific case of Seville, using the prepared documents and consultation with regional officials. The paper is structured as follows. The Introduction explains the decision-making process for "Facility Assessment and Data Modelling Preparation," emphasizing the importance of automation. This includes factors such as obscuration from adjacent buildings. Space constraints and other things that need to be included in the automation process. The next chapter is divided into four subsections on renewable energy sources and their integration. The first subsection covers various renewable energy sources. The second subsection discusses how to integrate renewable energy sources into buildings and infrastructures, including architectural considerations, system integration, and challenges that may arise. The third subsection describes the site evaluation process in detail, outlining necessary steps such as data collection, preliminary screening, detailed analysis, regulatory considerations, financial and technical feasibility assessments, and the use of automation tools. The final subsection presents a step-by-step methodology for site evaluation and data modeling, detailing the specific tools and software used at each stage to ensure a systematic and replicable process. The Seville Case Study section applies the proposed methodology to a specific case in Seville. This section details how the process was implemented, considering the provided documents and regional consultations. It highlights the absence of urban planning restrictions for the implementation of solar thermal, photovoltaic, or geothermal energy systems in Seville. Finally, the Conclusions summarize the findings and effectiveness of the

proposed methodology, reflecting on the Seville case study and its implications for future tasks.
This approach was applied to a real-world case study in Seville, Spain, to achieve a zero-emission residential building.

2 Theoretical Background

Renewable energy sources are essential in addressing the global energy challenges of the 21st century, offering sustainable alternatives to fossil fuels and mitigating the adverse effects of climate change. Unlike finite fossil fuels, renewable energy sources are derived from natural processes that are replenished continuously, ensuring a sustainable supply of energy. Primary renewable energy sources include solar, wind, biomass, heat pumps, and geothermal energy, each harnessing natural elements in innovative ways to generate electricity, provide heating, and fuel various industrial processes. Solar energy captures sunlight using photovoltaic cells or solar thermal systems, which convert it directly into electricity or heat. Wind energy utilizes the kinetic energy of wind through turbines to produce electricity, capitalizing on the natural and abundant wind patterns across the globe. Biomass energy leverages organic materials, such as plant and animal waste, to generate power and produce biofuels, offering a way to recycle waste and reduce landfill use. Heat pumps efficiently transfer heat from natural sources such as air, ground, or water to provide heating and cooling for residential and commercial buildings. Geothermal energy taps into the Earth's internal heat, accessing hot water and steam reservoirs beneath the surface to generate electricity and provide direct heating. These renewable energy sources are integral to achieving energy independence, enhancing energy security, and reducing greenhouse gas emissions. Through their reduction of pollution and preservation of natural resources, they provide major environmental benefits. Furthermore, the broad acceptance of renewable energy technology stimulates technological innovation and resilience as well as economic development, resulting in new businesses and employment possibilities. The shift to renewable energy does not, however, present without difficulties. It calls for strong policy frameworks to encourage adoption and guarantee fair access, [1], technology developments to increase efficiency and storage, and significant infrastructural investment to boost Certain renewable energy sources, such solar and wind power, have intermittent character that calls for the development of advanced grid management and energy storage technologies to guarantee a regular and dependable energy supply. Giving renewable energy sources top priority will help us to reach a sustainable energy future. These sources present a workable way to reduce dependency on fossil fuels, slow down global warming, and advance a better environment for next generations. Adopting and supporting these technologies will help civilizations all over build a stronger and more environmentally friendly energy source.

3 Methodology

3.1 Renewable Energy Sources

Among sustainable substitutes for fossil fuels are solar, wind, biomass, geothermal energy, and heat pumps. The several energy sources under evaluation in the assessment process are briefly compiled in this part.

3.1.1 Solar Energy

Technologies like photovoltaic (PV) cells and solar thermal systems enable the transformation of sunlight into heat and power. Citations include, [2], [3], [4], [5]. Solar energy is a crucial renewable resource with considerable potential to improve sustainability systems. Photovoltaic cells, generally composed of silicon, excite electrons within the semiconductor material, thereby turning them directly into electricity. This efficient, silent apparatus generates no greenhouse gas emissions or contaminants. Conversely, solar thermal systems harness and concentrate sunlight to generate heat, which can be employed directly or to drive steam turbines for electricity production. One major benefit of solar energy systems is their scalability, which qualifies both for large-scale solar farms and modest home installations. More affordable and effective solar panels resulting from technological advancements have made solar energy progressively competitive with conventional fossil fuels. Furthermore, solar energy provides security and independence from other fuels, therefore lowering reliance on imported fuels and strengthening energy resilience. Including solar energy into the grid helps distributed generation, which might lower transmission losses and improve grid stability. Though solar energy has numerous advantages, its generation depends on weather conditions and daylight availability, so it suffers intermittency. Still, developments in grid management systems and energy storage technologies, such as batteries, are helping to lessen these problems. Although the manufacturing and disposal of PV cells demand careful management to reduce the ecological impact, solar energy has rather little effect on the surroundings. All things considered, solar energy offers a workable way to lower carbon emissions and fight climate change and is a vital part of the worldwide change towards sustainable and renewable energy sources. PV systems generate the following equation's worth of energy:

$$E_{\text{solar}} = A \times G \times \eta \times H \quad (1)$$

Usually 15% to 20%, η is the efficiency of solar panels; E_{solar} is the energy generated by solar PV (kWh); H is the number of days in the period (for example, 365 for a year).

As such, Table 1 (Appendix) shows the solar energy parameters that will be used as input to the suggested approach. The main values applied to assess Seville's solar energy potential are shown in Table 1 (Appendix). Covers factors such as solar irradiation values, ranges of efficiency of PV panels, and the region that is accessible for photovoltaic (PV) installation. Derived from certified data, such as PVGIS or based on actual observations, all parameters guarantee accuracy and dependability in the simulation model. As shown in the table, the estimate of expected energy output and the evaluation of the feasibility of solar energy initiatives in the area depend on a methodical integration of several variables. Choosing suitable solar technology is the foundation of optimising energy output. Most often used technologies in Seville are monocrystalline and polycrystalline photovoltaic (PV) panels. Higher efficiency rates of monocrystalline panels make them especially appropriate for urban settings where space could be limited. On larger projects, polycrystalline panels provide a more reasonably priced choice. These systems maximise energy capture by considering elements including panel alignment, tilt angle, and shading. Moreover, by addressing the intermittency of solar energy, the integration of PV systems with energy storage solutions—such as lithium-ion batteries—improves system dependability. Smart grid technology among other demand-side management techniques help to maximise the equilibrium between energy supply and demand.

3.1.2 Wind Energy

By use of wind turbines, wind energy, [6], [7], [8], [9], harnesses the kinetic energy of wind to produce electricity. Usually grouped in wind farms, these turbines can be found onshore or offshore; offshore installations gain from more consistent and stronger winds. Wind energy is fundamentally based on wind spinning turbine blades to spin a shaft linked to a generator, generating electricity. Operating without greenhouse emissions, wind energy is a renewable, clean source of power that greatly helps to lower carbon footprints and slow down global warming. With current turbines able to produce significant volumes of electricity, often providing power to thousands of households, wind turbine efficiency has greatly changed over the years. Another benefit of wind energy is its scalability; it may be used in tiny, local projects as well as huge, commercial wind farms. Once the turbines are erected, wind is a free resource, hence the running expenses of wind energy are rather little. Still, the initial capital outlay might be somewhat large, including site preparation, infrastructure, and turbine expenses. The sporadic character of wind presents a difficulty since wind speed and consistency vary and thereby affects the stability of the power supply. Thanks to developments in grid integration technology and energy storage systems, this difficulty is being resolved and a more consistent supply of wind-generated electricity results. Environmental issues include how surrounding communities are visually and noise impacted as well as how wildlife, especially bats and birds, is impacted. Notwithstanding these obstacles, wind energy is a fast expanding industry driven by technical developments and government regulations meant to raise the capacity for renewable energy. Reducing dependency on fossil fuels and improving energy security, wind energy is absolutely essential for the change to a sustainable energy future. The following equation defines the energy generated by systems of wind turbines:

$$E_{\text{wind}} = \frac{1}{2} \times \rho \times A \times u^3 \times C_p \times T \times N \quad (2)$$

where E_{wind} is the energy output, ρ is air density, A is the swept area of the turbine blades, u is wind speed, C_p is the power coefficient, T is the operational hours, and N is the number of turbines.

As such, Table 2 (Appendix) shows the wind energy parameters that will be provided as input to the suggested technique. Focussing on measurements such air density, wind speed, and the power coefficient of wind turbines, Table 2 (Appendix) specifies the parameters related with wind energy modelling. Estimating the energy producing potential of wind systems in combination with solar energy integration depends on these principles. The table also shows the considered operational hours and turbine count, therefore providing information on hybrid renewable energy system scalability and optimisation. Like Table 1 (Appendix), the data sources and calculated values are precisely noted, therefore guaranteeing the openness and relevance of the study.

3.1.3 Biomass Energy

Biomass energy, [10], [11], [12], [13], involves the conversion of organic materials, such as agricultural residues, forest waste, and dedicated energy crops, into electricity, heat, or biofuels. This renewable energy source capitalizes on the carbon cycle, where plants absorb carbon dioxide during growth, which is then released when biomass is burned or decomposed, resulting in a relatively carbon-neutral process. Biomass can be converted into energy through various methods, including direct combustion, gasification, anaerobic digestion, and fermentation. Direct combustion includes burning biomass to produce heat, which can generate power through steam turbines. Gasification converts biomass into a combustible gas mixture, which can be used to produce electricity or synthetic fuels. Anaerobic digestion breaks down organic waste in the lack of oxygen to generate biogas fit for use as fuel for cars, heating, or generation of power. By fermentation techniques, biomass is turned into bioethanol, a renewable fuel alternative for petrol. Mostly advantageous is biomass energy's ability to use waste products, reduce landfill use, and improve waste management techniques. Furthermore, unlike some other renewable energy sources that are intermittent, biomass energy can present a steady and dependable power source. The sustainability of biomass energy is dictated by biomass feedstock acquisition and administration. Unsustainable methods such deforestation and intensive farming can compromise environmental benefits and lower biodiversity. By improving their efficiency and environmental performance, technological developments are helping biomass energy systems to become more competitive with conventional energy sources. Policy support, such as subsidies and mandates for renewable energy, also plays a crucial role in promoting biomass energy. As part of a diverse renewable energy portfolio, biomass energy contributes to reducing greenhouse gas emissions, enhancing energy security, and supporting rural economies through the development of biomass supply chains. The energy produced by biomass is given by the following equation:

$$E_{\text{biomass}} = Q \times H \tag{3}$$

where E_{biomass} is the energy produced, Q is heat output rate of the boiler (kW) and H is the number of hours operation.
Consequently, the biomass parameters that will be given as input to the proposed methodology are presented in Table 3 (Appendix).

3.1.4 Heat Pumps

Heat pumps, [14], [15], [16], [17], are devices that transfer heat from a source to a destination, known as a "heat sink," using a small amount of energy to move heat rather than generate it directly. This technology can be used for both heating and cooling purposes and is highly efficient compared to traditional heating systems. Among the numerous varieties of heat pumps are air-source, ground-source (geothermal), and water-source models. Thanks in part to technological advancements, air-source heat pumps (ASHP) effectively operate in freezing conditions by absorbing thermal energy from ambient air. Ground-source heat pumps, sometimes known as geothermal heat pumps, use the constant temperature of the earth for heating and cooling, therefore attaining amazing efficiency even if their initial expenditure for installation is very high. Water-source heat pumps use aquatic bodies as the heat exchange medium, such wells or lakes. Heat pump coefficient of performance (COP) indicates the heat output to energy input ratio, so determining their efficiency. A heat pump whose coefficient of performance (COP) of three or above produces three units of heat for every unit of power consumed. Less energy is needed and less greenhouse gas emissions follow from this higher efficiency. Versatile and included into many heating and cooling systems, including radiant floor heating, forced-air systems, and home hot water systems, are heat pumps. Heat pumps are more common because of growing knowledge of their environmental benefits and technological developments that have raised their dependability and efficiency.

Still challenges exist, including the initial installation costs and the need of suitable system design to maximise performance. Like rebates and tax credits, incentives and legislative assistance are crucial for helping heat pumps to be adopted. As part of a broader strategy to reduce reliance on fossil fuels and enhance energy efficiency, heat pumps offer a viable solution for sustainable heating and cooling. The energy produced by heat pumps is given by:

$$E_{\text{ASHP}} = W_{\text{input}} \times COP \times H \tag{4}$$

where E_{ASHP} is the energy produced, W_{input} is the electrical energy input, COP is the coefficient of performance, and H is the operational hours.
Consequently, the heat pumps parameters that will be given as input to the proposed methodology are presented in Table 4 (Appendix).

3.1.5 Geothermal Energy

Geothermal energy, [18], [19], harnesses the heat from the Earth's interior to generate electricity and provide heating. This renewable energy source capitalizes on the natural thermal energy stored beneath the Earth's crust, continuously replenished by the decay of radioactive elements and residual heat from the planet's formation. Geothermal energy systems generally entail accessing subterranean hot water or steam reservoirs via wells. This thermal energy can be utilised directly for heating applications, including district heating and greenhouse heating, or to produce electricity by driving turbines linked to generators. Geothermal power plants can be categorised into dry steam, flash steam, and binary cycle kinds. Dry steam plants directly utilise steam from geothermal reservoirs, whereas flash steam plants employ high-pressure hot water that converts to steam upon pressure reduction. Binary cycle plants transfer thermal energy from geothermal fluid to a secondary fluid having a lower boiling point, resulting in vaporisation that drives a turbine. Geothermal energy presents several benefits, such as a reliable and uninterrupted power supply, little greenhouse gas emissions, and a reduced land footprint relative to alternative energy sources. Furthermore, geothermal power facilities incur comparatively low operational and maintenance expenses post-establishment. The initial capital commitment for geothermal exploration and drilling can be substantial, and the viability of geothermal energy is contingent upon the presence of appropriate geothermal resources. Environmental issues encompass the risk of induced seismicity and the handling of geothermal fluids, which may contain dissolved minerals and gases. Technological improvements are enhancing the efficiency and environmental efficacy of geothermal systems, rendering them more competitive with alternative renewable energy sources. Policy support and incentives are essential for advancing geothermal energy development, especially in areas with significant geothermal potential. Geothermal energy is essential in a varied renewable energy portfolio for mitigating greenhouse gas emissions, bolstering energy security, and delivering dependable, sustainable energy solutions. The energy generated by a geothermal system is represented by the subsequent equation:

$$E_{\text{geo}} = Q \times H \tag{5}$$

where E_{geo} is the energy produced, Q Heat transfer rate (kW) and H is the operational hours.
Consequently, the heat pumps parameters that will be given as input to the proposed methodology are presented in Table 5 (Appendix).

4 Integrate Renewable Energy Sources in Buildings

The current European Union (EU) laws on renewable energy sources include numerous key clauses explicitly targeting buildings to boost their energy performance and integration of renewable energy.
Zero-Emission Buildings: With a more exact aim for public buildings by 2028, all newly built buildings by 2030 must reach zero emissions. This suggests that these buildings have to follow strict energy efficiency standards and use renewable energy sources to meet their energy demand, therefore greatly reducing their carbon effect.
The law requires, where practical, solar technologies be included into all new buildings by 2028. This relates to house buildings undergoing significant changes that have to follow rules by 2032. This mandate seeks to maximise the use of solar energy, a necessary component of the EU's objective to raise the share of renewables in its energy mix.
The Act defines particular energy performance class targets for buildings. Residential buildings must achieve a minimum energy performance grade of E by 2030 and class D by 2033.

Non-residential and public buildings comply with the same deadlines, guaranteeing a gradual yet consistent enhancement of energy efficiency in construction throughout the EU.

Particularly for the least efficient buildings, the regulation requires thorough restorations, which forces Member States to establish more information centres and cost-neutral rehabilitation schemes. Grant and subsidy-based financial aid will be given top priority for underprivileged households thereby guaranteeing fair access to energy-efficient renovations.

The prohibition of fossil fuels in heating systems for new constructions or major renovations will commence upon the directive's enactment, with a complete phase-out targeted for 2035, maybe extended to 2040 under certain circumstances. This legislation illustrates the EU's commitment to reducing dependence on fossil fuels and promoting the utilisation of renewable energy in buildings.

Authorisation Protocols: The regulation optimises permission procedures to expedite the incorporation of renewable energy in buildings, enabling swifter permits for renewable energy projects and infrastructure.

5 Local regulations and constraints

5.1 Regulatory Constraints in Renewable Energy: A Comprehensive Analysis

Renewable energy technologies include solar, wind, geothermal, heat pumps, and biomass define global sustainable energy transitions. Still, its application is closely controlled by several legal and administrative systems that vary greatly depending on the jurisdiction and sector. Regulatory constraints define the assessment of the feasibility, financial viability, and environmental effects of renewable energy projects. With an eye towards solar, wind, geothermal, heat pumps, and biomass energy, this chapter looks at the various rules controlling several renewable energy systems.

5.2 Solar Energy

Getting licenses presents a major legislative challenge for solar energy projects. For building, electrical work, and solar panel installation most sites call for licensing. These licenses ensure adherence to safety standards and grid connection rules. Installations have to follow local building codes, which could provide guidelines for roof load capacity and fire safety measures. These standards reduce fire hazards and ensure solar array structural integrity.

Zoning rules could restrict the placement of solar panels, especially in areas controlled by homeowners associations or approved historic districts. These rules try to balance aesthetic factors with the progress of renewable energy.

5.3 Wind Energy

Usually accompanied by environmental impact assessments, the installation of wind turbines calls for licensing. These permits assess possible effects on species, habitats, and surrounding populations.

Local zoning rules control wind turbine height and location to satisfy aesthetic issues and guarantee safety. Minimum distances set by setback rules help to reduce any risks from buildings, thoroughfares, and property borders.

Laws about noise: Noise rules could be put in place to allay worries about the noise generated by wind farms, therefore reducing any irritation to nearby houses.

5.4 Geothermal Energy

Permitting: Establishing geothermal systems calls for obtaining licenses, especially for geothermal well drilling. These permits guarantee adherence to historical site archaeological preservation criteria, groundwater protection policies, and environmental laws.

Environmental guidelines provide the parameters for geothermal drilling to guarantee the suitable disposal of drilling fluids and hence minimise environmental effects by protecting groundwater quality.

Geothermal projects have to follow construction codes about system design, safety, and connection with current infrastructure.

5.5 Heat Pumps

Installations of heat pumps could call for mechanical and electrical permits to guarantee adherence to performance criteria and safety rules.

Adherence to building rules and HVAC (heating, ventilation and air conditioning) guidelines is essentially what drives heat pump systems. These codes ensure safe and effective operation.

Standards for Energy Conservation: Minimum efficiency criteria could be needed to get rebates or incentives, therefore motivating the acceptance of heat pump technology with lower energy usage.

5.6 Biomass Energy

Permitting: Biomass energy systems, especially those using combustion, may need for air quality permits to control pollutants and guarantee adherence to health criteria. Biomass systems must follow local and national emissions criteria in order to reduce pollutants such carbon monoxide and particulate matter, therefore addressing public health and environmental problems.
Zoning rules can decide whether biomass systems are allowed, particularly larger projects that might impact surrounding communities and land use.
To reduce fire hazards and ensure safe operations, rules control the handling and storage of biomass fuels, including wood pellets.

5.7 Local regulations and constraints Conclusions

Selecting the most appropriate renewable energy sources for a construction requires thorough investigation of several elements and possible energy output during the period of site assessment. Techniques for improving power economy are quite vital, [1], [20]. Designed to fit the particular needs and features of the building, the proposed approach presented in Figure 1 (Appendix) aims to find ideal choices for the generation of sustainable energy.
The first element of the evaluation looks at whether installing heat pumps is viable. Confirming local regulations will help to determine whether heat pump installations are permissible. The examination also covers the availability of area for the heat pump unit installation. Calculating the Coefficient of Performance (COP) and the energy input quantity helps one to find the energy savings using heat pumps.
The use of photovoltaic (PV) systems comes first then. We have to take care of the reduced heat pump requirements. The assessment starts with the measuring of the available rooftop surface area since it will define the possible solar system size. Analysing the median sun irradiation for the site helps one evaluate the solar energy potential. Shading is investigated in order to find any obstacles that can reduce the solar panel performance.
Should the photovoltaic system's produced electricity be insufficient, the assessment process includes wind turbines. This entails assessing the typical wind speed and possible wind energy in the area as well as the legality of erecting building-mounted wind turbines. These wind conditions and the turbine characteristics define the expected energy output from wind turbines. The additional energy generation is included into the previous totals and matched with the energy consumption of the construction. The next choice is geothermal systems, depending on their installation being approved and technically feasible. The evaluation covers the feasibility of installing geothermal pipes and verifying the availability of appropriate area for heat pumps related with the system. The geothermal gradient and heat pump efficiency help one to ascertain the energy savings from geothermal systems. This contribution is compiled with energy generated from other sources and then matched to the use of the building.
The paper also looks at biomass's possible energy source value. This means evaluating the availability of local biomass sources as well as the presence of a pellet producing facility. One has to evaluate any difficulties with constructing storage and transportation. Using biomass for heating or electricity generation promises rather significant energy savings. The total energy produced—including biomass—is then evaluated in respect to the energy consumption of the building.
For the building, this comprehensive site assessment approach provides a thorough study of all practical renewable energy sources. The method guarantees an ideal and sustainable energy source by carefully evaluating and measuring the energy potential from solar systems, heat pumps, wind turbines, geothermal systems, and biomass. Every phase consists of a thorough assessment of the expected energy output in respect to the energy needs of the building, therefore directing the selection of the most effective renewable energy sources. This approach guarantees conformity to local regulations and pragmatic implementation aspects and helps sustainable energy planning.

5.8 Site Evaluation Process

Building a zero-emission house is a main objective of the quest of sustainable life. This paper offers a complete energy solution for a Seville, Spain, home. To completely meet the heating, cooling, and electrical energy needs of the building, the system combines solar photovoltaic (PV) panels, an air-source heat pump (ASHP), and battery storage. The aim is to create an energy-efficient system that guarantees a continuous and reliable power supply during times of low solar output, therefore minimising the required amount of solar panels. The used parameter values in the simulations match real-world conditions. Particularly:

- Solar irradiation: The values were calculated from empirical data gathered from the Photovoltaic Geographical Information System (PVGIS) and confirmed by local weather station observations.
- Energy Demand Profiles: Based on regional study and adjusted to fit Seville's meteorological circumstances using empirical data from AEMET, assumptions about heating and cooling needs were developed.
- Manufacturer requirements guided the selection of parameters including photovoltaic panel efficiency, inverter efficiency, and battery storage losses; they were then validated by system performance in Mediterranean conditions.
- Economic parameters—assumptions about installation costs, maintenance expenses, and subsidies—were tested against national agency data and European renewable energy projects.

5.9 Building's Energy Requirements

The building's usable space and the specific heating and cooling needs helped to determine its energy consumption. Here are the calculations:

- Cooling Demand: $20\,\mathrm{kWh/m^2}\cdot\mathrm{year}$
- Heating Demand: $12\,\mathrm{kWh/m^2}\cdot\mathrm{year}$
- Useful Area of the Building: $261.53\,\mathrm{m}^2$

Using these values, the total annual energy demands for the building were calculated: $E_{\text{cooling}} = 20 \times 261.53 = 5230.6\,\mathrm{kWh/year}$ $E_{\text{heating}} = 12 \times 261.53 = 3138.36\,\mathrm{kWh/year}$ $E_{\text{demand}} = E_{\text{cooling}} + E_{\text{heating}} = 5230.6 + 3138.36 = 8368.96\,\mathrm{kWh/year}$

5.10 Energy Efficiency with Air-Source Heat Pump

To reduce the electrical energy required for heating and cooling, an air-source heat pump (ASHP) was selected due to its high efficiency:

- Cooling Coefficient of Performance (COP): 3.5
- Heating Coefficient of Performance (COP): 3.0

The COP values indicate that the heat pump can deliver more energy for heating and cooling than it consumes in electricity. The required energy input for the heat pump was calculated as follows:

$$E_{\text{input, cooling}} = \frac{E_{\text{cooling}}}{\text{COP}_{\text{cooling}}} = \frac{5230.6}{3.5} = 1494.46\,\mathrm{kWh/year}$$

$$E_{\text{input, heating}} = \frac{E_{\text{heating}}}{\text{COP}_{\text{heating}}} = \frac{3138.36}{3.0} = 1046.12\,\mathrm{kWh/year}$$

$$E_{\text{input, heat pump}} = E_{\text{input, cooling}} + E_{\text{input, heating}} = 1494.46 + 1046.12 = 2540.58\,\mathrm{kWh/year}$$

By utilizing the heat pump, the building's total electricity demand for heating and cooling is significantly reduced to $2540.58\,\mathrm{kWh/year}$.

5.11 Solar PV System Design

Given Seville's high solar irradiance, solar PV panels are the ideal renewable energy source to meet the building's reduced energy demand. The calculations for determining the number of solar panels required are as follows:

- Solar Irradiance in Seville: $1700\,\mathrm{kWh/m^2}\cdot$ year
- Power Rating per Panel: $350\,\mathrm{W}$
- Energy Production per Panel:

$$E_{\text{per panel}} = 350\,\mathrm{W} \times 1700\,\frac{\mathrm{kWh}}{\mathrm{kW}\cdot\mathrm{year}} = 595\,\text{kWh/year per panel}$$

To meet the building's total reduced energy demand, the minimum number of panels required is:

$$\text{Number of Panels} = \frac{2540.58\,\mathrm{kWh/year}}{595\,\text{kWh/year per panel}} \approx 4.27\,\text{panels}$$

Rounding up, the calculation results in a need for 5 panels. Total Energy Production with 5 Panels:

$$E_{\text{total production}} = 5 \times 595\,\text{kWh/year per panel}$$
$$= 2975\,\text{kWh/year}$$

With this configuration, the PV system will generate $2975\,\text{kWh/year}$, which is slightly more than the building's reduced energy requirement, ensuring a small buffer to account for potential variations in solar irradiance.
The real surface area is approximately:

$$\text{Real Area} \approx 100,621\,\text{m}^2$$

So, the 5 panels, which need 1.7 square meters each, can be placed on the rooftop, and a lot of space will be available for the residents as well.

5.12 Battery Storage System

To guarantee continuous energy availability, particularly during the night or cloudy days when solar production is low, a battery storage system is incorporated into the design.

$$\text{Daily Energy Demand} = \frac{2540.58\,\text{kWh/year}}{365\,\text{days}}$$
$$\approx 6.96\,\text{kWh/day}$$

A battery with sufficient capacity to cover one day of energy demand, with a buffer for efficiency losses, was selected:

- Battery Capacity: $10\,\text{kWh}$
- Battery Efficiency: 90%

This battery capacity ensures that the building remains powered even when the solar PV system is not generating electricity.

5.13 Heat Pump Capacity

Given the building's peak heating and cooling demands, the required capacity of the air-source heat pump was determined:

- Peak Cooling Demand: $2.91\,\text{kW}$
- Peak Heating Demand: $1.74\,\text{kW}$

A single air-source heat pump with a capacity of 4 kW was determined to be sufficient to handle both the heating and cooling needs of the building.

5.14 Verification of Assumptions

The energy demands for cooling and heating were determined utilising standard climate data for Seville, sourced from validated meteorological databases, [21]. Degree-day calculations for heating and cooling were performed using the established thresholds of 18°C for heating and 24°C for cooling, [22]. These parameters align with values well recognised in the literature and building energy requirements for southern European climes. The assumptions were cross-validated using local building consumption trends and actual energy profiles from similar metropolitan areas in Seville. Sensitivity analyses were performed to examine variations in thermal comfort parameters, indicating minimal deviation from the baseline results. Solar irradiation data was sourced from legitimate entities, including the Spanish Meteorological Agency (AEMET) [23], and validated against global datasets [24]. Seville, located in southern Spain, demonstrates considerable solar exposure, with annual average irradiance exceeding 5 kWh/m²/day. The data were interpolated to match site-specific resolution and later confirmed by comparing historical and measured irradiance levels to ensure accuracy.

5.15 Feasibility of the Methodology

The approach of this work blends generalisable models for evaluating renewable energy with site-specific factors (such as climate, energy demand, and solar resource availability). Using well-known models for energy optimisation and simulation, such as HOMER Pro, [25], which shows good application in many geographical and climatic settings, guarantees of resilience were obtained. Flexible and able to be adjusted for different datasets, the modelling assumptions—energy consumption and solar irradiation—assure relevance in numerous locations with different environmental and socioeconomic setting.

5.16 Generalizability Beyond Seville

Although the technique is applicable worldwide, Seville was selected for its favourable conditions for renewable energy, marked by a solar-rich climate and mild seasonal change. The suggested methodology may assess the possibility for energy integration in different climates by changing input elements like local solar irradiance, temperature profiles, and demand patterns.

To highlight this, we conducted a secondary analysis with hypothetical climate data that resemble northern European and arid tropical climates. The results indicated that the model retains its functionality and adaptability, although the output results (e.g., system sizing, and energy yield) naturally depend on regional variations.

6 Results and Discussion

The integration of 22 solar PV panels, a 4 kW air-source heat pump, and a 40 kWh battery storage system effectively met the energy demands of the building, providing a reliable and zero-emission energy solution. The findings show how easily photovoltaic systems could be combined with heat pumps to reach sustainability and energy economy.

7 Conclusion

Emphasizing automation and efficiency, this paper exposed a methodical approach to site evaluation and data modelling in renewable energy projects. Using this technique in a house in Seville, Spain, successfully demonstrated how renewable energy sources might be included to achieve zero-emission building. With five solar PV panels, a 4 kW air-source heat pump, and a 10 kWh battery storage system totally meeting the building's annual energy demand of 8368.96 kWh/year with renewable energy. The air-source heat pump significantly reduces the building's electricity consumption for heating and cooling, while the solar PV system generates slightly more energy than required, providing a buffer for reliability. The battery storage system ensures continuous operation during periods of low solar production, contributing to the overall sustainability and resilience of the building.Future work will explore the use of parametric modeling to further optimize renewable energy systems across different building types and locations as well as the incorporation of syntactic patern recognition techniques [26] .

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used Quillbot/Grammar_Checker in order to proofread his paper. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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Conflict of Interest

The author has no conflict of interest to declare that is relevant to the content of this article.

Appendix

Table 1: Solar Energy parameters that will be given as input to the proposed methodology

Constants	Data types/sources
A: Available area for PV installation (m^2)	Value
G: Solar Irradiance ($kWh/m^2/day$)	Value from dataset
Type of solar Panel	Drop down list
η: Efficiency of the solar panels (typically between 15% - 20%)	Derived Value
Temperature Variations (°C) Roof Orientation and Tilt (degrees)	Value
Shading Analysis	Value
H: Number of days in the period	Value

Table 2: Wind Energy parameters that will be given as input to the proposed methodology

Constants	Data types/sources
ρ: Air density	Value
A: Swept area of the wind turbine blades (m^2)	Derived value
u: Average wind speed (m/s)	Value from dataset
Cp: Power coefficient of the wind turbine (typically 0.3 to 0.5)	Derived value
T: Number of hours in the period (e.g., 8,760 for a year)	Value
N: Number of wind turbines	Value

Table 3: Biomass parameters that will be given as input to the proposed methodology

Constants	Data types/sources
Q: Heat output rate of the boiler (kW)	Derived Value
H: Number of hours of operation	Value

Table 4: Heat Pumps parameters that will be given as input to the proposed methodology

Constants	Data types/sources
W_{input}: Electrical energy input (kW)	Value
COP: Coefficient of performance	Value from dataset
H: Number of hours of operation	Value

Table 5: Geothermal parameters that will be given as input to the proposed methodology

Constants	Data types/sources
Q: Heat transfer rate (kW)	Derived Value
H: Number of hours of operation	Value

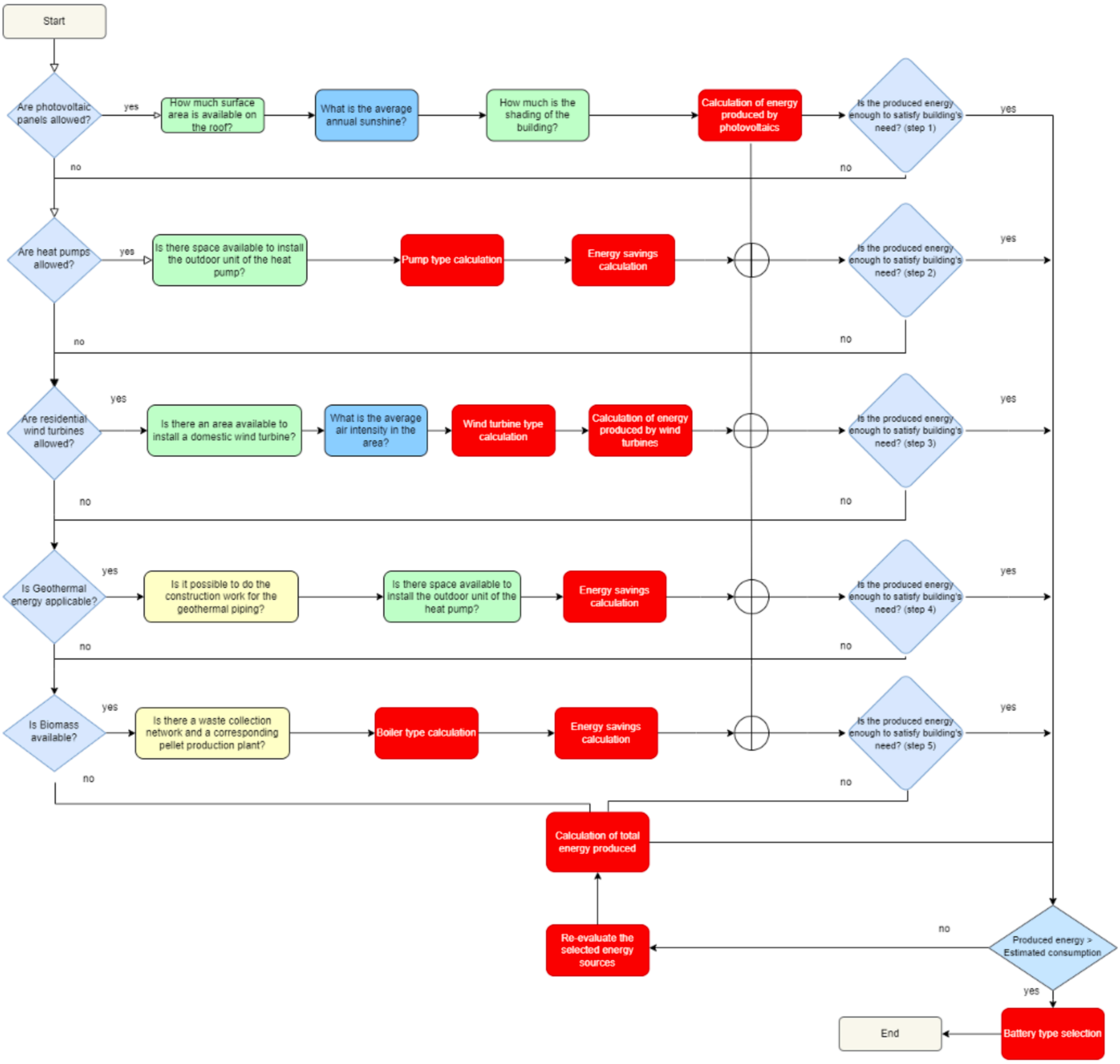

Figure 1: Flowchart of the proposed methodology